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(71) Demandeur/Applicant:
NANOCORE APS, DK

(72) Inventeurs/Inventors:
PEDERSEN, HENRIK, DK;
GONZALEZ SANCHEZ, MARTA, DK;
LOPEZ MORENO, ALEJANDRO, ES;
VILLALVA FERNANDEZ, JULIA, ES;
GONZALEZ-JUAREZ, MARIA DE LOURDES, DK;
EATON, MATTHEW DAVID, ES;
...

(74) Agent: DEETH WILLIAMS WALL LLP

(54) Titre : COMPOSITE DE NANOTUBES DE CARBONE COMPRENANT DES LIGANDS MECANIQUES
(54) Title: INDUSTRIAL USE OF THE LASSO PRINCIPLE FOR CARBON NANOTUBE COMPOSITE PRODUCTION

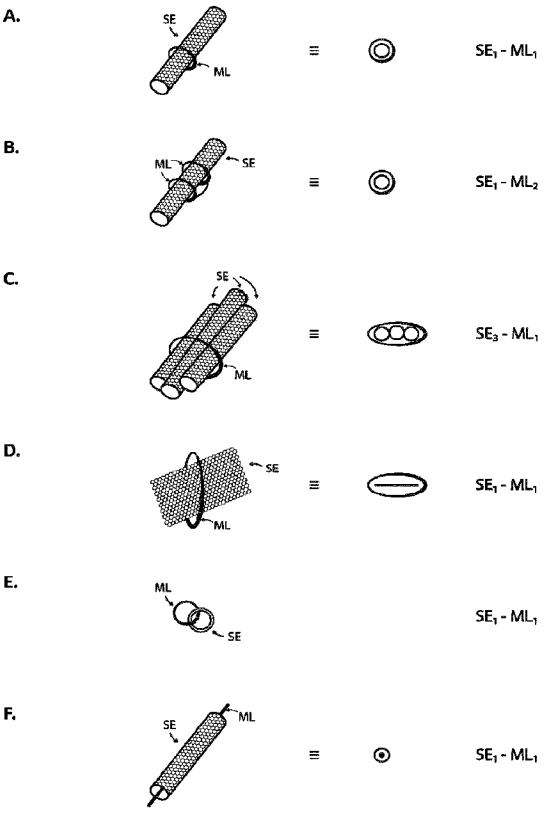


Fig. 1

(57) Abrégé/Abstract:
A composite material comprising carbon nanotubes is described, wherein said composite material does not comprise any carbon nanotube aggregates having a smallest dimension larger than 1 mm. The efficiency of dispersion and anchoring as well as processing capability of the commercially relevant carbon nanotube composites are significantly improved.

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(72) **Inventeurs(suite)/Inventors(continued):** PEREZ ALVAREZ, EMILIO MANUEL, ES; LUNDORF, MIKKEL DYBRO, DK; ISASTI IRIBAR, ION, DK; MIRANDA ALCAZAR, SILVIA, DK; RIVAS CARAMES, MARISOL, DK; NARANJO CHACON, ALICIA, DK; ZHANG, WANZHENG, CN; XU, WEI, CN; MENA HERNANDO, SOFIA, ES

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Abstract:

A composite material comprising carbon nanotubes is described, wherein said composite material does not comprise any carbon nanotube aggregates having a smallest dimension larger than 1 mm. The efficiency of dispersion and anchoring as well as processing capability of the commercially relevant carbon nanotube composites are significantly improved.

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INDUSTRIAL USE OF THE LASSO PRINCIPLE FOR CARBON NANOTUBE COMPOSITE PRODUCTION.

INTRODUCTION.

Technical field.

Composite materials, in particular materials where the strength of the material is of importance.

Background.

Nanocomposite materials comprising mechanical ligands and precursor-mechanical ligands, complexed to the filler molecules and covalently or non-covalently linked to the matrix molecules, can improve the beneficial characteristics of nanocomposites when employing fillers such as carbon nanotubes, boron nitride nanotubes, and graphene.

The approach dramatically improves both the dispersion and anchoring of the fillers in the nanocomposites, and thereby improves characteristics such as strength significantly. However, challenges remain, in particular with regard to i) improve the efficiency of dispersion of the fillers at high concentration, ii) minimize the time required to disperse the fillers, iii) disperse a high proportion of the different types of fillers present in current commercially available filler products, and iv) improve processing capability of such nanocomposites.

For carbon nanotubes these issues are particularly relevant. It is therefore of interest to identify approaches that can disperse and anchor a major proportion of the carbon nanotubes present in today's commercial products, thereby improving the efficiency of dispersion and anchoring as well as processing capability of the commercially relevant carbon nanotube composites.

It has been difficult to make carbon nanotube composites of high strength, although carbon nanotubes are very strong themselves. This is in part because the carbon nanotubes are difficult to anchor efficiently in the composite material. Here, it is described how mechanical bonding of the carbon nanotubes improves the dispersion of the nanotubes as well as their anchoring in the composite.

SUMMARY OF THE INVENTION.

What is provided is a method for effectively dispersing nanotubes, in particular carbon nanotubes in solvents as well as in composites. It is shown how the method irreversibly improves the dispersion, but also, how dispersion may first be effectuated and then the nanotubes be left unmarked (pristine) from the method, yet with only rather small nanotube aggregates left in the composite.

What is thus provided is a general process for the production of a SE1-ML complex, comprising the following steps:

Step Y1. Provide a SE1, where the SE1 is a nanotube;

Step Y2. Provide a precursor-ML, where the precursor-ML is a Ushape comprising two chemical moieties with affinity for the nanotube;

to obtain a nanotube-Ushape complex;

where Steps Y1-Y2 may be performed in any order.

A composite material comprising nanotubes is also provided, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 1 mm.

What is further provided is a means for the efficient anchoring of nanotubes, in particular carbon nanotubes, in composite materials.

What is thus provided is a general process for the production of a SE1-ML-SE2 complex, comprising the following steps:

Step 1a. Provide a SE1;

Step 1b. Provide a precursor-ML;

Step 1c. Optionally, provide a catalyst;

Step 1d. Provide a SE2;

to generate a SE1-ML-SE2 structure.

What is further provided is a means for applying the invention to industrial production of products made from composite materials, including minimizing the presence of nanotube

aggregates at high nanotube concentration; and improving the dispersion of commercial preparations of nanotubes, comprising many different nanotube species.

The composite material preferably does not comprise any nanotube aggregates having a smallest dimension larger than 1 mm, such as larger than 0.1 mm, such as larger than 0.01 mm, such as larger than 1 µm, such as larger than 0.1 µm, such as larger than 0.01 µm, such as larger than 2 nm.

Further provided is a composite material, having a volume of more than 50 nm^3 and comprising more than 0.01 w/w % nanotubes.

Further provided is a composite material, having a volume of more than 50 nm^3 and comprising more than 0.01 w/w % nanotubes, such as 0.01-0.1 w/w%, or 0.1-1 w/w%, or 2-3 w/w%, or 4-5 w/w%, or 5-10 w/w%, or 10-15 w/w%, or 15-20 w/w%, or 20-25 w/w%, or 25-30 w/w%, or 30-35 w/w%, or 35-40 w/w%, or 40-50 w/w%, or 50-60 w/w%, or 60-70 w/w%, or 60-80 w/w%, or 80-99.99 w/w%.

Further provided is a composite material, wherein the composite material has a mass of more than 10^{-15} g, such as more than 10^{-14} g, such as more than 10^{-13} g, such as more than 10^{-11} g, such as more than 10^{-10} g, such as more than 10^{-9} g, such as more than 10^{-8} g, such as more than 10^{-7} g, such as more than 10^{-6} g, such as more than 10^{-5} g, such as more than 10^{-4} g, such as more than 10^{-3} g, such as more than 10^{-2} g, such as more than 0.1 g, such as more than 1 g, such as more than 10 g, such as more than 100 g, such as more than 1 kg, such as more than 10 kg, such as more than 100 kg, such as more than 1000 kg, such as more than 10,000 kg; and/or

wherein the nanotube concentration is 0.01-0.1 w/w%, or 0.1-1 w/w%, or 2-3 w/w%, or 4-5 w/w%, or 5-10 w/w%, or 10-15 w/w%, or 15-20 w/w%, or 20-25 w/w%, or 25-30 w/w%, or 30-35 w/w%, or 35-40 w/w%, or 40-50 w/w%, or 50-60 w/w%, or 60-70 w/w%, or 60-80 w/w%, or 80-99.99 w/w%; and/or

where the nanotubes have an average length of at least 10 nm, such as at least 20 nm, such as at least 50 nm, such as at least 100 nm, such as at least 300 nm, such as at least 500 nm, such as at least 1 µm, or such as at least 20 µm.

Further provided is a composite material, having a volume of at least 100 nm^3, such as at least 300 nm^3, such as at least 1000 nm^3, such as at least 10000 nm^3, such as at least 100000 nm^3, such as at least 100000 nm^3, such as at least 1000000 nm^3, such as at least 10000000 nm^3, such as at least 100000000 nm^3, such as at least 1000000000 nm^3, such as at least 10 μm^3, such as at least 100 μm^3, such as at least 1000 μm^3, such as at least 10000 μm^3, such as at least 100000 μm^3, such as at least 1000000 μm^3, such as at least 10000000 μm^3, such as at least 100000000 μm^3, such as at least 1 mm^3, or such as at least 10 mm^3.

Further provided is a composite material, said composite material comprising at least a first and at least a second carbon nanotube, where the outer diameter of the second nanotube is more than 0.1 nm greater than the outer diameter of the first nanotube, and wherein said first and said second nanotubes are each complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a third carbon nanotube, where the outer diameter of the third nanotube is more than 0.1 nm greater than the outer diameter of the second nanotube, and wherein said first, second and said third nanotubes are each complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a fourth carbon nanotube, where the outer diameter of the fourth nanotube is more than 0.1 nm greater than the outer diameter of the third nanotube, and wherein said first, second, third and fourth nanotubes are complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a fifth carbon nanotube, where the outer diameter of the fifth nanotube is more than 0.1 nm greater than the outer diameter of the fourth nanotube, and wherein said first, second, third, fourth and fifth nanotubes are complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a sixth carbon nanotube, where the outer diameter of the sixth nanotube is more than 0.1 nm greater than the outer diameter of the fifth nanotube, and wherein said first, second, third, fourth, fifth and sixth nanotubes are complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a seventh carbon nanotube, where the outer diameter of the seventh nanotube is more than

0.1 nm greater than the outer diameter of the sixth nanotube, and wherein said first, second, third, fourth, fifth, sixth and seventh nanotubes are complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a eighth carbon nanotube, where the outer diameter of the eighth nanotube is more than 0.1 nm greater than the outer diameter of the seventh nanotube, and wherein said first, second, third, fourth, fifth, sixth, seventh and eighth nanotubes are complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a ninth carbon nanotube, where the outer diameter of the ninth nanotube is more than 0.1 nm greater than the outer diameter of the eighth nanotube, and wherein said first, second, third, fourth, fifth, sixth, seventh, eighth and ninth nanotubes are complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a tenth carbon nanotube, where the outer diameter of the tenth nanotube is more than 0.1 nm greater than the outer diameter of the ninth nanotube, and wherein said first, second, third, fourth, fifth, sixth, seventh, eighth, ninth and tenth nanotubes are complexed with mechanical ligands.

Further provided is a composite material, wherein a nanotube is complexed to a mechanical ligand that is a closed ring structure, and where the mechanical ligand comprises any of the following chemical moieties: hydroxyl, thiol, phenyl or other aromatic moiety.

Further provided is a composite material, comprising a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 0.3 and 0.6 nm, and the closed ring molecule comprises 10-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 0.6 and 0.7 nm, and the closed ring molecule comprises 15-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 0.7 and 0.8 nm, and the closed ring molecule comprises 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 0.8 and 0.9 nm, and the closed ring molecule comprises 25-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 1.0 and 1.2 nm, and the closed ring molecule comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 1.2 and 1.4 nm, and the closed ring molecule comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 1.4 and 1.7 nm, and the closed ring molecule comprises 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 1.7 and 2.0 nm, and the closed ring molecule comprises 50-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 2.0 and 2.5 nm, and the closed ring molecule comprises 60-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In the composite material described herein, the composite material may additionally comprise a polymer chosen from: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS,

PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

Further provided is a composite material, wherein at least one of said one or more mechanical ligands is bonded to a polymer chain, preferably a polymer chosen from: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In one aspect of the composite material, the nanotubes are selected from carbon nanotube, multiwall, single-wall, or double-wall nanotubes, or mixtures thereof.

In a further aspect of the composite material, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 10-15 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

Suitably, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 15-25 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 25-40 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 40-70 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 70-99,99 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 10-25 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 10-25 w/w%; and wherein the composite material has a volume of at least 10 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 10-25 w/w%; and wherein the composite material has a volume of at least 100 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.01 µm, wherein the nanotube concentration is 10-25 w/w%; and wherein the composite material has a volume of at least 10 μm^3.

The present technology also provides an ML-nanotube complex, comprising at least two mechanical ligands (ML) complexed to a single nanotube, and wherein said at least two mechanical ligands are covalently linked to one another. Further details of the mechanical ligand (ML) are provided in the following.

LEGENDS TO THE FIGURES

Figure 1. SE1-ML complexes. Various SE1-ML complexes are shown.

Figure 2. SE1-ML-SE2 complexes. Various SE1-ML-SE2 complexes are shown.

Figure 3. Formation of mechanical ligands (MLs). The formation of MLs from precursor-MLs is shown.

Figure 4. ROMP synthesis of 'Poly[N-(4-Tosylatebutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A1, synthesized in example A1).

Figure 5. 1H NMR of 'Poly[N-(4-Tosylatebutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A1, synthesized in example A1).

Figure 6. Synthesis of 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A2, synthesized in example A3).

Figure 7a. 1H NMR of 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A2, synthesized in example A3).

Figure 7b. FT-IR spectrum of 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A2, synthesized in example A3).

Figure 8. End-group (1H NMR) analysis of 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A2, synthesized in example A3)

Figure 9. Synthesis of 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, synthesized in example A6).

Figure 10. Comparative Infrared Spectra. Black: Pyrene_Ushape terminal alkyne, blue: 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A2, synthesized in example A3) and red: 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, synthesized in example A6).

Figure 11a. 1H NMR of 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, synthesized in example A6).

Figure 11b. UV-Vis. spectrum of 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, synthesized in example A6).

Figure 11c. TGA spectrum of 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, synthesized in example A6).

Figure 12. Nanoidentation measurement of 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, synthesized in example A6).

Figure 13. 1H NMR of 'Poly[N-(4-Tosylatebutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A4, synthesized in example A11).

Figure 14a. 1H NMR of 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A5, synthesized in example A13).

Figure 14b. FT-IR spectrum of 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A5, synthesized in example A13).

Figure 15. End-group (1H NMR) analysis of 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A5, synthesized in example A13).

Figure 16. Comparative Infrared Spectra. Black: Pyrene_Ushape terminal alkyne, blue: 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A5, synthesized in example A13) and red: 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A6, synthesized in example A16).

Figure 17a. 1H NMR of 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A6, synthesized in example A16).

Figure 17b. UV-Vis. spectrum of 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A6, synthesized in example A16).

Figure 18a. Synthesis of 'SWNT-polyUshape' composite (compound A8) with 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, from example A6).

Figure 18b. Optical Microscopy photo of compound A8

Figure 19. Raman spectra of 'SWNT-polyUshape' composite (compound A8), measured at 785 nm and 532 nm

Figure 20. Raman studies for a '2D versus G band' comparison of 'SWNT-polyUshape' composite (compound A8) and non-modified 6,5_SWNTs (compound A7) from example A19.

Figure 21. Average comparison of G and 2D band of 'SWNT-polyUshape' composite (compound A8) and non-modified 6,5_SWNTs (compound A7) from example A19

Figure 22. UV.Vis_NIR spectra (focused in the in the pyrene region) comparison between a) 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, from example A6) in black colour, b) 'SWNT-polyUshape' composite (compound A8) after step 8 in blue colour and c) 'SWNT-polyUshape' composite (compound A8) after step 11 in red colour

Figure 23. UV.Vis_NIR spectra (focused in the in the nanotube region) comparison between 'SWNT-polyUshape' composite (compound A8) in red colour and 6,5_SWNTs (compound A7) from example A19 in blue colour

Figure 24. AFM of 'SWNT-polyUshape' composite (compound A8)

Figure 25. SEM of 'SWNT-polyUshape' composite (compound A8)

Figure 26. SEM-in-lens of 'SWNT-polyUshape' composite (compound A8)

Figure 27. TEM of 'SWNT-polyUshape' composite (compound A8).

Figure 28. HRTEM of 'SWNT-polyUshape' composite (compound A8)

Figure 29. Raman studies for a '2D versus G band' comparison of composites obtained in examples A20 (compound A8 in red) and A24 (in blue)

Figure 30. Raman spectra comparison of a) compound A9 in blue line (example A27), b) compound A8 in red line (example A20) and c) compound A7 in black line (example A19), measured at 785 nm.

Figure 31. Raman studies for a '2D versus G band' comparison of a) compound A9 in green (example A27), b) compound A8 in red (example A20), c) compound A7 in orange (example A19) and d) compound obtained from 'control' experiment in blue

Figure 32. Average comparison of G and 2D band of a) compound A9 (example A27), b) compound A8 (example A20) and c) compound A7 (example A19), measured at 785 nm.

Figure 33. UV.Vis_NIR comparison spectra of 'SWNT-polyUshape Supramolecular' composite (compound A9) in blue, 'SWNT-polyUshape' composite (compound A8) in red and 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, from example A6) in grey.

Figure 34. HRTEM of 'SWNT-polyUshape Supramolecular' composite (compound A9)

Figure 35. Raman Spectroscopy of 'SWNT-polyUshape' composite in red line (compound A10) and non-modified 6,5_SWNTs (compound A7) in black line, measured at 785 nm. Note: Both spectra are the average from 30 different measurements

Figure 36. Raman studies for a '2D versus G band' comparison of 'SWNT-polyUshape' composite (compound A10) and non-modified 6,5_SWNTs (compound A7)

Figure 37. Nanoidentation measurements of compound A8

Figure 38. Synthesis of pyrene precursor-ML

Figure 39a-39b. Synthesis of Boc-diamine-carrying precursor-ML

Figure 39c. Analytical data for "Boc-diamine-carrying precursor-ML of Example B2"

Figure 40a. Preparation of macrocyclic molecule comprising bisphenol A (BPA)-motifs or bromo groups.

Figure 40b. Structure of macrocyclic molecule around a single-walled carbon nanotube

Figure 40c. Synthesis of bisphenol A (BPA) precursor-ML

Figure 40d. Analytical data for bisphenol A (BPA) precursor-ML and macrocyclic molecule

Figure 40e. Preparation of macrocyclic molecule comprising tert-butoxycarbonyl (Boc)-protected amino groups

Figure 40f. Structure of macrocyclic molecule comprising tert-butoxycarbonyl (Boc)-protected amino groups, wrapped around a single-walled carbon nanotube

Figure 40g. Preparation of macrocyclic molecule comprising amino groups

Figure 40h. Structure of macrocyclic molecule comprising amino groups, wrapped around a single-walled carbon nanotube

Figure 40i. Synthesis of bisphenol A (BPA) precursor-ML comprising amino groups

Figure 40j. Analytical data for bisphenol A (BPA) precursor-ML and macrocyclic molecule comprising amino groups.

Figure 41. Different nanofillers used to prepare viscous suspensions of 10 (w/w) % PMMA polymer

Figure 42. Electrospun fibers of PMMA polymer (A) and PMMA with different nanofillers based on SWNT (B-D). No Macroscopic differences were observed

Figure 43. Rectangular shaped PMMA fibers composite sample of dimensions of 1×4 cm placed at DMA Q800, TA instruments

Figure 44. SEM pictures of PMMA polymer fibers (A) and PMMA with different nanofillers based on SWNT (B-D).

Figure 45. Diameter distributions for PMMA fibers estimated from SEM pictures

Figure 46. Fiber area density distribution for PMMA electrospun fibers

Figure 47. Representative stress/strain curves of PMMA (grey) and its composites with SWNTs (black), "SWNT-SL of example H1" (blue) and "SWNT-ML of example B4" (red)

Figure 48. Representative stress/strain curves of PMMA (grey) and its composites with SWNTs (black), "SWNT-SL of example H1" (blue) and "SWNT-ML of example B4" (red).

Figure 49. Measured mechanical properties observed for PMMA polymer fibers and PMMA with different nanofillers based on SWNT. A. Young's Modulus. B. Tensile Strength C. Strain (%).

Figure 50. Different nanofillers used to prepare viscous suspensions of 25 (w/w) % PSU polymer

Figure 51. Electrospun fibers of PSU polymer (A) and PSU with different nanofillers based on SWNT (B-D). No Macroscopic differences were observed

Figure 52. SEM pictures of PSU polymer fibers (A) and PSU with different nanofillers based on SWNT (B-D).

Figure 53. Diameter distributions for PSU fibers estimated from SEM pictures

Figure 54. Fiber area density distribution for PSU electrospun fibers

Figure 55. Representative Stress-Strain curves of PSU (grey) and its composites with SWNTs (black), "SWNT-SL of example H1" (blue); "SWNT-ML of example B4" (red).

Figure 56. Representative stress/strain curves of PSU (grey) and its composites with SWNTs (black), "SWNT-SL of example H1" (blue); "SWNT-ML of example B4" (red).

Figure 57. Measured mechanical properties observed for PSU polymer fibers and PSU with different nanofillers based on SWNT (B-D). A. Young's Modulus. B. Tensile Strength C. Strain (%).

Figure 58. Synthetic scheme of "Pyrene U-Shape of Example AA1", such as compound AA1, following the procedure described in Example DD6.

Figure 59. Synthetic scheme of "Alkene U-Shape of Example AA2", such as compound AA2, following the procedure described in Example EE1.

Figure 60. Synthetic scheme of "Ester U-Shape of Example AA3", such as compound AA3, following the procedure described in Example EE2.

Figure 61. Synthetic scheme of "Acid U-Shape of Example AA4", such as compound AA4, following the procedure described in Example EE3.

Figure 62. Synthetic scheme of "Fluorenone U-Shape of Example AA5", including synthetic steps for the synthesis of compound AA5 and AA6, following the procedure described in Example AA5.

Figure 63. Synthetic scheme of "Chain U-Shape of Example AA6", such as compound AA7, following the procedure described in Example AA6.

Figure 64. Synthetic scheme of "Glycol U-Shape of Example AA7", such as compound AA8, following the procedure described in Example AA7.

Figure 65. Synthetic scheme of "Fully glycol U-Shape of Example AA8", including synthetic steps for the synthesis of compound AA9, AA10 and AA11, following the procedure described in Example AA8.

Figure 66. Synthetic scheme of "DER U-Shape of Example AA9", including synthetic steps for the synthesis of compound AA12 and AA13, following the procedure described in Example AA9.

Figure 67. Synthetic scheme of "Methyl alcohol U-Shape of Example AA10", such as compound AA14, following the procedure described in Example AA10.

Figure 68. Results of mechanical tensile test for the different PMMA-composites were summarized in table on Figure 68.

Figure 69. Results of mechanical tensile test for the different PVC-composites were summarized in table on Figure 69.

Figure 70. Results of mechanical tensile test for the different LDPE-composites were summarized in table on Figure 70.

Figure 71. Mixture of 0.1% ester MINTs and PMMA powder after ball milling (left) and custom-made single-screw extruder (right) TC1 and TC2 correspond to heating zones. Nozzle diameter 2.5 mm.

Figure 72. “Example CC 1”. Polymer formation.

Figure 73. “Example CC 2”. Polymer formation.

Figure 74. “Example CC 3”. Polymer formation.

Figure 75. “Example CC 4”. Polymer formation.

Figure 76. “Example CC 6”. Polymer formation.

Figure 77. “Example CC 7”. Conversion of terminal functionality.

Figure 78. “Example CC 8”. Conversion of terminal functionality.

Figure 79. “Example CC 9”. Polymer formation.

Figure 80. “Example CC 10”. Conversion of terminal functionality.

Figure 81. “Example CC 12” and “Example CC 13”. Click chemistry.

Figure 82. “Example CC19, 1”. ATRP´s initiator MINTs.

Figure 83. “Example CC19, 2.” ATRP PMMA grafting.

Figure 84. “Example CC 20.” ATRP PMMA grafting.

Figure 85. “Example CC21”. ROP PCL-MINTs composite.

Figure 86. “Example CC 22”. Amide bond formation.

Figure 87. Scheme of achievement of“Polyethoxy monoalkylated of Example DD4”. Inthe first line, the reactions start on commercial pyrene which is modified to obtainCompound DD1:“2,7-diBpinpyrene of ExampleDD1”. This one became reagent in thenextreaction and Compound DD2 (“2,7-Dihidroxypyrene of Example DD2”) isobtained. On the other hand, in the second line the Compound DD3 (“3-(2-(2-(2-chloroethoxy) ethoxy) ethoxy) prop-1-eneof Example DD3”) is formed by theaddition of allyl bromide to a solution of NaH and2-(2-(2-chloroethoxy) ethoxy) ethanol.Finally, in the bottom part Compound DD2(“2,7-Dihidroxypyrene of Example DD2”)reactwith compound DD3DD3 (“3-(2-(2-(2-chloroethoxy) ethoxy) ethoxy) prop-1-eneofExample DD3”)giving Compound DD4 (“Polyethoxy monoalkylated of Example DD4”).After that, compound DD4 reacts with α, α’-dibromo-o-xylene resulting in CompoundDD5 (“Polyethoxy U-Shape of ExampleDD5”).

Figure 88. Schematic representation of the synthesis of Compound DD7 (“Pyrene U-Shapeof Example DD6”) from Compound DD6 (monoalkylated pyrene). In this case, Compound DD6is dissolved in a mixture of Butanone and water in a basic media. After that,α, α’-dibromo-o-xylene was added to the reaction and this was stirred overnight. Giving asa resultCompound DD7(“Pyrene U-Shape of Example DD6”).

Figure 89. This figure shows the structure of Ushapes described in Examples EE1-EE8.

Figure 90. This figure shows the structures of macrocycles after Ring-closing Metathesis for the formation of MINTsdescribed in Examples EE9-EE14

Figure 91. This figure shows PS-amide MINTs (EE15a-c) a) after milling and heating at 200°C for 2 h; b) dissolved inchloroform (0.25 mg/mL). c) AFM micrograph of drop-casting showing high concentration of individualizedSWNT

Figure 92. Schematic of dogbone mold used to make dogbone shaped samples for tensile mechanical testing. Dimensions are in mm.

Figure 93. Average tensile modulus data of the Pyrene SWNT-ML-PP dogbones prepared in Example FF4 with standard deviation.

Figure 94. Average tensile modulus data of the Pyrene SWNT-ML-HDPE dogbones prepared per Example FF8 with standard deviation.

Figure 95. Average tensile modulus data of the Pyrene SWNT-ML-LDPE dogbones prepared in Example FF9 with standard deviation.

Figure 96. Films of Example FF11. (Left) 50% Carboxylic Acid SWNT-ML-PVA Film of Example FF11 and (right) 50% SWNT-PVA Film of Example FF11.

Figure 97. Average tensile modulus data of the 1.0wt% Amino SWNT-ML-Epoxy dogbones prepared in Example FF12 with standard deviation. Compared to neat epoxy and 1.0% SWNT-epoxy.

Figure 98. Indentation measurements. (left) Indentation force-displacement curves for neat PS-NH2 (blue) and PS-AMIDE- MINTs of Example EE15C (red). (center) Reduced modulus values for PS-NH2 and PS-AMIDE- MINTs of Example EE15C calculated from indentation curves. (right) Indentation hardness values for PS-NH2 and PS-AMIDE- MINTs of Example EE15C calculated from indentation curves.

Figure 99. AFM Indentation measurements. (left) AFM Indentation force-displacement curves for PS-reference (blue), neat PS-NH2 (orange) and PS-AMIDE- MINTs of Example EE15C (green). The JKR model fit for each curve is shown as a dashed line. (center) Reduced modulus values for PS-reference (blue), neat PS-NH2 (orange) and PS-AMIDE-MINTs of Example EE15C (green) calculated from indentation curves using the JKR model. (right) Histogram of reduced modulus values for PS-reference (blue), neat PS-NH2 (orange) and PS-AMIDE- MINTs of Example EE15C (green) calculated from indentation curves using the JKR model.

Figure 100: Synthesis of mono- and di-alkylated pyrene.

Figure 101: Synthesis of Diamino-Boc U-Shape GG2f.

Figure 102: Several alternatives for Diamino-Boc U-Shape Synthesis. a. Another synthetic route of Diamino-Boc U-Shape GG2e. b. Different conditions to prepare the Diamino-Boc spacer GG2e. c. Synthesis of a similar Diamino-Boc U-Shape using succinic anhydride.

Figure 103: The pyridine U-shape´s synthesis

Figure 104: Synthesis of Thiol U-Shape.

Figure 105: Synthesis of Amido U-Shape GG6d. a. Synthesis of Amido U-Shape GG6d b. Alternative route to obtain the Amido U-Shape GG6d.

Figure 106: Graphs of tensile test measurements to 0.1 % Pyridine-Mints-PMMA composites

Figure 107. Synthesis of a ROMP-U-shape derivative containing less U-shape units.

Figure 107 shows Compound HH-1 "ROMP-OTs derivate of Example HH11"

Figure 107shows Compound HH-2 "ROMP-N3 derivate of Example HH11"

Figure 107shows Compound HH-3, alkyne U-shape.

Figure 107shows Compound HH-4 "ROMP-U-shape derivate of Example HH11"

Figure 108. Synthesis of a ROMP-U-shape derivative containing free acid groups.

Figure 108 shows Compound HH-5, "ROMP-OTs-acid derivate of Example HH13"

Figure 108 shows Compound HH-6, "ROMP-N3-acid derivate of Example HH13"

Figure 108 shows Compound HH-7, "ROMP-U-shape-acid derivate of Example HH13"

Figure 109 . In situ polymerization of Nylon in the presence of ROMP polymer-coated carbon nanotubes having free terminal acyl chloride groups.

Figure 109 shows Compound HH-8, "ROMP polymer-coated SWNTs having free terminal acyl chloride groups of Example HH15"

Figure 109 shows Compound HH-9, "Nylon 6,6 reinforced with ROMP polymer-coated SWNTs of Example HH16"

Figure 110. Mechanochemical synthesis of nanotube-ML complexes using a mortar.

Figure 110 shows Compound HH-10

Figure 111. Mechanochemical synthesis of nanotube-ML complexes using a ball mill.

Figure 111 shows ethylene glycol pyrene precursor-ML (Compound HH-11).

Figure 112. Sequential mechanochemical synthesis of nanotube-ML complexes using a ball mill.

Figure 112 shows dialkylated pyrene precursor-ML (Compound HH-12)

Figure 113. Flow mechanochemical synthesis of nanotube-ML complexes

Figure 113 shows diamino precursor-ML (Compound HH-13)

Figure 114. Mechanochemical preparation of LDPE composites reinforced with SWNT-ML

Figure 114 shows pyrene precursor-ML (Compound HH-14)

Figure 115. Schematic of the processing of Commercial thermoset polyurethane (ALEXIT® BladeRep LEP 9) composites with diamino-boc MINTs

Figure 116. Photograph of the ALEXIT® BladeRep LEP 9 composite with diaino-boc MINTs

Figure 117 Thermoplastic polyurethane polymerization scheme

Figure 118 General formulation of thermoplastic polyurethane

Figure 119a. Different sequences of events leading to polymer composites

Figure 119b. Different sequences of events leading to ROMP polymer-carbon nanotube composite materials

Figure 119c. Sequence 1, reaction used to generate polystyrene-coated tuball SWNTs

Figure 119d. Sequence 2, reaction used to generate polyaminoacid-coated SWNTs.

Figure 119e. Sequence 3A, reaction used to generate polyurethane-coated Tuball SWNTs.

Figure 119f. Sequence 3B, reaction used to generate polyvinylchloride-coated SWNTs

Figure 119g. Sequence 3C, reaction used to generate epoxy-coated DWNTs

Figure 119h. Sequence 4, reaction used to generate polypropylene-coated SWNTs

Figure 120a. Connecting polymer and ML by amide-bond formation

Figure 120b. Connecting polymer and ML by amide-bond formation

Figure 120c. Connecting polymer and ML by amide-bond formation

Figure 121. Connecting polymer and ML by nucleophilic substitution

Figure 122. ROMP polymer-coated SWNT representations

Figure 123. Metathesis of double bonds, leading to attachment of polymers to the ROMP polymer-coated nanotubes or leading to crosslinking of the ROMP polymer-coated nanotubes.

Figure 124. A fishing rod made from sized SWNTs to which is added linear polyethylene chains comprising at least two double bonds.

Figure 125. A gear made from ROMP polymer-coated SWNTs that become cross-linked by linkers comprising aromatic chains and two double bonds.

Figure 126. A suitcase made from ROMP polymer-coated SWNTs to which is attached polystyrene without crosslinking separate SWNTs

Figure 127. Introduction of functional groups, by using linkers carrying the desired functionalities.

Figure 128. A roofing membrane made from ROMP polymer-coated SWNTs to which is added polypropylene by a Ziegler-Natta catalytic polymerization

Figure 129. A fishing line made from sized SWNTs to which is added polystyrene chains comprising one thiol, as well as polystyrene chains not carrying any thiols that can react with double bonds, and where the majority of the polystyrene chains do not become covalently linked to the sized SWNT until after processing (here extrusion).

Figure 130. A tire made from ROMP polymer-coated SWNTs to which is covalently linked cis-1,4-Polybutadiene

Figure 131. Vulcanization of modified SWNTs carrying double bonds

Figure 132. In situ polymerization leading to materials with thermoplastic or thermoset characteristics

Figure 133. General structure for azo compounds-based radical initiators

Figure 134. In situ polymerization involving azo compounds as initiators

Figure 135. SWNT carrying polystyrene

Figure 136. General structures generated by in situ polymerisation involving azo compounds as initiators

Figure 137. General structure for alkoxyamine and nitroxide-based radical initiators

Figure 138. SWNT-ML-polymer-TEMPO

Figure 139. SWNT-ML-polymer-polystyrene and SWNT-ML-polymer-polyisoprene

Figure 140. SWNT-ML-polymer-polystyrene

Figure 141. General structure for organic peroxides-based radical initiators

Figure 142. SWNT carrying polystyrene

Figure 143. In situ polymerisation involving ATRP initiators such as alkyl halides, to produce e.g., polystyrene-SWNT composite

Figure 144. General structures generated by in situ polymerisation involving ATRP initiators

Figure 145. SWNT-ML-polymer-RAFT initiator

Figure 146. General structures generated by in situ polymerisation involving RAFT initiators

Figure 147. In situ polymerisation involving organic photoinitiators

Figure 148. In situ polymerisation involving initiators that only react with one reactive group of a monomer that is asymmetric in the sense that it comprises two different reactive groups, both of which are involved in the polymerization process.

Figure 149. Ring-closing of a macrocycle around Tuball SWNTs

Figure 150. TGA analysis of "SWNT-ML composite of Example JJ36"

Figure 151. AC-HRTEM analysis of "SWNT-ML composite of Example JJ36"

Figure 152. Processing methodologies

Figure 153a. Bidentate compound carrying two MLs

Figure 153b. Pultrusion using drawn CNT forests, CNT thread or other types of CNT fibers and -lines

Figure 154a. Precursor-ML carrying protonated amines, binding to a carbon nanotube

Figure 154b. Precursor-ML carrying polar groups, binding to a carbon nanotube.

Figure 155. Recycling a thermoset-nanotube composite

Figure 156. Two approaches for making CNT-reinforced Kevlar.

Figure 157. Synthesis scheme for compound (ZZ-3)

Figure 158. Synthesis scheme for compound (ZZ-4)

Figure 159. Compound (ZZ-4) complexed to a nanotube

Figure 160. Synthesis scheme for compound (ZZ-6)

Figure 161. Synthesis scheme for compound (ZZ-7)

Figure 162. Compound (ZZ7) complexed to a nanotube

Figure 163. Synthesis scheme for compound (ZZ-14)

Figure 164. Synthesis scheme for compound (ZZ-15)

Figure 165. Compound (ZZ-15) complexed to a nanotube

Figure 166. Synthesis scheme for compound (ZZ-19)

Figure 167. Synthesis scheme for compound (ZZ-20)

Figure 168. Compound (ZZ-20) complexed to a nanotube

Figure 169. Taylor cone formation.

DETAILED DESCRIPTION OF THE INVENTION.

General components and processes.

General process.

In a preferred embodiment of the invention, a SE1-precursor-ML complex is formed by the following steps:

Step X1. Provide a SE1;

Step X2. Provide a precursor-ML;

to obtain a SE1-precursor-ML complex;

where Steps X1-X2 may be performed in any order.

In a preferred embodiment of the invention, SE1 is a nanotube, carbon nanotube, graphene, SWNT, MWNT, or nanowire, and the precursor-ML is a chemical structure comprising one or two or more chemical moieties with affinity for the SE1, e.g. a Ushape or another chemical entity comprising at least one ligand moiety with affinity for the SE1.

In another preferred embodiment of the invention, a nanotube-Ushape complex is formed by the following steps:

Step Y1. Provide a SE1, where the SE1 is a nanotube;

Step Y2. Provide a precursor-ML, where the precursor-ML is a Ushape comprising two chemical moieties with affinity for the nanotube;

to obtain a nanotube-Ushape complex;

where Steps Y1-Y2 may be performed in any order.

In another preferred embodiment of the invention, a nanotube-closed ring complex is formed by the following steps:

Step Z1. Provide a SE1, where the SE1 is a nanotube;

Step Z2. Provide a precursor-ML, where the precursor-ML is a Ushape comprising two chemical moieties with affinity for the nanotube;

Step Z3. Optionally, add a catalyst or a further reagent;

where Steps Z1-Z3 may be performed in any order;

to obtain a nanotube-ML complex where the ML is a closed ring around the nanotube;

In a preferred embodiment of the invention, a number of precursor-MLs are added in Step Z2, and all or some of these are converted to MLs, in the form of closed rings.

The MLs added in Step Z2 may all be the same or different.

The complex obtained following Step Z3 may comprise only MLs (e.g. closed rings), or may obtain on each nanotube one or more precursor-MLs (e.g. Ushapes) and one or more MLs (e.g. closed rings).

The presence of precursor-MLs (e.g. Ushapes) in the final complex may be attractive in cases where a high conductivity of the final composite is desired; the presence of MLs (e.g. closed rings) may be attractive where a practically irreversible mechanical bonding is desired.

Process for making CMUs and composite materials.

General process.

In a preferred embodiment of the invention, a composite material is produced by the following steps:

Step 1a. Provide a SE1;

Step 1b. Provide a precursor-ML;

Step 1c. Optionally, provide a catalyst;

Step 1d. Provide a SE2;

to generate a SE1-ML-SE2 structure.

Steps 1a, 1b, 1c, and 1d may be performed in any order.

Example 0 and Figure 119a examplify different variations of the general process, where the individual steps are performed in different order.

In a preferred embodiment of the invention, SE1 is a nanotube, the precursor-ML comprises at least one ligand moiety with affinity for the nanotube and comprising two reactive groups that can react to allow ring-closing of the Ushape around the nanotube, thereby forming the ML, and the SE2 is a polymer that may optionally be capable of reacting with a functional group of the ML, thereby covalently linking the SE2 to the ML.

SE2 may be a small molecule (e.g. a monomer, capable of reacting with other monomers to form a polymer) or may be a larger molecule (e.g. a polymer). Thus, in the Step 1d the SE2 that is provided may be a monomer which upon the polymerization reaction with other monomers becomes a polymer. Therefore, over time the SE2 may change from being a monomer to being a polymer.

In a similar way, the SE1 provided in the Step 1a may be initially provided in the form of a building block which then upon reaction with other building blocks ends up being a larger structure (e.g. a nanotube, graphene, polymer or mineral). Therefore, over time the SE1 may change from being a smaller chemical structure (a building block) to being a larger chemical structure (an extended chemical structure like e.g. a nanotube).

In a preferred embodiment SE2 is a polymer that is covalently linked to the precursor-ML in the first reaction of the process, as indicated by the following steps:

Step 2a. Provide a precursor-ML;

Step 2b. Provide a polymer and react polymer with precursor-ML to form a covalent bond between polymer and precursor-ML;

Step 2c. Provide a SE1 and allow precursor-ML to associate with SE1;

Step 2d. Provide a catalyst that is capable of mediating reaction of two functional groups of the precursor-ML, thereby forming the ML, mechanically bound to SE1;

to generate a SE1-ML-polymer structure.

Figure 119a describes the production of composite materials comprising nanotubes (as SE1) and polymer (as SE2). These sequences of events and the general approach of producing composite materials apply, however, to all kinds of SE1 and SE2, and therefore generally describe the production of polymer-, ceramics- and metal composites, and any other kind of composite materials. For non-polymer composites, the applicable SE2 can simply replace "polymer" in the various schemes of Figure 119a.

Moreover, the 8 different sequences of events, depicted in Figure 119a, may be combined in any way.

Sequence 1 of Figure 119a describes the initial binding of precursor-ML (in the figure: a Ushape) to a SE1 (in the figure: a nanotube), followed by formation of the SE1-ML complex, and finally addition of SE2 (in the figure: a polymer) and reaction between SE2 and ML to form the final product, SE1-ML-SE2. Thus, in a preferred embodiment of the invention, the following steps are performed:

Step 3a. Provide a precursor-ML;

Step 3b. Provide a SE1, to form a SE1-precursor ML complex;

Step 3c. The precursor-ML is turned into a ML, mechanically bound to the SE1, optionally by the addition of catalyst and/or reagent(s);

Step 3d. Provide a SE2 and covalently or non-covalently link it to the ML, optionally by the addition of catalyst and/or reagent(s);

to form a SE1-ML-SE2 structure.

Sequence 2 of Figure 119a describes the initial formation of a poly-precursor-ML (in the figure: poly-Ushape) by reaction of multiple precursor-MLs with one SE2 (in the figure: polymer), followed by addition of SE1 (in the figure: nanotube) and ring-closing around SE1, to form a SE1-ML-SE2 structure. Accordingly, this sequence of events can be described by the following process steps:

Step 4a. Provide a precursor-ML;

Step 4b. Provide a SE2, and attach one or more precursor-ML to SE2;

Step 4c. Provide a SE1, and allow complexation to form a SE1-precursor-ML-SE2 complex;

Step 4d. Convert the precursor-ML to a ML, mechanically bound to SE1;

to form a SE1-ML-SE2 complex.

Sequence 3A of Figure 119a describes the initial mixing of precursor-ML (in the figure: Ushape) and a portion of SE2 (in the figure: monomer), to generate the structure precursor-ML-portion of SE2 (in the figure: Ushape-monomer structure), and then SE1 (in the figure: nanotube) is added, precursor-ML-portion of SE2 is turned into ML-portion of SE2 structure, and finally the portions of SE2 are reacted to form SE2, and thereby generating a SE1-ML-SE2 structure. In this context, "the portion of SE2" is itself a SE2, as well as the full-size SE2 that is produced upon reaction of multiple "portions of SE2". Accordingly, the following steps are performed:

Step 5a. Provide a precursor-ML and a portion of SE2, and associate or react the two components to form a precursor-ML-portion of SE2 structure;

Step 5b. Provide a SE1 and allow SE1-precursor-ML complex formation;

Step 5c. Turn the precursor-ML into a ML, to form a SE1-ML-portion of SE2 structure;

Step 5d. Allow reaction of the portions of SE2 with each other;

to form a SE1-ML-SE2 structure.

Sequence 3B of Figure 119a describes the initial mixing of precursor-ML (in the figure: Ushape) and a portion of SE2 (in the figure: monomer), to generate the structure precursor-ML-portion of SE2 (in the figure: Ushape-monomer structure), and then SE1 (in the figure: nanotube) is added, to form the complex SE1-precursor-ML-portion of SE2, then the portions of SE2 are reacted to form the complex SE1-precursor-ML-SE2, and finally the precursor-ML is turned into ML, thereby generating the SE1-ML-SE2 structure. In this context, "the portion of SE2" is itself a SE2, as well as the full-size SE2 that is produced upon reaction of multiple "portions of SE2". Accordingly, the following steps are involved:

Step 6a. Provide a precursor-ML and a portion of SE2, and associate or react the two components to form a precursor-ML-portion of SE2 structure;

Step 6b. Provide a SE1 and allow SE1-precursor-ML-portion of SE2 complex formation;

Step 6c. Allow reaction between portions of SE2, attached to precursor-MLs, to form the SE1-precursor-ML-SE2 structure;

Step 6d. Convert the precursor-ML into a ML;

to form a SE1-ML-SE2 complex.

Sequence 3C of Figure 119a describes the initial mixing of precursor-ML (in the figure: Ushape) and a portion of SE2 (in the figure: monomer), to generate the structure precursor-ML-portion of SE2 (in the figure: Ushape-monomer structure), and then SE1 (in the figure: nanotube) is added, followed by complexation, conversion of precursor-ML into ML (in the figure: ring closing) and SE2 formation (in the figure: polymerization), thereby generating the SE1-ML-SE2 structure. In this context, "the portion of SE2" is itself a SE2, as well as the full-size SE2 that is produced upon reaction of multiple "portions of SE2". Accordingly, the following steps are performed:

Step 7a. Provide a precursor-ML and a portion of SE2, and associate or react the two components to form a precursor-ML-portion of SE2 structure;

Step 7b. Provide a SE1 and allow SE1-precursor-ML-portion of SE2 complex formation;

Step 7c. Allow conversion of the precursor-ML to a ML and formation of a SE2 from portions of SE2;

to form a SE1-ML-SE2 complex.

Sequence 4A of Figure 119a describes how precursor-MLs (in the figure: Ushapes) carrying a polymerization terminator moiety (PT) is first complexed to a SE1 (in the figure: nanotube) and then the precursor ML is converted to a ML (in the figure: closed ring) mechanically bound to the SE1, then portions of SE2 (in the figure: monomers) are added, and following the association of the portions of SE2 (in the figure: the polymerization of the monomers to form the polymer), the SE2 is attached to the ML through the PT, by way of the last reaction of the polymerization terminating on the polymerization terminator, to form a SE1-ML-SE2 structure. In this context, "the portion of SE2" is itself a SE2, as well as the full-size SE2 that

is produced upon reaction of multiple "portions of SE2". Accordingly, Sequence 4A can be summarized by the following steps:

Step 8a. A SE1, a precursor-ML carrying a polymerization terminator (PT), and optionally a catalyst capable of mediating the conversion of precursor-ML into ML, and a monomer is provided, leading to formation of the SE1-ML complex, where the ML carries a polymerization terminator moiety (PT).

Step 8b. Optionally, a catalyst is provided;

Step 8c. Polymerization proceeds to form a polymer in solution;

Step 8d. The growing polymer eventually terminates its polymerization on the polymerization terminator, thereby forming a SE1-ML-SE2 structure in which one ML is attached to one polymer.

Sequence 4B of Figure 119a describes how precursor-MLs (in the figure: Ushapes) carrying a reactive group (PT) is first complexed to a SE1 (in the figure: nanotube) and then the precursor ML is converted to a ML (in the figure: closed ring) mechanically bound to the SE1, and portions of SE2 (in the figure: monomers) are added, and following the association of the portions of SE2 (in the figure: the polymerization of the monomers to form the polymer, which in this case carries a reactive group capable of reaction with PT), then the SE2 is attached to the ML, through a reaction between PT and the one reactive group of the polymer, to form a SE1-ML-SE2 structure. In this context, "the portion of SE2" is itself a SE2, as well as the full-size SE2 that is produced upon reaction of multiple "portions of SE2". Accordingly, Sequence 4A can be summarized by the following steps:

Step 9a. A SE1, a precursor-ML carrying a reactive group (PT), and optionally a catalyst capable of mediating the conversion of precursor-ML into ML, and monomers are provided, leading to formation of the SE1-ML complex, where the ML carries a reactive group (PT).

Step 9b. Optionally, a catalyst is provided;

Step 9c. Polymerization proceeds to form a polymer in solution, where the polymer carries one reactive group capable of reacting with the other reactive group (PT);

Step 9d. Optionally, a catalyst and/or reagent(s) are provided;

Step 9e. The reactive group of the polymer is brought to react with the reactive group (PT) of the ML;

to form a SE1-ML-SE2 structure.

In some instances, it is desirable to first form the SE1-ML complex, e.g. in order to disperse the SE1 more efficiently, and then dissociate the SE1-ML complex to obtain SE1 in its "free" form (not complexed to ML), as this may allow the efficient dispersion of SE1 without the ML complexed. As an example, it might increase the electrical conductivity or heat conductivity of a composite material comprising SE1-ML complexes if the ML is dissociated from the SE1. Thus, in a preferred embodiment the following steps are performed in order to obtain well-dispersed, non-ML-complexed SE1 in a composite:

Step 10a. Provide a SE1;

Step 10b. Provide a precursor-ML;

Step 10c. Provide a catalyst and/or conditions allowing the precursor-ML to become a ML, complexed to the SE1;

Step 10d. Provide a SE2;

to generate a composite material comprising a SE1-ML-SE2 structure;

Step 10e. Dissociate the SE1-ML complex into a SE1 and a ML;

to obtain a composite material comprising ML, SE2, and non-ML-complexed SE1.

In a variation of the scheme immediately above, SE1 is a carbon nanotube, the precursor-ML is a UShape carrying two reactive groups, capable of reacting with each other and thereby turn the Ushape into a closed ring around the carbon nanotube (whereby the

precursor-ML becomes a ML). Thus, in a preferred embodiment of the invention, the following steps are performed:

Step 11a. Provide a carbon nanotube;

Step 11b. Provide a Ushape carrying two reactive groups, capable of reacting with each other to turn the Ushape into a closed ring structure, wrapped around the carbon nanotube, where the two reactive groups may both be double bonds, and where part of the Ushape (and hence part of the closed ring structure) comprises a cleavable moiety, such as a polypeptide;

Step 11c. Provide a catalyst, e.g. Grubb's second generation catalyst, under conditions allowing the catalyst to mediate the transformation of Ushape into closed ring around the carbon nanotube, thereby generating carbon nanotube-closed ring complexes;

Step 11d. Provide a polymer, e.g. nylon or other polyamide, polypropylene, polyethylene (HDPE or LDPE), PVC, polyurethane, polycarbonate, or polystyrene, and mix, to obtain a mixture of well-dispersed carbon nanotube-closed ring complexes in a matrix of polymer;

Step 11e. Add a cleaving agent capable of cleaving the closed ring, to open the closed ring, e.g. if the cleavable moiety of the Ushape is a polypeptide, then a protease is added capable of cleaving the polypeptide; and allow the cleaving agent to cleave the cleavable moiety, to obtain non-ML-complexed carbon nanotube in a matrix of polymer.

Depending on the efficiency with which the rings are removed from the carbon nanotube, the composite resulting from Step 11e may be more or less electrically conductive or heat conductive.

A composite material is provided which comprises nanotubes, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 1 mm.

A ML-nanotube complex is also provided, comprising at least two mechanical ligands (ML) complexed to a single nanotube, and wherein said at least two mechanical ligands are covalently linked to one another.

A Mechanical Ligand (ML) is capable of forming a mechanical bond with a structural entity, such as a nanotube, particularly a carbon nanotube (CNT). The ligand optionally changes the characteristics of the structural entity upon binding to it.

A mechanical bond is a bond between a mechanical ligand (ML) and a structural entity (SE) where at least one intramolecular covalent bond in either the SE or one intramolecular covalent bond in the ML must be broken in order to bring the structural entity and the mechanical ligand apart.

However, for a complex of an SE and an ML where the SE and/or ML has an aspect ratio of more than 100 (one hundred), a Mechanical Bond shall mean a bond between said ML and said SE where at least one intramolecular covalent bond in the SE or in the ML must be broken in order to bring the SE and the ML apart in a direction other than the direction of the largest dimension of said SE and/or said ML that has an aspect ratio of more than 100. An intramolecular covalent bond shall mean a covalent bond between atoms within a given molecule (i.e. within the SE or within the ML, but not between the SE and ML).

The following is an example of such a mechanical bond between MLs and SEs that keep the SE and the ML interlocked as a consequence of their topology: The ML is e.g. a closed ring such as a peptide, wrapped around a nanotube that has an aspect ratio larger than 100. The ends of the peptide have been covalently linked so that the peptide forms a continuous string of covalently linked atoms around the nanotube. The nanotube is a cylindrical structure with an aspect ratio of more than 100, which means that its length (along the cylindrical axis) is more than 100 times larger than its diameter (the diameter of the cylindrical structure). Theoretically, the ML (the closed ring peptide) and the SE (the nanotube) could be brought apart by moving the ML up or down the length of the nanotube (i.e. in the direction of the largest dimension of the nanotube), without breaking an intramolecular covalent bond of the closed ring peptide (the ML) or of the nanotube (the SE). However, it is impossible to bring the closed ring peptide and the nanotube apart in a direction other than the direction of the largest dimension of the nanotube (which has an aspect ratio of more than 100) without breaking an intramolecular covalent bond in the closed ring peptide or the nanotube, and therefore the closed ring peptide and the nanotube forms a mechanical bond between them.

MLs of the present invention may be used to increase the solubility or dispersion of structural entities, and are particularly useful when the structural entity has low solubility or

dispersion in a given solvent or composite material. Addition of the ML, and the formation of a mechanical bond between the ligand and the structural entity may then increase solubility, particularly if the ML carries chemical moieties that increase solubility or dispersion of the SE to which it is bound, in the solvent or matrix that surrounds it.

MLs of the present invention may also be used to preferentially disperse subgroups of structural entities. As an example, if a mechanical ligand is more likely to become attached to a nanotube of a certain chirality, relative to another nanotube of a different chirality, it will preferentially disperse this nanotube, provided that the ML carries chemical moieties that increase the solubility or dispersion of the nanotube that it binds.

ML-promoted solubilization or dispersion thus provides a means to obtain a better dispersion of e.g additives in composite materials. Thus, addition of a ML that binds the structural entity, to the additive stock solution, or to the polymerization reaction that generates the composite material, or at any other step of composite material production, can improve solubilization or dispersion of the additive during the process and/or in the final composite material.

CNTs (carbon nanotubes) may be difficult to disperse in solvents used in composite material production processes. Addition of CNT-binding MLs during production of e.g. CNT-reinforced polymers may often improve dispersion and/or solubilization, leading to a better distribution of the CNT in the final composite.

What is further provided is the preparation, structure and use of a complex comprising a structural entity (SE) and a ML, where the characteristics of the structural entity when bound by the ML is different from the characteristics of the structural entity when not bound by the ML, or alternatively, the characteristics of said complex is different from the characteristics of the structural entity (SE) and the ML.

The ML-structural entity complex may comprise one or more ligands and one or more structural entities, and thus can be described by the formula

$$\mathbf{SE_o\text{-}ML_p}$$

where SE is a structural entity, and
ML is a chemical moiety capable of mechanically binding to the SE, and
o and p are integers larger than zero.

Characteristics of the structural entity that may be perturbed, modified, increased or decreased, include any one or more of the following characteristics: Size of SE, Conductivity of SE, Density of SE, Specific density of SE, Strength of SE (e.g. Young's Modulus, tensile strength, other types of strength), Melting point of SE, Elongation at break of SE. For any of these characteristics of an SE, and in each characteristic's entire range, further characteristics of the SE that may be modified upon mechanical binding of the ML include any one or more of the following: stiffness, electrical conductivity, thermal conductivity, color, fluorescence, luminescence, UV protective capability, abrasion resistance, ductility, elasticity, flexibility, energy storage capability (including energy storage as heat or kinetic energy), information storage capability, hydrophilicity, hydrophobicity, polarity, aproticity, and charge, as well as the following characteristics where the unit of measure is indicated after each characteristic: Arc Resistance, sec; Impact Strength, Charpy, J/cm; Impact Strength, Izod Notched, J/cm ; Impact Strength, Izod Unnotched, J/cm ; Impact Strength, Charpy Notched Low Temp, J/cm; Impact Strength, Izod Notched Low Temp, J/cm; Impact Strength, Charpy Unnotched Low Temp, J/cm; Impact Strength, Charpy Unnotched, J/cm; Linear Mold Shrinkage, cm/cm; Maximum Service Temperature, Air, ; Melt Flow, g/10 min; Melting Point, ; Modulus of Elasticity, GPa; Moisture Absorption at Equilibrium, % ; Oxygen Transmission, cc-mm/m; Poisson's Ratio; Processing Temperature, ; Surface Resistance, ohm; Tensile Strength, Ultimate, MPa; Tensile Strength, Yield, MPa; Thermal Conductivity, W/m-K; UL RTI, Electrical, ; UL RTI, Mechanical with Impact, ; UL RTI, Mechanical without Impact, ; Vicat Softening Point, ; Water Absorption, %; Coefficient of Friction; Comparative Tracking Index, V; Compressive Yield Strength, MPa; CTE, linear 20; Deflection Temperature at 0.46 MPa, ; Deflection Temperature at 1.8 MPa, ; Density, g/cc; Dielectric Constant; Dielectric Constant, Low Frequency ; Dielectric Strength, kV/mm; Dissipation Factor; Dissipation Factor, Low Frequency ; Electrical Resistivity, ohm-cm; Elongation @ break, %; Flammability, UL94 ; Flexural Modulus, GPa; Flexural Yield Strength, MPa; Glass Temperature, ; Hardness, Barcol; Hardness, Rockwell E; Hardness, Rockwell M; Hardness, Rockwell R; Hardness, Shore A; Hardness, Shore D; Heat Capacity, J/g.

Depending on the application, an SE with a low, medium, or high degree of each of these characteristics is preferable in the present invention.

In a preferred embodiment, the characteristic of the SE that is modified by the binding of the ML is the strength (e.g. tensile strength, Young's modulus, elongation at break). Particularly preferred embodiments involve SE-ligand complexes where the strength of the SE is increased upon attachment to the ML. The term "reinforced structural entity" will be used in

the present invention to describe a complex of a structural entity and a ML in which the strength of the SE is increased compared to the strength of the SE when not bound by the ML.

In a preferred embodiment the reinforced structural entity is a component of a composite material unit (CMU) where said CMU may further be a component of a composite material. The reinforced structural entity, as well as the structural entity itself, in this case may be termed a filler or additive.

In another preferred embodiment the characteristic of the SE that is modified by the binding of the ML is the conductivity. Particularly preferred embodiments involve SE-ML complexes where the conductivity of the SE is increased upon binding of the ML. Such ML-structural entity complexes where the conductivity of the structural entity has been perturbed by the binding of a ML may be useful as sensor molecules in various electronic circuits. In some cases, it is preferred that the conductivity of the SE is decreased upon binding of the ML. This is commonly the case when the SE-ML complex is part of a sensor molecule or sensor apparatus.

In a preferred embodiment, the ML-SE complex consists of a structural entity (SE) to which is attached a number of MLs. The characteristics of the SE-ML complex changes as more MLs are bound. In some applications, a high number of MLs is desired. This may for example be the case where the SE-ML complex is used in a nanosensor context, where the ML is further attached to e.g. a receptor molecule that binds to the analyte in question, leading to a change in conductivity of the SE, which can be followed as a change in read-out of the sensor. The more MLs that are bound to the SE, the more receptor molecules can be immobilized on the SE-ML complex, and the more the read-out will change as the analyte or more analytes bind to the nanosensor.

Thus, depending on the context, the number of MLs bound per structural entity is preferably greater than 1, such as greater than 2, such as greater than 5, such as greater than 10, such as greater than 20, such as greater than 50, such as greater than 100, such as greater than 200, such as greater than 500, such as greater than 1000, such as greater than 10^4, such as greater than 10^5, such as greater than 10^6, such as greater than 10^7, such as greater than 10^8, such as greater than 10^9.

In other cases, a smaller number of MLs bound to the SE is preferred. As an example, if the SE-ML complex is part of a composition of CMUs, such as part of a composite material, the ML may interfere with the polymerization- or processing process that generates the composite material, wherefore it may be preferable to use a smaller number of MLs bound to an SE. Thus, depending on the context, the number of MLs attached to a structural entity is preferably less than 10^9, such as less than 10^8, such as less than 10^7, such as less than 10^6, such as less than 10^5, such as less than 10^4, such as less than 10^3, such as less than 10^2, such as less than 10, such as less than 2.

Thus, the preferred number of MLs per structural entity is often a compromise and depends on the context, and may be in the range of 1 to 2, or 2 to 10, or 10 to 100, or 100 to 1000, or 10^3 to 10^4, or 10^4 to 10^5, or 10^5 to 10^6, or 10^6 to 10^7, or 10^7 to 10^8, or 10^8 to 10^9.

As described above and below, the optimal number of MLs bound to a structural entity varies depending on the context of its use and the process of its generation.

In a preferred embodiment of said preferred embodiment, the SE is a nanotube, eg. a carbon nanotube, or a graphene molecule, bound by more than 1 ML, more preferably by more than 10 MLs, more preferably by more than 100 MLs, more preferably by more than 1000 MLs, more preferably by more than 10 000 MLs, more preferably by more than 100 000 MLs, even more preferably by more than 1 000 000 MLs. In a preferred embodiment of said preferred embodiment, the SE is a carbon nanotube, other nanotube or graphene molecule, bound by less than 10^9 MLs, such as less than 10^8 MLs, less than 10^7 MLs, less than 10^6 MLs, less than 10^5 MLs, less than 10^4 MLs, less than 10^3 MLs, less than 10^2 MLs, less than 10 MLs, less than 2 MLs.

The final chemical structure of the ML may be generated prior to association with the SE, or may be generated during or upon association with the SE. See (Figure 3) for examples of MLs that are generated during or upon association with an SE.

For MLs whose final structure is generated during or upon association with the SE, the affinity of the precursor-ML (ie. the chemical entity that binds to the SE, but is not yet capable of forming a mechanical bond – such as eg. a linear peptide binding to a carbon nanotube) for the SE, is an important characteristic of a ML. Thus, with a higher affinity of the precursor-ML for SE, a certain number of MLs, bound to SE, may be achieved with a lower amount of precursor-MLs added. Thus, in a preferred embodiment, the precursor-MLs have a dissociation constant for the SE, such as the carbon nanotube, other nanotube, or

the graphene, respectively, of less than 10^{-2} M, more preferably less than 10^{-3} M, more preferably less than 10^{-4} M, more preferably less than 10^{-5} M, more preferably less than 10^{-6} M, more preferably less than 10^{-7} M, more preferably less than 10^{-8} M, more preferably less than 10^{-9} M, more preferably less than 10^{-10} M, more preferably less than 10^{-12} M, more preferably less than 10^{-14} M, more preferably less than 10^{-16} M, more preferably less than 10^{-18} M, more preferably less than 10^{-20} M, more preferably less than 10^{-25} M, more preferably less than 10^{-30} M, more preferably less than 10^{-35} M, more preferably less than 10^{-40} M, more preferably less than 10^{-50} M.

In other contexts, it is preferable that the affinity of the precursor-ML is low. For example, if the relevant characteristics of the SE (such as conductivity of a carbon nanotube) is negatively affected by strong binding of a ML, it is preferable that the ML (and precursor-ML) binds with low affinity to the SE. Thus, in a preferred embodiment, the precursor-MLs have a dissociation constant for the SE, such as the carbon nanotube, other nanotube, or the graphene, respectively, of more than 10^{-50} M, more preferably more than 10^{-40} M, more preferably more than 10^{-35} M, more preferably more than 10^{-30} M, more preferably more than 10^{-25} M, more preferably more than 10^{-20} M, more preferably more than 10^{-18} M, more preferably more than 10^{-16} M, more preferably more than 10^{-14} M, more preferably more than 10^{-12} M, more preferably more than 10^{-10} M, more preferably more than 10^{-9} M, more preferably more than 10^{-8} M, more preferably more than 10^{-7} M, more preferably more than 10^{-6} M, more preferably more than 10^{-5} M, more preferably more than 10^{-4} M, more preferably more than 10^{-3} M, more preferably more than 10^{-2} M.

In a preferred embodiment of said preferred embodiment, the SE is a carbon nanotube or graphene molecule, bound by more than 1 ML, more preferably by more than 10 MLs, more preferably by more than 100 MLs, more preferably by more than 1000 MLs, more preferably by more than 10 000 MLs, more preferably by more than 100 000 MLs, even more preferably by more than 1 000 000 MLs, where the individual precursor MLs, corresponding to said MLs have a dissociation constant for the carbon nanotube or the graphene, respectively, of more than 10^{-50} M, more preferably more than 10^{-40} M, more preferably more than 10^{-35} M, more preferably more than 10^{-30} M, more preferably more than 10^{-25} M, more preferably more than 10^{-20} M, more preferably more than 10^{-18} M, more preferably more than 10^{-16} M, more preferably more than 10^{-14} M, more preferably more than 10^{-12} M, more preferably more than 10^{-10} M, more preferably more than 10^{-9} M, more preferably more than 10^{-8} M, more preferably more than 10^{-7} M, more preferably more than 10^{-6} M, more

preferably more than 10^{-5} M, more preferably more than 10^{-4} M, more preferably more than 10^{-3} M, more preferably more than 10^{-2} M.

In a preferred embodiment of said preferred embodiment, the SE is a carbon nanotube or graphene molecule, bound by less than 10^{9} MLs, such as less than 10^{8} MLs, less than 10^{7} MLs, less than 10^{6} MLs, less than 10^{5} MLs, less than 10^{4} MLs, less than 10^{3} MLs, less than 10^{2} MLs, less than 10 MLs, less than 2 MLs, where the individual pre-cursor MLs, corresponding to said MLs have a dissociation constant for the carbon nanotube or the graphene, respectively, of more than 10^{-50} M, more preferably more than 10^{-40} M, more preferably more than 10^{-35} M, more preferably more than 10^{-30} M, more preferably more than 10^{-25} M, more preferably more than 10^{-20} M, more preferably more than 10^{-18} M, more preferably more than 10^{-16} M, more preferably more than 10^{-14} M, more preferably more than 10^{-12} M, more preferably more than 10^{-10} M, more preferably more than 10^{-9} M, more preferably more than 10^{-8} M, more preferably more than 10^{-7} M, more preferably more than 10^{-6} M, more preferably more than 10^{-5} M, more preferably more than 10^{-4} M, more preferably more than 10^{-3} M, more preferably more than 10^{-2} M.

In a preferred embodiment of said preferred embodiment, the SE is a carbon nanotube, other nanotube, or graphene molecule, bound by 1 to 10, or 10 to 10^{2}, or 10^{2} to 10^{3}, or 10^{3} to 10^{4}, or 10^{4} to 10^{5}, or 10^{5} to 10^{6}, or 10^{6} to 10^{7}, or 10^{7} to 10^{8}, or 10^{8} to 10^{9} MLs, where the individual precursor MLs, corresponding to said MLs, have a dissociation constant for the carbon nanotube or the graphene, respectively, of 10^{-50} to 10^{-30} M, or 10^{-30} to 10^{-20} M, or 10^{-20} to 10^{-10} M, or 10^{-10} to 10^{-9} M, or 10^{-9} to 10^{-8} M, or 10^{-8} to 10^{-7} M, or 10^{-7} to 10^{-6} M, or 10^{-6} to 10^{-5} M, or 10^{-5} to 10^{-4} M, or 10^{-4} to 10^{-3} M, or 10^{-3} to 10^{-2} M.

What is further provided in this invention is a structure of, and a process for preparing, a Linker Unit (LU) of the following composition:

ML-LinkerL-Ligand2

where
ML is chemical entity that is capable of forming a mechanical bond with a structural entity,
LinkerL is a chemical bond or entity that links ML and Ligand2,
Ligand2 is a chemical entity that is capable of binding covalently or non-covalently to a structural entity, or alternatively, is capable of forming a mechanical bond with a structural entity,

and optionally, where
a structural entity, SE1, is bound to ML, and
a structural entity, SE2, is bound to Ligand2,
thereby forming a composite material unit (CMU) of the following composition:

SE1-ML-LinkerL-Ligand2-SE2

where
SE1 is a Structural Entity,
ML is chemical entity that is mechanically bound to SE1,
LinkerL is a chemical bond or entity that links ML and Ligand2,
Ligand2 is a chemical entity that is attached to SE2,
SE2 is a Structural Entity,

The LU thus may be used to link two structural entities. The LU as described in the present invention is capable of efficiently linking two or more structural entities.

A structural entity SE is a chemical or physical entity. A structural entity may be an atom (e.g. an ion), a molecule (e.g. a nylon polymer or a CNT), or part of a surface /material (e.g. metal).

SE1 can be identical to SE2; SE1 can be of the same type as SE2, e.g. can both be nanotubes; SE1 can be of a different type than SE2, e.g. SE1 may be a nanotube and SE2 may be a plastic polymer. SE1 binds an ML; SE2 may also bind an ML or may not bind an ML.

The CMU may be used in the preparation of composite materials with improved or novel characteristics. The CMU as described in the present invention links different parts of the composite material in an efficient manner. The link may either be covalent or non-covalent.

What is further claimed is a composition, and the process of preparing a composition, comprising two or more CMUs. The two or more CMUs may be identical, essentially identical or different.

CMUs can be the sole constituents of composite materials, or further components may be added to form composite materials with unique characteristics.

Preferred embodiments include compositions comprising CMUs and a matrix such as a metal, a ceramic or a polymer.

The various components of the Composite Material Unit (CMU) are described below.

Guidelines for using the present invention.

- When using the present invention to make composite materials, the characteristics sought for the composite material must first be defined. Then an appropriate matrix material and additive can be chosen, e.g. from Group 1: Polymers, or Group 2: Polymers and plastics, or Group 3: Additives. As an example, if light-weight material with high strength is sought, one may choose a light-weight polymer material (e.g. polypropylene) as one of the structural entities (SE1), and an additive with high strength (e.g. a carbon nanotube) as the other structural entity (SE2).
- Then it must be decided which ligands should be used. For good anchoring of the additive in the matrix one may choose to use a covalent bond as ligand between the polymer (SE2) and the linker. An appropriate covalent bond can be chosen from Group 6: Reactive groups and covalent bonds formed upon reactions, or Group 7: Covalent bond-forming chemical reactions, or Group 8: Covalent bonds. Thus, reactive groups on the polymer units must be present or introduced, for reaction with the linker unit. Alternatively, some or all of the polymer units must be covalently linked to the linker prior to the polymerization of the polymer matrix. In the example in which a CNT is chosen as additive, it would be appropriate to use a mechanical ligand, and thereby obtain a mechanical bond between the CNT (SE1) and the linker. In the design of a mechanical ligand, a SE1-binding moiety can be chosen from Group 4: Chemical motifs and the SEs they bind, or Group 5: Chemical motifs and the SEs they bind, or Group 10; CNT-binding moieties. The linker may be chosen from Group 9. Linkers. If a low degradability of the composite material is desired, ligands (ML and Ligand2) should be chosen to not comprise easily cleavable bonds such as amide bonds, and also, the ligands preferably should not comprise natural amino acids.
- Once the principal components (structural entities, ligands, and linkers) of the composite material have been defined, the formation of the CMU and composite

material in general can be performed, by adding the appropriate catalysts, reagents and components in appropriate amount and order.

- In the above example a composite material consisting of polypropylene (matrix material) and carbon nanotube (additive, providing strength), held together by a linker comprising a covalent ligand (covalent bond between linker and polypropylene) and a mechanical ligand (bound to carbon nanotube), will have been produced.

Further considerations may have to be taken into account when designing the process for producing the composite material:

- Solubility of the SEs is also an important parameter to consider. If the SE, that here functions as the additive, is soluble in both the solvent employed during the polymerization reaction and in the polymer itself, the SE will become evenly distributed in the composite material. However, sometimes a less soluble SE may be an advantage, as a decreased solubility might mediate interaction between SEs of the same kind, which may sometimes be an advantage, e.g. for efficient load transfer where efficient interaction is mediated by direct interactions between SEs of the same kind.

- When making composites comprising tube-like structures such as nanotubes with mechanical ligands in the form of rings around them, it is often desirable that the nature of the ring, i.e. its charge, polarity, content of various elements, etc., is similar to the nature of the structural entities that are in the composite. As an example, if one wishes to make a CNT-polyamide composite, it is desirable that the mechanical ligand har polyamide-like features. Thus, it is desirable that the mechanical ligand is itself a polyamide, and that the ring does not carry too many undesired chemical moieties. One such undesired chemical moiety could be a nanotube binding domain of the precursor-ML. Thus, it is desirable if means are applied that leads to a minimization or elimination of the content of such undesired chemical moieties in the final composites.

MLs and SeE

Structural Entity (SE).

A structural entity SE is a chemical or physical entity. A structural entity is typically used to anchor the CMU in place in the larger structure of the composite material, or alternatively, is

used to modify the characteristics of the composite material, e.g. by modifying the strength or flexibility of the composite material. A structural entity may also provide alternative characteristics such as conductivity, heat absorption, energy storage, etc. Finally, an SE can be a CMU.

When an SE is added to a composite material, e.g. to increase the strength of the composite material, it is in most cases an additive that makes it more expensive to produce the composite material and therefore makes the final composite material more expensive. Thus, depending on the context, the amount of SE added per composite material product is preferably less than 10^9 kg, such as less than 10^8 kg, such as less than 10^7 kg, such as less than 10^6 kg, such as less than 10^5 kg, such as less than 10^4 kg, such as less than 10^3 kg, such as less than 100 kg, such as less than 10 kg, such as less than 1 kg, such as less than 0.1 kg, such as less than 0.01 kg, such as less than 10^{-3} kg, such as less than 10^{-4} kg, such as less than 10^{-5} kg, such as less than 10^{-6} kg, such as less than 10^{-7} kg, such as less than 10^{-8} kg, such as less than 10^{-9} kg, such as less than 10^{-10} kg, such as less than 10^{-11} kg, such as less than 10^{-12} kg.

In other cases, the SE added to the composite material is an additive that makes it cheaper to produce the composite material and therefore makes the final composite material less expensive. Thus, depending on the context, the amount of SE added is preferably greater than 10^{-12} kg, such as greater than 10^{-11} kg, such as greater than 10^{-10} kg, such as greater than 10^{-9} kg, such as greater than 10^{-8} kg, such as greater than 10^{-7} kg, such as greater than 10^{-6} kg, such as greater than 10^{-5} kg, such as greater than 10^{-4} kg, such as greater than 10^{-3} kg, such as greater than 0.01 kg, such as greater than 0.1 kg, such as greater than 1 kg, such as greater than 10 kg, such as greater than 100 kg, such as greater than 10^3 kg, such as greater than 10^4 kg, such as greater than 10^5 kg, such as greater than 10^6 kg, such as greater than 10^7 kg, such as greater than 10^8 kg, such as greater than 10^9 kg.

Thus, the preferred compromise between addition of a large amount of SE and a low amount of SE depends on the context, and may be smaller than 10^{-12} kg, but may also be in the range of 10^{-12}–10^{-11} kg, 10^{-11}–10^{-10} kg, 10^{-10}–10^{-9} kg, 10^{-9}–10^{-8} kg, 10^{-8}–10^{-7} kg, 10^{-7}–10^{-6} kg, 10^{-6}–10^{-5} kg, 10^{-5}–10^{-4} kg, 10^{-4}–10^{-3} kg, 0.001–0.01 kg, 0.01–0.1 kg, 0.1–1 kg, 1–10 kg, 10–100 kg, 100–1,000 kg, 10^3–10^4 kg, 10^4–10^5 kg, 10^5–10^6 kg, 10^6–10^7 kg, 10^7–10^8 kg, 10^8–10^9 kg, or above 10^9 kg.

In most cases, it is not the absolute amount of SE that matters most, but rather the relative amount of SE versus total amount of material. Thus, depending on the context, the total weight of the SEs of a composite material relative to the weight of the composite material is preferentially greater than 0,00001%, more preferably greater than 0,0001%, more preferably greater than 0,001%, more preferably greater than 0,01%, more preferably greater than 0,1%, more preferably greater than 0,1%, more preferably greater than 1%, more preferably greater than 5%, more preferably greater than 10%, more preferably greater than 20%, more preferably greater than 30%, more preferably greater than 40%, more preferably greater than 50%, more preferably greater than 60%, more preferably greater than 70%, more preferably greater than 80%, more preferably greater than 90%, and even more preferably greater than 95%.

When producing an SE, the MW of the SE is an important parameter. In many cases, a low MW is preferred as smaller molecule are often less expensive to produce compared to larger molecules. Thus, depending on the context, the SE MW is preferably less than 10^9 Dal, such as less than 10^8 Dal, such as less than 10^7 Dal, such as less than 10^6 Dal, such as less than 10^5 Dal, such as less than 10^4 Dal, such as less than 10^3 Dal, such as less than 10^2 Dal, such as less than 10 Dal, such as less than 3 Dal.

In other cases, a high MW is preferred as larger molecules are often less expensive to purify. Thus, depending on the context, the molecular weight is preferably greater than 3 Dal, such as greater than 10 Dal, such as greater than 10^2 Dal, such as greater than 10^3 Dal, such as greater than 10^4 Dal, such as greater than 10^5 Dal, such as greater than 10^6 Dal, such as greater than 10^7 Dal, such as greater than 10^8 Dal, such as greater than 10^9 Dal.

Therefore, depending on the context, preferred molecular weight of structural entities include molecular weights ranging from 3 Dalton to more than 10^9 Dalton, such as from 3–10 Dal (e.g. Li+ or Na+), 10–100 Dal (e.g. benzene), 100–1000 Dal, 1000–10,000 Dal (e.g. a 20 amino acid natural polypeptide) 10,000–20,000 Dal (e.g a polymer chain such as nylon), 20,000–30,000 Dal, 30,000–40,000 Dal, 40,000–50,000 Dal, 50,000–70,000 Dal, 70,000–100,000 Dal, 100,000–200,000 Dal, 200,000–500,000 Dal, 500,000–1,000,000 Dal (e.g. carbon nanotube), 1,000,000–2,000,000 Dal, 2,000,000–4,000,000 Dal, 4,000,000–10,000,000 Dal, 10,000,000–100,000,000 Dal, 100,000,000–1,000,000,000 Dal, or particles with molecular weight larger than 10^9 Dal (e.g. gold particles).

Another important characteristic is the number of functional groups an SE comprises, as an SE with many functional groups will often be more expensive to synthesize. Thus, depending on the context, the number of functional groups on an SE is preferably less than 10^9, such as less than 10^8, such as less than 10^7, such as less than 10^6, such as less than 10^5, such as less than 10^4, such as less than 10^3, such as less than 100, such as less than 90, such as less than 80, such as less than 70, such as less than 60, such as less than 50, such as less than 40, such as less than 30, such as less than 25, such as less than 20, such as less than 15, such as less than 10, such as less than 9, such as less than 8, such as less than 7, such as less than 6, such as less than 5, such as less than 4, such as less than 3, such as less than 2.

In other cases a high number of functional groups is desired, as the functional groups can be used to link an SE to a ML or Ligand2 or another SE, or to increase the dispersibility of the SE. Thus, depending on the context, the number of functional groups on an SE is preferably greater than 1, such as greater than 2, such as greater than 3, such as greater than 4, such as greater than 5, such as greater than 6, such as greater than 7, such as greater than 8, such as greater than 9, such as greater than 10, such as greater than 15, such as greater than 20, such as greater than 25, such as greater than 30, such as greater than 40, such as greater than 50, such as greater than 60, such as greater than 70, such as greater than 90, such as greater than 100, such as greater than 10^3, such as greater than 10^4, such as greater than 10^5, such as greater than 10^6, such as greater than 10^7, such as greater than 10^8, such as greater than 10^9.

Thus, the preferred compromise between having an SE with many functional groups and an SE with few functional groups depends on the context, and may be in the range of 1–2, 2–3, 3–4, 4–5, 5–6, 6–7, 7–8, 8–9, 9–10, 10–15, 15–20, 20–25, 25–30, 30–40, 40–50, 50–60, 60–70, 70–80, 80–90, 90–100, 100–1,000, 10^3–10^4, 10^4–10^5, 10^5–10^6, 10^6–10^7, 10^7–10^8, 10^8–10^9, or above 10^9.

Particularly preferred structural entities include nanotubes such as carbon nanotubes, fullerenes, other carbon-based molecular structures, or any other kind of molecular-, supramolecular-, or macroscopic structures.

The SEs suitable for the present invention may have a number of characteristics.

SEs may be organic or inorganic.

In a preferred embodiment of the invention, the structural entity SE1 is a tube-like structure, such as a nanotube, nanowire, nanofiber, nanorod or other tube-like structure, preferably with a high aspect ratio, such as an aspect ratio of at least 10, such as at least 100, such as at least 1000, such as at least 10000, or such as at least 100000, and a covalently closed ring that is wrapped around the tube-like structure constitutes the mechanical ligand. Most preferably, the structural entity is a nanotube, particularly a carbon nanotube.

For any characteristics of an SE mentioned above, and in each characteristic's entire range, a further characteristic of importance is the molecular weight of the SE.

Molecular weight of SEs. The molecular weight is an important determinant for the characteristics of SEs, and for the characteristics of the CMUs they are part of. For example, larger polymers typically form stronger, less flexible materials, whereas smaller polymers typically are more flexible, but have lesser strength. Therefore, depending on the context, preferred molecular weight of structural entities include molecular weights ranging from 3 Dalton to more than 10^9 Dalton, such as from 3–10 Dal (e.g. Li+ or Na+), 10–100 Dal (e.g. benzene), 100–1000 Dal, 1000–10,000 Dal (e.g. a 20 amino acid natural polypeptide) 10,000–20,000 Dal (e.g a polymer chain such as nylon), 20,000–30,000 Dal, 30,000–40,000 Dal, 40,000–50,000 Dal, 50,000–70,000 Dal, 70,000–100,000 Dal, 100,000–200,000 Dal, 200,000–500,000 Dal, 500,000–1,000,000 Dal (e.g. carbon nanotube), 1,000,000–2,000,000 Dal, 2,000,000–4,000,000 Dal, 4,000,000–10,000,000 Dal, 10,000,000–100,000,000 Dal, 100,000,000–1,000,000,000 Dal, or particles with molecular weight larger than 10^9 Dal (e.g. gold particles).

In cases where the strength is of highest importance, typically a high molecular weight is preferred. Thus, depending on the context, the molecular weight is preferably greater than 3 Dal, such as greater than 10 Dal, such as greater than 10^2 Dal, such as greater than 10^3 Dal, such as greater than 10^4 Dal, such as greater than 10^5 Dal, such as greater than 10^6 Dal, such as greater than 10^7 Dal, such as greater than 10^8 Dal, such as greater than 10^9 Dal.

In cases where the flexibility is of highest importance, a low molecular weight is typically preferred. Thus, depending on the context, the molecular weight is preferably less than 10^9 Dal, such as less than 10^8 Dal, such as less than 10^7 Dal, such as less than 10^6 Dal, such as less than 10^5 Dal, such as less than 10^4 Dal, such as less than 10^3 Dal, such as less than 10^2 Dal, such as less than 10 Dal, such as less than 3 Dal.

For any characteristics of an SE mentioned above, and in each characteristic's entire range, a further characteristic of importance is the melting point of the SE.

Melting point of SE. The melting point of the SE is often an important parameter, since the melting point of the composite often is strongly dependent on the melting point of the SE. Some applications including CMUs of the present invention involve elevated temperatures, wherefore it is important that the CMU maintains its integrity and structure at such elevated temperatures. This is for example the case when said CMU is part of a composite material, used in an application that involves high temperatures. In these cases a high melting point is preferred.
Thus, depending on the context, the melting point of the SE is preferably greater than -20 ºC, such as greater than 0 ºC, such as greater than 50 ºC, such as greater than 100 ºC, such as greater than 200 ºC, such as greater than 400 ºC, such as greater than 600 ºC, such as greater than 800 ºC, such as greater than 1000 ºC, such as greater than 1500 ºC, such as greater than 2000 ºC, such as greater than 3000 ºC, such as greater than 4000 ºC, such as greater than 6000 ºC, such as greater than 8000 ºC.
In other cases, a composite material's flexibility at low temperatures is important, wherefore a low melting point may be advantageous. Thus, depending on the context, the melting point of the SE is preferably less than 8000 ºC, such as less than 6000 ºC, such as less than 4000 ºC, such as less than 3000 ºC , such as less than 2000 ºC, such as less than 1500 ºC, such as less than 1000 ºC, such as less than 800 ºC , such as less than 600 ºC, such as less than 400 ºC, such as less than 200 ºC, such as less than 100 ºC, such as less than 50 ºC , such as less than 0 ºC, such as less than -20 ºC.

Depending on the context, preferred melting points of SEs thus are below 0 ºC, such as between -20 ºC and 0 ºC; or may be higher, such as between 0 ºC and 50 ºC, or between 50 ºC and 100 ºC, or between 100 ºC and 200 ºC, or between 200 ºC and 300 ºC, or between 300 ºC and 400 ºC, or between 400 ºC and 500 ºC, or between 500 ºC and 600 ºC, or between 600 ºC and 700 ºC, or between 700 ºC and 800 ºC, or between 800 ºC and 900 ºC, or between 900 ºC and 1,000 ºC, or between 1,000 ºC and 1,100 ºC, or between 1,000 ºC and 1,200 ºC, or between 1,200 ºC and 1,400 ºC, or between 1,400 ºC and 1,600 ºC, or between 1,600 ºC and 1,800 ºC, or between 1,800 ºC and 2,000 ºC, or between 2,000 ºC and 2,200 ºC, or between 2,200 ºC and 2,400 ºC, or between 2,400 ºC and 2,600 ºC, or between 2,600 ºC and 2,800 ºC, or between 2,800 ºC and 3,000 ºC, or between 3,000 ºC and 3,200 ºC, or between 3,200 ºC and 3,400 ºC, or between 3,400 ºC and 3,600 ºC, or

between 3,600 °C and 3,800 °C, or between 3,800 °C and 4,000 °C, or between 4,000 °C and 4,200 °C, or between 4,200 °C and 4,400 °C, or between 4,400 °C and 4,600 °C, or between 4,600 °C and 4,800 °C, or between 4,800 °C and 5,000 °C, or between 5,000 °C and 5,200 °C, or between 5,200 °C and 5,400 °C, or between 5,400 °C and 5,600 °C, or between 5,600 °C and 5,800 °C, or between 5,800 °C and 6,000 °C, or between 6,000 °C and 6,200 °C, or between 6,200 °C and 6,400 °C, or between 6,400 °C and 6,600 °C, or between 6,600 °C and 6,800 °C, or between 6,800 °C and 7,000 °C, or between 7,000 °C and 7,200 °C, or between 7,200 °C and 7,400 °C, or between 7,400 °C and 7,600 °C, or between 7,600 °C and 7,800 °C, or between 7,800 °C and 8,000 °C, or between 8,000 °C and 8,200 °C, or between 8,400 °C and 8,600 °C, or between 8,600 °C and 8,800 °C, or between 8,800 °C and 9,000 °C, or between 9,000 °C and 9,200 °C, or between 9,200 °C and 9,400 °C, or between 9,400 °C and 9,600 °C, or between 9,600 °C and 9,800 °C, or between 9,800 °C and 10,000 °C, or between 10,000 °C and 11,000 °C, or between 11,000 °C and 12,000 °C, or between 12,000 °C and 13,000 °C, or between 13,000 °C and 14,000 °C, or between 14,000 °C and 15,000 °C, or between 15,000 °C and 16,000 °C, or between 16,000 °C and 17,000 °C, or between 17,000 °C and 18,000 °C, or between 18,000 °C and 19,000 °C, or between 19,000 °C and 20,000 °C, or above 20,000 °C. The matrix of a composite to a high degree determines the melting point of the composite; in particular, ceramics and metals have high melting points.

For any characteristics of an SE mentioned above, and in each characteristic's entire range, a further characteristic of importance is the conductivity of the SE.

Conductivity of SE. In certain applications, e.g. use of a composite material in wind turbine blades, it may be important that the propellers are non-conductive, in order to not attract lightning. In other cases it may be desirable to prepare composite materials of modest or high conductivity, in order to be able to detect cracks in the material by analytical measurement of the conductance of the material. Likewise, for SEs used in e.g. nanosensor technology it may be important that the SE is conductive, in order to be able to detect changes in conductivity induced by the association of an analyte with the SE. In some sensor applications it may be desirable to have high conductivity (if the analyte has a strong reducing effect on the conductance of the SE), or it may be desirable to use an SE with an intermediate conductivity in order to detect small changes in conductivity. In other applications, the composite material is used as an insulator, wherefore it is important that the SE has very low conductivity. Thus, depending on the application it may be desirable that

the SE has low, intermediate or high conductivity. Structural entities may have conductivities ranging from below 10^{-30} S/m to at least 10^{11} S/m and higher, such as from below 10^{-30} S/m to 10^{-25} S/m (e.g. Teflon), such as from 10^{-25} S/m to 10^{-20} S/m (e.g. PET), such as from 10^{-20} S/m to 10^{-15} S/m (e.g. Quarts (fused) and Paraffin), such as from 10^{-15} S/m to 10^{-10} S/m (e.g. Hard Rubber, Diamond, Glass), such as from 10^{-10} S/m to 10^{-5} S/m (e.g. GaAs, Silicon), such as from 10^{-5} S/m to 1 S/m, such as from 1 S/m to 10 S/m (e.g. Germanium), such as from 10 S/m to 10^{2} S/m, such as from 10^{2} S/m to 10^{4} S/m (e.g. graphite), such as from 10^{4} S/m to 10^{6} S/m (e.g. Nichrome, Mercury,), such as from 10^{6} S/m to 10^{8} S/m (e.g. Stainless steel, Titanium, Platinum, Iron, Lithium, Aluminum, Gold, Cupper, Silver), such as from 10^{8} S/m to 10^{9} S/m, such as from 10^{9} S/m to 10^{10} S/m, such as from 10^{10} S/m to 10^{11} S/m (e.g. Carbon nanotubes), such as from 10^{11} S/m to 10^{12} S/m (e.g. Carbon nanotubes), such as from 10^{12} S/m to 10^{14} S/m, and above 10^{14} S/m (e.g. superconducting material).

Thus, depending on the context, the conductivity of an SE is preferably greater than 10^{-30} S/m, such as greater than 10^{-25} S/m, such as greater than 10^{-20} S/m, such as greater than 10^{-15} S/m, such as greater than 10^{-10} S/m, such as greater than 10^{-5} S/m, such as greater than 1 S/m, such as greater than 10 S/m, such as greater than 10^{2} S/m, such as greater than 10^{4} S/m, such as greater than 10^{6} S/m, such as greater than 10^{8} S/m, such as greater than 10^{9} S/m, such as greater than 10^{10} S/m, such as greater than 10^{11} S/m, such as greater than 10^{12} S/m, such as greater than 10^{13} S/m, such as greater than 10^{14} S/m.

In other applications, and depending on the context, the conductivity is preferably less than 10^{14} S/m, such as less than 10^{13} S/m, such as less than 10^{12} S/m, such as less than 10^{11} S/m, such as less than 10^{10} S/m, such as less than 10^{9} S/m, such as less than 10^{8} S/m, such as less than 10^{6} S/m, such as less than 10^{4} S/m, such as less than 10^{2} S/m, such as less than 10 S/m, such as less than 1 S/m, such as less than 10^{-5} S/m, such as less than 10^{-10} S/m, such as less than 10^{-15} S/m, such as less than 10^{-20} S/m, such as less than 10^{-25} S/m, such as less than 10^{-30} S/m.

For any characteristics of an SE mentioned above, and in each characteristic's entire range, a further characteristic of importance is the density and strength of the SE, as well as the ratio between the density and the various types of strength.

Density and Strength of the SE. For certain applications, for example in the airplane or automotive industry, the strength and density of the composite material is of prime importance. Sometimes, one of the two features is by far the most important. For example, if

a structure such as a bridge must be built and the structure must carry a lot of weight, where this weight is much larger than the weight of the structure itself, the weight of the composite material from which the structure is built, has little importance. Only strength is important. In cases where no significant force is applied to the material other than gravity, the weight of the structure becomes important, but the stength is not important. This is for example the case where the composite material is used to make a sculpture that rests on some other structure.

Often, both low density and high strength is desired. However, as these two parameters often are opposing factors, a compromise will have to be made. Therefore, sometimes a high density is acceptable to gain strength, such as high tensile strength or large Young's Modulus. In other cases, low density is necessary, even if lower strength results. Thus, in preferred embodiments the SE may have relatively low Young's modulus or low tensile strength, and in other preferred embodiments the SE has large Young's modulus or large tensile strength; and likewise, in preferred embodiments the density can vary from very small to very large.

Preferred specific densities of SEs suitable for the present invention are lower than 0.01 kg/L, but may also include specific densities in the following ranges: 0.01–0.1 kg/L; 0.1–0.4 kg/L; 0.4–0.6 kg/L; 0.6–0.8 kg/L; 0.8–1 kg/L; 1–1.2 kg/L; 1.2–1.4 kg/L; 1.4–1.6 kg/L; 1.6–1.8 kg/L; 1.8–2 kg/L; 2–2.5 kg/L; 2.5–3 kg/L; 3–3.5 kg/L; 3.5–4 kg/L; 4–4.5 kg/L; 4.5–5 kg/L; 5–5.5 kg/L; 5.5–6 kg/L; 6–6.5 kg/L; 6.5–7 kg/L; 7–7.5 kg/L; 7.5–8 kg/L; 8–8.5 kg/L; 8.5–9 kg/L; 9–9.5 kg/L; 9.5–10 kg/L; 10–11 kg/L; 11–12 kg/L; 12–13 kg/L; 13–14 kg/L; 14–16 kg/L; 16–20 kg/L; 20–30 kg/L; or above 30 kg/L.

In some cases high specific densities are preferred. This may be the case when an anchor is made of a composite material comprising SEs, as the anchor should rest heavily on the bottom of the ocean. Thus, depending on the context, the specific density is preferably greater than 0.01 kg/L, such as greater than 0.05 kg/L, such as greater than 0.2 kg/L, such as greater than 0.4 kg/L, such as greater than 0.6 kg/L , such as greater than 0.8 kg/L, such as greater than 1 kg/L, such as greater than 1.2 kg/L, such as greater than 1.5 kg/L , such as greater than 2 kg/L, such as greater than 4 kg/L, such as greater than 6 kg/L, such as greater than 8 kg/L, such as greater than 10 kg/L, such as greater than 12 kg/L, such as greater than 14 kg/L, such as greater than 16 kg/L , such as greater than 20 kg/L, such as greater than 30 kg/L.

In many cases low specific density is preferred. This is for example the case if the SE is part of a composite material, used to make ships that must float on the water, wherefore the weight must be minimized. Thus, depending on the context, the specific density is preferably less than 30 kg/L, such as less than 20 kg/L, such as less than 16 kg/L, such as less than 14 kg/L, such as less than 12 kg/L, such as less than 10 kg/L, such as less than 8 kg/L, such as less than 6 kg/L, such as less than 4 kg/L, such as less than 2 kg/L, such as less than 1.5 kg/L, such as less than 1.2 kg/L, such as less than 1 kg/L, such as less than 0.8 kg/L, such as less than 0.6 kg/L, such as less than 0.4 kg/L, such as less than 0.2 kg/L, such as less than 0.05 kg/L, such as less than 0.01 kg/L.

The Young's modulus of SEs. In the majority of applications of composite materials, a high Young's modulus is preferred, as this will allow the material to recover its original shape after force has been applied to the material. Thus, depending on the context, the Young's modulus is preferably greater than 0.001 TPa, such as greater than 0.01 TPa, such as greater than 0.1 TPa, such as greater than 0.15 TPa, such as greater than 0.2 TPa, such as greater than 0.5 TPa, such as greater than 1 TPa, such as greater than 2 TPa, such as greater than 4 TPa, such as greater than 6 TPa, such as greater than 8 TPa, such as greater than 10 TPa.
However, in a few applications, a low Young's modulus is desirable. This is for example the case when the degree of deformation of a composite material is being used as a measure of how much force was applied to the material. Thus, depending on the context, the Young's modulus is preferably less than 10 TPa, such as less than 8 TPa, such as less than 6 TPa, such as less than 4 TPa, such as less than 2 TPa, such as less than 1 TPa, such as less than 0.5 TPa, such as less than 0.2 TPa, such as less than 0.15 TPa, such as less than 0.1 TPa, such as less than 0.01 TPa, such as less than 0.01 TPa.

The Young's modulus of SEs suitable for the present invention can thus be lower than 0.001 TPa, but may also include SEs with Young's Modulus in the following ranges: 0.001–0 .01 TPa; 0.01–0.03 TPa; 0.03–0.05 TPa; 0.05–0.07 TPa; 0.07–0.09 TPa; 0.09–0.1TPa; 0.1–0.11 TPa; 0.11–0.12 TPa; 0.12–0.13 TPa; 0.13–0.14 TPa; 0.14–0.15 TPa; 0.15–0.16 TPa; 0.16–0.17 TPa; 0.17–0.18 TPa; 0.18–0.19 TPa; 0.19–0.20 TPa; 0.20–0.22 TPa (e.g. stainless steel); 0.22–0.25 TPa; 0.25–0.30 TPa; 0.30–0.35 TPa; 0.35–0.40 TPa; 0.40–0.45 TPa; 0.45–0.50 TPa; 0.50–0.60 TPa; 0.60–0.80 TPa; 0.80–1.0 TPa; 1–2 TPa (e.g. single–walled carbon nanotubes); 2–3 TPa; 3–4 TPa; 4–5 TPa; 5–7 TPa; 7–10 TPa; or above 10 TPA.

Preferred tensile strength of SEs is in most cases high, as this will enable the generation of composite materials of high tensile strength, suitable for a large number of applications, e.g. stronger fishing lines and stronger cables. Thus, depending on the context, the tensile strength of SEs is preferably greater than 0.01 GPa, such as greater than 0.05 GPa, such as greater than 0.1 GPa, such as greater than 0.5 GPa, such as greater than 1 GPa, such as greater than 2 GPa, such as greater than 3 GPa, such as greater than 5 GPa, such as greater than 10 GPa, such as greater than 20 GPa, such as greater than 30 GPa, such as greater than 40 GPa, such as greater than 60 GPa, such as greater than 80 GPa, such as greater than 100 GPa, such as greater than 200 GPa.

However, in some cases a low tensile strength is advantageous, for example in cables or lines that must break for safety reasons, in order to avoid damage to individuals. Thus, depending on the context, the tensile strength of SEs is preferably less than 200 GPa, such as less than 100 GPa, such as less than 80 GPa, such as less than 60 GPa, such as less than 40 GPa, such as less than 30 GPa, such as less than 20 GPa, such as less than 10 GPa, such as less than 5 GPa, such as less than 3 GPa, such as less than 2 GPa, such as less than 1 GPa, such as less than 0.5 GPa, such as less than 0.1 GPa, such as less than 0.05 GPa, such as less than 0.01 GPa.

The tensile strength for SEs suitable for the present invention can thus be lower than 0.01 GPa, but may also include SEs with tensile strengths in the following ranges: 0.01–0.03 GPa; 0.03–0.05 GPa; 0.05–0.07 GPa; 0.07–0.09 GPa; 0.09–0.1GPa; 0.1–0.11 GPa; 0.11–0.12 GPa; 0.12–0.13 GPa; 0.13–0.14 GPa; 0.14–0.15 GPa; 0.15–0.16 GPa; 0.16–0.17 GPa; 0.17–0.18 GPa; 0.18–0.19 GPa; 0.19–0.20 GPa; 0.20–0.22 GPa; 0.22–0.25 GPa; 0.25–0.30 GPa; 0.30–0.35 GPa; 0.35–0.40 GPa; 0.40–0.45 GPa; 0.45–0.50 GPa; 0.50–0.60 GPa; 0.60–0.80 GPa; 0.80–1.0 GPa; 1–2 GPa (e.g. stainless steel); 2–3 GPa; 3–4 GPa; 4–5 GPa; 5–7 GPa; 7–10 GPa; 10–15 GPa; 15–20 GPa; 20–25 GPa; 25–30 GPa; 30–35 GPa; 35–40 GPa; 40–45 GPa; 45–50 GPa (e.g. single–walled carbon nanotubes); 50–55 GPa; 55–60 GPa; 60–65 GPa; 65–70 GPa; 70–75 GPa; 75–80 GPa; 80–85 GPa; 85–90 GPa; 90–100 GPa; 100–200 GPa, or above 200 GPa.

Ratio of strength to specific density is often important. The strength/specific density ratio for the structural entity that is preferred under the present invention is represented by all the ratios that can be obtained, by dividing the abovementioned strengths with the abovementioned specific densities. Thus, preferred embodiments have structural entities with strength/specific densities in the range 0.00003-1000 TPa L/Kg (where strength is

represented by Young's modulus). More specifically, the strength/specific density (Young's Modulus) of the SE is preferably in the range 0.00003–1,000 TPa L/Kg , more preferably 0.001–1,000 TPA L/Kg, more preferably 0.01–1,000 TPA L/Kg, more preferably 0.1–1,000 TPA L/Kg, more preferably 1–1,000 TPA L/Kg, more preferably 10–1,000 TPA L/Kg, more preferably 100–1,000 TPA L/Kg, and more preferably 500–1,000 TPA L/Kg, or higher.
In cases where e.g. the Young's modulus should be low (see above), the Young's modulus/specific density ratio is preferably less than 1,000 TPA L/kg, such as less than 500 TPA L/kg, such as less than 100 TPa L/kg, such as less than 10 TPa L/kg, such as less than 1 TPa L/kg, such as less than 0.1 TPa L/kg, such as less than 0.01 TPa L/kg, such as less than 0.001 TPa L/kg, such as less than 0.00003 TPa L/kg.
In cases where e.g. Young's modulus is preferably high, the Young's modulus/specific density ratio is preferably greater than 0.00003 TPa L/kg, such as greater than 0.001 TPa L/kg, such as greater than 0.01 TPa L/kg, such as greater than 0.1 TPa L/kg, such as greater than 1 TPa L/kg, such as greater than 10 TPa L/kg, such as greater than 100 TPa L/kg, such as greater than 500 TPa L/kg, such as greater than 1,000 TPA L/kg.

Where strength is measured as tensile strength, the preferred embodiments have structural entities with strength/specific density in the range 0.0003–20,000 GPa L/Kg. More specifically, the tensile strength/specific density of the SE is preferably in the range 0.0003–20,000 GPa L/Kg , more preferably 0.01–20,000 GPa L/Kg, more preferably 0.1–20,000 GPa L/Kg, more preferably 1–20,000 GPa L/Kg, more preferably 10–20,000 GPa L/Kg, more preferably 100–20,000 GPa L/Kg, more preferably 1,000–20,000 GPa L/Kg, more preferably 5,000–20,000 GPa L/Kg, and more preferably 10,000–20,000 GPa L/Kg, or higher.
In cases where e.g. the tensile strength is preferably low (see above), the tensile strength/specific density ratio is preferably less than 20,000 GPa L/kg, such as less than 10,000 GPa L/kg, such as less than 5,000 GPa L/kg, such as less than 1,000 GPa L/kg, such as less than 100 GPa L/kg, such as less than 10 GPa L/kg, such as less than 1 GPa L/kg, such as less than 0.1 GPa L/kg, such as less than 0.0003 GPa L/kg.
In cases where e.g. tensile strength is preferably high, the tensile strength/specific density ratio is preferably greater than 0.0003 GPa L/kg, such as greater than 0.1 GPa L/kg, such as greater than 1 GPa L/kg, such as greater than 10 GPa L/kg, such as greater than 100 GPa L/kg, such as greater than 1,000 GPa L/kg, such as greater than 5,000 GPa L/kg, such as greater than 10,000 GPa L/kg, such as greater than 20,000 GPA L/kg.

Preferred fracture toughness of SEs is in most cases high, as this will enable the generation of composite materials with a low risk of cracks propagating through the composite, ultimately leading to fracture. Examples of composite materials where a high fracture toughness is desirable includes, but are not limited to, wind turbine blades and airplane wings. Thus, depending on the context, the fracture toughness is preferably greater than 0.01 MPa·m^{½}, such as greater than 0.1 MPa·m^{½}, such as greater than 1 MPa·m^{½}, such as greater than 2 MPa·m^{½}, such as greater than 5 MPa·m^{½}, such as greater than 10 MPa·m^{½}, such as greater than 15 MPa·m^{½}, such as greater than 20 MPa·m^{½}, such as greater than 25 MPa·m^{½}, such as greater than 30 MPa·m^{½}, such as greater than 40 MPa·m^{½}, such as greater than 50 MPa·m^{½}, such as greater than 75 MPa·m^{½}, such as greater than 100 MPa·m^{½},

However, in some applications, a low fracture toughness is desirable. As an example, the fracture toughness of the windows in a train needs to be sufficiently low that a person can break the window using an appropriate tool in an emergency situation. Thus, depending on the context, the fracture toughness is preferably less than 100 MPa·m^{½}, such as less than 75 MPa·m^{½}, such as less than 50 MPa·m^{½}, such as less than 40 MPa·m^{½}, such as less than 30 MPa·m^{½}, such as less than 25 MPa·m^{½}, such as less than 20 MPa·m^{½}, such as less than 15 MPa·m^{½}, such as less than 10 MPa·m^{½}, such as less than 5 MPa·m^{½}, such as less than 2 MPa·m^{½}, such as less than 1 MPa·m^{½}, such as less than 0,1 MPa·m^{½}, such as less than 0.01 MPa·m^{½}.

The fracture toughness for SEs suitable for the present invention can thus be lower than 0.01 MPa·m^{½}, but may also include SEs with fracture toughness in the following ranges: 0.01–0.1 MPa·m^{½}, 0.1–1 MPa·m^{½}, 1–2 MPa·m^{½}, 2–5 MPa·m^{½}, 5–10 MPa·m^{½}, 10–15 MPa·m^{½}, 15–20 MPa·m^{½}, 20–25 MPa·m^{½}, 25–30 MPa·m^{½}, 30–40 MPa·m^{½}, 40–50 MPa·m^{½}, 50–75 MPa·m^{½}, 75–100 MPa·m^{½}, or above 100 MPa·m^{½}.

Bulk modulus of SEs. In the majority of applications of composite materials, a high bulk modulus is preferred, as this will allow the composite material to withstand a high compression, which is important in structural elements of buildings, bridges, etc. Thus, depending on the context, the bulk modulus is preferably greater than 0.001 GPa, such as greater than 0.01 GPa, such as greater than 0.1 GPa, such as greater than 1 GPa, such as greater than 10 GPa, such as greater than 50 GPa, such as greater than 100 GPa, such as greater than 200 GPa, such as greater than 300 GPa, such as greater than 400 GPa, such as greater than 500 GPa, such as greater than 600 GPa, such as greater than 700 GPa,

such as greater than 800 GPa, such as greater than 900 GPa, such as greater than 1,000 GPa.

However, in a few applications, a low bulk modulus is desirable. This is for example the case in some foam products, where it should be easy to compress the foam, e.g. using a person's body weight. Thus, depending on the context, the bulk modulus is preferably less than 1,000 GPa, such as less than 900 GPa, such as less than 800 GPa, such as less than 700 GPa, such as less than 600 GPa, such as less than 500 GPa, such as less than 400 GPa, such as less than 300 GPa, such as less than 200 GPa, such as less than 100 GPa, such as less than 50 GPa, such as less than 10 GPa, such as less than 1 GPa, such as less than 0.1 GPa, such as less than 0.01 GPa, such as less than 0.001 GPa.

The bulk modulus for SEs suitable for the present invention can thus be lower than 0.001 GPa, but may also include SEs with bulk modules in the following ranges: 0.001–0.01 GPa, 0.01–0.1 GPa, 0.1–1 GPa, 1–10 GPa, 10–100 GPa, 100–200 GPa, 200–300 GPa, 300–400 GPa, 400–500 GPa, 500–600 GPa, 600–700 GPa, 700–800 GPa, 800–900 GPa, 900–1,000 GPa, or above 1,000 GPa.

Shear modulus of SEs. In the majority of applications of composite materials, a high shear modulus is preferred, as this will allow the composite material to withstand large forces imposed on the composite material in opposite directions, e.g. brakes on bicycles, cars, wind turbines, etc. Thus, depending on the context, the shear modulus is preferably greater than 0.001 GPa, such as greater than 0.01 GPa, such as greater than 0.1 GPa, such as greater than 1 GPa, such as greater than 10 GPa, such as greater than 50 GPa, such as greater than 100 GPa, such as greater than 200 GPa, such as greater than 300 GPa, such as greater than 400 GPa, such as greater than 500 GPa, such as greater than 600 GPa, such as greater than 700 GPa, such as greater than 800 GPa, such as greater than 900 GPa, such as greater than 1,000 GPa.

However, in some applications, a low shear modulus is desirable. This is for example the case in plastic composite materials used for buttons, e.g. to turn on or off electronic equipment. Such buttons must have a low shear modulus so pressing them is sufficiently easy. Thus, depending on the context, the shear modulus is preferably less than 1,000 GPa, such as less than 900 GPa, such as less than 800 GPa, such as less than 700 GPa, such as less than 600 GPa, such as less than 500 GPa, such as less than 400 GPa, such as less than 300 GPa, such as less than 200 GPa, such as less than 100 GPa, such as less

than 50 GPa, such as less than 10 GPa, such as less than 1 GPa, such as less than 0.1 GPa, such as less than 0.01 GPa, such as less than 0.001 GPa.

The shear modulus for SEs suitable for the present invention can thus be lower than 0.001 GPa, but may also include SEs with shear modules in the following ranges: 0.001–0.01 GPa, 0.01–0.1 GPa, 0.1–1 GPa, 1–10 GPa, 10–100 GPa, 100–200 GPa, 200–300 GPa, 300–400 GPa, 400–500 GPa, 500–600 GPa, 600–700 GPa, 700–800 GPa, 800–900 GPa, 900–1,000 GPa, or above 1,000 GPa.

Other kinds of strength, such as torsional strength and impact strength, are also of importance. Thus, SEs with low, medium or high torsional strength, and SEs with low, medium or high impact strength are suitable for the present invention, and represent preferred embodiments.

For any characteristics of an SE mentioned above, and in each characteristic's entire range, a further characteristic of importance is the degree to which the SE can be elongated (stretched) without breaking.

Elongation at break. In many applications, a high elongation at break is preferred. This is for example important in components that absorb energy by deforming plastically such as crash barriers and car bumpers. Thus, depending on the context, the elongation at break is preferably greater than 0.1%, such as greater than 1%, such as greater than 5%, such as greater than 10%, such as greater than 20%, such as greater than 30%, such as greater than 40%, such as greater than 50%, such as greater than 60%, such as greater than 70%, such as greater than 80%, such as greater than 90%, such as greater than 100%, such as greater than 150%, such as greater than 200%, such as greater than 300%, such as greater than 400%, such as greater than 500%, such as greater than 800%, such as greater than 1,500%.

In other applications, a low elongation at break is preferred. This is important in composite materials that must not deform even under harsh conditions such as high pressure and elevated temperature; one such example is ceramic brakes on automobiles, aircrafts and trains. Thus, depending on the context, the elongation at break is preferably less than 1,500%, such as less than 800%, such as less than 500%, such as less than 400%, such as less than 300%, such as less than 200%, such as less than 150%, such as less than 100%, such as less than 90%, such as less than 80%, such as less than 70%, such as less than

60%, such as less than 50%, such as less than 40%, such as less than 30%, such as less than 20%, such as less than 10%, such as less than 5%, such as less than 1%, such as less than 0.1%.

SEs suitable for the present invention can thus have an elongation at break of less than 0.1%, or have elongation at break including the following ranges: 0.1–1%, 1–5%, 5–10%, 10–20%, 20–30%, 30–40%, 40–50%, 50–60%, 60–70%, 70–80%, 80–90%, 90–100%, 100–150%, 150–200%, 200–300%, 300–400%, 400–500%, 500–800%, 800–1,500%, or have elongation at break above 1,500%.

For any characteristics of an SE mentioned above, and in each characteristic's entire range, further characteristics of importance are size and shape of the SE.

Size of SE. The size and shape of the structural entity are important parameters. Thus, although depending on the characteristics of the structural entity, composite materials may benefit from SEs with extended shapes, preferably large in size, if the primary purpose is to increase the Young's modulus of the composite material, by including the SE. Thus, depending on the context, the size of the SE is preferably greater than 0.1 Å, such as greater than 2 Å, such as greater than 1 nm, such as greater than 10 nm, such as greater than 100 nm, such as greater than 1 µm, such as greater than 10 µm, such as greater than 100 µm, such as greater than 1 mm, such as greater than 10 mm.

For other applications, it may be an advantage to include SEs of smaller size, e.g. in order to increase molecular homogeneity of the composite material. In other cases, a primary characteristic of the composite material is even distribution of SEs and it may be generally desired that as little SE as possible should be used in the composite material, e.g. for economic reasons. In such cases, it may be desirable to include SEs of small size. Thus, depending on the context, the size of the SE is preferably less than 10 mm, such as less than 1 mm, such as less than 100 µm, such as less than 10 µm, such as less than 1 µm, such as less than 100 nm, such as less than 10 nm, such as less than 1 nm, such as less than 2 Å, such as less than 0.1 Å.

Often, the choice of size and shape will be a compromise between opposing interests. Thus, in preferred embodiments the SE may be very small to very large, depending on the application. For example, when making composite materials using thermoset polymers and glass fibers, typically long glass fibers in the size range 0.01–1 m are used, whereas when using thermoplastics shorter fibers of typically 1–10 mm are used.

Structural entities may vary in size from less than 1 Ångstrøm dimensions to the mm dimensions, such as from 0.1–2 Å (e.g. K^+), 2–10 Å (e.g. benzene), 1–10 nm (e.g a short polypeptide), 10–100 nm (e.g. a carbon nanotube, a protein), 100–1,000 nm (e.g a carbon fiber, PVC polymer molecule, a carbon nanotube), 1–10 µm (e.g. a gold particle), 10–100 µm (e.g. a nylon fiber), 100–1,000 µm (e.g an alumina fiber), 1–10 µm (e.g. a plant cell), 10–100 µm (e.g. a bamboo fiber), 100–1,000 µm (e.g. a silver particle), 1–10 mm (e.g. a carbon fiber), or particles larger than 10 mm in at least one dimension.

Further characteristics of SE. For any characteristics of an SE mentioned above, and in each characteristic's entire range, further characteristics of the SE that are of importance in the present invention are the stiffness, electrical conductivity, thermal conductivity, color, fluorescence, luminescence, UV protective capability, abrasion resistance, ductility, elasticity, flexibility, energy storage capability (energy storage as heat or kinetic energy), information storage capability, hydrophilicity, hydrophobicity, polarity, aproticity, and charge, as well as the following characteristics where the unit of measure is indicated after each characteristic: Arc Resistance, sec; Impact Strength, Charpy, J/cm; Impact Strength, Izod Notched, J/cm ; Impact Strength, Izod Unnotched, J/cm ; Impact Strength, Charpy Notched Low Temp, J/cm; Impact Strength, Izod Notched Low Temp, J/cm; Impact Strength, Charpy Unnotched Low Temp, J/cm; Impact Strength, Charpy Unnotched, J/cm; Linear Mold Shrinkage, cm/cm; Maximum Service Temperature, Air, ; Melt Flow, g/10 min; Melting Point, ; Modulus of Elasticity, GPa; Moisture Absorption at Equilibrium, % ; Oxygen Transmission, cc-mm/m; Poisson's Ratio; Processing Temperature, ; Surface Resistance, ohm; Tensile Strength, Ultimate, MPa; Tensile Strength, Yield, MPa; Thermal Conductivity, W/m-K; UL RTI, Electrical, ; UL RTI, Mechanical with Impact, ; UL RTI, Mechanical without Impact, ; Vicat Softening Point, ; Water Absorption, %; Coefficient of Friction; Comparative Tracking Index, V; Compressive Yield Strength, MPa; CTE, linear 20; Deflection Temperature at 0.46 MPa, ; Deflection Temperature at 1.8 MPa, ; Density, g/cc; Dielectric Constant; Dielectric Constant, Low Frequency ; Dielectric Strength, kV/mm; Dissipation Factor; Dissipation Factor, Low Frequency ; Electrical Resistivity, ohm-cm; Elongation @ break, %; Flammability, UL94 ; Flexural Modulus, GPa; Flexural Yield Strength, MPa; Glass Temperature, ; Hardness, Barcol; Hardness, Rockwell E; Hardness, Rockwell M; Hardness, Rockwell R; Hardness, Shore A; Hardness, Shore D; Heat Capacity, J/g. Depending on the application, an SE with a low, medium, or high degree of each of these characteristics is preferable in the present invention.

Further, SEs, in particular SE2, may be polymers or may be non-polymeric in structure.

The polymers can be divided into biological polymers and non-biological polymers.

Non-biological polymers include polymers that are not RNA, DNA or natural polypeptides, yet include PVC, epoxy, unnatural polypeptides (i.e. not solely comprising alpha-amino acids) and unnatural nucleic acids (e.g. PNA, LNA and other unnatural nucleic acids).

The following polymers represent preferred structural entities, suitable for the present invention:

Polymers. The following is a non-comprehensive list of preferred structural entities, in the form of polymers often categorized as the matrix material of a composite.

Group 1: Polymers.

1. Polymers of monoolefins and diolefins, for example polypropylene, polyisobutylene, polybut-1-ene, poly-4-methylpent-1-ene, polyvinylcyclohexane, polyisoprene or polybutadiene, as well as polymers of cycloolefins, for instance of cyclopentene or norbornene, polyethylene (which optionally can be crosslinked), for example high density polyethylene (HDPE), high density and high molecular weight polyethylene (HDPE-HMW), high density and ultrahigh molecular weight polyethylene (HDPE-UHMW), medium density polyethylene (MDPE), low density polyethylene (LDPE), linear low density polyethylene (LLDPE), (VLDPE) and (ULDPE).

Polyolefins, i.e. the polymers of monoolefins exemplified in the preceding paragraph, preferably polyethylene and polypropylene, can be prepared by different, and especially by the following, methods:

a) radical polymerisation (normally under high pressure and at elevated temperature).

b) catalytic polymerisation using a catalyst that normally contains one or more than one metal of groups IVb, Vb, VIb or VIII of the Periodic Table. These metals usually have one or more than one ligand, typically oxides, halides, alcoholates, esters, ethers, amines, alkyls, alkenyls and/or aryls that may be either π- or σ-coordinated. These metal complexes may be in the free form or fixed on substrates, typically on activated magnesium chloride, titanium(III) chloride, alumina or silicon oxide. These catalysts may be soluble or insoluble in

the polymerisation medium. The catalysts can be used by themselves in the polymerisation or further activators may be used, typically metal alkyls, metal hydrides, metal alkyl halides, metal alkyl oxides or metal alkyloxanes, said metals being elements of groups Ia, Na and/or IIia of the Periodic Table. The activators may be modified conveniently with further ester, ether, amine or silyl ether groups. These catalyst systems are usually termed Phillips, Standard Oil Indiana, Ziegler (-Natta), TNZ (DuPont), metallocene or single site catalysts (SSC).

2. Mixtures of the polymers mentioned under 1), for example mixtures of polypropylene with polyisobutylene, polypropylene with polyethylene (for example PP/HDPE, PP/LDPE) and mixtures of different types of polyethylene (for example LDPE/HDPE).

3. Copolymers of monoolefins and diolefins with each other or with other vinyl monomers, for example ethylene/propylene copolymers, linear low density polyethylene (LLDPE) and mixtures thereof with low density polyethylene (LDPE), propylene/but-1-ene copolymers, propylene/isobutylene copolymers, ethylene/but-1-ene copolymers, ethylene/hexene copolymers, ethylene/methylpentene copolymers, ethylene/heptene copolymers, ethylene/octene copolymers, ethylene/vinylcyclohexane copolymers, ethylene/cycloolefin copolymers (e.g. ethylene/norbornene like COC), ethylene/1 -olefins copolymers, where the 1 -olefin is generated in-situ; propylene/butadiene copolymers, isobutylene/isoprene copolymers, ethylene/vinylcyclohexene copolymers, ethylene/alkyl acrylate copolymers, ethylene/alkyl methacrylate copolymers, ethylene/vinyl acetate copolymers or ethylene/acrylic acid copolymers and their salts (ionomers) as well as terpolymers of ethylene with propylene and a diene such as hexadiene, dicyclopentadiene or ethylidene-norbornene; and mixtures of such copolymers with one another and with polymers mentioned in 1) above, for example polypropylene/ethylene-propylene copolymers, LDPE/ethylene-vinyl acetate copolymers (EVA), LDPE/ethylene-acrylic acid copolymers (EAA), LLDPE/EVA, LLDPE/EAA and alternating or random polyalkylene/carbon monoxide copolymers and mixtures thereof with other polymers, for example polyamides.

4. Hydrocarbon resins (for example C^5-C8) including hydrogenated modifications thereof (e.g. tackifiers) and mixtures of polyalkylenes and starch.

Homopolymers and copolymers from 1.) - 4.) may have any stereostructure including syndiotactic, isotactic, hemi-isotactic or atactic.. Stereoblock polymers are also included.

5. Polystyrene, poly(p-methylstyrene), poly(α-methylstyrene).

6. Aromatic homopolymers and copolymers derived from vinyl aromatic monomers including styrene, α-methylstyrene, all isomers of vinyl toluene, especially p-vinyltoluene, all isomers of ethyl styrene, propyl styrene, vinyl biphenyl, vinyl naphthalene, and vinyl anthracene, and mixtures thereof. Homopolymers and copolymers may have any stereostructure including syndiotactic, isotactic, hemi-isotactic or atactic; where atactic polymers are preferred. Stereoblock polymers are also included.

6a. Copolymers including aforementioned vinyl aromatic monomers and comonomers selected from ethylene, propylene, dienes, nitriles, acids, maleic anhydrides, maleimides, vinyl acetate and vinyl chloride or acrylic derivatives and mixtures thereof, for example styrene/butadiene, styrene/acrylonitrile, styrene/ethylene (interpolymers), styrene/alkyl methacrylate, styrene/butadiene/alkyl acrylate, styrene/butadiene/alkyl methacrylate, styrene/maleic anhydride, styrene/acrylonitrile/methyl acrylate; mixtures of high impact strength of styrene copolymers and another polymer, for example a polyacrylate, a diene polymer or an ethylene/propylene/diene terpolymer; and block copolymers of styrene such as styrene/butadiene/styrene, styrene/isoprene/styrene, styrene/ethylene/butylene/styrene or styrene/ethylene/propylene/styrene.

6b. Hydrogenated aromatic polymers derived from hydrogenation of polymers mentioned under 6.), especially including polycyclohexylethylene (PCHE) prepared by hydrogenating atactic polystyrene, often referred to as polyvinylcyclohexane (PVCH).

6c. Hydrogenated aromatic polymers derived from hydrogenation of polymers mentioned under 6a.).

Homopolymers and copolymers may have any stereostructure including syndiotactic, isotactic, hemi-isotactic or atactic; where atactic polymers are preferred. Stereoblock polymers are also included.

7. Graft copolymers of vinyl aromatic monomers such as styrene or α-methylstyrene, for example styrene on polybutadiene, styrene on polybutadiene-styrene or polybutadiene-acrylonitrile copolymers; styrene and acrylonitrile (or methacrylonitrile) on polybutadiene; styrene, acrylonitrile and methyl methacrylate on polybutadiene; styrene and maleic anhydride on polybutadiene; styrene, acrylonitrile and maleic anhydride or maleimide on polybutadiene; styrene and maleimide on polybutadiene; styrene and alkyl acrylates or methacrylates on polybutadiene; styrene and acrylonitrile on ethylene/propylene/diene terpolymers; styrene and acrylonitrile on polyalkyl acrylates or polyalkyl methacrylates,

styrene and acrylonitrile on acrylate/butadiene copolymers, as well as mixtures thereof with the copolymers listed under 6), for example the copolymer mixtures known as ABS, MBS, ASA or AES polymers.

8. Halogen-containing polymers such as polychloroprene, chlorinated rubbers, chlorinated and brominated copolymer of isobutylene-isoprene (halobutyl rubber), chlorinated or sulfo-chlorinated polyethylene, copolymers of ethylene and chlorinated ethylene, epichlorohydrin homo- and copolymers, especially polymers of halogen-containing vinyl compounds, for example polyvinyl chloride, polyvinylidene chloride, polyvinyl fluoride, polyvinylidene fluoride, as well as copolymers thereof such as vinyl chloride/vinylidene chloride, vinyl chloride/vinyl acetate or vinylidene chloride/vinyl acetate copolymers.

9. Polymers derived from α,β-unsaturated acids and derivatives thereof such as polyacrylates and polymethacrylates; polymethyl methacrylates, polyacrylamides and polyacryloni-triles, impact-modified with butyl acrylate.

10. Copolymers of the monomers mentioned under 9) with each other or with other unsaturated monomers, for example acrylonitrile/ butadiene copolymers, acrylonitrile/alkyl acrylate copolymers, acrylonitrile/alkoxyalkyl acrylate or acrylonitrile/vinyl halide copolymers or acrylonitrile/ alkyl methacrylate/butadiene terpolymers.

11. Polymers derived from unsaturated alcohols and amines or the acyl derivatives or acetals thereof, for example polyvinyl alcohol, polyvinyl acetate, polyvinyl stearate, polyvinyl benzoate, polyvinyl maleate, polyvinyl butyral, polyallyl phthalate or polyallyl melamine; as well as their copolymers with olefins mentioned in 1) above.

12. Homopolymers and copolymers of cyclic ethers such as polyalkylene glycols, polyethylene oxide, polypropylene oxide or copolymers thereof with bisglycidyl ethers.

13. Polyacetals such as polyoxymethylene and those polyoxymethylenes which contain ethylene oxide as a comonomer; polyacetals modified with thermoplastic polyurethanes, acrylates or MBS.

14. Polyphenylene oxides and sulfides, and mixtures of polyphenylene oxides with styrene polymers or polyamides.

15. Polyurethanes derived from hydroxyl-terminated polyethers, polyesters or polybutadienes on the one hand and aliphatic or aromatic polyisocyanates on the other, as well as precursors thereof.

16. Polyamides and copolyamides derived from diamines and dicarboxylic acids and/or from aminocarboxylic acids or the corresponding lactams, for example polyamide 4, poly-amide 6, polyamide 6/6, 6/10, 6/9, 6/12, 4/6, 12/12, polyamide 1 1 , polyamide 12, aromatic polyamides starting from m-xylene diamine and adipic acid; polyamides prepared from hexamethylenediamine and isophthalic or/and terephthalic acid and with or without an elastomer as modifier, for example poly-2,4,4,-trimethylhexamethylene terephthalamide or po-ly-m-phenylene isophthalamide; and also block copolymers of the aforementioned polyamides with polyolefins, olefin copolymers, ionomers or chemically bonded or grafted elastomers; or with polyethers, e.g. with polyethylene glycol, polypropylene glycol or polytetra-methylene glycol; as well as polyamides or copolyamides modified with EPDM or ABS; and polyamides condensed during processing (RIM polyamide systems).

17. Polyureas, polyimides, polyamide-imides, polyetherimides, polyesterimides, polyhydantoins and polybenzimidazoles.

18. Polyesters derived from dicarboxylic acids and diols and/or from hydroxycarboxylic acids or the corresponding lactones or lactides, for example polyethylene terephthalate, polybutylene terephthalate, poly-1 ,4-dimethylolcyclohexane terephthalate, polyalkylene naphthalate and polyhydroxybenzoates as well as copolyether esters derived from hydroxyl-terminated polyethers, and also polyesters modified with polycarbonates or MBS. Copolyesters may comprise, for example - but are not limited to - polybutylenesuccinate/terephtalate, polybutyleneadipate/terephthalate, polytetramethyleneadipate/terephthalate, polybutylensuccinate/adipate, polybutylensuccinate/carbonate, poly-3-hydroxybutyrate/octanoate copolymer, poly-3-hydroxybutyrate/hexanoate/decanoate terpolymer. Furthermore, aliphatic polyesters may comprise, for example - but are not limited to - the class of poly(hydroxyalkanoates), in particular, poly(propiolactone), poly(butyrolactone), poly(pivalolactone), poly(valerolactone) and poly(caprolactone), polyethylenesuccinate, polypropylenesuccinate, polybutylenesuccinate, polyhexamethylenesuccinate, polyethyleneadipate, polypropyleneadipate, polybutyleneadi-pate, polyhexamethyleneadipate, polyethyleneoxalate, polypropyleneoxalate, polybutylene-oxalate, polyhexamethyleneoxalate, polyethylenesebacate, polypropylenesebacate and

polybutylenesebacate, as well as corresponding polyesters modified with polycarbonates or MBS.

19. Polycarbonates and polyester carbonates.

20. Polyketones.

21. Polysulfones, polyether sulfones and polyether ketones.

22. Crosslinked polymers derived from aldehydes on the one hand and phenols, ureas and melamines on the other hand, such as phenol/formaldehyde resins, urea/formaldehyde resins and melamine/formaldehyde resins.

23. Drying and non-drying alkyd resins.

24. Unsaturated polyester resins derived from copolyesters of saturated and unsaturated dicarboxylic acids with polyhydric alcohols and vinyl compounds as crosslinking agents, and also halogen-containing modifications thereof of low flammability.

25. Crosslinkable acrylic resins derived from substituted acrylates, for example epoxy acrylates, urethane acrylates or polyester acrylates.

26. Alkyd resins, polyester resins and acrylate resins crosslinked with melamine resins, urea resins, isocyanates, isocyanurates, polyisocyanates or epoxy resins.

27. Crosslinked epoxy resins derived from aliphatic, cycloaliphatic, heterocyclic or aromatic glycidyl compounds, e.g. products of diglycidyl ethers of bisphenol A and bisphenol F, which are crosslinked with customary hardeners such as anhydrides or amines, with or without accelerators.

28. Natural polymers such as cellulose, rubber, gelatin and chemically modified homologous derivatives thereof, for example cellulose acetates, cellulose propionates and cellulose butyrates, or the cellulose ethers such as methyl cellulose; as well as rosins and their derivatives.

29. Blends of the aforementioned polymers (polyblends), for example PP/EPDM, Polyamide/EPDM or ABS, PVC/EVA, PVC/ABS, PVC/MBS, PC/ABS, PBTP/ABS, PC/ASA, PC/PBT, PVC/CPE, PVC/acrylates, POM/thermoplastic PUR, PC/thermoplastic PUR,

POM/acrylate, POM/MBS, PPO/HIPS, PPO/PA 6.6 and copolymers, PA/HDPE, PA/PP, PA/PPO, PBT/PC/ABS or PBT/PET/PC.

The polymers can be further divided into thermosets such as polyester resin, epoxy resin, and polyurethanes, and thermoplastics such as nylon, polycarbonate and polyethylene.

The polymers can be further divided into linear and branched polymers. The branched polymers may be further divided into short-chain branched polymers, long-chain branched polymers, star-branched polymers, ladder polymers and network polymers.

Polymers and plastics. In preferred embodiments, a suitable SE is chosen from the list comprising polymers & plastics.

Group 2: Polymers and plastics.

- polyimide, PTFE, PMMA, Kapton, Vespel, Cirlex, ABS
- polyimides (kapton, upilex, etc)

- polyamides
- polycarbonates (PC/lexan)
- polyesters (PET/mylar, melinex, dacron., PEN/teonex)
- polyethylenes (LDPE, HDPE)
- polypropylenes (PP)
- styrenics (polystyrenes/PS, acrylonitriles/ABS)

- vinyls (PVC, nylon)
- acrylics (PMMA/perspex, plexiglas)
- fluoroplastics (PTFE/teflon, FEP, PFA, PVDF)

- polysulphones (PES)
- ketones (PEEK)
- polyurethanes
- barrier resins (PVA/polyvinyl alcohol)
- epoxy resins (FR4)
- silicone resins
- elastomes (PDMS)

- biopolymers (wood, cellulose, starch based)

- conductive polymers (Pedot:PSS/baytron,orgacon, TIPS pentacene)
- light emitting polymers (white LEP, etc)
- copolymers
- metalised polymers
- Co-polymers
- Block co-polymers
- Rubber
- Latex

Polyacetylene, Polydiacetylenes, Polyethylene - very low density (VLDPE), Polyethylene - low density (LDPE), Polyethylene - linear low density (LLDPE), Polyethylene - medium density (MDPE), Polyethylene - high density (HDPE), Polyethylene - ultrahigh molecular weight (UHMWPE), Polyethylene - cross-linked polyethylene, Polyisoprene, Polybutadiene, Polypropylene, Polypropylene, Polypropylene, Poly-1-butene, Poly-1-hexene, Polymethylpentene, polyisobutylene, poly(ethylene propylene) , Poly-1-octene, Ethylene-propylene-diene rubbers, Ethylene-propylene bases thermoplastic elastomers, Polyhexene, Polyheptene, Polyoctene, Polystyrene-butadiene, Parylene, Polystyrene, Polymers of styrene in primary forms, Expansible polystyrene in primary forms, Expanded polystyrene (EPS), Poly(p-phenylene), High-impact polystyrene (HIPS), Poly(p-phenylene-vinylene), Poly(2,5-dioctyl-1,4-phenylenevinylene), Poly(2,6-naphthalenevinylene), Polyanthracene, Poly(anthracene-vinylene), Polyvinylchloride, Polychloroprene, Non plasticised PVC mixed with any other substance in primary forms, Plasticised PVC mixed with any other substance in primary forms, Polyvinylidene chloride (PVDC), Polytetrafluorethylene (PTFE), Polyvinylidene fluoride (PVDF), ethylene tetrafluoro-ethylene copolymer (Tefzel), Polyvinylfluoride, Polyperfluoropropylene, Polyoxymethylene, Polyethyleneoxide, Polypropyleneoxide, Poly(ethylene-propylene oxide), polybutyleneoxide, Polyphenylene ether (PPE), polyacrylate, polyacrylic acid, Polymethylmethacrylate, Polymethylacrylate, Poly(ethyl acrylate), Polyhydroxyethylmethacrylate, Polybutylacrylate, Polybutylmethacrylate, Ethylene vinyl acetate (EVA) and ethylene vinyl alcohol (EVOH), Poly vinyl acetate in primary forms, Poly vinyl acetate in aqueous dispersion in primary forms, Polyvinylacetate, Polyvinylalcohol, Polycarbonate, Polyetherketon, Polyetheretherketon, Polyethyleneterephthalate, Polybutyleneterephthalate, polylactic acid,

Polybutylene terephtalate (PBT), Other PET, Polycaprolactone (PCL), Polyglycolide (PG), Liqid crystalline polymers (aromatic) containing esters, Polyethylene adipate (PEA), Polytrimethylene terephthalate (PTT), Polyethylene naphthalate (PEN), Vectran, Alkyd resins, Polymers of vinyl esters or other vinyl polymers in primary forms, Polyacetals in primary forms, Bekalite, Phenol formaldehyde resins (PF), Diglycidyl Ether of Bisphenol-A (DGEBA), Phenolic (Novolac) Epoxy Resins, Poly-o-vinylbenzylalcohol, Poly-p-vinylbenzylalcohol, Polyvinyl formal, Polyvinyl acetal, Polyvinyl isobutyral, Polyvinyl butyral, Polyvinyl-n-butyl ether, Polytetramethylene sebacate, Polybutylene oxide, polypropylene oxide, Polyethylene adipate, Polyacrylonitrile (PAN) and copolymers, Acrylonitrile-butadiene-styrene (ABS) terpolymer, Styrene-acrylonitrile (SAN) copolymer, Polyaniline, Polypyrrole, Polymethacrylonitrile, Polysulphones, Polysulphides, ethylene chlorotrifluoro ethylene copolymer (ECTFE), fluorinated ethylene-propylene copolymer (Teflon FEP), polychlorotrifluoro-ethylene, Nylon PA1,1, Nylon PA1,2, Nylon PA1,3, Nylon PA1,4, Nylon PA1,5, Nylon PA1,6, Nylon PA2,1, Nylon PA6,6, Nylon PA6,10, Polyurethane based on, polyimide, polycaprolactam, aramid, Polyphenylene benzobisoxazole, Poly(m-phenyleneisophtalamide) (MPD-I) (Nomex®), Poly(p-phenyleneterephtalamide) (PPD-T) (Kevlar® and Twaron®), Polyisocyanurates, Polyimides, Bismaleimides (BMI), Polyacenaphthylene, Polyvinyl pyrrolidone, Vinyl chloride-vinyl acetate copolymers and other vinyl chloride copolymers in primary forms, perfluoroalkoxy Teflon PFA, Polydimethysiloxanes (PDMS), Organomodified siloxanes (OMS), Polymethylhydrosiloxane (PMHS), Silicones in primary forms, PolyAPTAC, (poly (acrylamido-N-propyltrimethylammonium chloride) and PolyMAPTAC (poly[(3-(methacryloylamino)-propyl] trimethylammonium chloride) are all suitable polymers for the structural entities SE.

Organic SEs include natural and unnatural polypeptides, lipids, polysaccharides, wood flour, etc.

The following additives represent preferred structural entities, suitable for the present invention: a carbon fibre, a carbon nanofibre, a carbon nanothread, a ceramic material, a composite material, a fullerene, a MWCNT, a SWCNT, graphane, graphene oxide, graphite, graphite, graphyne, a COOH-functionalized carbon nanotube, a OH-functionalized carbon nanotube, an NH2-functionalized carbon nanotube, an SH-functionalized CNT, COOH-functionalized graphene, multi-layer graphene, NH2-functionalized graphene, OH-functionalized graphene, reduced graphene oxide, thiol-functionalized graphene, a glass fibre, aramid, E-glass, iron, polyester, polyethylene, S-glass, steel, a battery, a borosilicate,

a buckyball, a buckytube, a capacitator, a carbon dome, a carbon material, a carbon megatube, a carbon nanofoam, a carbon polymer, a catalyst, a cathode, a coated carbon nanotube, a conductor, a covalent crystal, a crystal, a crystalline material, a defect-free graphene sheet, a defect-free MWCNT, a defect-free SWCNT, a dielectric material, a diode, a dodecahedrane, a doped glass, a fibre, a fullerite, a fused silica, a glue, a green ceramic, a lanthanides, a machinable ceramic, a metal alloy, a metal-functionalized carbon nanotube, a metalised dielectric, a metallised ceramic, a metalloid, a mineral, a non-covalent crystal, a piezoelectric material, a platinum group metal, a post-transition metal, a rare earth element, a sapphire, a semiconductor, a sensor, a silicon nitride, a single crystal fiber, a sol-gel, a synthetic diamond, a transition metal, a triple-wall carbon nanotube, a tungsten carbide, alumina, alumina trihydrate, aluminium, aluminum boride, aluminum oxide, aluminum trihydroxide, amorphous carbon, an actinides, an amalgam, an anode, an elastomers , an electrode, an endohedral fullerene, an insulator, an intermetallic, an ionic crystal, an organic material, anode, anthracite, asbestos , barium , bone, boron, brass, buckypaper, calcium carbonite, calcium metasilicate, calcium sulfate, calcium sulphate, carbon black, carbon nanofoam, cathode, chromium, clay, coal, copper, diamond, diamond-like carbon, double-layer graphene, exfoliated graphite, exfoliated silicate, flourinated graphene, fused silica, gallium arsenide, gallium nitride, germanium, glass, glass microsphere, glass ribbons, glassy carbon, gold, hardened steel, hydrous magnesium silicate, hyperdiamond, iron oxides, lead zirconium titanate, lignite, lithium niobate, lonsdaleite, magnesium dihydroxide, magnesium oxide, manganese, metal, metal oxide, mica, molybdenum, nickel, nylon, palladium, pencil lead, platinum, prismane, pyrolytic graphite, rubber, silica, silica gel, silicon, silicon carbide, silicon dioxide, silicon nitride, silver, soot, stainless steel, tantalum, titanium, titanium oxide, tooth cementum, tooth dentine, tooth enamel, tungsten, tungsten carbide, wood, zinc oxide, zirconia.

The SEs can be further divided into SEs comprising solely aliphatic moieties, comprising solely aromatic moieties, or comprising both aliphatic and aromatic moieties.

The SEs can be further divided into SEs comprising solely single bonds, solely double bonds, solely triple bonds, or a combination of single-, double- and triple bonds.

Biological polymers are here defined as the polymers involved in the transcriptional and translational process, i.e. natural nucleic acids (RNA or DNA), and natural polypeptides. Natural polypeptides can be further divided into peptides, proteins and antibodies.

In preferred embodiments, a suitable organic SE is chosen from the list comprising biologicals, such as hair, nail, horn, ligaments, bone, cornea, teeth, fibrous cartilage, vitreous cells, intervertebral disc, womb, skin, intestines, heart membranes, membranes, stomach membrane, cartilage, chronodrocites, intervertebral cartilage, bone enamel, ligaments, tendons and tooth enamel, organs, lung, heart, brain, skin, kidney, tooth material, bone material, tendon material, skin, hair, nails, a biological surface, such as a vein, a biological macromolecule, such as a protein, such as a naturally occuring protein, such as a consensus sequence protein, a modified protein, such as a mutant protein where one or more amino acids have been changed relative to the consensus sequence.

Preferred embodiments of SEs include gold particles, carbon nanotubes, carbon fibers, aluminum fibers, nanotubes, graphene, metal ions, metal, ceramic, polyester, concrete, polystyrene, BN (boron nitride aka "white graphene"), BNNT (boron nitride nanotubes), nanotubes and nanowires and nanocrystals and nanospheres and nanochains e.g. comprising any one or more of the following elements: C, Si, Se, Cu, S, Co, Zn, Al, Au, Ag, N, B and Cd.

Particularly preferred embodiments of SEs include arbon nanotubes, multi-walled carbon nanotubes, single-walled carbon nanotubes, functionalized carbon nanotubes, carbon nanofibres, carbon nanothreads, fullerenes,
aluminum nitride nanotubes(AlNNTs), boron carbon nanotubes (BCNNT), DNA nanotube, RNA nanotube, protein nanotube, silicon nanotube, titanium oxide nanotubes, tungsten sulfide nanotubes, gallium nitride nanotubes (GaNNTs),
aluminum phosphide nanotube (AlPNT), gallium phosphide nanotube (GaPNT),
carbon/diamond nanothread,
copper nanotubes, gold nanotubes, silver nanotube, platinum nanotube, zinc oxide nanotube, zinc ferrite nanotube, aluminium nanotube,
sulphide nanotubes such as WS_2 and MoS_2, selenide nanotubes such as Cadmium Selenide Nanotube CdSe, cobalt Selenide Nanotube, bismuth selenide nanotube, niobium selenide nanotubes, halide nanotubes, such as nickel chloride nanotubes, nanotubes of transition metal oxides such as SiO_2, TiO_2, MoO_3, V_2O_5 and

graphene, functionalized graphene, graphene oxide, graphyne, reduced graphyne, graphane, graphdiyne, graphone, fluorographene, chlorographene

In preferred embodiments, a suitable SE is chosen from the list comprising

- Concrete admixtures
- Chemical admixtures
- Mineral admixtures.
- Air entrainers
- Water reducers
- Set retarders
- Set accelerators
- Superplasticizers
- Corrosion inhibitors
- Shrinkage control admixtures
- Alkali-silica reactivity inhibitors
- Coloring admixtures.
- Plasticizers
- Water reducers
- Superplasticizer
- High range water reducers
- Organic polymers
- Lignin
- Naphthalene
- Melamine sulfonate superplasticisers
- Pozzolans and other cementitious materials
- Natural pozzolans (such as the volcanic ash used in Roman concrete)
- Fly ash
- Silica fume.
- Dispersants.
- Polycarboxylate ether superplasticizer (PCE)
- Polycarboxylate (PC)
- Coal
- Soot

- Carbon black

- Anthracite
- Lignite
- Kevlar
- Carbon fiber
- Carbon nanofiber
- Carbon allotropes
    - Activated carbon
        - Powdered activated carbon
        - Granular activated carbon
        - Extruded activated carbon
    - Fullerenes
        - Buckyball
        - Buckypaper
        - Buckytube
        - Dodecahedrane
        - Endohedral fullerenes
        - Gedodesic carbon domes
        - Prismane
        - Carbon nanotube
            - Single-wall carbon nanotubes
            - Double-wall carbon nanotubes
            - Triple-wall carbon nanotube
            - Multi-wall carbon nanotubes
            - Pristine carbon nanotubes
            - Coated carbon nanotubes
            - Perfect carbon nanotubes
            - Imperfect carbon nanotubes
            - Functionalized carbon nanotubes
                - Thiol-functionalized
                - Hydroxyl-functionalized
                - Carboxylic acid-functionalized
                - Amine-functionalized

- Carbon nanotubes that contain gadolinium
- Buckypaper

- Fullerite
  - Ultrahard fullerite
- Buckminsterfullerene
- Graphene
  - Single-layer graphene
  - Double-layer graphene
  - Triple-layer graphene
  - Multi-layer graphene
  - Pristine graphene
  - Coated graphene
  - Perfect graphene
  - Imperfect graphene
  - Functionalized graphene
    - Graphane
    - Flourinated graphene
    - Graphene oxide
    - Reduced graphene oxide
- Buckyball clusters
- Carbon megatubes
- Carbon polymers
- Carbon nano-onions
- Carbon nanobuds
- Fullerene rings

- Glassy carbon
- Diamond
  - Hyperdiamonds
  - Aggregated diamonds
- Graphite

        - Pyrolytic graphite
    - Pencil lead
    - Lonsdaleite
    - Amorphous carbon
    - Carbon nanofoam

- Metals
    - Transition metals, Lanthanides, Actinides, Rare earth elements, Platinum group metals (PGMs), Post-transition metals
    - (Al) aluminium
    - (Fe) steel and stainless steel
    - (Mo) molybdenum
    - (Cu) copper
    - (Ti) titanium
    - (Pt) platinum
    - (Au) gold
    - (Ni) nickel
    - (Pa) palladium
    - (Mn) manganese
    - (Ta) tantalum
    - (Cr) chromium
    - (Ag) silver
    - (Wo) Tungsten
- Metalloids
- Alloys
    - Stainless steel
    - Steel fibers
    - Hardened steel
    - Brass
    - Brass fibers
- Amalgams
- Intermetallics
- Glasses

- Glass fibre
- Glass spheres

- Crystal
  - Ionic crystals, Covalent crystals, Non-covalent crystals
  - Non-covalent crystal
- Crystalline materials
  - BK7, sapphire, fused silica
- Glue

- Ceramic
  - alumina, zirconia, machinable ceramic, green ceramic, PZT, silicon nitride, tungsten carbide

  - alumina (Al2O3)
  - silicon nitrides (bulk and thin film)
  - silicon carbides
  - lithium niobates
  - zirconia
  - metallised ceramic

- Elastomers
- Fibres
- Composite materials
  - Wood
  - Cellulose fibers
  - lignin
  - Bone
  - Tooth enamel
  - Tooth cementum

  - Tooth dentine
- Sol-gel
- Mineral
- Montmorrilonite nanoclays
- Cellulose nanowhiskers

        - Talc
        - Cellulose nanofibers (e.g. Curran)

- Organic-Inorganic
        - Organic-Inorganic hybrids
        - Polymer hybrids of poly (vinyl alcohol) and silica gel
    - Boron nitride nanotube
        - Single-wall boron nitride nanotubes
        - Double-wall boron nitride nanotubes
        - Triple-wall boron nitride nanotube
        - Multi-wall boron nitride nanotubes
        - Pristine boron nitride nanotubes
        - Coated boron nitride nanotubes
        - Perfect boron nitride nanotubes
        - Imperfect boron nitride nanotubes
        - Functionalized boron nitride nanotubes
            - Thiol-functionalized boron nitride nanotubes
            - Hydroxyl-functionalized boron nitride nanotubes
            - Carboxylic acid-functionalized boron nitride nanotubes
            - Amine-functionalized boron nitride nanotubes
        - Boron nitride nanotubes that contain gadolinium
        - Bucky paper
    - Boron nitride
        - Single-layer boron nitride
        - Double-layer boron nitride
        - Triple-layer boron nitride
        - Multi-layer boron nitride
        - Pristine boron nitride
        - Coated boron nitride
        - Perfect boron nitride
        - Imperfect boron nitride
        - Functionalized boron nitride
            - Flourinated boron nitride
            - Boron nitride oxide
            - Reduced boron nitride oxide

For any characteristics of an SE mentioned above or below, and in each characteristic's entire range, a further characteristic of importance is the content of elements in the SE. The kinds of elements in an SE will be reflected in the characteristics of the SE, but can in some cases also affect other parts of a CMU. As an example, the elements of SE1 may interfere with the integrity of SE2, or alternatively, if SE2 is made in situ, i.e. after the mixing of SE1 and the precursors from which SE2 will be made, SE1 may interfere with the formation of SE2 and/or its final form, through interaction of its elements with the reactive monomers that react to form SE2.

Identities and number of elements of a structural entity. The structural entity may be composed of only one type of element, two types of elements, three types of elements, four types of elements, or more than four types of elements.

SEs consisting of one element or one type of element. Preferred embodiments of SEs comprising only one element are often ions, and often serve an essential structural role in the CMU. The following ions are particularly preferred structural entities: K+, Cl-, Ca++, Mg++, Gd+++, Cu+, Cu2+, Fe2+, Fe3+, Hg2+, $Hg_2$2+, Pb2+, Pb4+, Sn2+, Sn4+, Cr2+, Cr3+, Mn2+, Mn3+, Co2+, Co3+. If comprising only one element, the element may be any one of the following: Lithium (Li), Beryllium (Be), Boron (B), Carbon (C), Nitrogen (N), Oxygen (O), Fluorine (F), Sodium (Na), Magnesium (Mg), Aluminium (Al), Silicon (Si), Phosphorus (P), Sulfur (S), Chlorine (Cl), Potassium (K), Calcium (Ca), Scandium (Sc), Titanium (Ti), Vanadium (V), Chromium (Cr), Manganese (Mn), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Gallium (Ga), Germanium (Ge), Arsenic (As), Selenium (Se), Bromine (Br), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), Niobium (Nb), Molybdenum (Mo), Technetium (Tc), Ruthenium (Ru), Rhodium (Rh), Palladium (Pd), Silver (Ag), Cadmium (Cd), Indium (In), Tin (Sn), Antimony (Sb), Tellurium (Te), Iodine (I), Caesium (Cs), Barium (Ba), Platinum (Pt), Gold (Au), Mercury (Hg), Thallium (Tl), Lead (Pb), Bismuth (Bi).

SEs comprising only one type of element have no polarity, and are therefore attractive in cases where no polarity is desired. This may e.g. be the case where the polymer (e.g. SE1) of a composite has no polarity, and where it therefore may be beneficial to add an additive (SE2) with no polarity as well.

The following structural entities comprising only one element or one type of element, are particularly preferred structural entities:

Comprising carbon atoms only: Buckyball, Buckypaper, Buckytube, Dodecahedrane, Endohedral fullerenes, Gedodesic carbon domes, Prismane, Pristine carbon nanotubes, Coated carbon nanotubes, Perfect carbon nanotubes, Imperfect carbon nanotubes, Fullerite, Ultrahard fullerite, Buckminsterfullerene, Graphene, Single-layer graphene, Double-layer graphene, Triple-layer graphene, Multi-layer graphene, Pristine graphene, Perfect graphene, Imperfect graphene, Buckyball clusters, Carbon megatubes, Carbon polymers, Carbon nano-onions, Carbon nanobuds, Fullerene rings, diamond, fullerenes in general, and specifically Carbon nanotubes, Single-wall carbon nanotubes, Double-wall carbon nanotubes, Triple-wall carbon nanotube, Multi-wall carbon nanotubes including single-walled carbon nanotubes and multiwalled nanotubes, and including Carbon nanotubes with the following chiral vectors (n, m); (0,0); (1,0); (2,0); (3,0); (4,0); (5,0); (6,0); (7,0); (8,0); (9,0); (10,0); (11,0); (12,0); (13,0); (14,0); (15,0); (16,0); (17,0); (18,0); (19,0); (20,0); (0,1); (1,1); (2,1); (3,1); (4,1); (5,1); (6,1); (7,1); (8,1); (9,1); (10,1); (11,1); (12,1); (13,1); (14,1); (15,1); (16,1); (17,1); (18,1); (19,1); (20,1); (0,2); (1,2); (2,2); (3,2); (4,2); (5,2); (6,2); (7,2); (8,2); (9,2); (10,2); (11,2); (12,2); (13,2); (14,2); (15,2); (16,2); (17,2); (18,2); (19,2); (20,2); (0,3); (1,3); (2,3); (3,3); (4,3); (5,3); (6,3); (7,3); (8,3); (9,3); (10,3); (11,3); (12,3); (13,3); (14,3); (15,3); (16,3); (17,3); (18,3); (19,3); (20,3); (0,4); (1,4); (2,4); (3,4); (4,4); (5,4); (6,4); (7,4); (8,4); (9,4); (10,4); (11,4); (12,4); (13,4); (14,4); (15,4); (16,4); (17,4); (18,4); (19,4); (20,4); (0,5); (1,5); (2,5); (3,5); (4,5); (5,5); (6,5); (7,5); (8,5); (9,5); (10,5); (11,5); (12,5); (13,5); (14,5); (15,5); (16,5); (17,5); (18,5); (19,5); (20,5); (0,6); (1,6); (2,6); (3,6); (4,6); (5,6); (6,6); (7,6); (8,6); (9,6); (10,6); (11,6); (12,6); (13,6); (14,6); (15,6); (16,6); (17,6); (18,6); (19,6); (20,6); (0,7); (1,7); (2,7); (3,7); (4,7); (5,7); (6,7); (7,7); (8,7); (9,7); (10,7); (11,7); (12,7); (13,7); (14,7); (15,7); (16,7); (17,7); (18,7); (19,7); (20,7); (0,8); (1,8); (2,8); (3,8); (4,8); (5,8); (6,8); (7,8); (8,8); (9,8); (10,8); (11,8); (12,8); (13,8); (14,8); (15,8); (16,8); (17,8); (18,8); (19,8); (20,8); (0,9); (1,9); (2,9); (3,9); (4,9); (5,9); (6,9); (7,9); (8,9); (9,9); (10,9); (11,9); (12,9); (13,9); (14,9); (15,9); (16,9); (17,9); (18,9); (19,9); (20,9); (0,10); (1,10); (2,10); (3,10); (4,10); (5,10); (6,10); (7,10); (8,10); (9,10); (10,10); (11,10); (12,10); (13,10); (14,10); (15,10); (16,10); (17,10); (18,10); (19,10); (20,10); (0,11); (1,11); (2,11); (3,11); (4,11); (5,11); (6,11); (7,11); (8,11); (9,11); (10,11); (11,11); (12,11); (13,11); (14,11); (15,11); (16,11); (17,11); (18,11); (19,11); (20,11); (0,12); (1,12); (2,12); (3,12); (4,12); (5,12); (6,12); (7,12); (8,12); (9,12); (10,12); (11,12); (12,12); (13,12); (14,12); (15,12); (16,12); (17,12); (18,12); (19,12); (20,12); (0,13); (1,13); (2,13); (3,13); (4,13); (5,13); (6,13); (7,13); (8,13); (9,13); (10,13); (11,13); (12,13); (13,13); (14,13); (15,13); (16,13); (17,13); (18,13); (19,13); (20,13); (0,14); (1,14); (2,14); (3,14); (4,14); (5,14); (6,14); (7,14); (8,14); (9,14); (10,14); (11,14); (12,14); (13,14); (14,14); (15,14); (16,14); (17,14); (18,14); (19,14);

(20,14); (0,15); (1,15); (2,15); (3,15); (4,15); (5,15); (6,15); (7,15); (8,15); (9,15); (10,15); (11,15); (12,15); (13,15); (14,15); (15,15); (16,15); (17,15); (18,15); (19,15); (20,15); (0,16); (1,16); (2,16); (3,16); (4,16); (5,16); (6,16); (7,16); (8,16); (9,16); (10,16); (11,16); (12,16); (13,16); (14,16); (15,16); (16,16); (17,16); (18,16); (19,16); (20,16); (0,17); (1,17); (2,17); (3,17); (4,17); (5,17); (6,17); (7,17); (8,17); (9,17); (10,17); (11,17); (12,17); (13,17); (14,17); (15,17); (16,17); (17,17); (18,17); (19,17); (20,17); (0,18); (1,18); (2,18); (3,18); (4,18); (5,18); (6,18); (7,18); (8,18); (9,18); (10,18); (11,18); (12,18); (13,18); (14,18); (15,18); (16,18); (17,18); (18,18); (19,18); (20,18); (0,19); (1,19); (2,19); (3,19); (4,19); (5,19); (6,19); (7,19); (8,19); (9,19); (10,19); (11,19); (12,19); (13,19); (14,19); (15,19); (16,19); (17,19); (18,19); (19,19); (20,19); (0,20); (1,20); (2,20); (3,20); (4,20); (5,20); (6,20); (7,20); (8,20); (9,20); (10,20); (11,20); (12,20); (13,20); (14,20); (15,20); (16,20); (17,20); (18,20); (19,20); (20,20)

In a preferred embodiment the structural entity is a CNT with the following chiral vectors (n, m):

n is between 0 and 20, such as between 0 and 10, such as between 0 and 5, such as between 0 and 2.

n is between 0 and 20, such as between 10 and 20, such as between 15 and 20, such as between 17 and 20.

p is between 0 and 20, such as between 0 and 10, such as between 0 and 5, such as between 0 and 2.

p is between 0 and 20, such as between 10 and 20, such as between 15 and 20, such as between 17 and 20.

Examples of structural entities consisting of only gold (Au) include gold nanotubes and gold nanowires.

Examples of structural entities consisting of only titanium include titanium rods and titanium plates.

Examples of structural entities consisting of only silver include silver fibres and silver cones.

Examples of structural entities consisting of only zinc include zinc nanotubes and zinc particles.

Examples of structural entities consisting of only copper include copper spheres and copper wires.

SEs consisting of two elements, or two types of elements. Examples of SEs comprising zinc and oxygen, or boron and nitride are ZnO nanorods, ZnO nanowires, ZnO nanotubes, ZnO Nanohelixes/nanosprings, seamless nanorings, nanopropellers, nanowires, such as single-crystal nanowires, ZnO nanobelts, polyhedral cages, single-wall boron nitride nanotubes, double-wall boron nitride nanotubes, triple-wall boron nitride nanotube, multi-wall boron nitride nanotubes, pristine boron nitride nanotubes, coated boron nitride nanotubes, perfect boron nitride nanotubes, imperfect boron nitride nanotubes, bucky paper, single-layer boron nitride, double-layer boron nitride, triple-layer boron nitride, multi-layer boron nitride, pristine boron nitride, coated boron nitride, perfect boron nitride and imperfect boron nitride.

If comprising only two elements, the elements may include any of the following: Hydrogen (H), Lithium (Li), Beryllium (Be), Boron (B), Carbon (C), Nitrogen (N), Oxygen (O), Fluorine (F), Sodium (Na), Magnesium (Mg), Aluminium (Al), Silicon (Si), Phosphorus (P), Sulfur (S), Chlorine (Cl), Potassium (K), Calcium (Ca), Scandium (Sc), Titanium (Ti), Vanadium (V), Chromium (Cr), Manganese (Mn), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Gallium (Ga), Germanium (Ge), Arsenic (As), Selenium (Se), Bromine (Br), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), Niobium (Nb), Molybdenum (Mo), Technetium (Tc), Ruthenium (Ru), Rhodium (Rh), Palladium (Pd), Silver (Ag), Cadmium (Cd), Indium (In), Tin (Sn), Antimony (Sb), Tellurium (Te), Iodine (I), Caesium (Cs), Barium (Ba), Platinum (Pt), Gold (Au), Mercury (Hg), Thallium (Tl), Lead (Pb), Bismuth (Bi).

Examples of structural entities consisting of only zinc (Zn) and oxygene (O) include ZnO nanotubes.

Examples of structural entities consisting of only carbon (C) and hydrogen (H) include polyethylene, polypropylene, polystyrene, graphane.

Examples of structural entities consisting of only boron (B) and nitrogen (N) include boron nitride and boron nitride nanotubes

Examples of structural entities consisting of two elements include polytetrafluoroethylene (comprising C, F).

Comprising C and O: Graphene oxide

Comprising C and F: Fluorinated graphene

SEs consisting of three elements, or three types of elements. If comprising only three elements, the elements may include any of the following:

Hydrogen (H), Lithium (Li), Beryllium (Be), Boron (B), Carbon (C), Nitrogen (N), Oxygen (O), Fluorine (F), Sodium (Na), Magnesium (Mg), Aluminium (Al), Silicon (Si), Phosphorus (P), Sulfur (S), Chlorine (Cl), Potassium (K), Calcium (Ca), Scandium (Sc), Titanium (Ti), Vanadium (V), Chromium (Cr), Manganese (Mn), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Gallium (Ga), Germanium (Ge), Arsenic (As), Selenium (Se), Bromine (Br), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), Niobium (Nb), Molybdenum (Mo), Technetium (Tc), Ruthenium (Ru), Rhodium (Rh), Palladium (Pd), Silver (Ag), Cadmium (Cd), Indium (In), Tin (Sn), Antimony (Sb), Tellurium (Te), Iodine (I), Caesium (Cs), Barium (Ba), Platinum (Pt), Gold (Au), Mercury (Hg), Thallium (Tl), Lead (Pb), Bismuth (Bi).

Examples of structural entities consisting of three elements include the following:

Comprising C, H, Cl: polyvinylchloride

Comprising C, H, O: poly(vinylalcohol)

Comprising C, H, N: polyacrylonitrile

Comprising C, H, Si: Poly[(dimethylsilylene)methylene]

Comprising C, H, S: Poly(thiophene)

Comprising C, S, H: thiol-functionalized graphene

Comprising C, O, H: hydroxide-functionalized graphene

Comprising C, S, H: thiol-functionalized carbon nanotubes

Comprising C, O, H: hydroxide-functionalized carbon nanotubes

Comprising B, N, O: boron nitride oxide
Comprising B, N, F: fluorinated boron nitride

SEs consisting of four elements, or four kinds of elements. If comprising only four elements, the elements may include any of the following: Hydrogen (H), Lithium (Li), Beryllium (Be), Boron (B), Carbon (C), Nitrogen (N), Oxygen (O), Fluorine (F), Sodium (Na), Magnesium (Mg), Aluminium (Al), Silicon (Si), Phosphorus (P), Sulfur (S), Chlorine (Cl), Potassium (K), Calcium (Ca), Scandium (Sc), Titanium (Ti), Vanadium (V), Chromium (Cr), Manganese

(Mn), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Gallium (Ga), Germanium (Ge), Arsenic (As), Selenium (Se), Bromine (Br), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), Niobium (Nb), Molybdenum (Mo), Technetium (Tc), Ruthenium (Ru), Rhodium (Rh), Palladium (Pd), Silver (Ag), Cadmium (Cd), Indium (In), Tin (Sn), Antimony (Sb), Tellurium (Te), Iodine (I), Caesium (Cs), Barium (Ba), Platinum (Pt), Gold (Au), Mercury (Hg), Thallium (Tl), Lead (Pb), Bismuth (Bi).

Examples of structural entities consisting of four elements include the following:

Comprising C, H, Cl, O: Poly(vinyl chloroacetate)

Comprising C, H, O, N: Proteins, peptides.

SEs consisting of more than four elements. If comprising more than four elements, the elements may include any of the following kinds: Hydrogen (H), Lithium (Li), Beryllium (Be), Boron (B), Carbon (C), Nitrogen (N), Oxygen (O), Fluorine (F), Sodium (Na), Magnesium (Mg), Aluminium (Al), Silicon (Si), Phosphorus (P), Sulfur (S), Chlorine (Cl), Potassium (K), Calcium (Ca), Scandium (Sc), Titanium (Ti), Vanadium (V), Chromium (Cr), Manganese (Mn), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Gallium (Ga), Germanium (Ge), Arsenic (As), Selenium (Se), Bromine (Br), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), Niobium (Nb), Molybdenum (Mo), Technetium (Tc), Ruthenium (Ru), Rhodium (Rh), Palladium (Pd), Silver (Ag), Cadmium (Cd), Indium (In), Tin (Sn), Antimony (Sb), Tellurium (Te), Iodine (I), Caesium (Cs), Barium (Ba), Platinum (Pt), Gold (Au), Mercury (Hg), Thallium (Tl), Lead (Pb), Bismuth (Bi).

Examples of structural entities consisting of more than four elements include the following:

Comprising C, H, N, O, P: Nucleic acids

A structural entity may consist of just one atom (in its non-charged form or as an ion, e.g. Gd or Gd+++), or may consist of several atoms, held together in an organized structure.

Comprising zinc only: Zinc nanotubes.

Example SEs. The following is a non-exhaustive list of structural entities: polymer, plastic, metal, additive, filler, inorganic polymer, organic polymer, supramolecular structure, fibers or filaments of human, animal or plant origin, macromolecular structure, polyethylene (PE), polypropylene (PP), polyvinylchloride (PVC), polystyrene (PS), poly(vinylalcohol) (PVAL), polyvinaylacetate (PVAC), poly(4-methyl-1-pentene), poly(1,4-butadiene), polyisoprene,

polyacrylonitrile (PAN), polymethylmethacrylate (PMMA), poly(n-alkylmethacrylate), poly(n-alkylacrylate), poly(ethylene terephtalate) (PETP), poly(butylenes terephtalate) (PBTP), polytetrafluoroethylene (PTFE), polyamide 6 (PA 6), polyamide n (PAn), polyamide 6,10 (PA 6,10), polyoxymethylene (POM), polyethyleneoxide (PEO), poly(vinylidene dichloride) (PVDC), poly(vinylidine difluoride) (PVDF), epoxy, boron nitride, boron nitride nanotubes, carbon nanotube, zinc nanotube, graphene, myosin, actin, metal, steel, Kevlar filament, metal-oxide, alloy, silk, cotton, wool, latex, rubber, aluminum, copper, polymers, ceramic, metals, cement, and concrete.

Example SEs also include naturally occurring and synthetic organic materials which are pure monomeric compounds or mixtures of such compounds, for example mineral oils, animal and vegetable fats, oil and waxes, or oils, fats and waxes based on synthetic esters (e.g. phthalates, adipates, phosphates or trimellitates) and also mixtures of synthetic esters with mineral oils in any weight ratios, typically those used as spinning compositions, as well as aqueous emulsions of such materials.

Additives. The following is a non-comprehensive list of preferred structural entities, often categorized as the additives of a composite material.

Group 3: Additives.

Calcium carbonate, silicates, glass fibres, glass bulbs, asbestos, talc, kaolin, mica, barium sulfate, metal oxides and hydroxides, wood fiber, carbon fiber, bamboo fiber, UV absorbers, colourants, plasticisers, aluminum fiber, carbon black, graphite, wood flour and flours or fibers of other natural products, synthetic fibers; nano-materials, very finely dispersed or exfoliated layer structures are particularly useful, as for example montmorillonite, bentonite and the like, as well as natural or synthetic nano-tube fillers like halloysites, zeolites or carbon-based nano-tubes or layer materials of the graphene or boron nitride type.

In a preferred embodiment, the structural entity is a nucleating agent. Nucleating agents minimize the size of the interphase around fillers. By incorporating the nucleating agent into the CMU of the present invention, it is possible to control the crystalizing tendency of the interphase, and in this way improve the quality of a composite material.
Nucleating agents suitable for the present invention includes, but are not limited to: aromatic carboxylic acid salts; sodium benzoate; talc; pigment colorants; phosphate ester salts; calcium carbonate; glass; chalk; clay; kaolin; silicates; pigments; cadmium red; cobalt yellow; chromium oxide; titanium dioxide; magnesium oxide; carbonates; sulfates; carbon

black; salts of carboxylic acids; benzophenone; polymers; organic liquids; polyamide-66; molybdenum disulfide; iron sulfide; titanium dioxide; sodium phenylphosphinate; potassium stearate; organic pigments; sodium benzoate; kaolin; triphenodithiazine; pimelic acid with calcium stearate; calcium stearate; pimelic acid; quinacridone permanent red dye; N,N-dicyclohexylnaphthalene-2,6-dicarboxamide; 1,2,3,4-bis-dibenzylidene sorbitol (DBS); 1,2,3,4-bis-(p-methoxybenzylidene sorbitol) (DOS); 1,2,3,4-bis-(3,4-dimethylbenzylidene sorbitol) (MBDS); 1,3:2,4-di(3,4-dimethylbenzylidene) sorbitol (DMDBS); metal salts of substituted aromatic heterocyclic phosphate; sodium 2,2´-methylene-bis-(4,6-di-t-butylphenylene)phosphate (NA-11); salts of 2,2´-methylene-bis-(4,6-di-t-butylphenylene)phosphate; lithium 2,2´-methylene-bis-(4,6-di-t-butylphenylene)phosphate; potassium 2,2´-methylene-bis-(4,6-di-t-butylphenylene)phosphate; linear trans quinacridone (LTQ); γ-modification of LTO; calcium carboxylates, calcium salts of suberic acid (Ca-sub), calcium salts of pimelic acid (Ca-pim); N,N´-dicyclohexyl-2,6-naphtalene dicarboxamide (NJS); bicyclo[2.2.1]heptane dicarboxylate salt (HPN-68); Hyperform HPN-20E; ionomers; metal oxides; metal hybrids; organic compounds; residual catalysts; polymers; fibers; hydroxyl group-containing triglyceride oils; organic acid metal salts.

As can be seen, the structural entities SE1 and SE2 may e.g. both be a polymer, both may be an additive, both may be a filler, or one may be an additive and the other a polymer, or some other structural entity.
SE1 or SE2 may be the most abundant part of a matrix material. For example, in a composite material of PVC and carbon nanotubes, where a linker carrying two MLs or Ligand2s, one of which is attached to a PVC polymer molecule and the other is attached to a carbon nanotube, and where the PVC polymers constitute ~99 % of the composite material and the carbon nanotubes constitute ~1 % of the composite material, the PVC is considered the matrix material of the composite.

SE1 and SE2 may be the same or different. Example pairs of SE1 and SE2 are shown below:

SE1	SE2
Carbon nanotube	Epoxy
Carbon nanotube	Polyvinyl
Carbon nanotube	Polystyrene
Graphene	Epoxy

Kevlar	Polypropylene
Silk	Metal (e.g. iron, zinc, copper)
Metal alloy	Collagen
Collagen	Carbon nanotube
Myosin	Steel
Actin	Carbon nanotube
Cement (C-S-H)	Nanotube
Carbon nanotube	Carbon nanotube
Graphene	Graphene
Carbon nanotube	Carbon nanotube
Polyvinyl	Polyvinyl
BN	BNNT

The abovementioned structural entities (SEs) may be modified. Thus, a structural entity may be modified by the addition of one or more functional groups. Examples of simple functional groups are OH, NH2, CO, COOH, SH. More complex functional groups are biotin, antibody, and metal chelate.

In a preferred embodiment this modification introduces a charged or polar group. The polar or charged group may be advantageous in order to make the SE soluble, or in order to allow strong ionic bond interactions with another SE or with a linker moiety. As an example, CNTs may be modified with charged or polar groups in order to make the CNTs soluble in polar solvents. In another preferred embodiment the modification of the SE introduces a reactive yet non-polar, non-charged group. Such groups may be preferable in cases where for example the polymerization reaction forming a composite material is inhibited by polar or charged groups. An example functionalisation is the introduction of a polyvinyl group on the surface of a CNT. Alternatively, the functionalization may be mediated by the binding of mechanical ligands that either themselves modify the characteristics of the CNT in a desired way, or mechanical ligands that carry functional groups that mediate the desired change in characteristics of the CNT.

Mechanical Ligand (ML) and Ligand2.

A precursor-ML, ML or Ligand2 suitable for the present invention may have a number of characteristics. One important characteristic is the affinity (or dissociation constant) of the interaction between the SE and either of the precursor-ML, ML, or Ligand2. A high affinity of

the precursor-ML for the SE will increase the number of precursor-MLs that are bound at a given time, and therefore may increase the number of precursor-MLs that are turned into a ML. However, if certain binding modes of the precursor-ML are incompatible with the formation of the ML, a lower affinity may be preferred, as a lower affinity is typically associated with faster off-rates and therefore faster kinetics of association/dissociation, which will allow the precursor-ML to be involved in a larger number of binding events, potentially increasing the likelihood of the correct binding mode to take place, and thereby promoting ML formation. Once the ML has been formed, a high affinity may serve to lock the ML at the position where it was formed, which can be advantageous in some cases. In other cases, an even distribution of the MLs on the SE may be promoted by MLs with lower affinity for the SE.
For Ligand2 it may be attractive in some cases that the Ligand2 is tightly associated with the SE, as this may increase eg. the strength of a composite material. If on the other hand flexibility of a composite material is desired, it may be advantageous that the Ligand2 binds the SE with lower affinity, allowing the Ligand2 to dissociate more easily from the SE.

For any characteristics of a precursor-ML, ML or Ligand2 mentioned above, and in each characteristic's entire range, a further characteristic of importance is the molecular weight (MW) of the precursor-ML, ML or Ligand2.

MW of precursor-ML, ML or Ligand2. The molecular weight of the precursor-ML, ML or Ligand2 may be of high economic importance (smaller compounds typically cost less to produce), and also, a smaller molecular weight is often indicative of a smaller surface of interaction with the SE, wherefore typically a higher number of precursor-ML, ML or Ligand2s can bind simultaneously to the SE if their MWs are low. Thus, depending on the context, the MW is preferably less than 100,000,000 Dal, such as less than 10,000,000 Dal, such as less than 5,000,000 Dal, such as less than 2,000,000 Dal, such as less than 1,000,000 Dal, such as less than 500,000 Dal, such as less than 200,000 Dal, such as less than 100,000 Dal, such as less than 40,000 Dal, such as less than 20,000 Dal, such as less than 10,000 Dal, such as less than 7,000 Dal, such as less than 5,000 Dal, such as less than 3,000 Dal, such as less than 2,000 Dal, such as less than 1,700 Dal, such as less than 1,400 Dal, such as less than 1,200 Dal, such as less than 1,000 Dal, such as less than 900 Dal, such as less than 800 Dal, such as less than 700 Dal, such as less than 600 Dal, such as less than 500 Dal, such as less than 400 Dal, such as less than 300 Dal, such as less than 200 Dal, such as less than 100 Dal, such as less than 1 Dal.

However, it is typically easier to prepare a precursor-ML, ML or Ligand2 of high affinity if its molecular weight is higher. Thus, depending on the context, the MW is preferably greater than 1 Dal, such as greater than 100 Dal, such as greater than 200 Dal, such as greater than 300 Dal, such as greater than 400 Dal, such as greater than 500 Dal, such as greater than 600 Dal, such as greater than 700 Dal, such as greater than 800 Dal, such as greater than 900 Dal, such as greater than 1,000 Dal, such as greater than 1,200 Dal, such as greater than 1,400 Dal, such as greater than 1,700 Dal, such as greater than 2,000 Dal, such as greater than 3,000 Dal, such as greater than 5,000 Dal, such as greater than 7,000 Dal, such as greater than 10,000 Dal, such as greater than 20,000 Dal, such as greater than 40,000 Dal, such as greater than 100,000 Dal, such as greater than 200,000 Dal, such as greater than 500,000 Dal, such as greater than 1,000,000 Dal, such as greater than 2,000,000 Dal, such as greater than 5,000,000 Dal, such as greater than 10,000,000 Dal, such as greater than 100,000,000 Dal.

Therefore, depending on the application and context, the molecular weight of a precursor-ML, ML or Ligand2 may preferably be low, medium or high. Preferred embodiments of the present invention therefore include precursor-ML, ML or Ligand2s with molecular weight of 1–100 Dal; 100–200 Dal, 200–300 Dal, 300–400 Dal, 400–500 Dal, 500–600 Dal, 600–700 Dal, 700–800 Dal, 800–900 Dal, 900–1000 Dal, 1,000–1200 Dal, 1,200–1,400 Dal, 1,400–1,700 Dal, 1,700–2,000 Dal, 2,000–3,000 Dal, 3,000–5,000 Dal, 5,000–7,000 Dal, 7,000–10,000 Dal, 10,000–20,000 Dal, 20,000–40,000 Dal, 40,000–100,000 Dal, 100,000–200,000 Dal, 200,000–500,000 Dal, 500,000–1,000,000 Dal, 1,000,000–2,000,000 Dal, 2,000,000–5,000,000 Dal, 5,000,000–10,000,000 Dal, 10,000,000–100,000,000 Dal, or larger than 100,000,000 Dal.

Chemical moieties. The precursor-ML's, ML's or Ligand2's content of chemical moieties is important, either because the chemical moiety is important for the interaction with the SE, or because the chemical moiety is important for reactivity or non-reactivity of the precursor-ML, ML or Ligand2 with e.g. the polymerization reaction. Generally preferred chemical moieties include –NH2, -COOH, -CONH2, -SH, phenyl, benzene, and . The following chemical motifs are preferred chemical motifs comprised within fullerene-binding precursor-MLs, MLs or Ligand2s, and are particularly preferred chemical motifs of CNT- and graphene-binding precursor-MLs, MLs, or Ligand2s, suitable for use in the present invention:

- Aromatic systems, including benzene, nitrobenzene, toluene, 1,2,3-trichlorbenzene, 1,2,4-trichlorobenzene, m-dinitrobenzene, p-nitrobenzene, naphthalene, anthracene,

fluoranthene, phenanthrene, pyrene, pyrene-diamine, pyrene-phenyl ester, dipyrene (phenyl ester), tetracycline, as well as their substituted variants;

- Halogens, nitro group, amine, thiol, alcohol, ester, amide, carboxylic acid, phenol, indole, imidazole, sulfonate and phophate;
- Alkane, including hexane and heptane;
- Soap-type molecules, including chemical motifs comprising a long alkane (incldiuing C4, C5, C6, C7, C8, C9, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25) and a polar end group such as sulfonate, for example SDBS, Sodium dodecylbenzenesulfonate;
- Lactames, such as N-methyl-pyrrolidone and lactones;
- Peptides, in particular peptides with hydrophilic amino acids at the ends of the peptide and hydrophobic amino acids in the middle.
- Peptides such as QLMHDYR, CPTSTGQAC, CTLHVSSYC, RLNPPSQMDPPF, QTWPPPLWFSTS, HTDWRLGTWHHS, ELWSIDTSAHRK, IFRLSWGTYFS, HWKHPWGAWDTL, ELWR, ELWRPTR, KPRSVSG-dansyl, TGTG-F-GTCT, TGTG-V-GTCT, TGTG-W-GTCT, TGTG-T-GTCT, TGTG-G-GTCT, TGTG-N-GTCT, TGTG-K-GTCT, TGTG-D-GTCT, MHGKTQATSGTIQS, DAEFRHDSGYEVHHQKLVFFAEDVGSNKGAIIGLMVGGVVIA, DAEFRHDSGYEVHHQKLVFFAEDVGSNKGAIIGLMVGGVV, CHKKPSKSC, RKLPDAPGMHTW, SCSDCLKSVDFIPSSLASS, YLTMPTP, FSWEAFA, HLESTPG, GETRAPL, RHEPPLA, GETQCAA, FPGRPSP, HTAQSTA, HKPDANR, FPGHSGP, THLPWQT, GETQCAA, FPGRPSP, HTAQSTA, VKTQATSREEPPRLPSKHRPG
- Amino acids such as phenylalanine, tyrosine, tryptophan, histidine;
- Heteroaromatic systems, including pyrole, thiophene, furane, pyrazole, imidazole, isoxazole, oxazole, isothiazole, thiazole, pyridine and perylene bisimides
- Fused ring systems, composed of either aromatic, non-aromatic or anti-aromatic rings or combinations thereof.

Affinity of non-covalent Ligand2. For non-covalent interactions, a low affinity (i.e. a high dissociation constant) may sometimes be preferred. For example, if flexibility of a composite material is desired, it may be preferred that the Ligand2-SE interaction is weak, allowing easy dissociation. Thus, depending on the context, the dissociation constant is preferably greater than 10^{-30} M, such as greater than 10^{-25} M, such as greater than 10^{-20} M, such as greater than 10^{-18} M, such as greater than 10^{-16} M, such as greater than 10^{-15} M, such as greater than 10^{-14} M, such as greater than 10^{-13} M, such as greater than 10^{-12} M, such as

greater than 10^{-11} M, such as greater than 10^{-10} M, such as greater than 10^{-9} M, such as greater than 10^{-8} M, such as greater than 10^{-7} M, such as greater than 10^{-6} M, such as greater than 10^{-5} M, such as greater than 10^{-4} M, such as greater than 10^{-3} M, such as greater than 10^{-2} M, such as greater than 10^{-1} M.

Alternatively, if high strength and low flexibility of a composite material is required, it may be desired to have a very tight binding of a non-covalent Ligand2 to the SE. Thus, depending on the context, the dissociation constant is preferably less than 10^{-1} M, such as less than 10^{-2} M, such as less than 10^{-3} M, such as less than 10^{-4} M, such as less than 10^{-5} M, such as less than 10^{-6} M, such as less than 10^{-7} M, such as less than 10^{-8} M, such as less than 10^{-9} M, such as less than 10^{-10} M, such as less than 10^{-11} M, such as less than 10^{-12} M, such as less than 10^{-13} M, such as less than 10^{-14} M, such as less than 10^{-15} M, such as less than 10^{-16} M, such as less than 10^{-18} M, such as less than 10^{-20} M, such as less than 10^{-25} M, such as less than 10^{-30} M.

Also, if a Ligand2's binding strength is strongly dependent on temperature, systems can be designed that are flexible at high temperatures and rigid at lower temperatures, effectuated by the Ligand2's affinity for the SE. Thus, preferred embodiments of non-covalently interacting Ligand2s of the present invention include Ligand2s whose dissociation constant for the interaction with SE is smaller than 10^{-30} M, and include Ligand2s whose dissociation constant is in one of the following ranges: 10^{-30}–10^{-25} M, 10^{-25}–10^{-20} M, 10^{-20}–10^{-18} M, 10^{-18}–10^{-16} M, 10^{-16}–10^{-15} M, 10^{-15}–10^{-14} M, 10^{-14}–10^{-13} M, 10^{-13}–10^{-12} M, 10^{-12}–10^{-11} M, 10^{-11}–10^{-10} M, 10^{-10}–10^{-9} M, 10^{-9}–10^{-8} M, 10^{-8}–10^{-7} M, 10^{-7}–10^{-6} M, 10^{-6}–10^{-5} M, 10^{-5}–10^{-4} M, 10^{-4}–10^{-3} M, 10^{-3}–10^{-2} M, 10^{-2}–10^{-1} M, or larger than 10^{-1} M.

As described above and below, the precursor-ML, ML and/or Ligand2 will often contain chemical motifs that interact with the SE. Below is a list of such preferred chemical motifs, appropriate for making CMUs by combination with the indicated SEs, and their binding strength for different SEs (e.g. in the form of a dissociation constant).

Group 4: Chemical motifs and the structural entities with which they react.

Chemical Motif[a]	MW [g/mol]	K_d[b] [M]	K_d/MW [M/Dal]	SE[c]	Affinity parameter value[d]	Ref.[e]
Nitrobenzene	123.1			MWNT	1,380 L/kg	Kragulj *et al.* 2013
Hexane	86.2			MWNT	2,291 L/kg	Kragulj *et al.* 2013
Benzene	78.1			MWNT	126 L/kg	Kragulj *et al.* 2013
Toluene	92.1			MWNT	331 L/kg	Kragulj *et al.* 2013
1,2,3-Trichloro-benzene	181.5			MWNT	12,882 L/kg	Kragulj *et al.* 2013
1,2,4-Trichloro-benzene	181.5			MWNT	5,370 L/kg	Kragulj *et al.* 2013
Naphtalene	128.2			MWNT	2,951 L/kg	Kragulj *et al.* 2013
Phenanthrene	178.2			MWNT	87,096 L/kg	Kragulj *et al.* 2013
Pyrene	202.3			MWNT	229,087 L/kg	Kragulj *et al.* 2013
Fluoranthene	202.3			MWNT	204,174 L/kg	Kragulj *et al.* 2013
Nitrobenzene	123.1			MWNT (acid treated, 3 hours)	575 L/kg	Kragulj *et al.* 2013
Hexane	86.2			MWNT (acid treated, 3 hours)	813 L/kg	Kragulj *et al.* 2013

Chemical Motif[a]	MW [g/mol]	K_d[b] [M]	K_d/MW [M/Dal]	SE[c]	Affinity parameter value[d]	Ref.[e]
Benzene	78.1			MWNT (acid treated, 3 hours)	302 L/kg	Kragulj *et al.* 2013
Toluene	92.1			MWNT (acid treated, 3 hours)	269 L/kg	Kragulj *et al.* 2013
1,2,3-Trichloro-benzene	181.5			MWNT (acid treated, 3 hours)	7,586 L/kg	Kragulj *et al.* 2013
1,2,4-Trichloro-benzene	181.5			MWNT (acid treated, 3 hours)	2,754 L/kg	Kragulj *et al.* 2013
Naphtalene	128.2			MWNT (acid treated, 3 hours)	4,786 L/kg	Kragulj *et al.* 2013
Phenanthrene	178.2			MWNT (acid treated, 3 hours)	199,526 L/kg	Kragulj *et al.* 2013
Pyrene	202.3			MWNT (acid treated, 3 hours)	457,088 L/kg	Kragulj *et al.* 2013
Fluoranthene	202.3			MWNT (acid treated, 3 hours)	371,535 L/kg	Kragulj *et al.* 2013
Nitrobenzene	123.1			MWNT (acid treated, 6 hours)	182 L/kg	Kragulj *et al.* 2013

Chemical Motif[a]	MW [g/mol]	K_d[b] [M]	K_d/MW [M/Dal]	SE[c]	Affinity parameter value[d]	Ref.[e]
Hexane	86.2			MWNT (acid treated, 6 hours)	562 L/kg	Kragulj *et al.* 2013
Benzene	78.1			MWNT (acid treated, 6 hours)	20 L/kg	Kragulj *et al.* 2013
Toluene	92.1			MWNT (acid treated, 6 hours)	32 L/kg	Kragulj *et al.* 2013
1,2,3-Trichloro-benzene	181.5			MWNT (acid treated, 6 hours)	8,511 L/kg	Kragulj *et al.* 2013
1,2,4-Trichloro-benzene	181.5			MWNT (acid treated, 6 hours)	9,772 L/kg	Kragulj *et al.* 2013
Naphtalene	128.2			MWNT (acid treated, 6 hours)	6,918 L/kg	Kragulj *et al.* 2013
Phenanthrene	178.2			MWNT (acid treated, 6 hours)	301,995 L/kg	Kragulj *et al.* 2013
Pyrene	202.3			MWNT (acid treated, 6 hours)	3,548,134 L/kg	Kragulj *et al.* 2013
Fluoranthene	202.3			MWNT (acid treated, 6 hours)	3,715,352 L/kg	Kragulj *et al.* 2013
Naphtalene	128.2			SWNT	10,000 L/kg	Ji *et al.* 2008

Chemical Motif[a]	MW [g/mol]	K_d[b] [M]	K_d/MW [M/Dal]	SE[c]	Affinity parameter value[d]	Ref.[e]
Naphtalene	128.2			MWNT	1,000 L/kg	Ji *et al.* 2008
Naphtalene	128.2			Activated carbon	1,000,000 L/kg	Ji *et al.* 2008
Naphtalene	128.2			Graphite	1,000 L/kg	Ji *et al.* 2008
Tetracycline	444.4			SWNT	100,000 L/kg	Ji *et al.* 2008
Tetracycline	444.4			MWNT	10,000 L/kg	Ji *et al.* 2008
Tetracycline	444.4			Activated carbon	10,000 L/kg	Ji *et al.* 2008
Tetracycline	444.4			Graphite	10,000 L/kg	Ji *et al.* 2008
QLMHDYR	962.1	1.6E-05	1.7E-08	PLLA (melt crystallization)	6.1E+04 M^{-1}	Matsuno *et al.* 2008
QLMHDYR	962.1	1.8E-04	1.8E-07	PMMA (atactic)	5.7E+03 M^{-1}	Matsuno *et al.* 2008
QLMHDYR	962.1	1.5E-04	1.5E-07	PLLA (amorphous)	6.8E+03 M^{-1}	Matsuno *et al.* 2008
QLMHDYR	962.1	6.7E-05	6.9E-08	PLLA (layer by layer)	1.5E+04 M^{-1}	Matsuno *et al.* 2008
QLMHDYR	962.1	2.1E-05	2.2E-08	PDLA	4.8E+04 M^{-1}	Matsuno *et al.* 2008
CPTSTGQAC	867	2.8E-07	3.2E-10	Platinum	3.6E+06 M^{-1}	Seker *et al.* 2011

Chemical Motif[a]	MW [g/mol]	K_d[b] [M]	K_d/MW [M/Dal]	SE[c]	Affinity parameter value[d]	Ref.[e]
CTLHVSSYC	1,012	1.1E-06	1.1E-09	Platinum	9.0E+05 M^{-1}	Seker *et al.* 2011
RLNPPSQMD-PPF	1,399	8.3E-06	6.0E-09	Silica	1.2E+05 M^{-1}	Seker *et al.* 2011
QTWPPPLWF-STS	1,447	8.1E-07	5.6E-10	Silica	1.2E+06 M^{-1}	Seker *et al.* 2011
HTDWRLGT-WHHS	1,533	1.3E-06	8.5E-10	PPV (hyper-branched)	7.7E+05 M^{-1}	Eijima *et al.* 2010
HTDWRLGT-WHHS	1,533	1.9E-05	1.3E-08	PPV (linear)	5.2E+04 M^{-1}	Eijima *et al.* 2010
ELWSIDTSA-HRK	1,443	2.7E-05	1.9E-08	PPV (hyper-branched)	3.7E+04 M^{-1}	Eijima *et al.* 2010
ELWSIDTSA-HRK	1,443	1.3E-05	9.0E-09	PPV (linear)	7.7E+04 M^{-1}	Eijima *et al.* 2010
Sodium dodecyl-benzenesulfonate	288.4	8.9E-04	3.1E-06	SWNT (8,6)	1.1E+03 M^{-1}	Sim *et al.* 2013
Sodium dodecyl-benzenesulfonate	288.4	7.1E-04	2.5E-06	SWNT (6,5)	1.4E+03 M^{-1}	Sim *et al.* 2013
Sodium dodecyl-benzenesulfonate	288.4	6.4E-04	2.2E-06	SWNT (10,2)	1.6E+03 M^{-1}	Sim *et al.* 2013
IFRLSWGTYFS	1,377	2.0E-05	1.5E-08	SWNT (HiPco, raw)	5.0E+04 M^{-1}	Li *et al.* 2013
HWKHPWGA-WDTL	1,534	5.0E-05	3.3E-08	MWNT (array)	2.0E+04 M^{-1}	Wang *et al.* 2003
ELWR	602.7	6.3E-04	1.0E-06	PMMA (isotactic)	1.6E+03 M^{-1}	Serizawa *et al.* 2007

Chemical Motif[a]	MW [g/mol]	K_d[b] [M]	K_d/MW [M/Dal]	SE[c]	Affinity parameter value[d]	Ref.[e]
ELWRPTR	957.1	3.6E-06	3.7E-09	PMMA (isotactic)	2.8E+05 M^{-1}	Serizawa *et al.* 2007
ELWRPTR	957.1	1.5E-04	1.5E-07	PMMA (syndio-tactic)	6.8E+03 M^{-1}	Serizawa *et al.* 2007
KPRSVSG	965	5.4E-06	5.6E-09	Ceramic fluorapatite	1.9E+05 M^{-1}	Islam *et al.* 2012
KPRSVSG	965	7.2E-06	7.5E-09	Ceramic hydroxyl-apatite	1.4E+05 M^{-1}	Islam *et al.* 2012
Pyrene	202.3	6.1E-02	3.0E-04	SWNT (plasma purified)	1.6E+01 M^{-1}	Juan *et al.* 2015
Pyrene	202.3	4.2E-02	2.1E-04	SWNT (plasma purified)	2.4E+01 M^{-1}	Juan *et al.* 2015
Pyrene	202.3	4.8E-02	2.4E-04	SWNT (plasma purified)	2.1E+01 M^{-1}	Juan *et al.* 2015
Pyrene	202.3	1.1E-01	5.5E-04	SWNT (plasma purified)	9.0E+00 M^{-1}	Juan *et al.* 2015
Pyrene	202.3	2.2E-01	1.1E-03	SWNT (plasma purified)	4.5E+00 M^{-1}	Juan *et al.* 2015
Pyrene	202.3	3.8E-04	1.9E-06	SWNT (plasma purified)	2.6E+03 M^{-1}	Juan *et al.* 2015

Chemical Motif[a]	MW [g/mol]	K_d[b] [M]	K_d/MW [M/Dal]	SE[c]	Affinity parameter value[d]	Ref.[e]
Pyrene	202.3	2.4E-02	1.2E-04	SWNT (6,5)	4.1E+01 M^{-1}	Juan *et al.* 2015
Pyrene	202.3	6.3E-01	3.1E-03	SWNT (6,5)	1.6E+00 M^{-1}	Juan *et al.* 2015
Pyrene	202.3	6.3E-01	3.1E-03	SWNT (6,5)	1.6E+00 M^{-1}	Juan *et al.* 2015
Pyrene	202.3	1.0E-03	4.9E-06	SWNT (6,5)	1.0E+03 M^{-1}	Juan *et al.* 2015
Pyrene diamine	230	4.5E-03	2.0E-05	SWNT (plasma purified)	2.2E+02 M^{-1}	Juan *et al.* 2015
Pyrene diamine	230	3.4E-02	1.5E-04	SWNT (6,5)	2.9E+01 M^{-1}	Juan *et al.* 2015
Pyrene phenyl ester	240	1.1E-02	4.6E-05	SWNT (plasma purified)	9.0E+01 M^{-1}	Juan *et al.* 2015
Pyrene phenyl ester	240	5.0E-02	2.1E-04	SWNT (plasma purified)	2.0E+01 M^{-1}	Juan *et al.* 2015
Dipyrene phenyl ester	440	1.5E-04	3.5E-07	SWNT (plasma purified)	6.5E+03 M^{-1}	Juan *et al.* 2015
Dipyrene phenyl ester	440	2.5E-04	5.7E-07	SWNT (plasma purified)	4.0E+03 M^{-1}	Juan *et al.* 2015
Bis-pyrene U-shape molecule	640	1.4E-04	2.2E-07	SWNT (plasma purified)	7.0E+03 M^{-1}	Juan *et al.* 2015

Chemical Motif[a]	MW [g/mol]	K_d[b] [M]	K_d/MW [M/Dal]	SE[c]	Affinity parameter value[d]	Ref.[e]
TGTGFGTCT	844			Quartz	–0.8 kcal/mol	Aby *et al.* 2012
TGTGVGTCT	796			Quartz	0.0 kcal/mol	Aby *et al.* 2012
TGTGWGTCT	883			Quartz	0.0 kcal/mol	Aby *et al.* 2012
TGTGTGTCT	798			Quartz	0.0 kcal/mol	Aby *et al.* 2012
TGTGGGTCT	754			Quartz	–0.9 kcal/mol	Aby *et al.* 2012
TGTGNGTCT	811			Quartz	–1.2 kcal/mol	Aby *et al.* 2012
TGTGKGTCT	825			Quartz	–0.2 kcal/mol	Aby *et al.* 2012
TGTGDGTCT	812			Quartz	–0.1 kcal/mol	Aby *et al.* 2012
TGTGFGTCT	844			Glass	–2.2 kcal/mol	Aby *et al.* 2012
TGTGVGTCT	796			Glass	–0.9 kcal/mol	Aby *et al.* 2012
TGTGWGTCT	883			Glass	–0.3 kcal/mol	Aby *et al.* 2012
TGTGTGTCT	798			Glass	–1.0 kcal/mol	Aby *et al.* 2012
TGTGGGTCT	754			Glass	–1.9 kcal/mol	Aby *et al.* 2012

Chemical Motif[a]	MW [g/mol]	K_d[b] [M]	K_d/MW [M/Dal]	SE[c]	Affinity parameter value[d]	Ref.[e]
TGTGNGTCT	811			Glass	–2.2 kcal/mol	Aby *et al.* 2012
TGTGKGTCT	825			Glass	–0.9 kcal/mol	Aby *et al.* 2012
TGTGDGTCT	812			Glass	–0.2 kcal/mol	Aby *et al.* 2012
TGTGFGTCT	844			PMMA	–2.2 kcal/mol	Aby *et al.* 2012
TGTGVGTCT	796			PMMA	–2.0 kcal/mol	Aby *et al.* 2012
TGTGWGTCT	883			PMMA	–0.9 kcal/mol	Aby *et al.* 2012
TGTGTGTCT	798			PMMA	–0.3 kcal/mol	Aby *et al.* 2012
TGTGGGTCT	754			PMMA	–2.1 kcal/mol	Aby *et al.* 2012
TGTGNGTCT	811			PMMA	–2.8 kcal/mol	Aby *et al.* 2012
TGTGKGTCT	825			PMMA	–1.2 kcal/mol	Aby *et al.* 2012
TGTGDGTCT	812			PMMA	–2.5 kcal/mol	Aby *et al.* 2012
TGTGFGTCT	844			HDPE	–3.9 kcal/mol	Aby *et al.* 2012
TGTGVGTCT	796			HDPE	–4.0 kcal/mol	Aby *et al.* 2012

Chemical Motif[a]	MW [g/mol]	K_d[b] [M]	K_d/MW [M/Dal]	SE[c]	Affinity parameter value[d]	Ref.[e]
TGTGWGTCT	883			HDPE	–2.1 kcal/mol	Aby *et al.* 2012
TGTGTGTCT	798			HDPE	–1.8 kcal/mol	Aby *et al.* 2012
TGTGGGTCT	754			HDPE	–3.6 kcal/mol	Aby *et al.* 2012
TGTGNGTCT	811			HDPE	–3.5 kcal/mol	Aby *et al.* 2012
TGTGKGTCT	825			HDPE	–3.9 kcal/mol	Aby *et al.* 2012
TGTGDGTCT	812			HDPE	–2.8 kcal/mol	Aby *et al.* 2012
m-Dinitrobenzene	168.11			Graphene	0.0569 L/mg	Chen *et al.* 2015
m-Dinitrobenzene	168.11			Graphene oxide	0.00299 L/mg	Chen *et al.* 2015
m-Dinitrobenzene	168.11			Graphene oxide (reduced)	0.162 L/mg	Chen *et al.* 2015
Nitrobenzene	123.06			Graphene	0.0118 L/mg	Chen *et al.* 2015
Nitrobenzene	123.06			Graphene oxide	0.00105 L/mg	Chen *et al.* 2015
Nitrobenzene	123.06			Graphene oxide (reduced)	0.0330 L/mg	Chen *et al.* 2015
p-Nitrotoluene	137.14			Graphene	0.0939 L/mg	Chen *et al.* 2015

Chemical Motif[a]	MW [g/mol]	K_d[b] [M]	K_d/MW [M/Dal]	SE[c]	Affinity parameter value[d]	Ref.[e]
p-Nitrotoluene	137.14			Graphene oxide	0.00395 L/mg	Chen *et al.* 2015
p-Nitrotoluene	137.14			Graphene oxide (reduced)	0.121 L/mg	Chen *et al.* 2015
MHGKTQATS-GTIQS$_7$	10,018	1.5E-10	1.5E-14	Gold	6.7E+09 M^{-1}	Brown 1997
DAEFRHDSGY-EVHHQKLVFF-AEDVGSNKGA-IIGLMVGGVVIA	4,514	6.3E-18	1.4E-21	Copper	1.6E+17 M^{-1}	Atwood *et al.* 2000
DAEFRHDSGY-EVHHQKLVFF-AEDVGSNKGA-IIGLMVGGVV	4,330	5.0E-11	1.2E-14	Copper	2.0E+10 M^{-1}	Atwood *et al.* 2000
CHKKPSKSC	1,015	4.1E-09	4.0E-12	Silica	2.5E+08 M^{-1}	Chen *et al.* 2006
RKLPDAPGM-HTW	1,408	1.3E-05	9.4E-09	Titanium	7.6E+04 M^{-1}	Sano *et al.* 2005
SCSDCLKSVD-FIPSSLASS	1,946	2.5E-07	1.3E-10	Titanium	4.0E+06 M^{-1}	Meyers *et al.* 2007
YLTMPTP	822	5.0E-12	6.1E-15	Polystyrene (syndiotactic)	2.0E+11 M^{-1}	Serizawa *et al.* 2007
FSWEAFA	857	8.5E-11	9.9E-14	Polystyrene (atactic)	1.2E+10 M^{-1}	Serizawa *et al.* 2007
FSWEAFA	857	3.4E-11	4.0E-14	Polystyrene (isotactic)	2.9E+10 M^{-1}	Serizawa *et al.* 2007

Chemical Motif[a]	MW [g/mol]	K_d[b] [M]	K_d/MW [M/Dal]	SE[c]	Affinity parameter value[d]	Ref.[e]
FSWEAFA	857	6.1E-12	7.1E-15	Polystyrene (syndiotactic)	1.6E+11 M^{-1}	Serizawa *et al.* 2007
HLESTPG	740	1.0E-10	1.4E-13	Polystyrene (atactic)	9.8E+09 M^{-1}	Serizawa *et al.* 2007
HLESTPG	740	6.5E-11	8.8E-14	Polystyrene (isotactic)	1.5E+10 M^{-1}	Serizawa *et al.* 2007
HLESTPG	740	7.9E-12	1.1E-14	Polystyrene (syndiotactic)	1.3E+11 M^{-1}	Serizawa *et al.* 2007
GETRAPL	743	6.7E-11	9.0E-14	Polystyrene (atactic)	1.5E+10 M^{-1}	Serizawa *et al.* 2007
GETRAPL	743	3.6E-11	4.9E-14	Polystyrene (isotactic)	2.8E+10 M^{-1}	Serizawa *et al.* 2007
GETRAPL	743	6.7E-12	9.0E-15	Polystyrene (syndiotactic)	1.5E+11 M^{-1}	Serizawa *et al.* 2007
RHEPPLA	819	5.6E-11	6.8E-14	Polystyrene (atactic)	1.8E+10 M^{-1}	Serizawa *et al.* 2007
RHEPPLA	819	2.1E-11	2.6E-14	Polystyrene (isotactic)	4.7E+10 M^{-1}	Serizawa *et al.* 2007
RHEPPLA	819	1.1E-11	1.3E-14	Polystyrene (syndiotactic)	9.4E+10 M^{-1}	Serizawa *et al.* 2007
GETQCAA	679	3.4E-11	5.0E-14	Polystyrene (atactic)	3.0E+10 M^{-1}	Serizawa *et al.* 2007
YLTMPTP	822	2.2E-11	2.6E-14	Polystyrene (atactic)	4.6E+10 M^{-1}	Serizawa *et al.* 2007
FPGRPSP	757	3.1E-11	4.1E-14	Polystyrene (atactic)	3.2E+10 M^{-1}	Serizawa *et al.* 2007

Chemical Motif[a]	MW [g/mol]	K_d[b] [M]	K_d/MW [M/Dal]	SE[c]	Affinity parameter value[d]	Ref.[e]
HTAQSTA	715	1.4E-11	2.0E-14	Polystyrene (atactic)	7.0E+10 M^{-1}	Serizawa *et al.* 2007
HKPDANR	837	2.5E-11	3.0E-14	PMMA (conditioned syndiotactic film)	4.0E+10 M^{-1}	Serizawa *et al.* 2007
FPGHSGP	698	1.0E-10	1.4E-13	PMMA (non-conditioned syndiotactic film)	1.0E+10 M^{-1}	Serizawa *et al.* 2007
THLPWQT	882	6.7E-11	7.6E-14	PMMA (non-conditioned syndiotactic film)	1.5E+10 M^{-1}	Serizawa *et al.* 2007
GETQCAA	679	7.4E-12	1.1E-14	Polystyrene (syndiotactic)	1.4E+11 M^{-1}	Serizawa *et al.* 2007
FPGRPSP	757	8.5E-12	1.1E-14	Polystyrene (syndiotactic)	1.2E+11 M^{-1}	Serizawa *et al.* 2007
HTAQSTA	715	1.0E-11	1.4E-14	Polystyrene (syndiotactic)	9.7E+10 M^{-1}	Serizawa *et al.* 2007
VKTQATSREE-PPRLPSKHRPG$_4$	9,433	1.0E-10	1.1E-14	Zeolite	1.0E+10 M^{-1}	Nygaard *et al.* 2002
PQAQDVELPQ-ELQDQHREVEV$_5$	12,366	4.0E-11	3.2E-15	SWNT (HiPco, purified)	2.5E+10 M^{-1}	Brown *et al.* 2008

[a]All chemical motifs denoted by capital letters are peptide sequences; for polypeptides, the subscripts denote how many times the peptide sequence is repeated. [b]K_d is the dissociation

constant. [c]MWNT is multi walled carbon nanotube; SWNT is single walled carbon nanotube; PLLA is polylactic acid; PMMA is poly(methyl methacrylate); PDLA is poly-D-lactide; PPV is poly(*p*-phenylene vinylene); HDPE is high-density polyethylene; numbers in brackets after SWNTs denote chirality, e.g. (6,5). [d]Affinity parameter values with the unit L/kg are affinities expressed as the adsorption distribution coefficient; affinity parameter values with the unit M^{-1} are affinities expressed as the affinity constant K_a, which is equal to $1/K_d$; affinity parameter values with the unit kcal/mol are affinities expressed as the standard-state adsorption free energy values ($\Delta G°_{ads}$); affinity parameter values with the unit L/mg are affinities expressed as Langmuir affinity constant (K_L).

For any characteristics of a precursor-ML, ML or Ligand2 mentioned above, and in each characteristic's entire range, a further characteristic of importance is the Affinity-to-MW ratio of the precursor-ML, ML or Ligand2, respectively.

Binding constant-to-MW ratio of precursor-ML, ML or Ligand2. In some cases, it is not the absolute affinity of a precursor-ML, ML or Ligand2 for an SE that is important, but rather the affinity-to-MW (K_B/MW) ratio that is important. As an example, if the economical cost of preparing two small Ligand2s with a combined binding constant for an SE of $K_B = 10^{10}$ M^{-1} is smaller than the cost of preparing one larger Ligand2 with the same binding constant, it may be desirable to use the smaller Ligand2s. Thus, depending on the context, the K_B/MW ratio is preferably greater than 1 M^{-1}/Dal, such as greater than 10^6 M^{-1}/Dal, such as greater than 10^{10} M^{-1}/Dal, such as greater than 10^{13} M^{-1}/Dal, such as greater than 10^{16} M^{-1}/Dal, such as greater than 10^{18} M^{-1}/Dal, such as greater than 10^{20} M^{-1}/Dal.

However, if the processing of the composite material is performed more easily using fewer precursor-MLs, MLs, or Ligand2s, it may be desirable to use larger precursor-MLs, MLs, or Ligand2s, respectively. Thus, depending on the context, the K_B/MW ratio is preferably less than 10^{20} M^{-1}/Dal, such as less than 10^{18} M^{-1}/Dal, such as less than 10^{16} M^{-1}/Dal, such as less than 10^{13} M^{-1}/Dal, such as less than 10^{10} M^{-1}/Dal, such as less than 10^6 M^{-1}/Dal, such as less than 1 M^{-1}/Dal.

Thus, the preferred compromise between many small precursor-MLs, MLs, or Ligand2s with relatively high K_B/MW ratios and fewer large precursor-MLs, MLs, or Ligand2s, respectively, with relatively low K_B/MW ratios depends on the context. Preferred embodiments include precursor-MLs, MLs, or Ligand2s with K_B/MW ratios of from 1 M^{-1}/Dal to $10^{20}M^{-1}$/Dal, more

preferably precursor-MLs, MLs, or Ligand2s with K_B/MW ratios of from 10^3 M^{-1}/Dal to $10^{20}M^{-1}$/Dal, more preferably precursor-MLs, MLs, or Ligand2s with K_B/MW ratios of from 10^6 M^{-1}/Dal to $10^{20}M^{-1}$/Dal, more preferably precursor-MLs, MLs, or Ligand2s with K_B/MW ratios of from 10^{10} M^{-1}/Dal to $10^{20}M^{-1}$/Dal, more preferably precursor-MLs, MLs, or Ligand2s with K_B/MW ratios of from 10^{13} M^{-1}/Dal to $10^{20}M^{-1}$/Dal, more preferably precursor-MLs, MLs, or Ligand2s with K_B/MW ratios of from 10^{16} M^{-1}/Dal to $10^{20}M^{-1}$/Dal, more preferably precursor-MLs, MLs, or Ligand2s with K_B/MW ratios of from 10^{18} M^{-1}/Dal to $10^{20}M^{-1}$/Dal, and more preferably precursor-MLs, MLs, or Ligand2s with K_B/MW ratios larger than $10^{20}M^{-1}$/Dal.

For any characteristics of a precursor-ML or Ligand2 mentioned above, and in each characteristic's entire range, a further characteristic of importance is the half-life of the precursor-ML-SE complex or the Ligand2-SE complex, respectively.

Half-life of precursor-ML or Ligand2. In many cases, precursor-MLs or Ligand2s with large half-lifes are preferred. This is for example the case for Ligand2s in composite materials where the characteristics of the composite material should change as little over time as possible, e.g. in structural elements of buildings, bridges, etc. Thus, depending on the context, the half-life is preferably greater than 0.01 second, such as greater than 0.1 second, such as greater than 1 second, such as greater than 10 seconds, such as greater than 1 minute, such as greater than 10 minutes, such as greater than 1 hour, such as greater than 5 hours, such as greater than 10 hours, such as greater than 24 hours, such as greater than 2 days, such as greater than 10 days, such as greater than 50 days, such as greater than 100 days, such as greater than 1 year, such as greater than 10 years.

In other cases, precursor-MLs or Ligand2s with short half-lifes are preferred. This may be the case if it is desirable that a material gives in after some prespecified time. Thus, depending on the context, the half-life is preferably less than 10 years, such as less than 1 year, such as less than 100 days, such as less than 50 days, such as less than 10 days, such as less than 2 days, such as less than 24 hours, such as less than 10 hours, such as less than 5 hours, such as less than 1 hour, such as less than 10 minutes, such as less than 1 minute, such as less than 10 seconds, such as less than 1 second, such as less than 0.1 second, such as less than 0.01 second.

Thus, the preferred compromise between long half-lifes and short half-lifes depends on the context and half-lifes suitable for the present invention can be shorter than 0.01 second, but

may also include half-lifes in the following ranges: 0.01–0.1 seconds, 0.1–1 seconds, 1–10 seconds, 10–60 seconds, 1–10 minutes, 10–60 minutes, 1–5 hours, 5–10 hours, 10–24 hours, 1–2 days, 2–10 days, 10–50 days, 50–100 days, 100–365 days, 1–10 years, or more than 10 years. Eg. when the Ligand2-SE interaction is characterized by an appropriately long half-life, the SE and Ligand2 will remain associated for a long time, and the composite material comprising such CMUs will retain its characteristics for a longer period of time.

Half-life-to-MW ratio of precursor-ML or Ligand2. In some cases, it is not the half-life (T½) of a precursor-ML or Ligand2 for an SE that is important, but rather the half-life-to-MW (T½/MW) ratio that is important. As an example, if the economical cost of preparing two small precursor-MLs with a combined half life for an SE of T½ = 5 days is smaller than the cost of preparing one larger precursor-ML with the same binding constant, it may be desirable to use the smaller precursor-MLs. Thus, depending on the context, the T½/MW ratio is preferably greater than 10^{-8} days/Dal, such as greater than 10^{-6} days/Dal, such as greater than 10^{-4} days/Dal, such as greater than 0.01 days/Dal, such as greater than 1 days/Dal, such as greater than 100 days/Dal, such as greater than 10,000 days/Dal.

However, if the processing of the composite material is performed more easily using fewer precursor-MLs or Ligand2s, it may be desirable to use larger precursor-MLs or Ligand2s. Thus, depending on the context, the T½/MW ratio is preferably less than 10,000 days/Dal, such as less than 100 days/Dal, such as less than 1 days/Dal, such as less than 0.01 days/Dal, such as less than 10^{-4} days/Dal, such as less than 10^{-6} days/Dal, such as less than 10^{-8} days/Dal.

Thus, the preferred compromise between a high and low T½/MW ratio depends on the context, and may be lower than 10^{-8} days/Dal, but may also be in the range of 10^{-8}–10^{-6} days/Dal, 10^{-6}–10^{-4} days/Dal, 10^{-4}–0.01 days/Dal, 0.01–1 days/Dal, 1–100 days/Dal, 100–10,000 days/Dal, or above 10,000 days/Dal.

For any characteristics of a precursor-ML, ML or Ligand2 mentioned above, and in each characteristic's entire range, a further characteristic of importance is the charge of the precursor-ML, ML or Ligand2.

Charge of precursor-ML, ML or Ligand2. The charge of the precursor-ML, ML or Ligand2 can be important. As an example, if the precursor-ML, ML or Ligand2 is used as a means to

prepare a nanosensor, where a conducting nanotube is used to sense the binding of certain analytes to another SE, linked to the nanotube by way of the precursor-ML, ML or Ligand2, then the charge of the precursor-ML, ML or Ligand2, respectively, is likely to have an effect on the conductivity of the nanotube (and hence, an effect on the read-out), which may not always be desirable. A precursor-ML, ML or Ligand2 carrying a charge may also be a disadvantage during the preparation of a composite material comprising CMUs, because the charge may interfere with e.g. polymerization of the matrix material. Alternatively, a ligand carrying a charge can help disperse an SE in certain solvents, in which case it will be an advantage to have a charged precursor-ML, ML or Ligand2.Thus, depending on the context, the net charge at pH 7 is preferably greater than -10, such as greater than -9, such as greater than -8, such as greater than -7, such as greater than -6, such as greater than -5, such as greater than -4, such as greater than -3, such as greater than -2, such as greater than -1, such as greater than 0, such as greater than 1, such as greater than 2, such as greater than 3, such as greater than 4, such as greater than 5, such as greater than 6, such as greater than 7, such as greater than 8, such as greater than 9, such as greater than 10, such as greater than 11, such as greater than 12, such as greater than 13. Preferred embodiments of the present invention include precursor-MLs, MLs or Ligand2s with a net charge at pH 7 of less than -10, or a net charge of -10, or -9, -8, -7, -6, -5, -4, -3, -2, -1, 0 (e.g. the amino acid alanine) , +1, +2, +3, +4, +5, +6, +7, +8, +9, +10, +11, +12, +13, or more than a net charge of +13.

Likewise, preferred embodiments of the present invention include precursor-MLs, MLs or Ligand2s with a total number of charges (positive or negative charges) of 0, 1, 2 (e.g. the amino acid alanine at pH 7), 3, 4, 5, 6 , 7, 8, 9, 10, 11, 12, 13–15, 15–20, 20–30, 30–50, 50–100, or more than 100.

For any characteristics of a precursor-ML, ML or Ligand2 mentioned above, and in each characteristic's entire range, a further characteristic of importance is the surface area of interaction of the precursor-ML, ML or Ligand2 with the SE.

Surface area of the interaction of the precursor-ML, ML or Ligand2 with the SE. The surface area of interaction between the precursor-ML, ML or Ligand2 and SE determines how many precursor-MLs, MLs, or Ligand2s can bind to a given SE. Therefore, the surface area of interaction can be an important parameter and in some cases, a large surface area of interaction is desirable, as it may allow the precursor-ML to bind with a higher affinity to the SE. Thus, depending on the context, the surface area of interaction is preferably greater

than 20 Å^2, such as greater than 100 Å^2, such as greater than 200 Å^2, such as greater than 300 Å^2, such as greater than 500 Å^2, such as greater than 700 Å^2, such as greater than 1,000 Å^2, such as greater than 2,000 Å^2, such as greater than 4,000 Å^2, such as greater than 8,000 Å^2, such as greater than 15,000 Å^2, such as greater than 30,000 Å^2, such as greater than 100,000 Å^2.

In other cases, a small surface area of interaction is desirable, e.g if a higher number of precursor-ML, ML or Ligand2 must be bound to the SE, and thus, depending on the context, the surface area of interaction is preferably less than 100,000 Å^2, such as less than 30,000 Å^2, such as less than 15,000 Å^2, such as less than 8,000 Å^2, such as less than 4,000 Å^2, such as less than 2,000 Å^2, such as less than 1,000 Å^2, such as less than 700 Å^2, such as less than 500 Å^2, such as less than 300 Å^2, such as less than 200 Å^2, such as less than 100 Å^2, such as less than 20 Å^2.

Preferred embodiments of the present invention include precursor-MLs, MLs, or Ligand2s that contact the SE over a surface area of less than 20 Å^2, or contact the SE over a surface area of 20–100 Å^2, 100–200 Å^2, 200–300 Å^2, 300–500 Å^2, 500–700 Å^2, 700–1,000 Å^2, 1,000–2,000 Å^2, 2,000–4,000 Å^2, 4,000–8,000 Å^2, 8,000–15,000 Å^2, 15,000–30,000 Å^2, 30,000–100,000 Å^2, or more than 100,000 Å^2.

For any characteristics of a precursor-ML, ML or Ligand2 mentioned above, and in each characteristic's entire range, further characteristics of importance are the Affinity-to-charge ratio of the precursor-ML, ML or Ligand2, respectively, the Affinity to area-of-interaction ratio of the precursor-ML, ML or Ligand2, respectively, the degradability and biodegradability of the precursor-ML, ML or Ligand2, respectively, and the intrinsic stability of the precursor-ML, ML or Ligand2, respectively.

Particularly the biodegradability is of importance. Degradation by enzymes such as peptidases, nucleases and other enzymes commonly found in nature can decrease the lifetime of a composite material, wherefore it is often advantageous to avoid the use of natural and unnatural oligonucleotides, natural and unnatural polypeptides (comprising natural and unnatural amino acids), and in general avoid the use of polyamides or amide bonds in general, or any other kind of chemical entity or bond that is commonly found in nature.

In short, when trying to avoid biodegradation, it is often advantageous to use components for the making of composite materials that do not resemble too strongly the chemical entities found in nature. Thus, use of precursor-MLs, MLs, or Ligand2s (and structural entities and linkers) that do not contain peptides or nucleotides is often preferable.

Chemical stability is also of importance. It is generally advantageous to use precursor-MLs, MLs, or Ligand2s that are chemically stable (e.g. stable towards high temperature, low or high pH, high pressure, etc), in order to ensure that the precursor-ML's, ML's or Ligand2's characteristics, especially the affinity for the structural entity, remain relatively constant under varying conditions.

In another preferred embodiment it is advantageous to use biodegradable components, to avoid e.g. long term pollution of the environment.

Precursor-MLs, MLs, or Ligand2s may be organic or inorganic.

Further, precursor-MLs, MLs, or Ligand2s may be polymers or may be non-polymeric in structure. Prefered polymeric precursor-MLs, MLs, or Ligand2s include the polymers listed above and below.

The polymeric precursor-MLs, MLs, or Ligand2s can be divided into biological polymers and non-biological polymers.

Biological polymers shall here be defined as the polymers involved in the transcriptional and translational process, i.e. natural nucleic acids (RNA or DNA), or natural polypeptides. Natural polypeptides can be further divided into peptides, proteins and antibodies.

Peptide-based precursor-MLs, MLs, or Ligand2s. The number of amino acids (AA) of the precursor-ML, ML or Ligand2 may be of high economic importance (smaller peptides typically cost less to produce), and also, a smaller peptide is often indicative of a smaller surface of interaction with the SE, wherefore typically a higher number of precursor-MLs, MLs, or Ligand2s can bind simultaneously to the SE if each precursor-ML, ML or Ligand2 comprise fewer amino acids. Thus, depending on the context, the peptide-based precursor-ML, ML or Ligand2 is preferably comprised of fewer than 100 AA, such as fewer than 90 AA, such as fewer than 80 AA, such as fewer than 70 AA, such as fewer than 60 AA, such as fewer than 50 AA, such as fewer than 40 AA, such as fewer than 30 AA, such as fewer than

25 AA, such as fewer than 20 AA, such as fewer than 15 AA, such as fewer than 10 AA, such as fewer than 9 AA, such as fewer than 8 AA, such as fewer than 7 AA, such as fewer than 6 AA, such as fewer than 5 AA, such as fewer than 4 AA, such as fewer than 3 AA, such as fewer than 2 AA.

However, it is typically easier to prepare a peptide-based precursor-ML, ML or Ligand2 of high affinity if it comprises more amino acids. Thus, depending on the context, the peptide-based precursor-ML, ML or Ligand2 is preferably comprised of more than 1 AA, such as more than 2 AA, such as more than 3 AA, such as more than 4 AA, such as more than 5 AA, such as more than 6 AA, such as more than 7 AA, such as more than 8 AA, such as more than 9 AA, such as more than 10 AA, such as more than 15 AA, such as more than 20 AA, such as more than 25 AA, such as more than 30 AA, such as more than 40 AA, such as more than 50 AA, such as more than 60 AA, such as more than 70 AA, such as more than 80 AA, such as more than 90 AA, such as more than 100 AA.

Thus, the preferred compromise between peptide-based precursor-MLs, MLs, or Ligand2s comprising few or many amino acids depends on the context, and may be lower than 2 AA, but may also be in the range: 2–3 AA, 3–4 AA, 4–5 AA, 5–6 AA, 6–7 AA, 7–8 AA, 8–9 AA, 9–10 AA, 10–15 AA, 15–20 AA, 20–25 AA, 25–30 AA, 30–40 AA, 40–50 AA, 50–60 AA, 60–70 AA, 70–80 AA, 80–90 AA, 90–100 AA, or more than 100 AA.

Preferred peptide-based precursor-MLs, MLs, or Ligand2s include the following peptides, as well as all shorter peptide sequences that may be derived from these peptid sequences:
PQAQDVELPQELQDQHREVEV$_5$ =
PQAQDVELPQELQDQHREVEVPQAQDVELPQELQDQHREVEVPQAQDVELPQELQDQHREVEVPQAQDVELPQELQDQHREVEVPQAQDVELPQELQDQHREVEV)

Non-biological polymers include polymers that are not RNA, DNA or natural polypeptides, e.g. including PVC, epoxy, unnatural polypeptides (i.e. not solely comprising alpha-amino acids) and unnatural nucleic acids (e.g. PNA, LNA and other unnatural nucleic acids).

The polymeric precursor-MLs, MLs, or Ligand2s can be further divided into linear and branched polymers. The branched polymers may be further divided into short-chain branched polymers, long-chain branched polymers, star-branched polymers, ladder polymers and network polymers.

The precursor-MLs, MLs, or Ligand2s can be further divided into precursor-MLs, MLs, or Ligand2s comprising solely aliphatic moieties, comprising solely aromatic moieties, or comprising both aliphatic and aromatic moieties.

The precursor-MLs, MLs, or Ligand2s can be further divided into precursor-MLs, MLs, or Ligand2s comprising solely single bonds, solely double bonds, solely triple bonds, solely aromatic bonds, or a combination of single-, double-, triple and aromatic bonds.

Organic precursor-MLs, MLs, or Ligand2s include natural and unnatural polypeptides, lipids, polysaccharides, wood, flour,

Inorganic precursor-MLs, MLs, or Ligand2s include metal ions, Cu+, Cu2+, Fe2+, Fe3+, Hg2+, $Hg_2$2+, Pb2+, Pb4+, Sn2+, Sn4+, Cr2+, Cr3+, Mn2+, Mn3+, Co2+, Co3+.

Identities and number of different elements of a Precursor-ML, ML or Ligand2. The Precursor-ML, ML or Ligand2 may be composed of only one element, two elements, three elements, four elements, or more than four elements.

Precursor-MLs, MLs, or Ligand2s consisting of one element. The precursor-ML, ML or Ligand2 may consist of just one atom (in its non-charged form or as an ion, e.g. Gd or Gd+++), or may consist of several atoms, held together in an organized structure.

The following ions are particularly preferred precursor-MLs, MLs, or Ligand2s : K+, Cl-, Ca++, Mg++, Gd+++, Cu+, Cu2+, Fe2+, Fe3+, Hg2+, $Hg_2$2+, Pb2+, Pb4+, Sn2+, Sn4+, Cr2+, Cr3+, Mn2+, Mn3+, Co2+, Co3+.

If comprising only one element, or one type of element, the element may be any one of the following elements: Lithium (Li), Beryllium (Be), Boron (B), Carbon (C), Nitrogen (N), Oxygen (O), Fluorine (F), Sodium (Na), Magnesium (Mg), Aluminium (Al), Silicon (Si), Phosphorus (P), Sulfur (S), Chlorine (Cl), Potassium (K), Calcium (Ca), Scandium (Sc), Titanium (Ti), Vanadium (V), Chromium (Cr), Manganese (Mn), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Gallium (Ga), Germanium (Ge), Arsenic (As), Selenium (Se), Bromine (Br), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), Niobium (Nb), Molybdenum (Mo), Technetium (Tc), Ruthenium (Ru), Rhodium (Rh), Palladium (Pd), Silver (Ag), Cadmium (Cd), Indium (In), Tin (Sn), Antimony (Sb), Tellurium (Te), Iodine (I),

Caesium (Cs), Barium (Ba), Platinum (Pt), Gold (Au), Mercury (Hg), Thallium (Tl), Lead (Pb), Bismuth (Bi).

Examples of precursor-MLs, MLs, or Ligand2s consisting of only carbon (C) include the following: Fullerenes including graphene and carbon nanotubes, carbon fiber, and pyrene.

Precursor-MLs, MLs, or Ligand2s consisting of two elements. If comprising only two elements, or two types of elements, the elements may include any of the following:

Hydrogen (H), Lithium (Li), Beryllium (Be), Boron (B), Carbon (C), Nitrogen (N), Oxygen (O), Fluorine (F), Sodium (Na), Magnesium (Mg), Aluminium (Al), Silicon (Si), Phosphorus (P), Sulfur (S), Chlorine (Cl), Potassium (K), Calcium (Ca), Scandium (Sc), Titanium (Ti), Vanadium (V), Chromium (Cr), Manganese (Mn), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Gallium (Ga), Germanium (Ge), Arsenic (As), Selenium (Se), Bromine (Br), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), Niobium (Nb), Molybdenum (Mo), Technetium (Tc), Ruthenium (Ru), Rhodium (Rh), Palladium (Pd), Silver (Ag), Cadmium (Cd), Indium (In), Tin (Sn), Antimony (Sb), Tellurium (Te), Iodine (I), Caesium (Cs), Barium (Ba), Platinum (Pt), Gold (Au), Mercury (Hg), Thallium (Tl), Lead (Pb), Bismuth (Bi).

Examples of precursor-MLs, MLs, or Ligand2s consisting of only carbon (C) and hydrogen (H) include the following: polyethylene, polypropylene, polystyrene, phenylacetylene, naphthalene, ethylbenzene, phenanthrene, pyrene, decane, benzo(a)pyrene, trans-cyclooctene, anhydrous 1-octyne, meso-1,2-diphenylethylene, 1,2,3,4-tetrahydro-naphthalene, benzo[a]phenanthrene, 1,1-di(phenyl)ethylene, 1,2-benzacenaphthene, 1,2-dihydroacenaphthylene, 1,2-benzanthracene, perylene, 1-iso-propyl-4-methylbenzene, N-dodecane, tert-butyl benzene, 1-methyl-naphthalene, α-n-hexadecene, 1-n-decene, phenylenemethyl-ethylene, trans-2-methylstyrene, ethylmethylbenzene, 2-methyl-naphthalene, 4-methyl-styrene, triphenylemethane, 1-phenyl-1-propyne, 2,2,4-trimethylpentane, 4-methyl phenyl acetylene, hexamethyl-benzene, [3.3.1]nonane, p-mentha-1,8-diene, acetnaphthylene, 1,2,4,5-tetramethyl benzene, 2,6,6-trimethylbicyclo[3.1.1]hept-2-ene, 1,2,4-trimethyl benzene, tricyclo[3.3.1.1{3,7}]decane, butylbenzene, 2,3-benzanthracene, 4-methyl-biphenyl, β-carotene, and derivatives thereof.

Comprising Al and Cl: Aluminium trichloride

Comprising Al and O: Aluminum oxide

Comprising Nb and O: Niobium oxide

Comprising C and F: Polytetrafluoroethylene, pentafluoropropylene, 1,1,4,4,4-pentafluoro-2-butyne, pentafluoro-ethane.

Comprising C and Cl: 1,1,2,2-tetrachloroethylene, hexachloro-benzene.

Precursor-MLs, MLs, or Ligand2s consisting of three elements. If comprising only three elements, or three types of elements, the elements may include any of the following:

Hydrogen (H), Lithium (Li), Beryllium (Be), Boron (B), Carbon (C), Nitrogen (N), Oxygen (O), Fluorine (F), Sodium (Na), Magnesium (Mg), Aluminium (Al), Silicon (Si), Phosphorus (P), Sulfur (S), Chlorine (Cl), Potassium (K), Calcium (Ca), Scandium (Sc), Titanium (Ti), Vanadium (V), Chromium (Cr), Manganese (Mn), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Gallium (Ga), Germanium (Ge), Arsenic (As), Selenium (Se), Bromine (Br), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), Niobium (Nb), Molybdenum (Mo), Technetium (Tc), Ruthenium (Ru), Rhodium (Rh), Palladium (Pd), Silver (Ag), Cadmium (Cd), Indium (In), Tin (Sn), Antimony (Sb), Tellurium (Te), Iodine (I), Caesium (Cs), Barium (Ba), Platinum (Pt), Gold (Au), Mercury (Hg), Thallium (Tl), Lead (Pb), Bismuth (Bi).

Examples of precursor-MLs, MLs, or Ligand2s consisting of three elements include:

Comprising C, H, Cl: Polyvinylchloride

Comprising C, H, O: Poly(vinylalcohol)

Comprising Ag, C, O: Silver carbonate, silver(I) oxalate

Comprising C, H, Cl: 3,3',4,4',5,5'-hexachlorobiphenyl; 1,2,4,5-TeCB; 2,4'-DDT; pentachloroethane; pentachloro-benzene

Precursor-MLs, MLs, or Ligand2s consisting of four elements. If comprising only four elements, or three types of elements, the elements may include any of the following:

Hydrogen (H), Lithium (Li), Beryllium (Be), Boron (B), Carbon (C), Nitrogen (N), Oxygen (O), Fluorine (F), Sodium (Na), Magnesium (Mg), Aluminium (Al), Silicon (Si), Phosphorus (P), Sulfur (S), Chlorine (Cl), Potassium (K), Calcium (Ca), Scandium (Sc), Titanium (Ti), Vanadium (V), Chromium (Cr), Manganese (Mn), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Gallium (Ga), Germanium (Ge), Arsenic (As), Selenium (Se), Bromine (Br), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), Niobium (Nb), Molybdenum (Mo), Technetium (Tc), Ruthenium (Ru), Rhodium (Rh), Palladium (Pd), Silver (Ag), Cadmium

(Cd), Indium (In), Tin (Sn), Antimony (Sb), Tellurium (Te), Iodine (I), Caesium (Cs), Barium (Ba), Platinum (Pt), Gold (Au), Mercury (Hg), Thallium (Tl), Lead (Pb), Bismuth (Bi).

Precursor-MLs, MLs, or Ligand2s consisting of four elements include:

Comprising C, H, Cl, O: 1,2,3,6,7,8-hexachlorooxanthrene; 4,4'-dichloro-benzophenone; Dieldrite; α,α-diphenylacetyl chloride; 1,2,3,4,6,7,8-H7CDF; 1,2,3,4,7,8-hexachlorooxanthrene; 2,3-dichloro-1,4-dihydro-1,4-dioxonaphthalene; 1,2,3,7,8,9-hexachlorooxanthrene.

Precursor-MLs, MLs, or Ligand2s consisting of more than four elements. If comprising more than four elements, the elements may include any of the following:

Hydrogen (H), Lithium (Li), Beryllium (Be), Boron (B), Carbon (C), Nitrogen (N), Oxygen (O), Fluorine (F), Sodium (Na), Magnesium (Mg), Aluminium (Al), Silicon (Si), Phosphorus (P), Sulfur (S), Chlorine (Cl), Potassium (K), Calcium (Ca), Scandium (Sc), Titanium (Ti), Vanadium (V), Chromium (Cr), Manganese (Mn), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Gallium (Ga), Germanium (Ge), Arsenic (As), Selenium (Se), Bromine (Br), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), Niobium (Nb), Molybdenum (Mo), Technetium (Tc), Ruthenium (Ru), Rhodium (Rh), Palladium (Pd), Silver (Ag), Cadmium (Cd), Indium (In), Tin (Sn), Antimony (Sb), Tellurium (Te), Iodine (I), Caesium (Cs), Barium (Ba), Platinum (Pt), Gold (Au), Mercury (Hg), Thallium (Tl), Lead (Pb), Bismuth (Bi).

Precursor-MLs, MLs, or Ligand2s consisting of more than four elements include:

Comprising N, H, Br, O, C: 1-amino-4-bromo-2-nitrobenzene, 5,7-dibromo-8-hydroxy quinolone; 4-Bromophenyl isothiocyanate; 2-(bromoacetyl)-thiophene

A precursor-ML, ML or Ligand2 may contain chemical motifs that bind SE, as described above. The following is a non-comprehensive list of such chemical motifs that bind SE, where the SE that the chemical motif binds to, or may bind to, follows in parenthesis. Some of these chemical motifs bind only weakly to the SEs.

Group 5: Chemical motifs and the SEs they bind.

- Polystyrene (carbon nanotube)
- Riboflavin (carbon nanotube)
- DNA (carbon nanotube)
- Porphyrine (carbon nanotube)

- Pyrenyl (carbon nanotube)
- SDBS (carbon nanotube)
- Polypeptide with sequence SVSVGMKPSPRPGGGK (hydroxyapatite)
- Polypeptide with sequence THRTSTLDYFVI (chlorine-doped polypyrrole)
- Benzene (carbon nanotubes)
- Naphthalene (carbon nanotubes)
- Biphenyl (carbon nanotubes)
- Fluorene (carbon nanotubes)
- Phenanthrene (carbon nanotubes)
- Anthracene (carbon nanotubes)
- Pyrene (carbon nanotubes; graphene)
- Triphenylene (carbon nanotubes)
- P-terphenyl (carbon nanotubes)
- Tetraphene (carbon nanotubes)
- Pyrenecarboxylic acid (carbon nanotubes)
- SDS (carbon nanotubes)
- SDSA (carbon nanotubes)
- DTAB (carbon nanotubes)
- NaDDBS (carbon nanotubes)
- Tween-60 (carbon nanotubes)
- Tween-80 (carbon nanotubes)
- Monostearate (carbon nanotubes)
- Monooleate (carbon nanotubes)
- PSPEO (carbon nanotubes)
- PVP (carbon nanotubes)
- Sulfonate (carbon nanotubes)

Subligands.

Ligand2 may comprise one or more subligands held together by one or more sub-linkers. As an example, Ligand2 may comprise two subligands, each of which is capable of binding SE1, and which are linked by a sub-linker. The subligands of Ligand2 may be linked in series or in parallel.

The subligands may be of varying affinities. In a preferred embodiment, the subligands of Ligand2 are arranged in series, and the SubLigand closest to LinkerL is of weak affinity, and therefore easy to dissociate from SE1, and the SubLigand farthest away from LinkerL is of high affinity and therefore difficult to dissociate from SE1. In composite materials where SE1 is a structural entity of high strength (e.g. a carbon nanotube) and SE2 is a polymer such as epoxy or poplypropylene, the composite material made up of CMUs comprising subligands as described immediately above will be very flexible, but will also be of high strength. By using SubLigands of varying affinities, as well as using linkers of varying lengths, the flexibility and strength of the composite material can be varied. Moreover, CMUs comprising Ligands with more than one SubLigand will add self-healing properties to a composite material in which they are used. Thus, if during applied stress to the composite material one of the SubLigand-SE interactions is interrupted, the other SubLigand may stay associated with the SE, and upon removal of the applied stress, the interrupted SubLigand-SE interaction may re-form, thereby re-establishing the shape of the composite material.
The subligands may also be arranged in parallel, in which case the corresponding composite material will be less flexible but often have higher strength.

Covalent bonds.

Mechanical ligands as well as Ligand2s typically comprise one or more covalent bonds. Ligand2s capable of covalently linking SEs with the linker may comprise functional groups such as OH, COOH, NH2, SH and CO, but can be any atom or molecule capable of forming a chemical bond with another atom or molecule. Below is shown a number of reactive/functional groups, and the covalent bond that each pair of functional groups may form. These functional groups as well as the covalent bond that they form, may be contained in SEs, Linkers, precursor-MLs, MLs and Ligand2s of the present invention:

Group 6: Reactive groups, and covalent bond formed upon reaction.

Functional group 1	Functional group 2	Covalent bond formed
NH2	COOH	CONH (amide bond)
SH	SH	SS (disulfide bond)
CO (aldehyde)	NH2	CNH (secondary amine bond)

Covalent bond-forming chemical reactions suitable for forming the covalent bond of or between SEs, Linkers, precursor-MLs, MLs and/or Ligand2s, including the ring-forming reactions of precursor-MLs to produce MLs, include any one or more of the reactions in the list below.

Group 7: Covalent bond-forming chemical reactions.

- Chemical reactions for synthesizing polymers, small molecules, or other chemical compounds such as those listed in March's Advanced Organic Chemistry, Organic Reactions, Organic Syntheses, organic text books, journals such as Journal of the American Chemical Society, Journal of Organic Chemistry, Tetrahedron, etc., and Carruther's Some Modern Methods of Organic Chemistry can be used. For example, substitution reactions, carbon-carbon bond forming reactions, elimination reactions, acylation reactions, and addition reactions. An illustrative but not exhaustive list of aliphatic nucleophilic substitution reactions useful in the present invention includes, for example, SN2 reactions, SNI reactions, SNi reactions, allylic rearrangements, nucleophilic substitution at an aliphatic trigonal carbon, and nucleophilic substitution at a vinylic carbon.
- Specific aliphatic nucleophilic substitution reactions with oxygen nucleophiles include, for example, hydrolysis of alkyl halides, hydrolysis of gen-dihalides, hydrolysis of 1,1,1-trihalides, hydrolysis of alkyl esters or inorganic acids, hydrolysis of diazo ketones, hydrolysis of acetal and enol ethers, hydrolysis of epoxides, hydrolysis of acyl halides, hydrolysis of anhydrides, hydrolysis of carboxylic esters, hydrolysis of amides, alkylation with alkyl halides (Williamson Reaction), epoxide formation, alkylation with inorganic esters, alkylation with diazo compounds, dehydration of alcohols, transetherification, alcoholysis of epoxides, alkylation with onium salts, hydroxylation of silanes, alcoholysis of acyl halides, alcoholysis of anhydrides, esterfication of carboxylic acids, alcoholysis of carboxylic esters (transesterfication), alcoholysis of amides, alkylation of carboxylic acid salts, cleavage of ether with acetic anhydride, alkylation of carboxylic acids with diazo compounds, acylation of carboxylic acids with acyl halides; acylation of carlpoxylic acids with carboxylic acids, formation of oxoniiim salts, preparation of peroxides arid hydroperoxides, preparation of inorganic esters (e.g., nitrites, nitrates, sulfonates), preparation of alcohols from amines, arid preparation of mixed organic-inorganic anhydrides.

- Specific aliphatic nucleophilic substitution reactions with sulfur nucleophiles, which tend to be better nucleophiles than their oxygen analogs, include, for example, attack by SH at an alkyl carbon to form thiols, attack by S at an alkyl carbon to form thioethers, attack by SH or SR at an acyl carbon, formation of disulfides, formation of Bunte salts, alkylation of sulfuric acid salts, and formation of alkyl thiocyanates.
- Aliphatic nucleophilic substitution reactions with nitrogen nucleophiles include, for example, alkylation of amines, N-arylation of amines, replacement of a hydroxy by an amino group, transamination, transamidation, alkylation of amines with diazo compounds, animation of epoxides, amination of oxetanes, amination of aziridines, amination of alkanes, formation of isocyanides, acylation of amines by acyl halides, acylation of amines by anhydrides, acylation of amines by carboxylic acids, acylation of amines by carboxylic esters, acylation of amines by amides, acylation of amines by other acid derivatives, N-alkylation or N-arylation of amides and imides, N-acylation of amides and imides, formation of aziridines from epoxides, formation of nitro compounds, formation of azides, formation of isocyanates and isothiocyanates, and formation of azoxy compounds. Aliphatic nucleophilic substitution reactions with halogen nucleophiles include, for example, attack at an alkyl carbon, halide exchange, formation of alkyl halides from esters of sulfuric and sulfonic acids, formation of alkyl halides from alcohols, formation of alkyl halides from ethers, formation of halohydrins from epoxides, cleavage of carboxylic esters with lithium iodide, conversion of diazo ketones to alpha-halo ketones, conversion of amines to halides, conversion of tertiary amines to cyanamides (the von Braun reaction), formation of acyl halides from carboxylic acids, and formation of acyl halides from acid derivatives.
- Aliphatic nucleophilic substitution reactions using hydrogen as a nudeophile include, for example, reduction of alkyl halides, reduction of tosylates, other sulfonates, and similar compounds, hydrogenolysis of alcohols, hydrogenolysis of esters (Barton-McCombie reaction), hydrogenolysis of nitriles, replacement of alkoxyl by hydrogen, reduction of epoxides, reductive cleavage of carboxylic esters, reduction of a C-N bond, desulfurization, reduction of acyl halides, reduction of carboxylic acids, esters, and anhydrides to aldehydes, and reduction of amides to aldehydes.
- Aliphatic nucleophilic substitution reactions using carbon nucleophiles include, for example, coupling with silanes, coupling of alkyl halides (the Wurtz reaction), the reaction of alkyl halides and sulfonate esters with Group I (I A), and II (II A) organometallic reagents, reaction of alkyl halides and sulfonate esters with

organocuprates, reaction of alkyl halides and sulfonate esters with other organometallic reagents; allylic and propargylic coupling with a halide substrate, coupling of organometallic reagents with esters of sulfuric and sulfonic acids, sulfoxides, and sulfones, coupling involving alcohols, coupling of organometallic reagents with carboxylic esters, coupling of organometallic reagents with compounds containing an esther linkage, reaction of organometallic reagents with epoxides, reaction of organometallics with aziridine, alkylation at a carbon bearing an active hydrogen, alkylation of ketones, nitriles, and carboxylic esters, alkylation of carboxylic acid salts, alkylation at a position alpha to a heteroatom (alkylation of 1,3-dithianes), alkylation of dihydro-l,3-oxazine (the Meyers synthesis of aldehydes, ketones, and carboxylic acids), alkylation with trialkylboranes, alkylation at an alkynyl carbon, preparation of nitriles, direct conversion of alkyl halides to aldehydes and ketones, conversion of alkyl halides, alcohols, or alkanes to carboxylic acids and their derivatives, the conversion of acyl halides to ketones with organometallic compounds, the conversion of anhydrides, carboxylic esters, or amides to ketones with organometallic compounds, the coupling of acyl halides, acylation at a carbon bearing an active hydrogen, acylation of carboxylic esters by carboxylic esters (the Claisen and Dieckmann condensation), acylation of ketones and nitriles with carboxylic esters, acylation of carboxylic acid salts, preparation of acyl cyanides, and preparation of diazo ketones, ketonic decarboxylation.

- Reactions which involve nucleophilic attack at a sulfonyl sulfur atom may also be used in the present invention and include, for example, hydrolysis of sulfonic acid derivatives (attack by OH), formation of sulfonic esters (attack by OR), formation of sulfonamides (attack by nitrogen), formation of sulfonyl halides (attack by halides), reduction of sulfonyl chlorides (attack by hydrogen), and preparation of sulfones (attack by carbon).
- Aromatic electrophilic substitution reactions may also be used. Hydrogen exchange reactions are examples of aromatic electrophilic substitution reactions that use hydrogen as the electrophile. Aromatic electrophilic substitution, reactions which use nitrogen electrophiles include, for example, nitration and nitro-dehydrogenation, nitrosation of nitroso-de-hydrogenation, diazonium coupling, direct introduction of the diazonium group, and amination or amino-dehydrogenation. Reactions of this type with sulfur electrophiles include, for example, sulfonation, sulfo-dehydrogenation, halosulfonation, halosulfo-dehydrogenation, sulfurization, and sulfonylation. Reactions using halogen electrophiles include, for example, halogenation, and halo-

dehydrogenation. Aromatic electrophilic substitution reactions with carbon electrophiles include, for example, Friedel-Crafts alkylation, alkylation, alkyl-dehydrogenation, Friedel-Crafts arylation (the Scholl reaction), Friedel-Crafts acylation, formylation with disubstituted formamides, formylation with zinc cyanide and HCl (the Gatterman reaction), formylation with chloroform (the Reimer-Tiemami reaction), other formylations, formyl-dehydrogenation, carboxylation with carbonyl halides, carboxylation with carbon dioxide (the Kolbe-Schmitt reaction), amidation with isocyanates, N-alkylcarbamoyl-dehydrogenation, hydroxyalkylation, hydroxyalkyl-dehydrogenation, cyclodehydration of aldehydes and ketones, haloalkylation, halo-dehydrogenation, aminoalkylation, amidoalkylation, dialkylaminoalkylation, dialkylamino-dehydrogenation, thioalkylation, acylation with nitriles (the Hoesch reaction), cyanation, and cyano-de hydrogenation. Reactions using oxygen electrophiles include, for example, hydroxylation and hydroxy-dehydrogenation.

- Rearrangement reactions include, for example, the Fries rearrangement, migration of a nitro group, migration of a nitroso group (the Fischer-Hepp Rearrangement), migration of an arylazo group, migration of a halogen (the Orton rearrangement), migration of an alkyl group, etc. Other reaction on an aromatic ring include the reversal of a Friedel-Crafts alkylation, decarboxylation of aromatic aldehydes, decarboxylation of aromatic acids, the Jacobsen reaction, deoxygenation, desulfonation, hydro-desulfonation, dehalogenation, hydro-dehalogenation, and hydrolysis of organometallic compounds.
- Aliphatic electrophilic substitution reactions are also useful. Reactions using the SEI, SE2 (front), SE2 (back), SEi, addition-elimination, and cyclic mechanisms can be used in the present invention. Reactions of this type with hydrogen as the leaving group include, for example, hydrogen exchange (deuterio-de-hydrogenation, deuteriation), migration of a double bond, and keto-enol tautomerization. Reactions with halogen electrophiles include, for example, halogenation of aldehydes and ketones, halogenation of carboxylic acids and acyl halides, and halogenation of sulfoxides and sulfones. Reactions with nitrogen electrophiles include, for example, aliphatic diazonium coupling, nitrosation at a carbon bearing an active hydrogen, direct formation of diazo compounds, conversion of amides to alpha-azido amides, direct amination at an activated position, and insertion by nitrenes. Reactions with sulfur or selenium electrophiles include, for example, sulfenylation, sulfonation, and selenylation of ketones and carboxylic esters. Reactions with carbon electrophiles

include, for example, acylation at an aliphatic carbon, conversion of aldehydes to beta-keto esters or ketones, cyanation, cyano-de-hydrogenation, alkylation of alkanes, the Stork enamine reaction, and insertion by carbenes. Reactions with metal electrophiles include, for example, metalation with organometallic compounds, metalation with metals and strong bases, and conversion of enolates to silyl enol ethers. Aliphatic electrophilic substitution reactions with metals as leaving groups include, for example, replacement of metals by hydrogen, reactions between organometallic reagents and oxygen, reactions between organometallic reagents and peroxides, oxidation of trialkylboranes to borates, conversion of Grignard reagents to sulfur compounds, halo-demetalation, the conversion of organometallic compounds to amines, the conversion of organometallic compounds to ketones, aldehydes, carboxylic esters and amides, cyano-de-metalation, transmetalation with a metal, transmetalation with a metal halide, transmetalation with an organometallic compound, reduction of alkyl halides, metallo-de-halogenation, replacement of a halogen by a metal from an organometallic compound, decarboxylation of aliphatic acids, cleavage of alkoxides, replacement of a carboxyl group by an acyl group, basic cleavage of beta-keto esters and beta-diketones, haloform reaction, cleavage of non-enolizable ketones, the Haller-Bauer reaction, cleavage of alkanes, decyanation, and hydro-de-cyanation. Electrophilic substitution reactions at nitrogen include, for example, diazotization, conversion of hydrazines to azides, N-nitrosation, N-nitroso-de-hydrogenation, conversion of amines to azo compounds, N-halogenation, N-halo-de-hydrogenation, reactions of amines with carbon monoxide, and reactions of amines with carbon dioxide.

- Aromatic nudeophilic substitution reactions may also be used in the present invention. Reactions proceeding via the SNAr mechanism, the SNI mechanism, the benzyne mechanism, the SRN1 mechanism, or other mechanism, for example, can be used. Aromatic nudeophilic substitution reactions with oxygen nucleophiles include, for example, hydroxy-de-halogenation, alkali fusion of sulfonate salts, and replacement of OR or OAr. Reactions with sulfur nucleophiles include, for example, replacement by SH or SR. Reactions using nitrogen nucleophiles include, for example, replacement by NH2, NHR, or NR2, and replacement of a hydroxy group by an amino group: Reactions with halogen nucleophiles include, for example, the introduction halogens. Aromatic nudeophilic substitution reactions with hydrogen as the nucleophile include, for example, reduction of phenols and phenolic esters and ethers, and reduction of halides and nitro compounds. Reactions with carbon

nucleophiles include, for example, the Rosenmund-von Braun reaction, coupling of organometallic compounds with aryl halides, ethers, and carboxylic esters, arylation at a carbon containing an active hydrogen, conversions of aryl substrates to carboxylic acids, their derivatives, aldehydes, and ketones, and the Ullmann reaction. Reactions with hydrogen as the leaving group include, for example, alkylation, arylation, and amination of nitrogen heterocycles. Reactions with N2+ as the leaving group include, for example, hydroxy-de-diazoniation, replacement by sulfur-containing groups, iodo-de-diazoniation, and the Schiemann reaction. Rearrangement reactions include, for example, the von Richter rearrangement, the Sommelet-Hauser rearrangement, rearrangement of aryl hydroxylamines, and the Smiles rearrangement. Reactions involving free radicals can also be used, although the free radical reactions used in nudeotide-templated chemistry should be carefully chosen to avoid modification or cleavage of the nucleotide template. With that limitation, free radical substitution reactions can be used in the present invention. Particular free radical substitution reactions include, for example, substitution by halogen, halogenation at an alkyl carbon, allylic halogenation, benzylic halogenation, halogenation of aldehydes, hydroxylation at an aliphatic carbon, hydroxylation at an aromatic carbon, oxidation of aldehydes to carboxylic acids, formation of cyclic ethers, formation of hydroperoxides, formation of peroxides, acyloxylation, acyloxy-de-hydrogenation, chlorosulfonation, nitration of alkanes, direct conversion of aldehydes to amides, amidation and amination at an alkyl carbon, simple coupling at a susceptible position, coupling of alkynes, arylation of aromatic compounds by diazonium salts, arylation of activated alkenes by diazonium salts (the Meerwein arylation), arylation and alkylation of alkenes by organopalladium compounds (the Heck reaction), arylation and alkylation of alkenes by vinyltin compounds (the StHIe reaction), alkylation and arylation of aromatic compounds by peroxides, photochemical arylation of aromatic compounds, alkylation, acylation, and carbalkoxylation of nitrogen heterocydes. Particular reactions in which N2+ is the leaving group include, for example, replacement of the diazonium group by hydrogen, replacement of the diazonium group by chlorine or bromine, nitro-de-diazoniation, replacement of the diazonium group by sulfur-containing groups, aryl dimerization with diazonium salts, methylation of diazonium salts, vinylation of diazonium salts, arylation of diazonium salts, and conversion of diazonium salts to aldehydes, ketones, or carboxylic acids. Free radical substitution reactions with metals as leaving groups include, for example, coupling of Grignard reagents,

coupling of boranes, and coupling of other organometallic reagents. Reaction with halogen as the leaving group are included. Other free radical substitution reactions with various leaving groups include, for example, desulfurization with Raney Nickel, conversion of sulfides to organolithium compounds, decarboxylase dimerization (the Kolbe reaction), the Hunsdiecker reaction, decarboxylative allylation, and decarbonylation of aldehydes and acyl halides.

- Reactions involving additions to carbon-carbon multiple bonds are also used. Any mechanism may be used in the addition reaction including, for example, electrophilic addition, nucleophilic addition, free radical addition, and cyclic mechanisms. Reactions involving additions to conjugated systems can also be used. Addition to cyclopropane rings can also be utilized. Particular reactions include, for example, isomerization, addition of hydrogen halides, hydration of double bonds, hydration of triple bonds, addition of alcohols, addition of carboxylic acids, addition of H2S and thiols, addition of ammonia and amines, addition of amides, addition of hydrazoic acid, hydrogenation of double and triple bonds, other reduction of double and triple bonds, reduction of the double and triple bonds of conjugated systems, hydrogenation of aromatic rings, reductive cleavage of cyclopropanes, hydroboration, other hydrometalations, addition of alkanes, addition of alkenes and/or alkynes to alkenes and/or alkynes (e.g., pi-cation cyclization reactions, hydro-alkenyl-addition), ene reactions, the Michael reaction, addition of organometallics to double and triple bonds not conjugated to carbonyls, the addition of two alkyl groups to an alkyne, 1,4-addition of organometallic compounds to activated double bonds, addition of boranes to activated double bonds, addition of tin and mercury hydrides to activated double bonds, acylation of activated double bonds and of triple bonds, addition of alcohols, amines, carboxylic esters, aldehydes, etc., carbonylation of double and triple bonds, hydrocarboxylation, hydroformylation, addition of aldehydes, addition of HCN, addition of silanes, radical addition, radical cydization, halogenation of double and triple bonds (addition of halogen, halogen), halolactonization, halolactamization, addition of hypohalous acids and hypohalites (addition of halogen, oxygen), addition of sulfur compounds (addition of halogen, sulfur), addition of halogen and an amino group (addition of halogen, nitrogen), addition of NOX and NO2X (addition of halogen, nitrogen), addition of XN3 (addition of halogen, nitrogen), addition of alkyl halides (addition of halogen, carbon), addition of acyl halides (addition of halogen, carbon), hydroxylation (addition of oxygen, oxygen) (e.g., asymmetric dihydroxylation reaction with OSO4), dihydroxylation of aromatic rings, epoxidation (addition of

oxygen, oxygen) (e.g., Sharpless asymmetric epoxidation), photooxidation of dienes (addition of oxygen, oxygen), hydroxysulfenylation (addition of oxygen, sulfur), oxyamination (addition of oxygen, nitrogen), diamination (addition of nitrogen, nitrogen), formation of aziridines (addition of nitrogen), aminosulferiylation (addition of nitrogen, sulfur), acylacyloxylation and acylamidation (addition of oxygen, carbon or nitrogen, carbon), 1,3-dipolar addition; (addition of oxygen, nitrogen, carbon), Diels-Alder reaction, heteroatom Diels-Alder reaction, all carbon 3 +2 cycloadditions, dimerization of alkenes, the addition of carbenes and carbenoids to double and triple bonds, trimerization and tetramerization of alkynes, and other cycloaddition reactions.

- In addition to reactions involving additions to carbon-carbon multiple bonds, addition reactions to carbon-hetero multiple bonds can be used in nucleotide-templated chemistry. Exemplary reactions include, for example, the addition of water to aldehydes and ketones (formation of hydrates), hydrolysis of carbon-nitrogen double bond, hydrolysis of aliphatic nitro compounds, hydrolysis of nitriles, addition of alcohols and thiols to aldehydes and ketones, reductive alkylation of alcohols, addition of alcohols to isocyanates, alcoholysis of nitriles, formation of xanthates, addition of H2S and thiols to carbonyl compounds, formation of bisulfite addition products, addition of amines to aldehydes and ketones, addition of amides to aldehydes, reductive alkylation of ammonia or amines, the Mannich reaction, the addition of amines to isocyanates, addition of ammonia or amines to nitriles, addition of amines to carbon disulfide and carbon dioxide, addition of hydrazine derivative to carbonyl compounds, formation of oximes, conversion of aldehydes to nitriles, formation of gem-dihalides from aldehydes and ketones, reduction of aldehydes and ketones to alcohols, reduction of the carbon-nitrogen double bond, reduction of nitriles to amines, reduction of nitriles to aldehydes, addition of Grignard reagents and organolithium reagents to aldehydes and ketones, addition of other organometallics to aldehydes and ketones, addition of trialkylallylsilanes to aldehydes and ketones, addition of conjugated alkenes to aldehydes (the Baylis-Billmah reaction), the Reformatsky reaction, the conversion of carboxylic acid salts to ketones with organometallic compounds, the addition of Grignard reagents to acid derivatives, the addition of Organometallic compounds to CO2 and CS2, addition of organometallic compounds to C=IM compounds, addition of carbenes and diazoalkanbs to C=N compounds, addition of Grignard reagents to nitriles and isocyanates, the Aldol reaction, Mukaiyama Aldol and related reactions, Aldol-type

reactions between carboxylic esters or amides and aldehydes or ketones, the Knoevenagel reaction (e.g., the Nef reaction, the Favorskii reaction), the Peterson alkenylation reaction, the addition of active hydrogen compounds to CO2 and CS2, the Perkin reaction, Darzens glycidic ester condensation, the Tollens reaction, the Wittig reaction, the Tebbe alkenylation, the Petasis alkenylation, alternative alkenylations, the Thorpe reaction, the Thorpe-Ziegler reaction, addition of silanes, formation of cyanohydrins, addition of HCN to C=N and C-N bonds, the Prins reaction, the benzoin condensation, addition of radicals to C=O, C=S, C=N compounds, the Ritter reaction, acylation of aldehydes and ketones, addition of aldehydes to aldehydes, the addition of isocyanates to isocyanates (formation of carbodiimides), the conversion of carboxylic acid salts to nitriles, the formation of epoxides from aldehydes and ketones, the formation of episulfides and episulfones, the formation of beta-lactones and oxetanes (e.g., the Paterno-Buchi reaction), the formation of beta-lactams, etc. Reactions involving addition to isocyanides include the addition of water to isocyanides, the Passerini reaction, the Ug reaction, and the formation of metalated aldimines.

- Elimination reactions, including alpha, beta, and gamma eliminations, as well as extrusion reactions, can be performed using nucleotide-templated chemistry, although the strength of the reagents and conditions employed should be considered. Preferred elimination reactions include reactions that go by El, E2, ElcB, or E2C mechanisms. Exemplary reactions include, for example, reactions in which hydrogen is removed from one side (e.g., dehydration of alcohols, cleavage of ethers to alkenes, the Chugaev reaction, ester decomposition, cleavage of quarternary ammonium hydroxides, cleavage of quaternary ammonium salts with strong bases, cleavage of amine oxides, pyrolysis of keto-ylids, decomposition of toluene-p-sulfonylhydrazones, cleavage of sulfoxides, cleavage of selenoxides, cleavage of sulfornes, dehydrogalogenation of alkyl halides, dehydrohalogenation of acyl halides, dehydrohalogenation of sulfonyl halides, elimination of boranes, conversion of alkenes to alkynes, decarbonylation of acyl halides), reactions in which neither leaving atom is hydrogen (e.g., deoxygenation of vicinal diols, cleavage of cyclic thionocarbonates, conversion of epoxides to episulfides and alkenes, the Ramberg-Backlund reaction, conversion of aziridines to alkenes, dehalogenatïon of vicinal dihalides, dehalogenation of alpha-halo acyl halides, and elimination of a halogen and a hetero group), fragmentation reactions (i.e., reactions in which carbon is the positive leaving group or the electrofuge, such as, for example, fragmentation of

gamma-amino and gamma-hydroxy halides, fragmentation of 1,3-diols, decarboxylation of beta-hydroxy carboxylic acids, decarboxylation of (3-lactones, fragmentation of alpha-beta-epoxy hydrazones, elimination of CO from bridged bicydic compounds, and elimination Of CO2 from bridged bicydic compounds), reactions in which C=N or C=N bonds are formed (e.g., dehydration of aldoximes or similar compounds, conversion of ketoximes to nitriles, dehydration of unsubstituted amides, and conversion of I\I-alkylformamides to isocyanides), reactions in which C=O bonds are formed (e.g., pyrolysis of beta-hydroxy alkenes), and reactions in which N=N bonds are formed (e.g., eliminations to give diazoalkenes). Extrusion reactions include, for example, extrusion of N2 from pyrazolines, extrusion of N2 from pyrazoles, extrusion of N2 from triazolines, extrusion of CO, extrusion Of CO2, extrusion Of SO2, the Story synthesis, and alkene synthesis by twofold extrusion.

- Rearrangements, including, for example, nudeophilic rearrangements, electrophilic rearrangements, prototropic rearrangements, and free-radical rearrangements, can also be performed. Both 1,2 rearrangements and non-1,2 rearrangements can be performed. Exemplary reactions include, for example, carbon-to-carbon migrations of R, H, and Ar (e.g., Wagner-Meerwein and related reactions, the Pinacol rearrangement, ring expansion reactions, ring contraction reactions, acid-catalyzed rearrangements of aldehydes and ketones, the dienone-phenol rearrangement, the Favorskii rearrangement, the Arndt-Eistert synthesis, homologation of aldehydes, and homologation of ketones), carbon-to-carbon migrations of other groups (e.g., migrations of halogen, hydroxyl, amino, etc.; migration of boron; and the Neber rearrangement), carbon-to-nitrogen migrations of R and Ar (e.g., the Hofmann rearrangement, the Curtius rearrangement, the Lossen rearrangement, the Schmidt reaction, the Beckman rearrangement, the Stieglits rearrangement, and related rearrangements), carbon-to-oxygen migrations of R and Ar (e.g., the Baeyer-Villiger rearrangement and rearrangment of hydroperoxides), nitrogen-to-carbon, oxygen-to-carbon, and sulfur-to-carbon migration (e.g., the Stevens rearrangement, and the Wittig rearrangement), boron-to-carbon migrations (e.g., conversion of boranes to alcohols (primary or otherwise), conversion of boranes to aldehydes, conversion of boranes to carboxylic acids, conversion of vinylic boranes to alkenes, formation of alkynes from boranes and acetylides, formation of alkenes from boranes and acetylides, and formation of ketones from boranes and acetylides), electrocyclic rearrangements (e.g., of cydobutenes and 1,3-cyclohexadienes, or conversion of stilbenes to phenanthrenes), sigmatropic rearrangements (e.g., (1 ,j) sigmatropic

migrations of hydrogen, (lj) sigmatropic migrations of carbon, conversion of vinylcydopropanes to cyclopentenes, the Cope rearrangement, the Claisen rearrangement, the Fischer indole synthesis, (2,3) sigmatropic rearrangements, and the benzidine rearrangement), other cyclic rearrangements (e.g., metathesis of alkenes, the di-n-methane and related rearrangements, and the Hofmann-Loffler and related reactions), and non-cyclic rearrangements (e.g., hydride shifts, the Chapman rearrangement, the Wallach rearrangement, and dybtropic rearrangements).

Oxidative and reductive reactions may also be performed. Exemplary reactions may involve, for example, direct electron transfer, hydride transfer, hydrogen-atom transfer, formation of ester intermediates, displacement mechanisms, or addition-elimination mechanisms. Exemplary oxidations include, for example, eliminations of hydrogen (e.g., aromatization of six-membered rings, dehydrogenations yielding carbon-carbon double bonds, oxidation or dehydrogenation of alcohols to aldehydes and ketones, oxidation of phenols and aromatic amines to quinones, oxidative cleavage of ketones, oxidative cleavage of aldehydes, oxidative cleavage of alcohols, ozonolysis, oxidative cleavage of double bonds and aromatic rings, oxidation of aromatic side chains, oxidative decarboxylation, and bisdecarboxylation), reactions involving replacement of hydrogen by oxygen (e.g., oxidation of methylene to carbonyl, oxidation of methylene to OH, CO2R, or OR, oxidation of arylmethanes, oxidation of ethers to carboxylic esters and related reactions, oxidation of aromatic hydrocarbons to quinones, oxidation of amines or nitro compounds to aldehydes, ketones, or dihalides, oxidation of primary alcohols to carboxylic acids or carboxylic esters, oxidation of alkenes to aldehydes or ketones, oxidation of amines to nitroso compounds and hydroxylamines, oxidation of primary amines, oximes, azides, isocyanates, or nitroso compounds, to nitro compounds, oxidation of thiols and other sulfur compounds to sulfonic acids), reactions in which oxygen is added to the subtrate (e.g., oxidation of alkynes to alpha-diketones, oxidation of tertiary amines to amine oxides, oxidation of thioesters to sulfoxides and sulfones, and oxidation of carboxylic acids to peroxy acids, and oxidative coupling reactions (e.g., coupling involving carbanoins, dimerization of silyl enol ethers or of lithium enolates, and oxidation of thiols to disulfides). Exemplary reductive reactions include, for example, reactions involving replacement of oxygen by hydrogen {e.g., reduction of carbonyl to methylene in aldehydes and ketones, reduction of carboxylic acids to alcohols, reduction of amides to amines, reduction of carboxylic esters to ethers, reduction of cyclic anhydrides to lactones and acid derivatives to alcohols, reduction of carboxylic esters to alcohols, reduction of carboxylic acids and esters to alkanes, complete reduction of

epoxides, reduction of nitro compounds to amines, reduction of nitro compounds to hydroxylamines, reduction of nitroso compounds and hydroxylamines to amines, reduction of oximes to primary amines or aziridines, reduction of azides to primary amines, reduction of nitrogen compounds, and reduction of sulfonyl halides and sulfonic acids to thiols), removal of oxygen from the substrate {e.g., reduction of amine oxides and azoxy compounds, reduction of sulfoxides and sulfones, reduction of hydroperoxides and peroxides, and reduction of aliphatic nitro compounds to oximes or nitrites), reductions that include cleavage {e.g., de-alkylation of amines and amides, reduction of azo, azoxy, and hydrazo compounds to amines, and reduction of disulfides to thiols), reductive coupling reactions {e.g., bimolecular reduction of aldehydes and ketones to 1,2-diols, bimolecular reduction of aldehydes or ketones to alkenes, acyloin ester condensation, reduction of nitro to azoxy compounds, and reduction of nitro to azo compounds), and. reductions in which an organic substrate is both oxidized and reduced {e.g., the Cannizzaro reaction, the Tishchenko reaction, the Pummerer rearrangement, and the Willgerodt reaction).

Covalent bonds relevant for the present invention, including those formed above, are listed in the following.

Group 8: Covalent bonds.

A single bond, such as a single carbon-carbon bond, a carbon-heteroatom single bond, a heteroatom-heteroatom single bond, a double bond,such as a carbon-carbon double bond or a carbon-heteroatom double bond, a heteroatom-heteroatom double, bond, triple bond, such as a carbon-carbon triple bond or a carbon-heteroatom triple bond, a heteroatom-heteroatom triple bond, -CH2-, -C(O)-, -NH-, -O-, -S-, -SO2-, -CH2CH2-, -C(O)CH2-, -CH2C(O)-, -NHCH2-, -CH2NH-, -OCH2-, -CH2O-, -SCH2-, -CH2S-, -SO2CH2-, -CH2SO2-, -NHC(O)-, -C(O)NH-, -NHSO2-, -SO2NH-, -CH2CH2CH2-, -CH2CH2C(O)-, -CH2CH2NH-, -CH2CH2O-, -CH2CH2S-, -CH2CH2SO2-, -CH2C(O)CH2-, -CH2NHCH2-, -CH2OCH2-, -CH2SCH2-, -CH2SO2CH2-, -C(O)CH2CH2-, -NHCH2CH2-, -OCH2CH2-, -SCH2CH2-, -SO2CH2CH2-, -CH2C(O)NH-, -CH2SO2NH-, -CH2NHC(O)-, -CH2NHSO2-, -C(O)NHCH2-, -SO2NHCH2-, -NHC(O)CH2-, -NHSO2CH2-, and -NHC(O)NH-

Linkers.

A linker may consist of just one bond, or a number of covalent and/or non-covalent bonds. A linker may have any length. A longer and more flexible linker will more easily allow the precursor-MLs, MLs and Ligand2s and SEs to interact independently of the linker; however,

a short linker connecting two precursor-MLs, MLs or Ligand2s bound to the same SE may result in high synergy in the binding of the two precursor-MLs, MLs or Ligand2s to the same SE – but may also interfere with efficient binding of the two precursor-MLs, MLs and Ligand2s because of linker constraints and/or inapropriate orientation of the interacting molecules. Thus, in some cases a short linker is preferable; in other cases a long linker is preferable. The linker may thus have a length of 0.1–100,000 nm, such as in the ranges of 0.1–0,4 nm, 0,4–1 nm, 1–2 nm, 2–4 nm, 4–8 nm, 8–15 nm, 15–25 nm, 25–40 nm, 40–100 nm, 100–200 nm, 200–500 nm, 500–1,000 nm, 1,000–10,000 nm, or 10,000–100,000 nm, or larger.

In a preferred embodiment the linker has a length of less than 1 μm, such as less than 100 nm, such as less than 50 nm, such as less than 40 nm, such as less than 30, such as less than 25 nm, such as less than 20 nm, such as less than 15 nm, such as less than 10 nm, such as less than 5 nm, such as less than 2 nm, such as less than 1 nm, such as less than 0.7 nm, such as less than 0.5 nm, such as less than 0.2 nm. Shorter linker lengths will often result in composite materials with higher tensile strength, wherefore it may be desirable to use shorter linkers to obtain higher strength of the composite material. In another preferred embodiment the linker has a length of more than 0.1 nm, such as more than 0.2 nm, such as more than 0.3 nm, such as more than 0.6 nm, such as more than 0.8 nm, such as more than 1nm, such as more than 2 nm, such as more than 4 nm, such as more than 6 nm, such as more than 8 nm, such as more than 12 nm, such as more than 15 nm, such as more than 20 nm, such as more than 25 nm, such as more than 50 nm, such as more than 80 nm, such as more than 100 nm, such as more than 200 nm, such as more than 500 nm, such as more than 1 μm, such as more than 5 μm. Longer linkers will often lead to composite materials with higher flexibility, wherefore it may be desirable to increase the length of the linker if a higher flexibility is desired.

Shorter linker lengths may result in composite materials with higher tensile strength, and longer linkers may result in increased flexibility of the composite material. Therefore, the appropriate compromise between strength and flexibility of a composite material may be obtained by appropriate choice of linker length. In a preferred embodiment the linker length is between 1 and 10 nm, less preferably between 0.5 nm and 25 nm, as this linker length often is a good compromise between flexibility and strength of the composite material.

A linker may connect two, three, four or more precursor-MLs, MLs or Ligand2s. Thus, the linker may be linear (connecting two precursor-MLs, MLs or Ligand2s) or may be branched (connecting three or more precursor-MLs, MLs and Ligand2s).

Example linkers are organic molecules such as consisting of alkanes or alkenes, or polyvinyl, polypropylene, ethylene glycol, and the linkers may consist of just one element (e.g. carbon) or several elements (e.g. C, O, N).

A linker may comprise or consist of any polymer mentioned above or below, or may comprise or consist of any part of any polymer mentioned above or below, such as any number of repeating units of any polymer mentioned above or below, such as e.g. one, two, three, four or more repeating units of any polymer mentioned above or below.

Group 9: Linkers.

The following is a non-comprehensive list of linkers: alkanes, alkenes, alkynes or combinations thereof (C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C12, C13, C14, C15, C16, C17, C18, C19, C20) and any other alkane, alkene, alkyne or combinations thereof comprising between 20 and 30 carbon atoms, or between 30 and 40 carbon atoms, or between 40 and 50 carbon atoms, or more than 50 carbon atoms; polyethylene glycol.

Any of the structural entities listed above or below may also be used as a linker.

The linkers may be modified. The modifications may be added to the linker before, after or during synthesis of the composite material unit or composite material. The modification may involve covalent attachment of aromatic or aliphatic rings, charged or polar groups such as NH2, CO, COOH, and COSH.

Ideally, the chemical and physical characteristics of the linker should be similar to at least some of the characteristics of the structural entities of the CMU, in order to prepare composite materials where the characteristics of the matrix material and the additive are not significantly perturbed by the presence of the linker. However, under certain circumstances, such as for example when using carbon nanotubes as the additive, using processes and conditions under which e.g. solubility of the carbon nanotubes in the solution or matrix material is low, the linker may due to its solubility characteristics help make the carbon nanotube more soluble, because the linker becomes bound to the carbon nanotube by way of the precursor-ML, ML and/or Ligand2s.

<u>CMUs – combination of SE1, ML, Linker, Ligand2, and SE2.</u>

A composite material unit (CMU) comprises a first structural entity (SE1), a mechanical ligand (ML), a Linker, a Ligand (Ligand2), and a second structural entity (SE2). Preferred CMUs of the present invention include anyone of the following CMUs, here identified as any specific combination of said first structural entity (SE1),ML, Linker, Ligand2, and second structural entity (SE2):

SE1-ML-Linker-Ligand2-SE2 (a CMU)

where SE1 is any specific Structural Entity, or any specific type of Structural Entity, listed above or below;

where ML is any specific mechanical ligand, or any specific type of mechanical ligand, listed above or below;

where Linker is any specific Linker, or any specific type of Linker, listed above or below;

where Ligand2 is any specific Ligand2, or any specific type of Ligand2, listed above or below;

and where SE2 is any specific Structural Entity, or any specific type of Structural Entity, listed above or below.

What is further provided is a polymeric structure of CMUs, consisting of a number of repeats of the structure SE1-ML-Linker-Ligand2-SE2-Ligand2-Linker-ML-SE1. Thus, the overall structure of said polymeric structure of CMUs is (SE1-ML-Linker-Ligand2-SE2-Ligand2-Linker-ML-)$_n$SE1, where n is an integer larger than zero.

For n=1, the polymeric structure of CMUs is thus described by the structure -SE1-ML-Linker-Ligand2-SE2-Ligand2-Linker-ML-SE1.

For n=2, the polymeric structure of CMUs is thus described by the structure SE1-ML-Linker-Ligand2-SE2-Ligand2-Linker-ML- SE1-ML-Linker-Ligand2-SE2-Ligand2-Linker-ML-SE1.

For n=3, the polymeric structure of CMUs is thus described by the structure SE1-ML-Linker-Ligand2-SE2-Ligand2-Linker-ML- SE1-ML-Linker-Ligand2-SE2-Ligand2-Linker-ML- SE1-ML-Linker-Ligand2-SE2-Ligand2-Linker-ML-SE1.

For n=5, the polymeric structure of CMUs is thus described by the structure SE1-ML-Linker-Ligand2-SE2-Ligand2-Linker-ML- SE1-ML-Linker-Ligand2-SE2-Ligand2-Linker-ML- SE1-

ML-Linker-Ligand2-SE2-Ligand2-Linker-ML- SE1-ML-Linker-Ligand2-SE2-Ligand2-Linker-ML- SE1-ML-Linker-Ligand2-SE2-Ligand2-Linker-ML-SE1.

Preferred polymeric structures of CMUs are the polymeric structures where SE1 is a carbon nanotube, and n=1, 2, 3, 4 ,5, 6, 7, 8, 9, 10-20, 20-100, or 100-1000, or higher.

Other preferred polymeric structures of CMUs are the polymeric structures where SE1 is a nanotube, and n=1, 2, 3, 4 ,5, 6, 7, 8, 9, 10-20, 20-100, or 100-1000, or higher.

Other preferred polymeric structures of CMUs are the polymeric structures where SE1 is a nanotube or graphene, SE2 is a nanotube or graphene, and n=1, 2, 3, 4 ,5, 6, 7, 8, 9, 10-20, 20-100, or 100-1000, or higher.

Other preferred polymeric structures of CMUs are the polymeric structures where SE1 is a nanotube, SE2 is a plast polymer, and n=1, 2, 3, 4 ,5, 6, 7, 8, 9, 10-20, 20-100, or 100-1000, or higher.

Other preferred polymeric structures of CMU are the polymeric structures where SE1 is a carbon nanotube, SE2 is not a carbon nanotube, and the number of repeats is two or higher.

Methods of preparing composite material units and composite materials.
The individual components of the composite material units (CMU), i.e. the structural entities (SEs), the MLs, Ligand2s, and the linker(s), may be synthesized before, during or after linking the SE, ML, Ligand2, and linker(s).

The following three processes for the synthesis of reinforced polymers (composite materials comprising a polymer component and an additive) are examples of processes where the individual components of the CMU are prepared before, during or after linking its SEs, linker(s), Ligand2 and ML:
Solution mixing: The additive (e.g. a nanotube dispersion) is mixed with a solution of preformed polymer (e.g. polyvinyl alcohol, polystyrene, polycarbonate, or poly(methyl methacrylate)) and precursor-MLs, MLs and/or Ligand2s and linker(s). CMUs will now form in the solution, whereafter the solvents are evaporated, leaving the reinforced polymer as a solid material. In this approach, the linker, precursor-ML or ML, Ligand2, polymer, and structural entities (polymer and additive) may associate during incubation in solvent, or may be partly associated prior to their mixing with the other components.
Melt processing: This process employs thermoplastic polymers (e.g. high-impact polystyrene, acrylonitrile-butadiene-styrene, polypropylene) that soften and melt when

heated. The preformed, thermoplastic polymers are melted and then mixed with precursor-MLs, MLs and/or Ligand2slinkers and additive(s). Upon lowering of the temperature, and optionally fibre-spinning, melt-spinning, extrusion or other relevant process, reinforced polymers of desired characteristics are formed. As for solution mixing, the linker, precursor-ML, ML, Ligand2, polymer, and structural entities (polymer and additive) may associate during incubation, or may be partly associated prior to their mixing with the other components.

In situ polymerization: In this process, the monomer(s) rather than the polymer(s) are used as starting material, whereafter the polymerization is carried out in situ. Thus, the additive is mixed with the monomer (e.g. epoxy resin), linkers and precursor-MLs, MLs and/or Ligand2s. As for the two processes described immediately above, the linker and precursor-MLs, MLs and/or Ligand2s may be preformed as one moiety which is then added to the polymerization mixture. In the example of a reinforced epoxy, one would therefore use an excess of the non-modified epoxy resin, plus a modified epoxy resin which had been coupled to a precursor-ML, ML and/or Ligand2s capable of binding the additive in question.

Precursor-MLs, MLs and Ligand2s, linkers and SEs suitable for the present invention include small compact molecules, linear structures, polymers, polypeptides, poly-ureas, polycarbamates, scaffold structures, cyclic structures, natural compound derivatives, alpha-, beta-, gamma-, and omega-peptides, mono-, di- and tri-substituted peptides, L- and D-form peptides, cyclohexane- and cydopentane-backbone modified beta-peptides, vinylogous polypeptides, glycopolypeptides, polyamides, vinylogous sulfonamide peptide, Polysulfonamide
conjugated peptide (i.e., having prosthetic groups), Polyesters, Polysaccharides, polycarbamates, polycarbonates, polyureas, poly-peptidylphosphonates, Azatïdes, peptoids (oligo N-substituted glycines), Polyethers, ethoxyformacetal oligomers, poly-thioethers, polyethylene, glycols (PEG), polyethylenes, polydisulfides, polyarylene sulfides, Polynucleotides, PNAs, LNAs, Morpholinos, oligo pyrrolinone, polyoximes, Polyimines, Polyethyleneimine, Polyacetates, Polystyrenes, Polyacetylene, Polyvinyl, Lipids, Phospholipids, Glycolipids, poiycycles, (aliphatic), polycycles (aromatic), polyheterocydes, Proteoglycan, Polysiloxanes, Polyisocyanides, Polyisocyanates, polymethacryiates, Monofunctional, Difunctional, Trifunctional and Oligofunctional open-chain hydrocarbons. Monofunctional, Difunctional, Trifunctional and Oligofunctional Nonaromatic Carbocycles, Monocyclic, Bicyclic, Tricyclic and Polycydic Hydrocarbons, Bridged Polycyclic Hydrocarbones, Monofunctional, Difunctional, Trifunctional and Oligofunctional Nonaromatic,

Heterocycles, Monocyclic, Bicydic, Tricyclic and Polycyclic Heterocycles, bridged Polycyclic Heterocycles, Monofunctional, Difunctional, Trifunctional and Oligofunctional Aromatic Carbocycles.
Monocyclic, Bicydic, Tricyclic and Polycyclic Aromatic Carbocycles.
Monofunctional, Difunctional, Trifunctional and Oligofunctional Aromatic Hetero-cycles.
Monocyclic, Bicydic, Tricyclic and Polycyclic Heterocycles. Chelates, fullerenes, and any combination of the above.

In preferred embodiments, the structural entity, the precursor-ML, ML or Ligand2, the linker or the composite material comprises one or more entities chosen from the list comprising:

Aluminium antimonide – AlSb, Aluminium arsenide – AlAs, Aluminium chloride – AlCl3, Aluminium fluoride – AlF3, Aluminium hydroxide – Al(OH)3, Aluminium nitrate – Al(NO3)3, Aluminium nitride – AlN, Aluminium oxide – Al2O3, Aluminium phosphide – AlP, Aluminium sulfate – Al2(SO4)3, Ammonia – NH3, Ammonium bicarbonate – NH4HCO3, Ammonium cerium(IV) nitrate – (NH4)2Ce(NO3)6, Ammonium chloride – NH4Cl, Ammonium hydroxide – NH4OH, Ammonium nitrate – NH4NO3, Ammonium sulfate – (NH4)2SO4, Ammonium tetrathiocyanatodiamminechromate(III) – NH4[Cr(SCN)4(NH3)2], Antimony hydride – SbH3, Antimony pentachloride – SbCl5, Antimony pentafluoride – SbF5, Antimony trioxide – Sb2O3, Arsenic trioxide (Arsenic(III) oxide) – As2O3, Arsenous acid – As(OH)3, Arsine – AsH3, Baking soda – NaHCO3, Barium chloride – BaCl2, Barium chromate – BaCrO4, Barium hydroxide – Ba(OH)2, Barium iodide – BaI2, Barium nitrate – Ba(NO3)2, Barium sulfate – BaSO4, Barium titanate – BaTiO3, Beryllium borohydride – Be(BH4)2, Beryllium bromide – BeBr2, Beryllium carbonate – BeCO3, Beryllium chloride – BeCl2, Beryllium fluoride – BeF2, Beryllium hydride – BeH2, Beryllium hydroxide – Be(OH)2, Beryllium iodide – BeI2, Beryllium nitrate – Be(NO3)2, Beryllium nitride – Be3N2, Beryllium oxide – BeO, Beryllium sulfate – BeSO4, Beryllium sulfite – BeSO3, Beryllium telluride – BeTe, Bismuth(III) oxide – Bi2O3, Bismuth(III) telluride – Bi2Te3, Borane – Diborane: B2H6, Pentaborane: B5H9 Decaborane: B10H14, Borax – Na2B4O7·10H2O, Boric acid – H3BO3, Boron carbide – B4C, Boron nitride – BN, Boron oxide – B2O3, Boron suboxide – B6O, Boron trichloride – BCl3, Boron trifluoride – BF3, Bromine pentafluoride – BrF5, Bromine trifluoride – BrF3, Cacodylic acid – (CH3)2AsO2H, Cadmium arsenide – Cd3As2, Cadmium bromide – CdBr2, Cadmium chloride – CdCl2, Cadmium fluoride – CdF2, Cadmium iodide – CdI2, Cadmium nitrate – Cd(NO3)2, Cadmium selenide – CdSe (of quantum dot fame), Cadmium sulfate – CdSO4, Cadmium telluride – CdTe, Caesium bicarbonate – CsHCO3, Caesium carbonate – Cs2CO3, Caesium chloride – CsCl, Caesium chromate – Cs2CrO4,

Caesium fluoride – CsF, Caesium hydride – CsH, Calcium carbide – CaC2, Calcium chlorate – Ca(ClO3)2, Calcium chloride – CaCl2, Calcium chromate – CaCrO4, Calcium cyanamide – CaCN2, Calcium fluoride – CaF2, Calcium hydride – CaH2, Calcium hydroxide – Ca(OH)2, Calcium sulfate (Gypsum) – CaSO4, Carbon dioxide – CO2, Carbon disulfide – CS2, Carbon monoxide – CO, Carbon tetrabromide – CBr4, Carbon tetrachloride – CCl4, Carbon tetraiodide – CI4, Carbonic acid – H2CO3, Carbonyl fluoride – COF2, Carbonyl sulfide – COS, Carboplatin – C6H12N2O4Pt, carborundum SiC, Cerium aluminium – CeAl, Cerium cadmium – CeCd, Cerium magnesium – CeMg, Cerium mercury – CeHg, Cerium silver – CeAg, Cerium thallium – CeTl, Cerium zinc – CeZn, Cerium(III) bromide – CeBr3, Cerium(III) chloride – CeCl3, Cerium(IV) sulfate – Ce(SO4)2, Chrome-alum; K2SO4Cr2(SO4)3.24H2O, Chromic acid – CrO3, Chromium trioxide (Chromic acid) – CrO3, Chromium(II) chloride – CrCl2 (also chromous chloride), Chromium(II) sulfate – CrSO4, Chromium(III) chloride – CrCl3, Chromium(III) oxide – Cr2O3, Chromium(IV) oxide – CrO2, Chromyl chloride – CrO2Cl2, Cisplatin (cis-platinum(II) chloride diammine)– PtCl2(NH3)2, Cobalt(II) bromide – CoBr2, Cobalt(II) carbonate – CoCO3, Cobalt(II) chloride – CoCl2, Cobalt(II) sulfate – CoSO4, Columbite – Fe2+Nb2O6, Copper(I) chloride – CuCl, Copper(I) oxide – Cu2O, Copper(I) sulfide – Cu2S, Copper(II) carbonate – CuCO3, Copper(II) chloride – CuCl2, Copper(II) hydroxide – Cu(OH)2, Copper(II) nitrate – Cu(NO3)2, Copper(II) oxide – CuO, Copper(II) sulfate – CuSO4, Copper(II) sulfide – CuS, Cyanogen – (CN)2, Cyanogen chloride – CNCl, Cyanuric chloride – C3Cl3N3, Decaborane (Diborane) – B10H14, Diammonium phosphate – (NH4)2HPO4, Diborane – B2H6, Dichlorosilane – SiH2Cl2, Digallane – Ga2H6, Dinitrogen pentoxide (nitronium nitrate) – N2O5, Disilane – Si2H6, Disulfur dichloride S2Cl2, Dysprosium(III) chloride – DyCl3, Erbium(III) chloride – ErCl3, Erbium-copper – ErCu, Erbium-gold – ErAu, Erbium-Iridium – ErIr, Erbium-silver – ErAg, Europium(III) chloride – EuCl3, Fluorosulfuric acid – FSO2(OH), Gadolinium(III) chloride – GdCl3, Gadolinium(III) oxide – Gd2O3, Gallium antimonide – GaSb, Gallium arsenide – GaAs, Gallium nitride – GaN, Gallium phosphide – GaP, Gallium trichloride – GaCl3, Germanium (IV) nitride – Ge3N4, Germanium telluride – GeTe, Germanium(II) bromide – GeBr2, Germanium(II) chloride – GeCl2, Germanium(II) fluoride – GeF2, Germanium(II) iodide – GeI2, Germanium(II) oxide – GeO, Germanium(II) selenide – GeSe, Germanium(II) sulfide – GeS, Germanium(III) hydride – Ge2H6, Germanium(IV) bromide – GeBr4, Germanium(IV) chloride – GeCl4, Germanium(IV) fluoride – GeF4, Germanium(IV) hydride (Germane)– GeH4, Germanium(IV) iodide – GeI4, Germanium(IV) oxide – GeO2, Germanium(IV) selenide – GeSe2, Germanium(IV) sulfide – GeS2, Gold ditelluride – AuTe2, Gold(I) bromide – AuBr, Gold(I) chloride – AuCl, Gold(I) iodide – AuI, Gold(I) sulfide – Au2S,

Gold(I,III) chloride – Au4Cl8, Gold(III) bromide – (AuBr3)2, Gold(III) chloride – (AuCl3)2, Gold(III) chloride – AuCl3, Gold(III) fluoride – AuF3, Gold(III) iodide – AuI3, Gold(III) oxide – Au2O3, Gold(III) selenide – Au2Se3, Gold(III) selenide – AuSe, Gold(III) sulfide – Au2S3, Gold(V) fluoride – AuF5, Hafnium fluoride, Hafnium tetrachloride – HfCl4, Hexadecacarbonylhexarhodium – Rh6CO16, Hydrazine – N2H4, Hydrazoic acid – HN3, Hydrobromic acid – HBr, Hydrochloric acid – HCl, Hydrogen bromide – HBr, Hydrogen chloride – HCl, Hydrogen fluoride – HF, Hydrogen peroxide – H2O2, Hydrogen selenide – H2Se, Hydrogen sulfide – H2S, Hydrogen telluride – H2Te, Hydroiodic acid – HI, Hydroxylamine – NH2OH, Hypochlorous acid – HClO, Hypophosphorous acid – H3PO2, Indium antimonide – InSb, Indium arsenide – InAs, Indium nitride – InN, Indium phosphide – InP, Indium(I) chloride, Iodic acid – HIO3, Iodine heptafluoride – IF7, Iodine monochloride – ICl, Iodine pentafluoride – IF5, Iridium(IV) chloride, Iron(II) chloride – FeCl2 including hydrate, Iron(II) oxide – FeO, Iron(II,III) oxide – Fe3O4, Iron(III) chloride – FeCl3, Iron(III) nitrate – Fe(NO3)3(H2O)9, Iron(III) oxide – Fe2O3, Iron(III) thiocyanate, Iron-sulfur cluster, Krypton difluoride - KrF2, Lanthanum aluminium – LaAl, Lanthanum cadmium – LaCd, Lanthanum carbonate – La2(CO3)3, Lanthanum magnesium – LaMg, Lanthanum mercury – LaHg, Lanthanum silver – LaAg, Lanthanum tallium – LaTl, Lanthanum zinc – LaZn, Lead zirconate titanate – Pb[TixZr1-x]O3 (e.g., x = 0.52 is Lead zirconium titanate), Lead(II) carbonate – Pb(CO3), Lead(II) chloride – PbCl2, Lead(II) iodide – PbI2, Lead(II) nitrate – Pb(NO3)2, Lead(II) oxide – PbO, Lead(II) phosphate – Pb3(PO4)2, Lead(II) selenide – PbSe, Lead(II) sulfate – Pb(SO4), Lead(II) sulfide – PbS, Lead(II) telluride – PbTe, Lead(IV) oxide – PbO2, Lithium aluminium hydride – LiAlH4, Lithium bromide – LiBr, Lithium carbonate (Lithium salt) – Li2CO3, Lithium chloride – LiCl, Lithium hydride – LiH, Lithium hydroxide – LiOH, Lithium iodide – LiI, Lithium nitrate – LiNO3, Lithium sulfate – Li2SO4, Magnesium antimonide – MgSb, Magnesium carbonate – MgCO3, Magnesium chloride – MgCl2, Magnesium oxide – MgO, Magnesium phosphate – Mg3(PO4)2, Magnesium sulfate – MgSO4, Manganese(II) chloride – MnCl2, Manganese(II) phosphate – Mn3(PO4)2, Manganese(II) sulfate monohydrate – MnSO4.H2O, Manganese(III) chloride – MnCl3, Manganese(IV) fluoride – MnF4, Manganese(IV) oxide (manganese dioxide) – MnO2, Mercury fulminate – Hg(ONC)2, Mercury(I) chloride – Hg2Cl2, Mercury(I) sulfate – Hg2SO4, Mercury(II) chloride – HgCl2, Mercury(II) selenide – HgSe, Mercury(II) sulfate – HgSO4, Mercury(II) sulfide – HgS, Mercury(II) telluride – HgTe, Metaphosphoric acid – HPO3, Molybdate orange, Molybdenum disulfide – MoS2, Molybdenum hexacarbonyl – C6O6Mo, Molybdenum trioxide – MoO3, Molybdic acid – H2MoO4, Neodymium(III) chloride – NdCl3, Nessler's reagent – K2[HgI4], Nickel(II) carbonate – NiCO3, Nickel(II) chloride – NiCl2 and

hexahydrate, Nickel(II) hydroxide – Ni(OH)2, Nickel(II) nitrate – Ni(NO3)2, Nickel(II) oxide – NiO, Niobium oxychloride – NbOCl3, Niobium pentachloride – NbCl5, Nitric acid – HNO3, Nitrogen dioxide – NO2, Nitrogen monoxide – NO, Nitrosylsulfuric acid – NOHSO4, Osmium tetroxide (osmium(VIII) oxide) – OsO4, Osmium trioxide (osmium(VI) oxide) – OsO3, Oxybis(tributyltin) – C24H54OSn2, Oxygen difluoride – OF2, Ozone – O3, Palladium(II) chloride – PdCl2, Palladium(II) nitrate – Pd(NO3)2, Pentaborane – B5H9, Pentasulfide antimony – Sb2S5, Perchloric acid – HClO4, Perchloryl fluoride – ClFO3, Persulfuric acid (Caro's acid) – H2SO5, Perxenic acid – H4XeO6, Phenylarsine oxide – (C6H5)AsO, Phenylphosphine – C6H7P, Phosgene – COCl2, Phosphine – PH3, Phosphite – HPO32-, Phosphomolybdic acid – HMoNiO6P-4, Phosphoric acid – H3PO4, Phosphorous acid (Phosphoric(III) acid) – H3PO3, Phosphorus pentabromide – PBr5, Phosphorus pentafluoride – PF5, Phosphorus pentasulfide – P4S10, Phosphorus pentoxide – P2O5, Phosphorus sesquisulfide – P4S3, Phosphorus tribromide – PBr3, Phosphorus trichloride – PCl3, Phosphorus trifluoride – PF3, Phosphorus triiodide – PI3, Phosphotungstic acid – H3PW12O40, Platinum(II) chloride – PtCl2, Platinum(IV) chloride – PtCl4, Plutonium dioxide (Plutonium(IV) oxide) – PuO2, Plutonium(III) chloride – PuCl3, Potash Alum– K2SO4.Al2(SO4)3·24H2O, Potassium aluminium fluoride – KAlF4, Potassium borate – K2B4O7•4H2O, Potassium bromide – KBr, Potassium calcium chloride – KCaCl3, Potassium carbonate – K2CO3, Potassium chlorate – KClO3, Potassium chloride – KCl, Potassium ferrioxalate – K3[Fe(C2O4)3], Potassium hydrogen fluoride – HF2K, Potassium hydrogencarbonate – KHCO3, Potassium hydroxide – KOH, Potassium iodide – KI, Potassium monopersulfate – K2SO4·KHSO4·2KHSO5, Potassium nitrate – KNO3, Potassium perbromate – KBrO4, Potassium perchlorate – KClO4, Potassium permanganate – KMnO4, Potassium sulfate – K2SO4, Potassium sulfide – K2S, Potassium titanyl phosphate – KTiOPO4, Potassium vanadate – KVO3, Praseodymium(III) chloride – PrCl3, Protonated molecular hydrogen – H3+, Prussian blue (Iron(III) hexacyanoferrate(II)) – Fe4[Fe(CN)6]3, Pyrosulfuric acid – H2S2O7, Radium chloride – RaCl2, Radon difluoride – RnF2, Rhodium(III) chloride – RhCl3, Rubidium bromide – RbBr, Rubidium chloride – RbCl, Rubidium fluoride – RbF, Rubidium hydroxide – RbOH, Rubidium iodide – RbI, Rubidium nitrate – RbNO3, Rubidium oxide – Rb2O, Rubidium telluride – Rb2Te, Ruthenium(VIII) oxide – RuO4, Samarium(II) iodide – SmI2, Samarium(III) chloride – SmCl3, Scandium(III) chloride – ScCl3 and hydrate, Scandium(III) fluoride – ScF3, Scandium(III) nitrate – Sc(NO3)3, Scandium(III) oxide – Sc2O3, Scandium(III) triflate – Sc(OSO2CF3)3, Selenic acid – H2SeO4, Selenious acid – H2SeO3, Selenium dioxide – SeO2, Selenium trioxide – SeO3, Silane – SiH4, Silica gel – SiO2·nH2O, Silicic acid – [SiOx(OH)4-2x]n,

Silicochloroform – Cl3HSi, Silicofluoric acid – H2SiF6, Silicon dioxide – SiO2, Silver chloride – AgCl, Silver iodide – AgI, Silver nitrate – AgNO3, Silver sulfide – Ag2S, Silver(I) fluoride – AgF, Silver(II) fluoride – AgF2, Soda lime –, Sodamide – NaNH2, Sodium borohydride – NaBH4, Sodium bromate – NaBrO3, Sodium bromide – NaBr, Sodium carbonate – Na2CO3, Sodium chlorate – NaClO3, Sodium chloride – NaCl, Sodium cyanide – NaCN, Sodium ferrocyanide – Na4Fe(CN)6, Sodium hydride – NaH, Sodium hydrogen carbonate (Sodium bicarbonate) – NaHCO3, Sodium hydrosulfide – NaSH, Sodium hydroxide – NaOH, Sodium iodide – NaI, Sodium monofluorophosphate (MFP) – Na2PFO3, Sodium nitrate – NaNO3, Sodium nitrite – NaNO2, Sodium percarbonate – 2Na2CO3.3H2O2, Sodium persulfate – Na2S2O8, Sodium phosphate; see Trisodium phosphate – Na3PO4, Sodium silicate – Na2SiO3, Sodium sulfate – Na2SO4, Sodium sulfide – Na2S, Sodium sulfite – Na2SO3, Sodium tellurite – Na2TeO3, Stannous chloride (tin(II) chloride) – SnCl2, Stibine – SbH3, Strontium chloride – SrCl2, Strontium nitrate – Sr(NO3)2, Strontium titanate – SrTiO3, Sulfamic acid – H3NO3S, Sulfane – H2S, Sulfur dioxide – SO2, Sulfuric acid – H2SO4, Sulfurous acid – H2SO3, Sulfuryl chloride – SO2Cl2, Tantalum carbide – TaC, Tantalum(V) oxide – Ta2O5, Telluric acid – H6TeO6, Tellurium dioxide – TeO2, Tellurium tetrachloride – TeCl4, Tellurous acid – H2TeO3, Terbium(III) chloride – TbCl3, Tetraborane(10) – B4H10, Tetrachloroauric acid – AuCl3, Tetrafluorohydrazine – N2F4, Tetramminecopper(II) sulfate – [Cu(NH3)4]SO4, Tetrasulfur tetranitride – S4N4, Thallium(I) carbonate – Tl2CO3, Thallium(I) fluoride – TlF, Thallium(III) oxide Tl2O3, Thallium(III) sulfate, Thionyl chloride – SOCl2, Thiophosgene – CSCl2, Thiophosphoryl chloride – Cl3PS, Thorium dioxide – ThO2, Thortveitite – (Sc,Y)2Si2O7, Thulium(III) chloride – TmCl3, Tin(II) chloride – SnCl2, Tin(II) fluoride – SnF2, Tin(IV) chloride – SnCl4, Titanium boride – TiB2, Titanium carbide – TiC, Titanium dioxide (B) (titanium(IV) oxide) – TiO2, Titanium dioxide (titanium(IV) oxide) – TiO2, Titanium nitride – TiN, Titanium(II) chloride – TiCl2, Titanium(III) chloride – TiCl3, Titanium(IV) bromide (titanium tetrabromide) – TiBr4, Titanium(IV) chloride (titanium tetrachloride) – TiCl4, Titanium(IV) iodide (titanium tetraiodide) – TiI4, Trifluoromethanesulfonic acid – CF3SO3H, Trifluoromethylisocyanide – C2NF3, Trimethylphosphine – C3H9P, Trioxidane – H2O3, Tripotassium phosphate – K3PO4, Trisodium phosphate – Na3PO4, Triuranium octaoxide (pitchblende or yellowcake) – U3O8, Tungsten carbide – WC, Tungsten hexacarbonyl – W(CO)6, Tungsten(VI) chloride – WCl6, Tungsten(VI) Fluoride – WF6, Tungstic acid – H2WO4, Uranium hexafluoride – UF6, Uranium pentafluoride – UF5, Uranium tetrachloride – UCl4, Uranium tetrafluoride – UF4, Uranyl carbonate – UO2CO3, Uranyl chloride – UO2Cl2, Uranyl fluoride – UO2F2, Uranyl hydroxide – (UO2)2(OH)4, Uranyl hydroxide – UO2(OH)2, Uranyl nitrate – UO2(NO3)2,

Uranyl sulfate – UO2SO4, Vanadium carbide – VC, Vanadium oxytrichloride (Vanadium(V) oxide trichloride) – VOCl3, Vanadium(II) chloride – VCl2, Vanadium(II) oxide – VO, Vanadium(III) bromide – VBr3, Vanadium(III) chloride – VCl3, Vanadium(III) fluoride – VF3, Vanadium(III) nitride – VN, Vanadium(III) oxide – V2O3, Vanadium(IV) chloride – VCl4, Vanadium(IV) fluoride – VF4, Vanadium(IV) oxide – VO2, Vanadium(IV) sulfate – VOSO4, Vanadium(V) oxide – V2O5, Water – H2O, Xenic acid – H2XeO4, Xenon difluoride – XeF2, Xenon hexafluoroplatinate – Xe[PtF6], Xenon tetrafluoride – XeF4, Xenon tetroxide – XeO4, Ytterbium(III) chloride – YbCl3, Ytterbium(III) oxide – Yb2O3, Yttrium aluminium garnet – Y3Al5O12, Yttrium barium copper oxide – YBa2Cu3O7, Yttrium cadmium – YCd, Yttrium copper – YCu, Yttrium gold – YAu, Yttrium iridium – YIr, Yttrium iron garnet – Y3Fe5O12, Yttrium magnesium – YMg, Yttrium rhodium – YRh, Yttrium silver – YAg, Yttrium zinc – YZn, Yttrium(III) antimonide – YSb, Yttrium(III) arsenide – YAs, Yttrium(III) bromide – YBr3, Yttrium(III) fluoride – YF3, Yttrium(III) oxide – Y2O3, Yttrium(III) sulfide – Y2S3, Zinc bromide – ZnBr2, Zinc carbonate – ZnCO3, Zinc chloride – ZnCl2, Zinc cyanide – Zn(CN)2, Zinc fluoride – ZnF2, Zinc iodide – ZnI2, Zinc oxide – ZnO, Zinc selenide – ZnSe, Zinc sulfate – ZnSO4, Zinc sulfide – ZnS, Zinc telluride – ZnTe, Zirconia hydrate – ZrO2.nH2O, Zirconium carbide – ZrC, Zirconium hydroxide – Zr(OH)4, Zirconium nitride – ZrN, Zirconium orthosilicate – ZrSiO4, Zirconium tetrahydroxide – H4O4Zr, or Zirconium tungstate – ZrW2O8, Zirconium(IV) chloride – ZrCl4, Zirconium(IV) oxide – ZrO2.

Combinations of SEs, precursor-MLs, MLs and Ligand2s and linkers, and composite materials.

Preferred embodiments include i) Embodiments in which ML and Ligand2 are both capable of mechanically binding, or are both mechanically bound, to SE1 and SE2, respectively, ii) Embodiments in which ML and Ligand2 are both capable of non-covalent binding, or are both non-covalently bound, to SE1 and SE2, respectively, iii) Embodiments in which Ligand2 is covalently bound to SE2, and where for each of i), ii) and iii), SE1 and SE2 are defined as follows:

- SE1 is a metal; more preferably SE1 is a metal and SE2 is a ceramic; more preferably SE1 is a metal and SE2 is a polymer; yet more preferably SE1 is metal and SE2 is a metal, or

- SE1 is a polymer; more preferably SE1 is a polymer and SE2 is a ceramic; more preferably SE1 is a polymer and SE2 is a polymer; yet more preferably SE1 is polymer and SE2 is a metal, or
- SE1 is a ceramic; more preferably SE1 is a ceramic and SE2 is a ceramic; more preferably SE1 is a ceramic and SE2 is a polymer; yet more preferably SE1 is ceramic and SE2 is a metal, or
- SE1 is a fullerene; more preferably SE1 is a fullerene and SE2 is a ceramic; more preferably SE1 is a fullerene and SE2 is a polymer; yet more preferably SE1 is fullerene and SE2 is a metal, or
- SE1 is a carbon nanotube; more preferably SE1 is a carbon nanotube and SE2 is a ceramic; more preferably SE1 is a carbon nanotube and SE2 is a polymer; yet more preferably SE1 is carbon nanotube and SE2 is a metal, or
- SE1 is a graphene; more preferably SE1 is a graphene and SE2 is a ceramic; more preferably SE1 is a graphene and SE2 is a polymer; yet more preferably SE1 is graphene and SE2 is a metal, or
- SE1 is a diamond or diamond film; more preferably SE1 is a diamond or diamond film and SE2 is a ceramic; more preferably SE1 is a diamond or diamond film and SE2 is a polymer; yet more preferably SE1 is diamond or diamond film and SE2 is a metal, or
- SE1 is a nanotube; more preferably SE1 is a nanotube and SE2 is a ceramic; more preferably SE1 is a nanotube and SE2 is a polymer; yet more preferably SE1 is nanotube and SE2 is a metal, or
- SE1 is an epoxy polymer; more preferably SE1 is an epoxy polymer and SE2 is a ceramic; more preferably SE1 is an epoxy polymer and SE2 is a polymer; yet more preferably SE1 is an epoxy polymer and SE2 is a metal, or
- SE1 is a quartz; more preferably SE1 is a quartz and SE2 is a ceramic; more preferably SE1 is a quartz and SE2 is a polymer; yet more preferably SE1 is quartz and SE2 is a metal, or
- SE1 is a carbon nanofiber; more preferably SE1 is a carbon nanofiber and SE2 is a ceramic; more preferably SE1 is a carbon nanofiber and SE2 is a polymer; yet more preferably SE1 is carbon nanofiber and SE2 is a metal, or
- SE1 is a linear polymer; more preferably SE1 is a linear polymer and SE2 is a ceramic; more preferably SE1 is a linear polymer and SE2 is a polymer; yet more preferably SE1 is linear polymer and SE2 is a metal, or

- SE1 is a short-chain branched polymer; more preferably SE1 is a short-chain branched polymer and SE2 is a ceramic; more preferably SE1 is a short-chain branched polymer and SE2 is a polymer; yet more preferably SE1 is short-chain branched polymer and SE2 is a metal, or
- SE1 is a long-chain branched polymer; more preferably SE1 is a long-chain branched polymer and SE2 is a ceramic; more preferably SE1 is a long-chain branched polymer and SE2 is a polymer; yet more preferably SE1 is long-chain branched polymer and SE2 is a metal, or
- SE1 is a ladder-type polymer; more preferably SE1 is a ladder-type polymer and SE2 is a ceramic; more preferably SE1 is a ladder-type polymer and SE2 is a polymer; yet more preferably SE1 is ladder-type polymer and SE2 is a metal, or
- SE1 is a star-branched polymer; more preferably SE1 is a star-branched polymer and SE2 is a ceramic; more preferably SE1 is a star-branched polymer and SE2 is a polymer; yet more preferably SE1 is star-branched polymer and SE2 is a metal, or
- SE1 is a network polymer; more preferably SE1 is a network polymer and SE2 is a ceramic; more preferably SE1 is a network polymer and SE2 is a polymer; yet more preferably SE1 is network polymer and SE2 is a metal.

In any of the above examples, SE1 and SE2 may be components of a CMU. Said CMU may be part of a composite material, or the CMU may be a sensor or some other partly isolated entity.

Particularly preferred LUs include LUs that comprise a ML that binds CNT
Particularly preferred LUs include LUs that consist of two MLs that bind CNT
Particularly preferred LUs include LUs that comprise two MLs that bind graphene
Particularly preferred LUs include LUs that consist of two MLs that bind graphene
Particularly preferred LUs include LUs that comprise two MLs that bind bornitride
Particularly preferred LUs include LUs that consist of two MLs that bind bornitride
Particularly preferred LUs include LUs that comprise two MLs that bind bornitride nanotube
Particularly preferred LUs include LUs that consist of two MLs that bind bornitride nanotube
Particularly preferred LUs include LUs that comprise two MLs where one binds CNT and the other binds graphene
Particularly preferred LUs include LUs that consist of two MLs where one binds CNT and the other binds bornitride

Particularly preferred LUs include LUs that comprise two MLs where one binds CNT and the other binds bornitride nanotube
Particularly preferred LUs include LUs that consist a ML and a Ligand2 where one binds graphene and the other binds bornitride nanotube
Preferably, SE1 is a ceramic material, a COOH-functionalized CNT, a OH-functionalized carbon nanotube, an NH2-functionalized carbon nanotube, an SH-functionalized CNT, COOH-functionalized graphene, multi-layer graphene, NH2-functionalized graphene, OH-functionalized graphene, a glass fibre, aramid, E-glass, iron, polyester, polyethylene, S-glass, steel, a battery, a borosilicate, a buckyball, a buckytube, a capacitator, a carbon dome, a carbon material, a carbon megatube, a carbon nanofoam, a carbon polymer, a catalyst, a cathode, a coated carbon nanotube, a conductor, a covalent crystal, a crystal, a crystalline material, a defect-free graphene sheet, a defect-free MWCNT, a defect-free SWCNT, a dielectric material, a diode, a dodecahedrane, a doped glass, a fibre, a fullerite, a fused silica, a glue, a green ceramic, a lanthanides, a machinable ceramic, a metal alloy, a metal-functionalized carbon nanotube, a metalised dielectric, a metallised ceramic, a metalloid, a mineral, a non-covalent crystal, a piezoelectric material, a platinum group metal, a post-transition metal, a rare earth element, a sapphire, a semiconductor, a sensor, a silicon nitride, a single crystal fiber, a sol-gel, a synthetic diamond, a transition metal, a triple-wall carbon nanotube, a tungsten carbide, alumina, alumina trihydrate, aluminium, aluminum boride, aluminum oxide, aluminum trihydroxide, amorphous carbon, an actinides, an amalgam, an anode, an elastomers , an electrode, an endohedral fullerene, an insulator, an intermetallic, an ionic crystal, an organic material, anode, anthracite, asbestos , barium , bone, boron, brass, buckypaper, calcium carbonite, calcium metasilicate, calcium sulfate, calcium sulphate, carbon black, carbon nanofoam, cathode, chromium, clay, coal, copper, diamond, diamond-like carbon, double-layer graphene, exfoliated graphite, exfoliated silicate, flourinated graphene, fused silica, gallium arsenide, gallium nitride, germanium, glass, glass microsphere, glass ribbons, glassy carbon, gold, hardened steel, hydrous magnesium silicate, hyperdiamond, iron oxides, lead zirconium titanate, lignite, lithium niobate, lonsdaleite, magnesium dihydroxide, magnesium oxide, manganese, metal oxide, mica, molybdenum, nickel, nylon, palladium, pencil lead, platinum, prismane, pyrolytic graphite, rubber, silica, silica gel, silicon, silicon carbide, silicon dioxide, silicon nitride, silver, soot, stainless steel, tantalum, titanium, titanium oxide, tooth cementum, tooth dentine, tooth enamel, tungsten, tungsten carbide, wood, zinc oxide, zirconia, a nanofibre, a plastic, a fibre, a nanomaterial, graphite, a cellulose nanofibre, a ceramic, curran, a nanothread, a

functionalized nanotube, a plastic material, a metal material, a polymer material, or a thio-functionalized graphene molecule

More preferably, SE1 is a graphane molecule, a graphene oxide molecule, a graphyne molecule, a reduced graphene oxide molecule, or a metal

Most preferably, SE1 is a carbon fibre, a carbon nanofibre, a carbon nanothread, a composite material, a fullerene, a MWCNT, a SWCNT, a graphene molecule, a nanotube, a boron nitride sheet, a one-layer molecule, a one-atom layer molecule, a boron nitride nanotube, a functionalized CNT, a functionalized graphene, a functionalized boron nitride nanotube or sheet, a multi-walled nanotube, or a single-walled nanotube

Preferably, SE2 is a biopolymer, a block copolymer, a conductive polymer, a cross-linked polyethylene, a flouroplastic, a high density polypropylene, a low density polypropylene, a medium density polyethylene, a medium density polypropylene, a polyacrylonitrile, a polycaprolactone molecule, a polychloroprene, a polychlorotrifluoroethylene, a polyester molecule, a polyimide, a polylactic acid, a polyphenol, a polysulphone, a polytetrafluoroethylene, a polyurea, a polyurethane, a polyvinyl, a silicone, an elastomer, an inorganic polymer, an ultra-high-molecular-weight polyethylene, a melamin resin, a neoprene, a superlinear polyethylene, a poly(ethylene-vinyl acetate) (PEVA), a polyamide, a polyoxymethylene (POM), polyethylene, polyurethaner, epoxy-based polymer, poly ethylvinyl acetate , polystyrene, polypropylene, polyether, polyethylene oxide, polypropylene oxide, polyacrylates, a polymer, a non-biologic polymer, a biologic polymer, polyaromatic polymer, polyaliphatic polymer, a polymer consisting of C, a polymer consisting of C and H, a polymer consisting of C and H and O, a polymer comprising C, a polymer comprising C and H, a polymer comprising C and H and O, polytetrafluoroethylene (PTFE), a polymer comprising C, a polymer comprising O, a polymer comprising N, a polymer comprising Cl, a polymer comprising H, a polymer comprising a carbonyl, a polymer comprising an OH, a polymer comprising an amide bond, a polymer comprising F, a polymer comprising S, a polymer comprising Si, a polymer consisting of C and H and O and N, a polymer comprising C and H and O and N, a polymer consisting of C and H and Cl, a polymer comprising C and H and Cl, a polymer consisting of C and H and F, a polymer comprising C and H and F, a shape memory polymer, a polymer consiting of 4-(ethoxycarbonyl)benzoic ester, a polymer consiting of butyl, a polymer consiting of chloro-ethyl, a polymer consiting of ethyl, a polymer consiting of ethyl-acetate, a polymer consiting of ethyl-nitril, a polymer consiting of ethylbenzene, a polymer consiting of isobutyl, a polymer consiting of isopentyl, a polymer consiting of isopropyl, a polymer consiting of methyl, a polymer consiting of methyl 2-methyl-

propionate, a polymer consiting of neopentyl, a polymer consiting of pentyl, a polymer consiting of phenyl-sulfide, a polymer consiting of propanoic acid, a polymer consiting of propanoic acid methyl ester, a polymer consiting of propyl, a polymer consiting of sec-butyl, a polymer consiting of sec-pentyl, a polymer consiting of tert-butyl, a polymer consiting of tert-pentyl, a polymer consiting of tetra-flouro-ethyl, a polymer comprising 2-methyl-propanoic acid methyl ester, a polymer comprising 4-(2-phenylpropan-2-yl)phenyl hydrogen carbonate, a polymer comprising 4-(4-phenoxybenzoyl)benzaketone, a polymer comprising 4-(ethoxycarbonyl)benzoic ester, a polymer comprising butyl, a polymer comprising chloro-ethyl, a polymer comprising ethyl, a polymer comprising ethyl-acetate, a polymer comprising ethyl-nitril, a polymer comprising ethylbenzene, a polymer comprising isobutyl, a polymer comprising isopentyl, a polymer comprising isopropyl, a polymer comprising methyl, a polymer comprising methyl 2-methyl-propionate, a polymer comprising neopentyl, a polymer comprising pentyl, a polymer comprising phenyl-sulfide, a polymer comprising propanoic acid, a polymer comprising propanoic acid methyl ester, a polymer comprising propyl, a polymer comprising sec-butyl, a polymer comprising sec-pentyl, a polymer comprising tert-butyl, a polymer comprising tert-pentyl, or a polymer comprising tetra-flour-ethyl

More preferably, SE2 is a polyacrylate, a polyolefine, an acrylonitrile butadiene styrene polymer (ABS), an organic polymer, a styrene acrylonitrile copolymer, a styrene butadiene latex, an unsaturated polyester (UPR), a bis-maleimide (BMI), a polymeric cyanate ester, A6 nylon, a polyarylether-etherketone (PEEK), a polyethylenimine (PEI), a poly-ether-ketone-ketone (PEKK), a poly(methyl methacrylate) (PMMA), a polyphenylene sulfide (PPS) , poly(ethylvinyl alcoho)l(EVA), a carbon fibre, a carbon nanofibre, a carbon nanothread, a composite material, a fullerene, a graphane molecule, a graphene oxide molecule, a graphyne molecule, a reduced graphene oxide molecule, a metal, a boron nitride sheet, a one-layer molecule, a one-atom layer molecule, a functionalized CNT, a functionalized graphene, a functionalized boron nitride, a multi-walled nanotube, or a single-walled nanotube.

Most preferably, SE2 is a copolymer, a high density polyethylene (HDPE), a linear low density polyethylene (LLDPE), a low density polyethylene (LDPE), a nylon, a polyamide (PA), a polycarbonate (PC), a polyethylene (PE), a polymer, a polypropylene (PP), a polystyrene (PS), an epoxy-based polymer, a polyethylene terephtalate (PET), a polyvinylchloride (PVC), a MWCNT, a SWCNT, a graphene molecule, a nanotube, or a boron nitride nanotube.

Preferably, the ML or Ligand2 comprises any of the following molecule structures: compound 1 from de Juan et al., 2015, doi: 10.1039/c5sc02916c, compound 2 from de Juan et al., 2015, doi: 10.1039/c5sc02916c, compound 3 from de Juan et al., 2015, doi: 10.1039/c5sc02916c, compound 4 from de Juan et al., 2015, doi: 10.1039/c5sc02916c, compound 5 from de Juan et al., 2015, doi: 10.1039/c5sc02916c, 1,2,3-Trichlorobenzene, 1,2,4-Trichlorobenzene, 9,10-dihydroanthracene, covalent bond, non-covalent bond, peptide composed of 5 amino acids, peptide composed of 6 amino acids, pyrene phenyl ester, small molecule with a molecular weight of 12 to 1200 dalton, benzene, biphenyl, peptide with the sequence CPTSTGQAC , peptide with the sequence CTLHVSSYC , dodecyl-trimethylammonium bromide (DTAB) , peptide with the sequence ELWR, peptide with the seqeunce ELWRPTR , with the sequence ELWSIDTSAHRK, fluoranthene, hexane, peptide with the sequence HTDWRLGTWHHS, peptide with the sequence KPRSVSG-dansyl, m-dinitrobenzene, , monooleate, monostearate, nitrobenzene, p-nitrotoluene, p-terphenyl, polycyclic carbonhydrides, polystyrene-polyethylene oxide copoymer, polyvinylpyrrolidone, porphyrine, pyrenecarboxylicacid, pyrenyl, peptide with the sequence QLMHDYR, peptide with the sequence QTWPPPLWFSTS , riboflavin, peptide with the sequence RLNPPSQMDPPF , sodium Dodecyl Benzene Sulphonate (SDBS), sodium dodecyl sulfate (SDS), tetraphene, peptide with the sequence IFRLSWGTYFS , peptide with the sequence KTQATSESGSAGRQMFVADMG, peptide with the sequence KTQATSRGTRGMRTSGGFPVG, peptide with the sequence KTQATSVPRKAARRWEQVDSV, peptide with the sequence MHGKTQATSGTIQS, peptide with the sequence PQAQDVELPQELQDQHREVEV, peptide with the sequence SKTSGRDQSKRVPRYWNVHRD, peptide with the sequence SKTSRESSAVQMGKARFLCT, toluene, trans-1,2-diaminocyclohexane-N,N,N9,N9-tetraacetic acid (CDTA), triphenylene, tween-60, tween-80, aromatic molecule, aromatic amino acid, aromatic ring, heteoaromatic ring, non-aromatic molecule, triple bond, Annulene, Aceanthrylene, Acenaphthylene, Acephenanthrylene, Anthracene, as-Indacene, Azulene, Benzene, Biphenylene, Chrysene, Coronene, Decacene, Decahelicene, Decaphene, Fluoranthene, Fluorene, Heptacene, Heptahelicene, Heptaphene, Heptaphenylene, Hexacene, Hexahelicene, Hexaphene, Hexaphenylene, Indene, Naphthalene, Nonacene, Nonahelicene, Nonaphene, Nonaphenylene, Octacene, Octahelicene, Octaphene, Octaphenylene, Ovalene, Pentacene, Pentalene, Pentaphene, Pentaphenylene, Perylene, Phenalene, Phenanthrene, Picene, Pleiadene, Polyacene, Polyalene, Polyaphene, Polyhelicene, Polynaphthylene, Polyphenylene, Pyranthrene, Rubicene, s-Indacene, Tetracene, Tetranaphthylene, Tetraphene, Tetraphenylene, Trinaphthylene, Triphenylene,

1,10-Phenanthroline, 1,5-Naphthyridine, 1,6-Naphthyridine, 1,7-Naphthyridine, 1,7-Phenanthroline, 1,8-Naphthyridine, 1,8-Phenanthroline, 1,9-Phenanthroline, 2,6-Naphthyridine, 2,7-Naphthyridine, 2,7-Phenanthroline, 2,8-Phenanthroline, 2,9-Phenanthroline, 3,7-Phenanthroline, 3,8-Phenanthroline, 4,7-Phenanthroline, Acridarsine, Acridine, Acridophosphine, Arsanthrene, Arsanthridine, Arsindole, Arsindolizine, Arsinoline, Arsinolizine, Boranthrene, Carbazole, Chromene, Cinnoline, Furan, Imidazole, Indazole, Indole, Indolizine, Isoarsindole, Isoarsinoline, Isochromene, Isoindole, Isophosphindole, Isophosphinoline, Isoquinoline, Isoselenochromene, Isotellurochromene, Isothiochromene, Mercuranthrene, Oxanthrene, Perimidine, Phenanthridine, Phenarsazinine, Phenazine, Phenomercurazine, Phenophosphazinine, Phenoselenazine, Phenotellurazine, Phenothiarsinine, Phenothiazine, Phenoxaphosphinine, Phenoxarsinine, Phenoxaselenine, Phenoxastibinine, Phenoxatellurine, Phenoxathiine, Phenoxazine, Phosphanthrene, Phosphanthridine, Phosphindole, Phosphindolizine, Phosphinoline, Phosphinolizine, Phthalazine, Pteridine, Purine, Pyran, Pyrazine, Pyrazole, Pyridazine, Pyridine, Pyrimidine, Pyrrole, Pyrrolizine, Quinazoline, Quinoline, Quinolizine, Quinoxaline, Selenanthrene, Selenochromene, Selenoxanthene, Silanthrene, Telluranthrene, Tellurochromene, Telluroxanthene, Thianthrene, Thiochromene, Thioxanthene, or Xanthene

More preferably, ML and/or Ligand2 comprises a diamino pyrene, covalent ligand, anthracene, peptide with the sequence IFRLSWGTYFS, naphtalene, phenanthrene, aminogroup-containing carbonhydride, peptide with the sequence HWKHPWGAWDTL, bis-pyrene, dipyrene (phenyl ester), tetracycline, peptide with the sequence DAEFRHDSGYEVHHQKLVFFAEDVGSNKGAIIGLMVGGVV, or peptide with the sequence DAEFRHDSGYEVHHQKLVFFAEDVGSNKGAIIGLMVGGVVIA.

Most preferably, ML and/or Ligand2 comprises a pyrene, aromatic system, such as benzene, nitrobenzene, toluene, 1,2,3-trichlorbenzene, 1,2,4-trichorobenzene, m-dinitrobenzene, p-nitrobenzene, naphthalene, anthracene, fluoranthene, phenanthrene, pyrene, pyrene-diamine, pyrene-phenyl ester, dipyrene (phenyl ester), tetracycline, as well as their substituted variants, a halogen, nitro group, amine, thiol, alcohol, ester, amide, carboxylic acid, phenol, indole, imidazole, sulfonate or phophate, C1-C10 alkane, such as hexane and heptane, detergent including chemical motifs comprising a C4-C25 alkane and a polar end group such as sulfonate, for example SDBS, Sodium dodecylbenzenesulfonate, lactam, such as N-methyl-pyrrolidone and lactone, amino acid residue such as phenylalanine, tyrosine, tryptophan, histidine, heteroaromatic system, including pyrole, thiophene, furane, pyrazole, imidazole, isoxazole, oxazole, isothiazole, thiazole, pyridine and

perylene bisimides, fused ring system, composed of either aromatic, non-aromatic or anti-aromatic rings or combinations thereof

Preferably, Ligand2 is a non-covalent bond, a single bond, a double bond, a triple bond, peptide with the sequence DAEFRHDSGYEVHHQKLVFFAEDVGSNKGAIIGLMVGGVV, peptide with the sequence DAEFRHDSGYEVHHQKLVFFAEDVGSNKGAIIGLMVGGVVIA or covalent ligand.

More preferably, Ligand2 is an aminogroup-containing carbonhydride, peptide with the sequence HWKHPWGAWDTL, bis-pyrene, dipyrene (phenyl ester), or tetracycline.

Preferably, ML and/orLigand2 comprises a peptide, anthracene, peptide with the sequence IFRLSWGTYFS , pyrene, diamino pyrene, naphtalene, phenanthrene, aromatic system, such as benzene, nitrobenzene, toluene, 1,2,3-trichlorbenzene, 1,2,4-trichorobenzene, m-dinitrobenzene, p-nitrobenzene, naphthalene, anthracene, fluoranthene, phenanthrene, pyrene, pyrene-diamine, pyrene-phenyl ester, dipyrene (phenyl ester), tetracycline, as well as their substituted variants, a halogen, nitro group, amine, thiol, alcohol, ester, amide, carboxylic acid, phenol, indole, imidazole, sulfonate or phophate, C1-C10 alkane, such as hexane and heptane, detergent including chemical motifs comprising a long alkane (incldluing C4, C5, C6, C7, C8, C9, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25) and a polar end group such as sulfonate, for example SDBS, Sodium dodecylbenzenesulfonate, lactam, such as N-methyl-pyrrolidone and lactone, amino acid residue such as phenylalanine, tyrosine, tryptophan, histidine, a heteroaromatic system, including pyrole, thiophene, furane, pyrazole, imidazole, isoxazole, oxazole, isothiazole, thiazole, pyridine and perylene bisimides, fused ring system, composed of either aromatic, non-aromatic or anti-aromatic rings or combinations thereof, or an amide bond, made up of two amide bonds arranged in parallel

Preferably, the Linker is a covalent bond, a nylon polymer molecule, an alkyl chain, a branched alkyl, an aromatic molecule, a heteroaromatic molecule, a dendrimer, a polyeethylene glycol, or a C1-C50 hydrocarbon chain, with 0-20 double bonds and 0-20 triple bonds.

More preferably, the Linker is a polymer, a polyolefine, a polypropylene (PP), a polystyrene (PS), an acrylonitrile butadiene styrene polymer (ABS), an epoxy-based polymer, an organic polymer, a polyethylene terephtalate (PET), a polyvinylchloride (PVC), a styrene acrylonitrile copolymer, a styrene butadiene latex, an unsaturated polyester (UPR), a bis-maleimide (BMI), a polymeric cyanate ester, a polyarylether-etherketone (PEEK), a polyethylenimine

(PEI), a poly-ether-ketone-ketone (PEKK), a poly(methyl methacrylate) (PMMA), a polyphenylene sulfide (PPS) or poly(ethylvinyl alcoho)l(EVA).

Most preferably, Linker is a linear molecule, a branched molecule, a rigid molecule, a flexible molecule, a polymer, a linear polymer, a branched polymer, a copolymer, a nylon, a polyacrylate, a polyamide (PA), a polycarbonate (PC), a polyethylene (PE), a high density polyethylene (HDPE), a linear low density polyethylene (LLDPE), or a low density polyethylene (LDPE)

Preferred matrices are inorganic matter, biologic matter, non-biologic matter, polymers.

Most preferred matrices are a metal, a ceramic, organic matter, a plastic, a resin, a copolymer, a high density polyethylene (HDPE), a linear low density polyethylene (LLDPE), a low density polyethylene (LDPE), a nylon, a polyamide (PA), a polycarbonate (PC), a polyethylene (PE), a polymer, a polypropylene (PP), a polystyrene (PS), an epoxy-based polymer, a polyethylene terephtalate (PET), or a polyvinylchloride (PVC)

Preferred polymerisation methods are a polycondensation., a uv-induced polymerisation., a step-growth polymerisation, a chain-growth polymerisation, an emulsion polymerisation, a solution polymerisation, a suspension polymerisation, and a precipitation polymerization.

Preferred processing methods are injection molding, compression molding, transfer molding, blow molding, extrusion, injection molding, liquid casting, DMC, SMC, RIM, RRIM, GRP (hand-layup), GRP (spray and match die), filament winding, pultrusion, rotational molding, thermoforming, screw extrusion, calendering, powder injection molding, thixomolding, coating, cold pressure molding, encapsulation, filament winding, laminating, contact molding and slush molding,

Preferred embodiments are a CMU; or a composite material comprising a CMU;

or a composite material comprising a CMU and a matrix chosen from; a metal, a ceramic, organic matter, a plastic, a resin, a copolymer, a high density polyethylene (HDPE), a linear low density polyethylene (LLDPE), a low density polyethylene (LDPE), a nylon, a polyamide (PA), a polycarbonate (PC), a polyethylene (PE), a polymer, a polypropylene (PP), a polystyrene (PS), an epoxy-based polymer, a polyethylene terephtalate (PET), a polyvinylchloride (PVC); wherein the CMU is chosen from the following;

C1.1.1: a CMU, where SE1 is a carbon fibre.

C1.1.2: a CMU, where SE1 is a carbon fibre and SE2 is copolymer.

C1.1.3: a CMU, where SE1 is a carbon fibre, and SE2 is a high density polyethylene.

C1.1.4: a CMU, where SE1 is a carbon fibre, and SE2 is a linear low density polyethylene.

C1.1.5: a CMU, where SE1 is a carbon fibre, and SE2 is a low density polyethylene.

C1.1.6: a CMU, where SE1 is a carbon fibre, and SE2 is a nylon.

C1.1.7: a CMU, where SE1 is a carbon fibre, and SE2 is a polyamide.

C1.1.8: a CMU, where SE1 is a carbon fibre, and SE2 is a polycarbonate.

C1.1.9: a CMU, where SE1 is a carbon fibre, and SE2 is a polyethylene.

C1.1.10: a CMU, where SE1 is a carbon fibre, and SE2 is a polymer.

C1.1.11: a CMU, where SE1 is a carbon fibre, and SE2 is a polypropylene.

C1.1.12: a CMU, where SE1 is a carbon fibre, and SE2 is a polystyrene.

C1.1.13: a CMU, where SE1 is a carbon fibre, and SE2 is an epoxy-based polymer.

C1.1.14: a CMU, where SE1 is a carbon fibre, and SE2 is a polyethylene terephtalate.

C1.1.15: a CMU, where SE1 is a carbon fibre, and SE2 is a polyvinylchloride.

C1.1.16: a CMU, where SE1 is a carbon fibre, and SE2 is a MWCNT.

C1.1.17: a CMU, where SE1 is a carbon fibre, and SE2 is a SWCNT.

C1.1.18: a CMU, where SE1 is a carbon fibre, and SE2 is a GS.

C1.1.19: a CMU, where SE1 is a carbon fibre, and SE2 is a nanotube.

C1.1.20: a CMU, where SE1 is a carbon fibre, and SE2 is a BNNT.

C1.1.21: a CMU, where SE1 is a carbon fibre, and SE2 is a polyacrylate.

C1.1.22: a CMU, where SE1 is a carbon fibre, and SE2 is a polyolefine.

ophan, or histidine, and SE2 is an epoxy-based polymer.

Desired characteristics of composite materials described herein.

For any characteristics of composite material mentioned above and below, and in each characteristic's entire range, further characteristics of the composite material that are of importance in the present invention are the crystallinity of the matrix material, stiffness, electrical conductivity, thermal conductivity, color, fluorescence, luminescence, UV protective capability, abrasion resistance, ductility, elasticity, flexibility, energy storage capability (energy storage as heat or kinetic energy), information storage capability, hydrophilicity, hydrophobicity, polarity, aproticity, and charge, as well as the following characteristics where the unit of measure is indicated after each characteristic: Arc Resistance, sec; Impact Strength, Charpy, J/cm; Impact Strength, Izod Notched, J/cm ; Impact Strength, Izod Unnotched, J/cm ; Impact Strength, Charpy Notched Low Temp, J/cm; Impact Strength, Izod Notched Low Temp, J/cm; Impact Strength, Charpy Unnotched Low Temp, J/cm; Impact Strength, Charpy Unnotched, J/cm; Linear Mold Shrinkage, cm/cm; Maximum Service Temperature, Air, ; Melt Flow, g/10 min; Melting Point, ; Modulus of Elasticity, GPa; Moisture Absorption at Equilibrium, % ; Oxygen Transmission, cc-mm/m; Poisson's Ratio; Processing Temperature, ; Surface Resistance, ohm; Tensile Strength, Ultimate, MPa; Tensile Strength, Yield, MPa; Thermal Conductivity, W/m-K; UL RTI, Electrical, ; UL RTI, Mechanical with Impact, ; UL RTI, Mechanical without Impact, ; Vicat Softening Point, ; Water Absorption, %; Coefficient of Friction; Comparative Tracking Index, V; Compressive Yield Strength, MPa; CTE, linear 20; Deflection Temperature at 0.46 MPa, ; Deflection Temperature at 1.8 MPa, ; Density, g/cc; Dielectric Constant; Dielectric Constant, Low Frequency ; Dielectric Strength, kV/mm; Dissipation Factor; Dissipation Factor, Low Frequency ; Electrical Resistivity, ohm-cm; Elongation @ break, %; Flammability, UL94 ; Flexural Modulus, GPa; Flexural Yield Strength, MPa; Glass Temperature, ; Hardness, Barcol; Hardness, Rockwell E; Hardness, Rockwell M; Hardness, Rockwell R; Hardness, Shore A; Hardness, Shore D; Heat Capacity, J/g.
Depending on the application, composite material with a low, medium, or high degree of each of these characteristics is preferable in the present invention.

Composite material.

The composite materials of the present invention may have a number of characteristics. One such characteristic is the number of different CMUs in the composite. Several different CMUs may be preferred in cases where a number of different characteristics of the composite is sought, and wherefore several different CMUs may be used, each representing one or more sought characteristic.

Number of different CMUs in the composite. The composite may comprise 2 or more different CMUs, preferably 3 or more, such as 4 or more, 5 or more, 6 or more, 7 or more, 8 or more, 9 or more, 10 or more, 15 or more, 20 or more, 30 or more or 50 or more different CMUs.

For any characteristics of a composite material mentioned above, and in each characteristic's entire range, a further characteristic of importance is the number of CMUs per area or volume in the composite.

Number of CMUs per area or volume in the composite. Often it is not the absolute number of CMUs in a composite material, but rather the number of CMUs per area or volume that is most important for obtaining the desired properties of the composite material. If the CMUs are solely providing attractive characteristics at a small cost, it will in most cases be preferable to have as many CMUs as practically possible per square millimeter or per cubic millimeter. However, if the CMU provides advantageous characteristics (e.g. high strength) as well as disadvantageous characteristics (e.g. high conductivity), a compromise must be sought where the desired characteristic (e.g. a certain strength) is obtained, and where the disadvantageous characteristics (e.g. conductivity) is kept appropriately low.
Thus, depending on the context, the total number of of CMUs per square millimeter of the composite material is preferably less than 10^{12}, such as less than 10^{10}, such as less than 10^{9}, such as less than 10^{8}, such as less than 10^{7}, such as less than 10^{6}, such as less than 10^{5}, such as less than 10^{4}, such as less than 10^{3}, such as less than 100, such as less than 10.

As described above, sometimes the highest possible number of CMUs per square millimeter is sought. Thus, depending on the context, the total number of of CMUs per square millimeter of the composite material is preferably more than 10, such as more than 100, such as more than 10^{3}, such as more than 10^{4}, such as more than 10^{5}, such as more than 10^{6}, such as more than 10^{7}, such as more than 10^{8}, such as more than 10^{9}, such as more than 10^{10}, such as more than 10^{12}.

Composite materials may thus preferably comprise only a few CMUs per square millimeter, such as less than 10 CMUs per square millimeter, or may comprise more, such as 10-100 CMUs per square millimeter, such as 100-1000 CMUs per square millimeter, such as 10^{3}-10^{4} CMUs per square millimeter, such as 10^{4}-10^{5} CMUs per square millimeter, such as 10^{5}-10^{6} CMUs per square millimeter, such as 10^{6}-10^{7} CMUs per square millimeter, such as 10^{7}-

10^8 CMUs per square millimeter, such as 10^8-10^9 CMUs per square millimeter, such as 10^9-10^{10} CMUs per square millimeter, such as 10^{10}-10^{11} CMUs per square millimeter, such as 10^{11}-10^{12} CMUs per square millimeter, or more than 10^{12} per square millimeter.

Thus, depending on the context, the total number of of CMUs per cubic millimeter of the composite material is preferably less than 10^{18}, such as less than 10^{16}, such as less than 10^{14}, such as less than 10^{12}, such as less than 10^{10}, such as less than 10^8, such as less than 10^7, such as less than 10^6, such as less than 10^4, such as less than 1000, such as less than 100.

As described above, sometimes the highest possible number of CMUs per cubic millimeter is sought. Thus, depending on the context, the total number of of CMUs per cubic millimeter of the composite material is preferably more than 100, such as more than 1000, such as more than 10^4, such as more than 10^6, such as more than 10^8, such as more than 10^{10}, such as more than 10^{12}, such as more than 10^{14}, such as more than 10^{16}, such as more than 10^{18}, such as more than 10^{20}.

Composite materials may thus preferably comprise only a few CMUs per cubic millimeter, such as less than 100 CMUs per cubic millimeter, or may comprise more, such as 100-1000 CMUs per cubic millimeter, such as 10^3-10^5 CMUs per cubic millimeter, such as 10^5-10^8 CMUs per cubic millimeter, such as 10^8-10^{11} CMUs per cubic millimeter, such as 10^{11}-10^{14} CMUs per cubic millimeter, such as 10^{14}-10^{16} CMUs per cubic millimeter, such as 10^{16}-10^{18} CMUs per cubic millimeter, such as 10^{18}-10^{20} CMUs per cubic millimeter, or more than 10^{20} per cubic millimeter.

For any characteristics of a composite material mentioned above, and in each characteristic's entire range, a further characteristic of importance is the number of different SEs in the composite.

Number of different SEs in the composite. The composite may comprise 2 or more different SE, preferably 3 or more, such as 4 or more, 5 or more, 6 or more, 7 or more, 8 or more, 9 or more, 10 or more, 15 or more, 20 or more, 30 or more or 50 or more different SEs.

For any characteristics of a composite material mentioned above, and in each characteristic's entire range, a further characteristic of importance is the melting point of the composite material.

Melting point of composite material. The melting point of the composite material is an important parameter and in some cases, such as ceramic brakes for automobiles, aircrafts and trains, a high melting point is desired. Thus, depending on the context, the melting point of the composite material is preferably greater than -20 °C, such as greater than 0 °C, such as greater than 50 °C, such as greater than 100 °C, such as greater than 200 °C, such as greater than 400 °C, such as greater than 600 °C, such as greater than 800 °C, such as greater than 1,000 °C, such as greater than 1,500 °C, such as greater than 2,000 °C, such as greater than 3,000 °C, such as greater than 4,000 °C, such as greater than 6,000 °C, such as greater than 8,000 °C.
In other cases, a composite material's flexibility at low temperatures is important, wherefore a low melting point may be advantageous. Thus, depending on the context, the melting point of the composite material is preferably less than 8,000 °C, such as less than 6,000 °C, such as less than 4,000 °C, such as less than 3,000 °C, such as less than 2,000 °C, such as less than 1,500 °C, such as less than 1,000 °C, such as less than 800 °C, such as less than 600 °C, such as less than 400 °C, such as less than 200 °C, such as less than 100 °C, such as less than 50 °C , such as less than 0 °C, such as less than -20 °C.

Composite materials may have melting points below 0 °C, such as between -20 °C and 0 °C; or may be higher, such as between 0 °C and 50 °C, or between 50 °C and 100 °C, or between 100 °C and 200 °C, or between 200 °C and 300 °C, or between 300 °C and 400 °C, or between 400 °C and 500 °C, or between 500 °C and 600 °C, or between 600 °C and 700 °C, or between 700 °C and 800 °C, or between 800 °C and 900 °C, or between 900 °C and 1,000 °C, or between 1,000 °C and 1,100 °C, or between 1,000 °C and 1,200 °C, or between 1,200 °C and 1,400 °C, or between 1,400 °C and 1,600 °C, or between 1,600 °C and 1,800 °C, or between 1,800 °C and 2,000 °C, or between 2,000 °C and 2,200 °C, or between 2,200 °C and 2,400 °C, or between 2,400 °C and 2,600 °C, or between 2,600 °C and 2,800 °C, or between 2,800 °C and 3,000 °C, or between 3,000 °C and 3,200 °C, or between 3,200 °C and 3,400 °C, or between 3,400 °C and 3,600 °C, or between 3,600 °C and 3,800 °C, or between 3,800 °C and 4,000 °C, or between 4,000 °C and 4,200 °C, or between 4,200 °C and 4,400 °C, or between 4,400 °C and 4,600 °C, or between 4,600 °C and 4,800 °C, or between 4,800 °C and 5,000 °C, or between 5,000 °C and 5,200 °C, or between 5,200 °C and 5,400 °C, or between 5,400 °C and 5,600 °C, or between 5,600 °C and 5,800 °C, or between 5,800 °C and 6,000 °C, or between 6,000 °C and 6,200 °C, or between 6,200 °C and 6,400 °C, or between 6,400 °C and 6,600 °C, or between 6,600 °C and 6,800 °C, or between 6,800 °C and 7,000 °C, or between 7,000 °C and 7,200 °C, or between 7,200 °C

and 7,400 °C, or between 7,400 °C and 7,600 °C, or between 7,600 °C and 7,800 °C, or between 7,800 °C and 8,000 °C, or between 8,000 °C and 8,200 °C, or between 8,400 °C and 8,600 °C, or between 8,600 °C and 8,800 °C, or between 8,800 °C and 9,000 °C, or between 9,000 °C and 9,200 °C, or between 9,200 °C and 9,400 °C, or between 9,400 °C and 9,600 °C, or between 9,600 °C and 9,800 °C, or between 9,800 °C and 10,000 °C, or between 10,000 °C and 11,000 °C, or between 11,000 °C and 12,000 °C, or between 12,000 °C and 13,000 °C, or between 13,000 °C and 14,000 °C, or between 14,000 °C and 15,000 °C, or between 15,000 °C and 16,000 °C, or between 16,000 °C and 17,000 °C, or between 17,000 °C and 18,000 °C, or between 18,000 °C and 19,000 °C, or between 19,000 °C and 20,000 °C, or above 20,000 °C.

For any characteristics of a composite material mentioned above, and in each characteristic's entire range, a further characteristic of importance is the density and strength of the composite material.

Density and Strength of the composite material. For certain applications, for example in the airplane or automotive industry, the strength and density of the composite material is of prime importance. Often, both low density and high strength is desired. However, as these two parameters often are opposing factors, a compromise will have to be made. Therefore, sometimes a high density is acceptable to gain strength, such as high tensile strength or large Young's Modulus. In other cases, low density is necessary, even if lower strength results. Thus, in preferred embodiments the composite material may have relatively low Young's modulus or low tensile strength, and in other preferred embodiments the composite material has large Young's modulus or large tensile strength; and likewise, in preferred embodiments the density can vary from very small to very large.

The specific density of composite materials of the present invention may be lower than 0.01 kg/L, but may also include specific densities in the following ranges: 0.01–0.1 kg/L; 0.1–0.4 kg/L; 0.4–0.6 kg/L; 0.6–0.8 kg/L; 0.8–1 kg/L; 1–1.2 kg/L; 1.2–1.4 kg/L; 1.4–1.6 kg/L; 1.6–1.8 kg/L; 1.8–2 kg/L; 2–2.5 kg/L; 2.5–3 kg/L; 3–3.5 kg/L; 3.5–4 kg/L; 4–4.5 kg/L; 4.5–5 kg/L; 5–5.5 kg/L; 5.5–6 kg/L; 6–6.5 kg/L; 6.5–7 kg/L; 7–7.5 kg/L; 7.5–8 kg/L; 8–8.5 kg/L; 8.5–9 kg/L; 9–9.5 kg/L; 9.5–10 kg/L; 10–11 kg/L; 11–12 kg/L; 12–13 kg/L; 13–14 kg/L; 14–16 kg/L; 16–20 kg/L; 20–30 kg/L; or above 30 kg/L.

In some cases high specific densities are preferred. This may be the case when the composite material is e.g. an anchor, as an anchor should rest heavily on the bottom. Thus,

depending on the context, the specific density is preferably greater than 0.01 kg/L, such as greater than 0.05 kg/L, such as greater than 0.2 kg/L, such as greater than 0.4 kg/L, such as greater than 0.6 kg/L , such as greater than 0.8 kg/L, such as greater than 1 kg/L, such as greater than 1.2 kg/L, such as greater than 1.5 kg/L , such as greater than 2 kg/L, such as greater than 4 kg/L, such as greater than 6 kg/L, such as greater than 8 kg/L, such as greater than 10 kg/L, such as greater than 12 kg/L, such as greater than 14 kg/L, such as greater than 16 kg/L , such as greater than 20 kg/L, such as greater than 30 kg/L.

In many cases low specific density is preferred. This is for example the case if the composite material is used to make ships that must float on the water, wherefore the weight must be minimized. Thus, depending on the context, the specific density is preferably less than 30 kg/L, such as less than 20 kg/L, such as less than 16 kg/L, such as less than 14 kg/L, such as less than 12 kg/L, such as less than 10 kg/L, such as less than 8 kg/L, such as less than 6 kg/L, such as less than 4 kg/L, such as less than 2 kg/L, such as less than 1.5 kg/L, such as less than 1.2 kg/L, such as less than 1 kg/L, such as less than 0.8 kg/L, such as less than 0.6 kg/L, such as less than 0.4 kg/L, such as less than 0.2 kg/L, such as less than 0.05 kg/L, such as less than 0.01 kg/L.

The Young's modulus of composite materials. In the majority of applications of composite materials, a high Young's modulus is preferred, as this will allow the material to recover its original shape after force has been applied to the material. Thus, depending on the context, the Young's modulus is preferably greater than 0.001 TPa, such as greater than 0.01 TPa, such as greater than 0.1 TPa, such as greater than 0.15 TPa, such as greater than 0.2 TPa, such as greater than 0.5 TPa, such as greater than 1 TPa, such as greater than 2 TPa, such as greater than 4 TPa, such as greater than 6 TPa, such as greater than 8 TPa, such as greater than 10 TPa.
However, in a few applications, a low Young's modulus is desirable. This is for example the case when the degree of deformation of a composite material is being used as a measure of how much force was applied to the material. Thus, depending on the context, the Young's modulus is preferably less than 10 TPa, such as less than 8 TPa, such as less than 6 TPa, such as less than 4 TPa, such as less than 2 TPa, such as less than 1 TPa, such as less than 0.5 TPa, such as less than 0.2 TPa, such as less than 0.15 TPa, such as less than 0.1 TPa, such as less than 0.01 TPa, such as less than 0.01 TPa.

The Young's modulus of composite materials suitable for the present invention can thus be lower than 0.001 TPa, but may also include SEs with Young's Modulus in the following

ranges: 0.001–0 .01 TPa; 0.01–0.03 TPa; 0.03–0.05 TPa; 0.05–0.07 TPa; 0.07–0.09 TPa; 0.09–0.1TPa; 0.1–0.11 TPa; 0.11–0.12 TPa; 0.12–0.13 TPa; 0.13–0.14 TPa; 0.14–0.15 TPa; 0.15–0.16 TPa; 0.16–0.17 TPa; 0.17–0.18 TPa; 0.18–0.19 TPa; 0.19–0.20 TPa; 0.20–0.22 TPa (e.g. stainless steel); 0.22–0.25 TPa; 0.25–0.30 TPa; 0.30–0.35 TPa; 0.35–0.40 TPa; 0.40–0.45 TPa; 0.45–0.50 TPa; 0.50–0.60 TPa; 0.60–0.80 TPa; 0.80–1.0 TPa; 1–2 TPa (e.g. single–walled carbon nanotubes); 2–3 TPa; 3–4 TPa; 4–5 TPa; 5–7 TPa; 7–10 TPa; or above 10 TPA.

Preferred tensile strength of composite materials is in most cases high, as this is suitable for a large number of applications, e.g. stronger fishing lines and stronger cables. Thus, depending on the context, the tensile strength of the composite material is preferably greater than 0.01 GPa, such as greater than 0.05 GPa, such as greater than 0.1 GPa, such as greater than 0.5 GPa, such as greater than 1 GPa, such as greater than 2 GPa, such as greater than 3 GPa, such as greater than 5 GPa, such as greater than 10 GPa, such as greater than 20 GPa, such as greater than 30 GPa, such as greater than 40 GPa, such as greater than 60 GPa, such as greater than 80 GPa, such as greater than 100 GPa, such as greater than 200 GPa.

However, in some cases a low tensile strength is advantageous, for example in cables or lines that must break for safety reasons, in order to avoid damage to individuals. Thus, depending on the context, the tensile strength of the composite material is preferably less than 200 GPa, such as less than 100 GPa, such as less than 80 GPa, such as less than 60 GPa, such as less than 40 GPa, such as less than 30 GPa, such as less than 20 GPa, such as less than 10 GPa, such as less than 5 GPa, such as less than 3 GPa, such as less than 2 GPa, such as less than 1 GPa, such as less than 0.5 GPa, such as less than 0.1 GPa, such as less than 0.05 GPa, such as less than 0.01 GPa.

The tensile strength for composite materials suitable for the present invention can thus be lower than 0.01 GPa, but may also include composite materials with tensile strengths in the following ranges: 0.01–0.03 GPa; 0.03–0.05 GPa; 0.05–0.07 GPa; 0.07–0.09 GPa; 0.09–0.1GPa; 0.1–0.11 GPa; 0.11–0.12 GPa; 0.12–0.13 GPa; 0.13–0.14 GPa; 0.14–0.15 GPa; 0.15–0.16 GPa; 0.16–0.17 GPa; 0.17–0.18 GPa; 0.18–0.19 GPa; 0.19–0.20 GPa; 0.20–0.22 GPa; 0.22–0.25 GPa; 0.25–0.30 GPa; 0.30–0.35 GPa; 0.35–0.40 GPa; 0.40–0.45 GPa; 0.45–0.50 GPa; 0.50–0.60 GPa; 0.60–0.80 GPa; 0.80–1.0 GPa; 1–2 GPa (e.g. stainless steel); 2–3 GPa; 3–4 GPa; 4–5 GPa; 5–7 GPa; 7–10 GPa; 10–15

GPa; 15–20 GPa; 20–25 GPa; 25–30 GPa; 30–35 GPa; 35–40 GPa; 40–45 GPa; 45–50 GPa (e.g. single–walled carbon nanotubes); 50–55 GPa; 55–60 GPa; 60–65 GPa; 65–70 GPa; 70–75 GPa; 75–80 GPa; 80–85 GPa; 85–90 GPa; 90–100 GPa; 100–200 GPa, or above 200 GPa.

Often, it is the ratio of strength to density that is most important. The strength/specific density ratio for the composite material that is preferred under the present invention is represented by all the ratios that can be obtained, by dividing the abovementioned strengths with the abovementioned specific densities. Thus, preferred embodiments have composite materials with strength/specific densities in the range 0,00003-1000 TPa L/Kg (where strength is represented by Young's modulus). More specifically, the strength/specific density (Young's Modulus) of the composite material is preferably in the range 0.00003-1000 TPa L/Kg, more preferably 0.001-1000 TPA L/Kg, more preferably 0.01-1000 TPA L/Kg, more preferably 0, 1-1000 TPA L/Kg, more preferably 1-1000 TPA L/Kg, more preferably 10-1000 TPA L/Kg, more preferably 100-1000 TPA L/Kg, and more preferably 500-1000 TPA L/Kg, or higher. Where strength is measured as Tensile strength, the preferred embodiments have composite materials with strength/specific density in the range 0.0003-20000 GPa L/Kg. More specifically, the tensile strength/specific density of the composite material is preferably in the range 0.0003-20000 TPa L/Kg, more preferably 0.01-20000 TPA L/Kg, more preferably 0, 1-20000 TPA L/Kg, more preferably 1-20000 TPA L/Kg, more preferably 10-20000 TPA L/Kg, more preferably 100-20000 TPA L/Kg, more preferably 1000-20000 TPA L/Kg, more preferably 5000-20000 TPA L/Kg, and more preferably 10000-20000 TPA L/Kg, or higher.

Ratio of strength to specific density is often important. The strength/specific density ratio for the composite material that is preferred under the present invention is represented by all the ratios that can be obtained, by dividing the abovementioned strengths with the abovementioned specific densities. Thus, preferred embodiments have composite material with strength/specific densities in the range 0.00003-1,000 TPa L/Kg (where strength is represented by Young's modulus). More specifically, the strength/specific density (Young's Modulus) of the composite material is preferably in the range 0.00003–1,000 TPa L/Kg, more preferably 0.001–1,000 TPA L/Kg, more preferably 0.01–1,000 TPA L/Kg, more preferably 0.1–1,000 TPA L/Kg, more preferably 1–1,000 TPA L/Kg, more preferably 10–1,000 TPA L/Kg, more preferably 100–1,000 TPA L/Kg, and more preferably 500–1,000 TPA L/Kg, or higher.

In cases where e.g. the Young's modulus should be low (see above), the Young's modulus/specific density ratio is preferably less than 1,000 TPA L/kg, such as less than 500 TPA L/kg, such as less than 100 TPa L/kg, such as less than 10 TPa L/kg, such as less than 1 TPa L/kg, such as less than 0.1 TPa L/kg, such as less than 0.01 TPa L/kg, such as less than 0.001 TPa L/kg, such as less than 0.00003 TPa L/kg.
In cases where e.g. Young's modulus is preferably high, the Young's modulus/specific density ratio is preferably greater than 0.00003 TPa L/kg, such as greater than 0.001 TPa L/kg, such as greater than 0.01 TPa L/kg, such as greater than 0.1 TPa L/kg, such as greater than 1 TPa L/kg, such as greater than 10 TPa L/kg, such as greater than 100 TPa L/kg, such as greater than 500 TPa L/kg, such as greater than 1,000 TPA L/kg.

Where strength is measured as tensile strength, the preferred embodiments have composite materials with strength/specific density in the range 0.0003–20,000 GPa L/Kg. More specifically, the tensile strength/specific density of the composite material is preferably in the range 0.0003–20,000 GPa L/Kg, more preferably 0.01–20,000 GPa L/Kg, more preferably 0.1–20,000 GPa L/Kg, more preferably 1–20,000 GPa L/Kg, more preferably 10–20,000 GPa L/Kg, more preferably 100–20,000 GPa L/Kg, more preferably 1,000–20,000 GPa L/Kg, more preferably 5,000–20,000 GPa L/Kg, and more preferably 10,000–20,000 GPa L/Kg, or higher.
In cases where e.g. the tensile strength is preferably low (see above), the tensile strength/specific density ratio is preferably less than 20,000 GPa L/kg, such as less than 10,000 GPa L/kg, such as less than 5,000 GPa L/kg, such as less than 1,000 GPa L/kg, such as less than 100 GPa L/kg, such as less than 10 GPa L/kg, such as less than 1 GPa L/kg, such as less than 0.1 GPa L/kg, such as less than 0.0003 GPa L/kg.
In cases where e.g. tensile strength is preferably high, the tensile strength/specific density ratio is preferably greater than 0.0003 GPa L/kg, such as greater than 0.1 GPa L/kg, such as greater than 1 GPa L/kg, such as greater than 10 GPa L/kg, such as greater than 100 GPa L/kg, such as greater than 1,000 GPa L/kg, such as greater than 5,000 GPa L/kg, such as greater than 10,000 GPa L/kg, such as greater than 20,000 GPA L/kg.

Preferred fracture toughness of composite materials is in most cases high, as this results in a low risk of cracks propagating through the composite, ultimately leading to fracture. Examples of composite materials where a high fracture toughness is desirable includes, but are not limited to, wind turbine blades and airplane wings. Thus, depending on the context, the fracture toughness is preferably greater than 0.01 $MPa \cdot m^{½}$, such as greater than 0.1

$MPa \cdot m^{½}$, such as greater than 1 $MPa \cdot m^{½}$, such as greater than 2 $MPa \cdot m^{½}$, such as greater than 5 $MPa \cdot m^{½}$, such as greater than 10 $MPa \cdot m^{½}$, such as greater than 15 $MPa \cdot m^{½}$, such as greater than 20 $MPa \cdot m^{½}$, such as greater than 25 $MPa \cdot m^{½}$, such as greater than 30 $MPa \cdot m^{½}$, such as greater than 40 $MPa \cdot m^{½}$, such as greater than 50 $MPa \cdot m^{½}$, such as greater than 75 $MPa \cdot m^{½}$, such as greater than 100 $MPa \cdot m^{½}$,

However, in some applications, a low fracture toughness is desirable. As an example, the fracture toughness of the windows in a train needs to be sufficiently low that a person can break the window using an appropriate tool in an emergency situation. Thus, depending on the context, the fracture toughness is preferably less than 100 $MPa \cdot m^{½}$, such as less than 75 $MPa \cdot m^{½}$, such as less than 50 $MPa \cdot m^{½}$, such as less than 40 $MPa \cdot m^{½}$, such as less than 30 $MPa \cdot m^{½}$, such as less than 25 $MPa \cdot m^{½}$, such as less than 20 $MPa \cdot m^{½}$, such as less than 15 $MPa \cdot m^{½}$, such as less than 10 $MPa \cdot m^{½}$, such as less than 5 $MPa \cdot m^{½}$, such as less than 2 $MPa \cdot m^{½}$, such as less than 1 $MPa \cdot m^{½}$, such as less than 0,1 $MPa \cdot m^{½}$, such as less than 0.01 $MPa \cdot m^{½}$.

The fracture toughness for composite materials suitable for the present invention can thus be lower than 0.01 $MPa \cdot m^{½}$, but may also include composite materials with fracture toughness in the following ranges: 0.01–0.1 $MPa \cdot m^{½}$, 0.1–1 $MPa \cdot m^{½}$, 1–2 $MPa \cdot m^{½}$, 2–5 $MPa \cdot m^{½}$, 5–10 $MPa \cdot m^{½}$, 10–15 $MPa \cdot m^{½}$, 15–20 $MPa \cdot m^{½}$, 20–25 $MPa \cdot m^{½}$, 25–30 $MPa \cdot m^{½}$, 30–40 $MPa \cdot m^{½}$, 40–50 $MPa \cdot m^{½}$, 50–75 $MPa \cdot m^{½}$, 75–100 $MPa \cdot m^{½}$, or above 100 $MPa \cdot m^{½}$.

Bulk modulus of composite materials. In the majority of applications of composite materials, a high bulk modulus is preferred, as this will allow the composite material to withstand a high compression, which is important in structural elements of buildings, bridges, etc. Thus, depending on the context, the bulk modulus is preferably greater than 0.001 GPa, such as greater than 0.01 GPa, such as greater than 0.1 GPa, such as greater than 1 GPa, such as greater than 10 GPa, such as greater than 50 GPa, such as greater than 100 GPa, such as greater than 200 GPa, such as greater than 300 GPa, such as greater than 400 GPa, such as greater than 500 GPa, such as greater than 600 GPa, such as greater than 700 GPa, such as greater than 800 GPa, such as greater than 900 GPa, such as greater than 1,000 GPa.

However, in a few applications, a low bulk modulus is desirable. This is for example the case in some foam products, where it should be easy to compress the foam, e.g. using a person's body weight. One such example may be skiing boots where the foam must be able to deform, in order to take up the shape of the skier's foot. Thus, depending on the context,

the bulk modulus is preferably less than 1,000 GPa, such as less than 900 GPa, such as less than 800 GPa, such as less than 700 GPa, such as less than 600 GPa, such as less than 500 GPa, such as less than 400 GPa, such as less than 300 GPa, such as less than 200 GPa, such as less than 100 GPa, such as less than 50 GPa, such as less than 10 GPa, such as less than 1 GPa, such as less than 0.1 GPa, such as less than 0.01 GPa, such as less than 0.001 GPa.

The bulk modulus for composite materials suitable for the present invention can thus be lower than 0.001 GPa, but may also include composite materials with bulk modules in the following ranges: 0.001–0.01 GPa, 0.01–0.1 GPa, 0.1–1 GPa, 1–10 GPa, 10–100 GPa, 100–200 GPa, 200–300 GPa, 300–400 GPa, 400–500 GPa, 500–600 GPa, 600–700 GPa, 700–800 GPa, 800–900 GPa, 900–1,000 GPa, or above 1,000 GPa.

Shear modulus of composite materials. In the majority of applications of composite materials, a high shear modulus is preferred, as this will allow the composite material to withstand large forces imposed on the composite material in parallel, but opposite directions, e.g. brakes on bicycles, cars, wind turbines, etc. Thus, depending on the context, the shear modulus is preferably greater than 0.001 GPa, such as greater than 0.01 GPa, such as greater than 0.1 GPa, such as greater than 1 GPa, such as greater than 10 GPa, such as greater than 50 GPa, such as greater than 100 GPa, such as greater than 200 GPa, such as greater than 300 GPa, such as greater than 400 GPa, such as greater than 500 GPa, such as greater than 600 GPa, such as greater than 700 GPa, such as greater than 800 GPa, such as greater than 900 GPa, such as greater than 1,000 GPa.

However, in some applications, a low shear modulus is desirable. This is for example the case in plastic composite materials used for buttons, e.g. to turn on or off electronic equipment. Such buttons must have a low shear modulus so pressing them is sufficiently easy. Thus, depending on the context, the shear modulus is preferably less than 1,000 GPa, such as less than 900 GPa, such as less than 800 GPa, such as less than 700 GPa, such as less than 600 GPa, such as less than 500 GPa, such as less than 400 GPa, such as less than 300 GPa, such as less than 200 GPa, such as less than 100 GPa, such as less than 50 GPa, such as less than 10 GPa, such as less than 1 GPa, such as less than 0.1 GPa, such as less than 0.01 GPa, such as less than 0.001 GPa.

The shear modulus for composite materials suitable for the present invention can thus be lower than 0.001 GPa, but may also include composite materials with shear modules in the following ranges: 0.001–0.01 GPa, 0.01–0.1 GPa, 0.1–1 GPa, 1–10 GPa, 10–100 GPa, 100–200 GPa, 200–300 GPa, 300–400 GPa, 400–500 GPa, 500–600 GPa, 600–700 GPa, 700–800 GPa, 800–900 GPa, 900–1,000 GPa, or above 1,000 GPa.

Other kinds of strength, such as torsional strength and impact strength, are also of importance. Thus, composite materials with low, medium or high torsional strength, and composite materials with low, medium or high impact strength are suitable for the present invention, and thus represent preferred embodiments.

For any characteristics of a composite material mentioned above, and in each characteristic's entire range, a further characteristic of importance is the conductivity of the composite material.

Conductivity of composite material. In certain applications, e.g. use of a composite material in wind turbine blades, it may be important that the propellers are non-conductive, in order to not attract lightning. In other cases, it may be desirable to prepare composite materials of modest or high conductivity, in order to be able to detect cracks in the material by analytical measurement of the conductance of the material. Likewise, for composite materials used in e.g. nanosensor technology it may be important that the composite material is conductive, in order to be able to detect changes in conductivity induced by the association of an analyte with the composite material. In some sensor applications it may be desirable to have high conductivity (if the analyte has a strong reducing effect on the conductance of the composite material), or it may be desirable to use a composite material with an intermediate conductivity in order to detect small changes in conductivity. Thus, depending on the application it may be desirable that the composite material has low, intermediate or high conductivity. Composite materials may have conductivities ranging from below 10^{-30} S/m to at least 10^{11} S/m and higher, such as from below 10^{-30} S/m to 10^{-25} S/m (e.g. Teflon), such as from 10^{-25} S/m to 10^{-20} S/m (e.g. PET), such as from 10^{-20} S/m to 10^{-15} S/m (e.g. Quarts (fused) and Paraffin), such as from 10^{-15} S/m to 10^{-10} S/m (e.g. Hard Rubber, Diamond, Glass), such as from 10^{-10} S/m to 10^{-5} S/m (e.g. GaAs, Silicon), such as from 10^{-5} S/m to 1 S/m, such as from 1 S/m to 10 S/m (e.g. Germanium), such as from 10 S/m to 10^{2} S/m, such as from 10^{2} S/m to 10^{4} S/m (e.g. graphite), such as from 10^{4} S/m to 10^{6} S/m (e.g. Nichrome, Mercury,), such as from 10^{6} S/m to 10^{8} S/m (e.g. Stainless steel, Titanium, Platinum, Iron,

Lithium, Aluminum, Gold, Coper, Silver), such as from 10^8 S/m to 10^9 S/m, such as from 10^9 S/m to 10^{10} S/m, such as from 10^{10} S/m to 10^{11} S/m (e.g. Carbon nanotubes), such as from 10^{11} S/m to 10^{12} S/m (e.g. Carbon nanotubes), such as from 10^{12} S/m to 10^{14} S/m, and above 10^{14} S/m (e.g. superconducting material).

Thus, depending on the context, the conductivity of a composite material is preferably greater than 10^{-30} S/m, such as greater than 10^{-25} S/m, such as greater than 10^{-20} S/m, such as greater than 10^{-15} S/m, such as greater than 10^{-10} S/m, such as greater than 10^{-5} S/m, such as greater than 1 S/m, such as greater than 10 S/m, such as greater than 10^2 S/m, such as greater than 10^4 S/m, such as greater than 10^6 S/m, such as greater than 10^8 S/m, such as greater than 10^9 S/m, such as greater than 10^{10} S/m, such as greater than 10^{11} S/m, such as greater than 10^{12} S/m, such as greater than 10^{13} S/m, such as greater than 10^{14} S/m.

In other applications, and depending on the context, the conductivity is preferably less than 10^{14} S/m, such as less than 10^{13} S/m, such as less than 10^{12} S/m, such as less than 10^{11} S/m, such as less than 10^{10} S/m, such as less than 10^9 S/m, such as less than 10^8 S/m, such as less than 10^6 S/m, such as less than 10^4 S/m, such as less than 10^2 S/m, such as less than 10 S/m, such as less than 1 S/m, such as less than 10^{-5} S/m, such as less than 10^{-10} S/m, such as less than 10^{-15} S/m, such as less than 10^{-20} S/m, such as less than 10^{-25} S/m, such as less than 10^{-30} S/m.

For any characteristics of a composite material mentioned above, and in each characteristic's entire range, a further characteristic of importance is the degree to which the composite material can be elongated (stretched) without breaking.

Elongation at break. In many applications, a high elongation at break is preferred. This is for example important in composite materials that absorb energy by deforming plastically such as crash barriers and car bumpers. Thus, depending on the context, the elongation at break of a composite material is preferably greater than 0.1%, such as greater than 1%, such as greater than 5%, such as greater than 10%, such as greater than 20%, such as greater than 30%, such as greater than 40%, such as greater than 50%, such as greater than 60%, such as greater than 70%, such as greater than 80%, such as greater than 90%, such as greater than 100%, such as greater than 150%, such as greater than 200%, such as greater than 300%, such as greater than 400%, such as greater than 500%, such as greater than 800%, such as greater than 1,500%.

In other applications, a low elongation at break is preferred. This is important in composite materials that must not deform even under harsh conditions such as high pressure and elevated temperature; one such example is ceramic brakes on automobiles, aircrafts and trains. Thus, depending on the context, the elongation at break of a composite material is preferably less than 1,500%, such as less than 800%, such as less than 500%, such as less than 400%, such as less than 300%, such as less than 200%, such as less than 150%, such as less than 100%, such as less than 90%, such as less than 80%, such as less than 70%, such as less than 60%, such as less than 50%, such as less than 40%, such as less than 30%, such as less than 20%, such as less than 10%, such as less than 5%, such as less than 1%, such as less than 0.1%.

Composite materials suitable for the present invention can thus have an elongation at break of less than 0.1%, or have elongation at break including the following ranges: 0.1–1%, 1–5%, 5–10%, 10–20%, 20–30%, 30–40%, 40–50%, 50–60%, 60–70%, 70–80%, 80–90%, 90–100%, 100–150%, 150–200%, 200–300%, 300–400%, 400–500%, 500–800%, 800–1,500%, or have elongation at break above 1,500%.

For any characteristics of a composite material mentioned above, and in each characteristic's entire range, a further characteristic of importance is the size of the composite material.

Size of composite material. The size and shape of the composite material are important parameters. Thus, although depending on the characteristics of the composite material, composite materials may benefit from being large in size, as measured by the total weight of a piece of the composite material, the largest single dimension of a piece of composite material, or the total volume of a piece of composite material. Thus, depending on the context, the total weight of the composite material is preferably greater than 10^{-12} kg, such as greater than 10^{-11} kg, such as greater than 10^{-10} kg, such as greater than 10^{-9} kg, such as greater than 10^{-8} kg, such as greater than 10^{-7} kg, such as greater than 10^{-6} kg, such as greater than 10^{-5} kg, such as greater than 10^{-4} kg, such as greater than 10^{-3} kg, such as greater than 0.01 kg, such as greater than 0.1 kg, such as greater than 1 kg, such as greater than 10 kg, such as greater than 100 kg, such as greater than 10^{3} kg, such as greater than 10^{4} kg, such as greater than 10^{5} kg, such as greater than 10^{6} kg, such as greater than 10^{7} kg, such as greater than 10^{8} kg, such as greater than 10^{9} kg.

And the largest dimension of a composite material is preferably, depending on the context, greater than 0.1 Å, such as greater than 2 Å, such as greater than 1 nm, such as greater than 10 nm, such as greater than 100 nm, such as greater than 1 μm, such as greater than 10 μm, such as greater than 100 μm, such as greater than 1 mm, such as greater than 10 mm, such as greater than 100 mm, such as greater than 1 m, such as greater than 10 m, such as greater than 100 m, such as greater than 1,000 m.

And the total volume of a composite material is preferably, depending on the context, greater than 1 nm^3, such as greater than 1,000 nm^3, such as greater than 1,000,000 nm^3, such as greater than 1 μm^3, such as greater than 1,000 μm^3, such as greater than 1,000,000 μm^3, such as greater than 1 mm^3, such as greater than 1,000 mm^3, such as greater than 1,000,000 mm^3, such as greater than 1 m^3, such as greater than 10 m^3, such as greater than 100 m^3, such as greater than 1,000 m^3.

On the other hand, a composite material, depending on other characteristics of the composite material, may benefit from being small in size, as measured by the total weight of a piece of the composite material, the largest single dimension of a piece of composite material, or the total volume of a piece of composite material. Thus, depending on the context, the total weight of the composite material is preferably less than 10^9 kg, such as less than 10^8 kg, such as less than 10^7 kg, such as less than 10^6 kg, such as less than 10^5 kg, such as less than 10^4 kg, such as less than 10^3 kg, such as less than 100 kg, such as less than 10 kg, such as less than 1 kg, such as less than 0.1 kg, such as less than 0.01 kg, such as less than 10^{-3} kg, such as less than 10^{-4} kg, such as less than 10^{-5} kg, such as less than 10^{-6} kg, such as less than 10^{-7} kg, such as less than 10^{-8} kg, such as less than 10^{-9} kg, such as less than 10^{-10} kg, such as less than 10^{-11} kg, such as less than 10^{-12} kg.

And the largest dimension of a composite material is preferably, depending on the context, less than 1,000 m, such as less than 100 m, such as less than 10 m, such as less than 1 m, such as less than 100 mm, such as less than 10 mm, such as less than 1 mm, such as less than 100 μm, such as less than 10 μm, such as less than 1 μm, such as less than 100 nm, such as less than 10 nm, such as less than 1 nm, such as less than 2 Å, such as less than 0.1 Å.

And the total volume of a composite material is preferably, depending on the context, less than 1,000 m^3, such as less than 100 m^3, such as less than 10 m^3, such as less than 1 m^3, such as less than 1,000,000 mm^3, such as less than 1,000 mm^3, such as less than 1 mm^3,

such as less than 1,000,000 μm^3, such as less than 1,000 μm^3, such as less than 1 μm^3, such as less than 1,000,000 nm^3, such as less than 1,000 nm^3, such as less than 1 nm^3.

Often, the choice of size and shape will be a compromise between opposing interests. Thus, in preferred embodiments the composite material may be very small to very large, depending on the application.

Therefore, the preferred compromise between high and low weight of the composite material depends on the context, and may be smaller than 10^{-12} kg, but may also be in the range of 10^{-12}–10^{-11} kg, 10^{-11}–10^{-10} kg, 10^{-10}–10^{-9} kg, 10^{-9}–10^{-8} kg, 10^{-8}–10^{-7} kg, 10^{-7}–10^{-6} kg, 10^{-6}–10^{-5} kg, 10^{-5}–10^{-4} kg, 10^{-4}–10^{-3} kg, 0.001–0.01 kg, 0.01–0.1 kg, 0.1–1 kg, 1–10 kg, 10–100 kg, 100–1,000 kg, 10^3–10^4 kg, 10^4–10^5 kg, 10^5–10^6 kg, 10^6–10^7 kg, 10^7–10^8 kg, 10^8–10^9 kg, or above 10^9 kg.

Therefore, the preferred compromise between large and small dimensions of the composite material depends on the context, and may be smaller than 0.01 Å, but may also be in the range of 0.1–2 Å, 0.2–1 nm, 1–10 nm, 10–100 nm, 0.1–1 µm, 1–10 µm, 10–100 µm, 0.1–1 mm, 1–10 mm, 10–100 mm, 0.1–1 m, 1–10 m, 10–100 m, 100–1,000 m, or above 1,000 m.

Therefore, the preferred compromise between a large and a low volume of the composite material depends on the context, and may be smaller than 1 nm^3, but may also be in the range of 1–1,000 nm^3, 1,000–1,000,000 nm^3, 0.001–1 μm^3, 1–1,000 μm^3, 1,000–1,000,000 μm^3, 0.001–1 mm^3, 1–1,000 mm^3, 1,000–1,000,000 mm^3, 0.001–1m^3, 1–10 m^3, 10–100 m^3, 100–1,000 m^3, or above 1,000 m^3.

For any characteristics of a composite material mentioned above, and in each characteristic's entire range, a further characteristic of importance is the number of SEs in the composite material.

In many applications, a high number of SEs in a composite material is preferred, as the characteristics of the SE (e.g. high tensional strength) become more pronounced in the composite material. Thus, depending on the context, the total number of SEs in a composite material is preferably greater than 1E+00, such as greater than 1E+01, such as greater than 1E+02, such as greater than 1E+03, such as greater than 1E+04, such as greater than 1E+05, such as greater than 1E+06, such as greater than 1E+07, such as greater than 1E+08, such as greater than 1E+09, such as greater than 1E+10, such as greater than 1E+11, such as greater than 1E+12, such as greater than 1E+13, such as greater than 1E+14, such as greater than 1E+15, such as greater than 1E+16, such as greater than

1E+17, such as greater than 1E+18, such as greater than 1E+19, such as greater than 1E+20.

In other applications, a low number of SEs in a composite material is preferred, as it makes processing of the composite material easier and/or reduces the cost of the final composite material. Thus, depending on the context, the total number of SEs in a composite material is preferably less than 1E+20, such as less than 1E+19, such as less than 1E+18, such as less than 1E+17, such as less than 1E+16, such as less than 1E+15, such as less than 1E+14, such as less than 1E+13, such as less than 1E+12, such as less than 1E+11, such as less than 1E+10, such as less than 1E+09, such as less than 1E+08, such as less than 1E+07, such as less than 1E+06, such as less than 1E+05, such as less than 1E+04, such as less than 1E+03, such as less than 1E+02, such as less than 1E+01, such as less than 2E+00.

Thus, the preferred compromise between a high and a low number of SEs in a composite material depends on the context, and may be smaller than 2, but may also be in the range of 1E+00–1E+01, 1E+01–1E+02, 1E+02–1E+03, 1E+03–1E+04, 1E+04–1E+05, 1E+05–1E+06, 1E+06–1E+07, 1E+07–1E+08, 1E+08–1E+09, 1E+09–1E+10, 1E+10–1E+11, 1E+11–1E+12, 1E+12–1E+13, 1E+13–1E+14, 1E+14–1E+15, 1E+15–1E+16, 1E+16–1E+17, 1E+17–1E+18, 1E+18–1E+19, 1E+19–1E+20, or above 1E+20.

For any characteristics of a composite material mentioned above, and in each characteristic's entire range, a further characteristic of importance is the total weight of the SEs in the composite material.

In many applications, a high total weight of an SE in a composite material is preferred, as the preferred characteristics of the SE (e.g. a high Young's modulus) then become more pronounced in the composite material. Thus, depending on the context, the total weight of SEs in a composite material is preferably greater than 1E-15 kg, such as greater than 1E-14 kg, such as greater than 1E-13 kg, such as greater than 1E-12 kg, such as greater than 1E-11 kg, such as greater than 1E-10 kg, such as greater than 1E-09 kg, such as greater than 1E-08 kg, such as greater than 1E-07 kg, such as greater than 1E-06 kg, such as greater than 1E-05 kg, such as greater than 1E-04 kg, such as greater than 1E-03 kg, such as greater than 1E-02 kg, such as greater than 1E-01 kg, such as greater than 1E+00 kg, such as greater than 1E+01 kg, such as greater than 1E+02 kg, such as greater than 1E+03 kg, such as greater than 1E+04 kg, such as greater than 1E+05 kg, such as greater than 1E+06 kg, such as greater than 1E+07 kg, such as greater than 1E+08 kg, such as greater than 1E+09 kg.

In other applications, a low total weight of an SE in a composite material is preferred, as it reduces the total weight of the composite material. Thus, depending on the context, the total number of SEs in a composite material is preferably less than 1E+09 kg, such as less than 1E+08 kg, such as less than 1E+07 kg, such as less than 1E+06 kg, such as less than 1E+05 kg, such as less than 1E+04 kg, such as less than 1E+03 kg, such as less than 1E+02 kg, such as less than 1E+01 kg, such as less than 1E+00 kg, such as less than 1E-01 kg, such as less than 1E-02 kg, such as less than 1E-03 kg, such as less than 1E-04 kg, such as less than 1E-05 kg, such as less than 1E-06 kg, such as less than 1E-07 kg, such as less than 1E-08 kg, such as less than 1E-09 kg, such as less than 1E-10 kg, such as less than 1E-11 kg, such as less than 1E-12 kg, such as less than 1E-13 kg, such as less than 1E-14 kg, such as less than 1E-15 kg.

Thus, the preferred compromise between a high and a low total weight of an SE in a composite material depends on the context, and may be smaller than 1E-15 kg, but may also be in the range of 1E-15–1E-14 kg, 1E-14–1E-13 kg, 1E-13–1E-12 kg, 1E-12–1E-11 kg, 1E-11–1E-10 kg, 1E-10–1E-09 kg, 1E-09–1E-08 kg, 1E-08–1E-07 kg, 1E-07–1E-06 kg, 1E-06–1E-05 kg, 1E-05–1E-04 kg, 1E-04–1E-03 kg, 1E-03–1E-02 kg, 1E-02–1E-01 kg, 1E-01–1E+00 kg, 1E+00–1E+01 kg, 1E+01–1E+02 kg, 1E+02–1E+03 kg, 1E+03–1E+04 kg, 1E+04–1E+05 kg, 1E+05–1E+06 kg, 1E+06–1E+07 kg, 1E+07–1E+08 kg, 1E+08–1E+09 kg, or above 1E+09 kg.

For any characteristics of a composite material mentioned above, and in each characteristic's entire range, a further characteristic of importance is the total number of CMUs in the composite material.

In many applications, a high number of CMUs in a composite material is preferred, as the characteristics of the CMUs (e.g. high tensional strength) then become more pronounced in the composite material. Thus, depending on the context, the total number of CMUs in a composite material is preferably greater than 1E+00, such as greater than 1E+01, such as greater than 1E+02, such as greater than 1E+03, such as greater than 1E+04, such as greater than 1E+05, such as greater than 1E+06, such as greater than 1E+07, such as greater than 1E+08, such as greater than 1E+09, such as greater than 1E+10, such as greater than 1E+11, such as greater than 1E+12, such as greater than 1E+13, such as greater than 1E+14, such as greater than 1E+15, such as greater than 1E+16, such as greater than 1E+17, such as greater than 1E+18, such as greater than 1E+19, such as greater than 1E+20.

In other applications, a low number of CMUs in a composite material is preferred, as it makes processing of the composite material easier and reduces the cost of the final composite material. Thus, depending on the context, the total number of CMUs in a composite material is preferably less than 1E+20, such as less than 1E+19, such as less than 1E+18, such as less than 1E+17, such as less than 1E+16, such as less than 1E+15, such as less than 1E+14, such as less than 1E+13, such as less than 1E+12, such as less than 1E+11, such as less than 1E+10, such as less than 1E+09, such as less than 1E+08, such as less than 1E+07, such as less than 1E+06, such as less than 1E+05, such as less than 1E+04, such as less than 1E+03, such as less than 1E+02, such as less than 1E+01, such as less than 2E+00.

Thus, the preferred compromise between a high and a low number of CMUs in a composite material depends on the context, and may be smaller than 2, but may also be in the range of 1E+00–1E+01, 1E+01–1E+02, 1E+02–1E+03, 1E+03–1E+04, 1E+04–1E+05, 1E+05–1E+06, 1E+06–1E+07, 1E+07–1E+08, 1E+08–1E+09, 1E+09–1E+10, 1E+10–1E+11, 1E+11–1E+12, 1E+12–1E+13, 1E+13–1E+14, 1E+14–1E+15, 1E+15–1E+16, 1E+16–1E+17, 1E+17–1E+18, 1E+18–1E+19, 1E+19–1E+20, or 1E+20-1E+30.

For any characteristics of a composite material mentioned above, and in each characteristic's entire range, a further characteristic of importance is homogeneity of the composite material.

A material can be homogeneous on a number of levels. Here, homogeneity is defined at the following levels: macroscopic homogeneity (objects ≥ 0.01 m), milliscopic homogeneity (objects 1–10 mm), microscopic homogeneity (objects 1–1,000 µm), nanoscopic homogeneity (objects 1–1,000 nm), and picoscopic homogeneity (objects 1–1,000 pm). For composite materials, homogeneity is here defined as the additive being uniformly dispersed in the composite material as evaluated by the naked eye or microscopy. Composite materials can be homogeneous on the macroscopic, milliscopic, microscopic and nanoscopic level, but not on the picoscopic level, as individual atoms can be visualized at the picoscopic level.

In many applications, the homogeneity of the composite material is an important characteristic, as a homogeneous dispersion of SEs in the composite material results in a better transfer of the properties of the SE (e.g. tensile strength) to the composite material.

Thus, depending on the context, the composite material is preferably homogenous on a level less than the macroscopic level, such as a level less than the milliscopic level, such as a level less than the microscopic level.

In other applications, the homogeneity of the composite material is a less important characteristic, and processing costs can be reduced and a less expensive material produced, if the composite material is less homogeneous. Thus, depending on the context, the composite material is preferably homogenous on a level greater than the nanoscopic level, such as greater than than the microscopic level, such as greater than the milliscopic level, such as greater than the macroscopic level.

Thus, the preferred compromise between a high and a low homogeneity depends on the context, and may be less than on the nanoscopic level, but may also be in the range of the nanoscopic–microscopic level, the microscopic–milliscopic level, the milliscopic–macroscopic level, or above the macroscopic level.

Further characteristics of composite material. For any characteristics of an composite material mentioned above, and in each characteristic's entire range, further characteristics of the composite material that are of importance in the present invention are the stiffness, electrical conductivity, thermal conductivity, color, fluorescence, luminescence, UV protective capability, abrasion resistance, ductility, elasticity, flexibility, energy storage capability (energy storage as heat or kinetic energy), information storage capability, hydrophilicity, hydrophobicity, polarity, aproticity, and charge, as well as the following characteristics where the unit of measure is indicated after each characteristic: Arc Resistance, sec; Impact Strength, Charpy, J/cm; Impact Strength, Izod Notched, J/cm ; Impact Strength, Izod Unnotched, J/cm ; Impact Strength, Charpy Notched Low Temp, J/cm; Impact Strength, Izod Notched Low Temp, J/cm; Impact Strength, Charpy Unnotched Low Temp, J/cm; Impact Strength, Charpy Unnotched, J/cm; Linear Mold Shrinkage, cm/cm; Maximum Service Temperature, Air, ; Melt Flow, g/10 min; Melting Point, ; Modulus of Elasticity, GPa; Moisture Absorption at Equilibrium, % ; Oxygen Transmission, cc-mm/m; Poisson's Ratio; Processing Temperature, ; Surface Resistance, ohm; Tensile Strength, Ultimate, MPa; Tensile Strength, Yield, MPa; Thermal Conductivity, W/m-K; UL RTI, Electrical, ; UL RTI, Mechanical with Impact, ; UL RTI, Mechanical without Impact, ; Vicat Softening Point, ; Water Absorption, %; Coefficient of Friction; Comparative Tracking Index, V; Compressive Yield Strength, MPa; CTE, linear 20; Deflection Temperature at 0.46 MPa, ;

Deflection Temperature at 1.8 MPa, ; Density, g/cc; Dielectric Constant; Dielectric Constant, Low Frequency ; Dielectric Strength, kV/mm; Dissipation Factor; Dissipation Factor, Low Frequency ; Electrical Resistivity, ohm-cm; Elongation @ break, %; Flammability, UL94 ; Flexural Modulus, GPa; Flexural Yield Strength, MPa; Glass Temperature, ; Hardness, Barcol; Hardness, Rockwell E; Hardness, Rockwell M; Hardness, Rockwell R; Hardness, Shore A; Hardness, Shore D; Heat Capacity, J/g.

Depending on the application, a composite material with a low, medium, or high degree of each of these characteristics is preferable in the present invention.

Example Composite Materials.

The CMUs described herein may be used to form composite materials comprising a large number of CMUs.

Structural entities and preferred embodiments.

Polymer and additive. In a preferred embodiment the matrix of a composite material is non-polar. As a result, non-polar additives (e.g. CNT, graphene) will typically integrate more efficiently in the polymer, making the composite material more homogeneous, which is often an advantage, as described above. Polar additives, on the other hand, may in some cases have a strong effect on the electronic and thermal characteristics of the composite material compared to the matrix material without the additive, because of the non-polarity of the matrix and the polarity of the additive. This can be advantageous in certain cases, e.g. when used in sensor applications. A preferred embodiment thus is a composite material where the matrix (SE2) is non-polar and the additive (SE1) is polar. Another preferred embodiment is a composite material where SE1 is non-polar, and the other structural entity of the same CMU is polar (i.e. SE2 is polar).

Nanosensor. The remarkable sensitivity of carbon nanotube or graphene properties (e.g. carbon nanotube conductivity) to the surface adsorbates permits the use of carbon nanotubes and grapheme as highly sensitive sensors.

In a preferred embodiment, one of the structural entities of a CMU comprises an entity chosen from the list of

nucleic acid, single-stranded DNA, double-stranded DNA, protein, antibody, enzyme, receptor, where each entity may be attached to another entity chosen from the list comprising carbon nanotube, single-walled carbon nanotube, multi-walled carbon nanotube,

graphene, single layer graphene, multi-layer graphene, or graphene oxide. If a CMU comprises e.g. a structural entity SE1 (e.g. an antibody) that binds to a molecule X, and if the other structural entity SE2 is e.g. a conducting CNT, the CMU may be used as a nanosensor for the detection of molecule X.

CNT-reinforced polymer. In a preferred embodiment, one of the structural entities of a CMU is a polymer and the other structural entity of the same CMU is an additive providing increased strength to the composite material made of the CMUs, compared to the material that does not contain the additive. In a preferred embodiment of said embodiment the precursor-ML, ML, or Ligand2 attaching the additive to the linker is capable of non-covalently binding said additive. In a preferred embodiment of said embodiment the additive is a carbon nanotube.

Mixed polymer composite material. In some circumstances it may be desirable to mix two or more polymers. In one preferred embodiment, SE1 represents a molecule of one kind of polymer and SE2 represents a molecule of another kind of polymer. As an example, SE1 may be PVC and SE2 may be polycarbamate. In another preferred embodiment, SE1 represents a polymer molecule and SE2 is an additive, and the composite material additionally comprises one or more polymer types different from SE1.

In a preferred embodiment, the CMU comprises two structural entities SE1 and SE2, where SE1 is an additive of high strength, and SE2 is a polymer and part of the matrix material in a composite material. Ligand2 comprises a large number of SubLigands, such as 4, 5, 6 or more Subligands, where the dissociation constant of the individual SubLigands is relatively high, such as in the range between 10^{-10}-10^{-2} M. Such relatively weak interactions of the individual SubLigand with SE2, e.g. in a setting where a large number of serially connected SubLigands can interact with SE2, will provide a very high degree of flexibility and self-healing to a composite material made of such CMUs.

In another preferred embodiment, the CMU comprises two structural entities SE1 and SE2, where SE1 is an additive of high strength, and SE2 is a polymer and part of the matrix material in a composite material. The Ligand2-SE2 interaction is covalent.

In a preferred embodiment, SE1 and SE2 are both a carbon nanotube, and the linker connecting SE1 and SE2 is of a length between 0.1 nm and 10 nm. In a preferred embodiment, the composite material is a material made up of a large number of CMUs, each of which comprise two structural entities SE, both of which are carbon nanotubes, and

Ligand2 is either mechanically bound to a carbon nanotube or is non-covalently bound to a carbon nanotube. The linker is relatively short, such as e.g. between 1 and 10 nm. The material is essentially a tight aggregate of carbon nanotubes. As a result, the material is of high strength.

In another preferred embodiment, SE1 and SE2 are both graphene, and the linker connecting SE1 and SE2 is of a length between 0.1 nm and 10 nm. The resulting CMU will have higher strength than each of the two individual graphenes.

In a preferred embodiment, a composite material comprises more than one kind of CMUs. For example, if the composite material is intended to function as a glue between two surfaces, it may be desirable to have one kind of CMU (e.g. made up of a polymer (SE1) and a strengthening additive such as graphene (SE2) that is the core of a reinforced polymer that does not easily break apart, and another kind of CMU (e.g. comprising the same polymer (SE1) but a third structural entity (SE3) that is part of the two surfaces that must be glued together.

Carbon nanotube-reinforced ceramics

Ceramics cover a wide range of materials, including structural materials and technical ceramics. Concrete and piezoelectric materials are prototypical ceramics. Ceramics are usually defined as solids with a mixture of metallic or semi-metallic and non-metallic elements (often, although not always, oxygen), and they are often quite hard, non-conducting and corrosion-resistant.

Concrete is the most widely used construction material, which among other things comprises silicates. Concrete is produced by mixing cement with sand and water and adding aggregates. Other ingredients in the concrete are termed admixtures, for example air and water reducers such as superplasticizers. An example of a superplasticizer is Mapai, Dynamon SP1. Retarders and accelerators are other useful admixtures. Another ingredient in many concrete mixtures is supplementary cementitious materials also called pozzolans. These materials include fly ash, slag cement (sometimes called ground granulated blast furnace slag or slag cement), silica fume, and metakaolin. Supplementary cementitious materials are used as replacement for cement and since they have a very small particle size they reduce the permeability of concrete.

The relative amount of the water and cement is one of the key parameters that determines the strength of concrete – a lower water-to-cement ratio gives higher strength but at the expense of a higher viscosity.

Addition of fillers such as fullerenes, e.g. CNTs, to concrete in the form of linker units (LUs) or composite material units (CMUs) according to the present invention may help disperse the CNTs more efficiently, and increase the strength of the concrete.

In a preferred embodiment, SE1 or SE2 is a silicate, superplastiziser (e.g. Mapai, Dynamon SP1), a retarder, an accelerator, a pozzolan, or metakaolin, and optionally, SE1 is a carbon nanotube or graphene. In said preferred embodiment, the water-to-cement ratio is preferably lower than 0,01; more preferably between 0,01 and 0,1; more preferably between 0,1 and 0,2; more preferably between 0,2 and 0,3; more preferably between 0,3 and 0,5; more preferably between 0,5 and 1; more preferably between 1 and 2; more preferably between 2 and 5; or even more preferably between 5 and 10.

AA. Nanotube composites without nanotube aggregates.

Formation of nanotube-ML complexes can lead to efficient dispersion of the nanotubes, even when otherwise strongly agglomerating carbon nanotubes are employed. Many of the Examples of this patent application show that nanotube aggregates can be dissolved and a major fraction of the nanotubes be coated with MLs and in this way composites can be made where nanotube aggregates are not detectable. One such example is Example A20 (and the related Examples A1-A32, including analyses of the formed composite), but many of the examples of this patent application show that nanotube aggregates are minute or undetectable, even by high resolution electron microcopy (**Examples……**).

When producing composites, it is in most cases desirable to keep the ML complexed with the nanotube, and in this way avoid a potential reaggregation of the nanotubes. However, in certain cases, such as e.g. if a heat conductive or electrically conductive composite is sought, it may be desirable to remove some or all of the MLs from the nanotubes after the nanotubes have been efficiently dispersed by complexing with the MLs, as this may improve electrical conductivity and especially heat conductivity. This may be done by e.g. cleaving the ML with UV light, hydrolysis, reduction, or any other means that will strip the nanotube for its complexed MLs.

Cleavable precursor-MLs and MLs can be designed in many different ways. Below some of these are shown, along with general procedures for their cleavage:

- Heat-cleavable ML. The precursor-ML may be designed to contain a heat-cleavable moiety that will become part of the closed ring of the ML. Then, after formation of the ML-nanotube complexes and the resulting dispersion of the ML-nanotube in the preparation or final composite material, the ML may be cleaved by heating the composite material and/or applying an electrical current through the composite material and/or subjecting the composite material to a magnetic field, leaving the pristine (naked) nanotube without any MLs complexed to it. UV-cleavable ML. The precursor-ML may be designed to contain a UV-cleavable moiety that will become part of the closed ring of the ML. Then, after formation of the ML-nanotube complexes and the resulting dispersion of the ML-nanotube in the preparation or final composite material, the ML may be cleaved by UV-light, leaving the pristine (naked) nanotube without any MLs complexed to it.
- ML with cleavable disulfide bond. The precursor-ML may be designed to contain a disulfide moiety that will become part of the closed ring of the ML. Then, after formation of the ML-nanotube complexes and the resulting dispersion of the ML-nanotube in the preparation or final composite material, the ML may be cleaved by addition of DTT and reduction of the disulfide bond, leaving the pristine (naked) nanotube without any MLs complexed to it.
- ML with hydrolysable ester bond. The precursor-ML may be designed to contain an ester moiety that will become part of the closed ring of the ML. Then, after formation of the ML-nanotube complexes and the resulting dispersion of the ML-nanotube in the preparation or final composite material, the ML may be cleaved by addition of strong base or strong acid and water, by hydrolysis of the ester bond, leaving the pristine (naked) nanotube without any MLs complexed to it.
- ML with dynamic covalent bond. The precursor-ML may be designed to contain a dynamic covalent bond that will become part of the closed ring of the ML. Then, after formation of the ML-nanotube complexes and the resulting dispersion of the ML-nanotube in the preparation or final composite material, the ML may be cleaved by addition of reagents that form a covalent bond with the dynamic covalent bond of the ring, thereby cleaving the ML, leaving the pristine (naked) nanotube without any MLs complexed to it. An example of such dynamic covalent bond is the ring-closing double bond formed by ring-closing metathesis of two double bonds, using Grubb's second generation catalyst, as applied in many of the Examples of this patent application. Addition of a large excess (relative to the amount of MLs) of appropriate compounds carrying double bonds, and addition of e.g. Grubb's second generation catalyst, will lead to reaction of the added reagents with the double bond of the ML, thereby leading to its cleavage, thereby leaving the pristine (naked) nanotube without any MLs complexed to it.

As described above, in some cases it is desirable to keep the MLs complexed to and wrapped around the nanotube, and therefore to produce composites with no nanotube aggregates or at least small nanotube aggregates, where in the composites the MLs are complexed to the nanotube.

Thus, in a preferred embodiment of the invention a preparation of nanotubes or a collection of CMUs or a composite material comprises nanotubes of an average length larger than 10 nm, and at a concentration of at least 0,01 w/w% nanotube, where each nanotube is

complexed to one or more MLs, and where the composite has a volume of at least 100 nm^3, and does not comprise any nanotube aggregate with smallest dimension larger than 3 nm.

In other cases it is desirable to remove the MLs from the nanotubes after the nanotubes have been dispersed.

Thus, in a preferred embodiment of the invention a

A composite material comprising nanotubes is also provided, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 1 mm.

What is further provided is a means for the efficient anchoring of nanotubes, in particular carbon nanotubes, in composite materials.

What is further provided is a means for applying the invention to industrial production of products made from composite materials, including minimizing the presence of nanotube aggregates at high nanotube concentration; and improving the dispersion of commercial preparations of nanotubes, comprising many different nanotube species.

The composite material preferably does not comprise any nanotube aggregates having a smallest dimension larger than 1 mm, such as larger than 0.1 mm, such as larger than 0.01 mm, such as larger than 1 µm, such as larger than 0.1 µm, such as larger than 0.01 µm, such as larger than 2 nm.

Further provided is a composite material, having a volume of more than 50 nm^3 and comprising more than 0.01 w/w % nanotubes.

Further provided is a composite material, having a volume of more than 50 nm^3 and comprising more than 0.01 w/w % nanotubes, such as 0.01-0.1 w/w%, or 0.1-1 w/w%, or 2-3 w/w%, or 4-5 w/w%, or 5-10 w/w%, or 10-15 w/w%, or 15-20 w/w%, or 20-25 w/w%, or 25-30 w/w%, or 30-35 w/w%, or 35-40 w/w%, or 40-50 w/w%, or 50-60 w/w%, or 60-70 w/w%, or 60-80 w/w%, or 80-99.99 w/w%.

Further provided is a composite material, wherein the composite material has a mass of more than 10^{-15} g, such as more than 10^{-14} g, such as more than 10^{-13} g, such as more than 10^{-11} g, such as more than 10^{-10} g, such as more than 10^{-9} g, such as more than 10^{-8} g, such as more than 10^{-7} g, such as more than 10^{-6} g, such as more than 10^{-5} g, such as more than 10^{-4} g, such as more than 10^{-3} g, such as more than 10^{-2} g, such as more than 0.1 g, such as

more than 1 g, such as more than 10 g, such as more than 100 g, such as more than 1 kg, such as more than 10 kg, such as more than 100 kg, such as more than 1000 kg, such as more than 10,000 kg; and/or

wherein the nanotube concentration is 0.01-0.1 w/w%, or 0.1-1 w/w%, or 2-3 w/w%, or 4-5 w/w%, or 5-10 w/w%, or 10-15 w/w%, or 15-20 w/w%, or 20-25 w/w%, or 25-30 w/w%, or 30-35 w/w%, or 35-40 w/w%, or 40-50 w/w%, or 50-60 w/w%, or 60-70 w/w%, or 60-80 w/w%, or 80-99.99 w/w%; and/or

where the nanotubes have an average length of at least 10 nm, such as at least 20 nm, such as at least 50 nm, such as at least 100 nm, such as at least 300 nm, such as at least 500 nm, such as at least 1 μm, or such as at least 20 μm.

Further provided is a composite material, having a volume of at least 100 nm^3, such as at least 300 nm^3, such as at least 1000 nm^3, such as at least 10000 nm^3, such as at least 100000 nm^3, such as at least 100000 nm^3, such as at least 1000000 nm^3, such as at least 10000000 nm^3, such as at least 100000000 nm^3, such as at least 1000000000 nm^3, such as at least 10 μm^3, such as at least 100 μm^3, such as at least 1000 μm^3, such as at least 10000 μm^3, such as at least 100000 μm^3, such as at least 1000000 μm^3, such as at least 10000000 μm^3, such as at least 100000000 μm^3, such as at least 1 mm^3, or such as at least 10 mm^3.

Further provided is a composite material, wherein a nanotube is complexed to a mechanical ligand that is a closed ring structure, and where the mechanical ligand comprises any of the following chemical moieties: hydroxyl, thiol, phenyl or other aromatic moiety.

Further provided is a composite material, comprising a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 0.3 and 0.6 nm, and the closed ring molecule comprises 10-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 0.6 and 0.7 nm, and the closed ring molecule comprises 15-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 0.7 and 0.8 nm, and the closed ring molecule comprises 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 0.8 and 0.9 nm, and the closed ring molecule comprises 25-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 1.0 and 1.2 nm, and the closed ring molecule comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 1.2 and 1.4 nm, and the closed ring molecule comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 1.4 and 1.7 nm, and the closed ring molecule comprises 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 1.7 and 2.0 nm, and the closed ring molecule comprises 50-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 2.0 and 2.5 nm, and the closed ring molecule comprises 60-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In the composite material described herein, the composite material may additionally comprise a polymer chosen from: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS,

PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

Further provided is a composite material, wherein at least one of said one or more mechanical ligands is bonded to a polymer chain, preferably a polymer chosen from: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In one aspect of the composite material, the nanotubes are selected from carbon nanotube, multiwall, single-wall, or double-wall nanotubes, or mixtures thereof.

In a further aspect of the composite material, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 10-15 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

Suitably, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 15-25 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 25-40 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 40-70 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 70-99,99 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 10-25 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 10-25 w/w%; and wherein the composite material has a volume of at least 10 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 10-25 w/w%; and wherein the composite material has a volume of at least 100 μm^3.

In a further aspect, said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.01 µm, wherein the nanotube concentration is 10-25 w/w%; and wherein the composite material has a volume of at least 10 μm^3.

BB. Composite materials comprising nanotube-ML complexes involving several different types of nanotubes.

As described elsewhere herein mechanical ligands (MLs) may be designed to efficiently bind a specific nanotube, thereby improving the dispersion and anchoring of the nanotube in the matrix. However, many different forms of nanotubes (e.g. nanotubes of different element compositions, chiralities, structures, and diameters) are produced under the manufacturing conditions used today. As an example, Tuballs is a product manufactured by OCSiAl. The Tuballs product contains carbon nanotubes with of many different chiralities and diameters.

Using Tuballs or other sources of carbon nanotubes that contain multiple forms of the nanotube will lead to composite materials with sub-optimal characteristics, unless MLs are designed so that they can interact and from mechanical bonds with most of the different

carbon nanotubes present in the composite. In other words, in some cases the final composite material should ideally contain many different mechanical ligand structures, capable of forming mechanical bonds with virtually all of the carbon nanotubes of that material. Or alternatively, the MLs and/or precursor MLs should be designed in a way that allows one ML to bind several different types of carbon nanotubes with different chiralities and/or diameter.

Preparations of nanotubes typically comprise many different types of nanotubes. These may have different diameter, chirality, content of elements, etc. This is particularly relevant for commercial nanotube products where focus is more on volume than purity. One such example is Tuballs carbon nanotube products, from OCSiAl. This carbon nanotube product is one of a few products that is currently being produced to industrial scale, i.e. approximately 100 tons produced per year. In the Tuballs product, one carbon nanotube chirality is dominant, but more than 10 different carbon nanotube chiralities are present in the Tuballs product in significant amounts. Being able to form ML-nanotube complexes of e.g. these 11 different nanotube chiralities, rather than just one of them, could increase the reinforcement dramatically, e.g. 10-100 fold, or more.

When a nanotube preparation is used as filler to reinforce a polymer or other type of matrix (e.g. ceramics, metal), it is important to efficiently disperse and anchor most of the nanotubes, and not just one or a few – in order to achieve a high reinforcement. In the present invention, efficient dispersion and anchoring is achieved by the binding of MLs to the nanotube, allowing for efficient covalent or non-covalent interaction between the ML and the matrix material, or between the (individualized) nanotube and the matrix material. Thus, efficient dispersion and anchoring requires ML-nanotube complex formation, and in order to obtain efficient reinforcement of the nanotube composite material it thus is important that a major fraction of the types of nanotubes are complexed to MLs.

By appropriate design of the precursor-MLs and resulting MLs, it is possible to, in the same composite material, obtain more than one type of nanotube that have been complexed with one or more MLs. An example of this is shown in Example JJ36-JJ38, where in the same carbon nanotube preparation SWNTs and DWNTs of different outer diameters, were identified.

In a preferred embodiment, the invention allows mechanical ligand formation with nanotubes of different diameter and different chirality, in the same composite material sample, thereby enabling efficient dispersion and efficient anchoring of these several different nanotubes.

In order to efficiently disperse and anchor several different nanotubes with different diameters and chirality, the affinity of the precursor-ML for the nanotube, the final ring length (number of atoms in the ring that forms around the given nanotube), the tendency to form dimers, trimers and multimers in solution or in the solid or molten matrix, the tendency to form dimers, trimer and multimers when bound to the nanotube, must be adjusted relatively and absolutely.

Thus, in a preferred embodiment a composite material is provided, said composite material comprising at least a first and at least a second carbon nanotube, where the outer diameter

of the second nanotube is more than 0.1 nm greater than the outer diameter of the first nanotube, and wherein said first and said second nanotubes are each complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a third carbon nanotube, where the outer diameter of the third nanotube is more than 0.1 nm greater than the outer diameter of the second nanotube, and wherein said first, second and said third nanotubes are each complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a fourth carbon nanotube, where the outer diameter of the fourth nanotube is more than 0.1 nm greater than the outer diameter of the third nanotube, and wherein said first, second, third and fourth nanotubes are complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a fifth carbon nanotube, where the outer diameter of the fifth nanotube is more than 0.1 nm greater than the outer diameter of the fourth nanotube, and wherein said first, second, third, fourth and fifth nanotubes are complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a sixth carbon nanotube, where the outer diameter of the sixth nanotube is more than 0.1 nm greater than the outer diameter of the fifth nanotube, and wherein said first, second, third, fourth, fifth and sixth nanotubes are complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a seventh carbon nanotube, where the outer diameter of the seventh nanotube is more than 0.1 nm greater than the outer diameter of the sixth nanotube, and wherein said first, second, third, fourth, fifth, sixth and seventh nanotubes are complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a eighth carbon nanotube, where the outer diameter of the eighth nanotube is more than 0.1 nm greater than the outer diameter of the seventh nanotube, and wherein said first, second, third, fourth, fifth, sixth, seventh and eighth nanotubes are complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a ninth carbon nanotube, where the outer diameter of the ninth nanotube is more than 0.1 nm greater than the outer diameter of the eighth nanotube, and wherein said first, second, third, fourth, fifth, sixth, seventh, eighth and ninth nanotubes are complexed with mechanical ligands.

Further provided is a composite material, said composite material further comprising at least a tenth carbon nanotube, where the outer diameter of the tenth nanotube is more than 0.1 nm greater than the outer diameter of the ninth nanotube, and wherein said first, second, third, fourth, fifth, sixth, seventh, eighth, ninth and tenth nanotubes are complexed with mechanical ligands.

In another preferred embodiment of the invention a composite material comprises two or more nanotube-ML complexes where the two or more nanotubes comprise significantly different ratios of two elements ("significantly different ratios of two elements" shall in this paragraph mean that the ratios are at least 10% different), such as 2 or more nanotubes comprising significantly different ratios of two elements where the 2 or more nanotubes are all complexed with MLs, such as 3 or more nanotubes comprising significantly different ratios of two elements where the 3 or more nanotubes are all complexed with MLs, such as 4 or more nanotubes comprising significantly different ratios of two elements where the 4 or more nanotubes are all complexed with MLs, such as 5 or more nanotubes comprising significantly different ratios of two elements where the 5 or more nanotubes are all complexed with MLs.

In another preferred embodiment of the invention a composite material comprises two or more nanotube-ML complexes where the two or more nanotubes comprise significantly different ratios of three elements ("significantly different ratios of two elements" shall in this paragraph mean that the ratios are at least 10% different), such as 2 or more nanotubes comprising significantly different ratios of three elements where the 2 or more nanotubes are all complexed with MLs, such as 3 or more nanotubes comprising significantly different ratios of three elements where the 3 or more nanotubes are all complexed with MLs, such as 4 or more nanotubes comprising significantly different ratios of three elements where the 4 or more nanotubes are all complexed with MLs, such as 5 or more nanotubes comprising significantly different ratios of three elements where the 5 or more nanotubes are all complexed with MLs.

In another preferred embodiment of the invention a composite material comprises two or more nanotube-ML complexes where the two or more nanotubes each comprise the element carbon but also each comprise an additional element that is different in the two or more nanotubes, such as 2 or more nanotubes each comprising carbon but each additionally comprising different elements and where all the nanotubes are complexed with MLs, such as

3 or more nanotubes each comprising carbon but each additionally comprising different elements and where all the nanotubes are complexed with MLs, such as 4 or more nanotubes each comprising carbon but each additionally comprising different elements and where all the nanotubes are complexed with MLs.

CC. Non-covalent linkage of polymer to nanotube-ML complex.

In most cases a strong interaction between the nanotube-ML complex and the polymer is desired. A strong interaction between polymer and nanotube-ML complex may improve the quality of the composite material in several ways: i) it may help disperse the nanotube-ML complexes more efficiently during e.g. shear mixing, because the polymer will function as a handle that pulls one nanotube-ML complex from another nanotube-ML complex, ii) it may increase the anchoring efficiency in the matrix, thereby iii) increasing e.g. the tensile strength of the final product.

In some cases, a weak interaction between the nanotube-ML complex and the matrix (polymer) and hence low strength (e.g. high Young's modulus) is desired. This is the case for leading edge coating of wind turbine blades. Coatings for leading edge protection are typically based on elastomers, as a soft (flexible) outer coating of the wind turbine blade is desired. A major issue for such leading edge coatings is the impact fatigue generated by the continuous impact of rain drops on the leading edge during rainfall, particularly with big wind turbines where the wing tip speed approaches 300 km/h. Impact by rain drops generates very small cracks that may propagate and eventually lead to major damage of the leading edge of the blade. It is desirable to limit crack propagation by inclusion of a high concentration of (well-dispersed) nanotubes, as the numerous nanotubes would then serve as stopping blocks for crack propagation.

Thus, ideally, to make a good leading edge coating one would want to add a high concentration of nanotubes to the commercial polyurethane coating (in order to limit crack propagation) but at the same time ensure a very weak interaction between the nanotube-ML complexes and the polymer, so that the anchoring of the nanotubes would be poor and hence the strength (particularly Young's Modulus) would not increase much relative to the commercially available PU coating.

In one embodiment of the invention, a composite material comprises a number of nanotubes, some or all of which are complexed to one or more mechanical ligands (MLs), and a polymer matrix consisting of individual polymer molecules (e.g. linear polyethylene molecules) or a network of crosslinked molecules (e.g. cross-linked epoxy polymer), where neither the nanotube nor the ML is covalently attached to the polymer. In this composite material, the efficiency of anchoring of the nanotubes in the matrix depends on a number of factors, including i) strength of direct non-covalent bonds between nanotube and polymer, ii)

strength of direct non-covalent bonds between ML and polymer, and iii) number of MLs per nanotube. The number of MLs can affect the anchoring efficiency by e.g. providing attracting or repulsive forces between the ML and the polymer, but may also affect the direct interaction between nanotube and polymer by masking the surface of the nanotubes so that it cannot directly and non-covalently interact with the polymer.

As described above, in most cases the anchoring efficiency of the nanotubes in the matrix is desired to be high, but in some cases is desired to be low. These anchoring efficiencies may be reached by designing strong or weak or repulsive non-covalent bonds between the nanotube and the polymer; by designing strong or weak or repulsive non-covalent bonds between the ML and the polymer; and by tuning the number of MLs per nanotube.

As an example of a relatively strong interaction, two aromatic molecules (e.g. two phenyls) would interact relatively strongly and non-covalently. One aromatic entity could be attached to an ML complexed to a nanotube, the other aromatic entity could be part of the polymer – then the polymer and nanotube would be non-covalently attached to each other through one relatively strong bond.

As an example of a medium strength interaction, two small hydrophobic molecules (e.g. methyl groups or ethyl groups) could non-covalently bind to each other. As an example, a methyl group carried by an ML complexed to a nanotube could interact non-covalently with an ethyl group of a polymer.

As an example of a repulsive interaction, two negatively charged groups (e.g. glutamate and aspartate) would repel each other. As an example, if a polyamide polymer carried a glutamate, and if a ML complexed to a nanotube carried an aspartate, the nanotube and the polymer would repel each other, i.e. the nanotube would be very poorly anchored in the polymer matrix.

As another example of an attractive force between a nanotube and a polymer, the polymer might comprise aromatic groups that could stack on the surface of a carbon nanotube with its sp2-hybridized structure, and hence, non-covalently interact and thereby help to anchor the nanotube in the matrix.

It is thus clear from these examples that the nanotube, the polymer and the ML may be designed in a way so that they either increase or decrease the non-covalent interactions between polymer and nanotube, polymer and ML, or even between ML and nanotube. The nanotube may contain any of these chemical entities, either as a result of its synthesis or as a result of its post-synthesis functionalization.

Appropriate chemical entities for the weak, strong or repulsive non-covalent interaction between nanotube, polymer and/or ML include the following chemical entities (general and specific chemical structures):

<u>General chemical structures:</u>

Aliphatic compound, aromatic compound, alkyl, alkane, alkene, alkyne, cyclic aliphate, cyclic aromate, polycyclic aromate, polycyclic aliphate, bridged cyclic aromate, bridged cyclic aliphate, etc.**

Specific chemical structures:

Thiol, hydroxyl, carbonyl, carboxy anhydride, carboxylic acid, single bond, double bond, triple bond, N=N, azide,etc **

DD. Composite materials comprising pairs of nanotubes and mechanical ligands with matching sizes.

A key component of nanotube composites of the present invention is the nanotube-mechanical ligand (nanotube-ML) complex. The efficiency of nanotube-ML formation and the load transfer that may be achieved by using nanotube-ML complexes as fillers in composites, is dependent on the structure of the nanotube as well as of the precursor-ML and the ML, but the relative size of nanotube and ML (e.g. the circumference of the nanotube relative to the number of atoms in the closed-ring molecule) is also of significant importance.

A ML-nanotube complex is provided, comprising at least two mechanical ligands (ML) complexed to a single nanotube, and wherein said at least two mechanical ligands are covalently linked to one another.

Formation of the ML-nanotube complex. For efficient formation of an ML complexed to the nanotube, the precursor-ML must be able to non-covalently interact with the nanotube, ideally with several parts of the precursor-ML, and at the same time the interaction should be reversible enough that the termini of the precursor-ML with reasonable probability will encounter each other and react, and thereby form a ML. The precursor-ML should not be too tightly bound or the ML too tightly wrapped around the nanotube, as this will make the termini of the precursor-ML less likely to get into reactive distance of each other. At the same time, the termini should not be separated by a linker that is so long that the two ends for this reason have a low likelihood of getting into reactive distance of each other. In other words, the precursor-ML should be large enough to provide structural flexibility, but at the same time be small enough to maximize the chance of a productive encounter between the reactive groups on the termini.

Thus, in a preferred embodiment the precursor-ML is of an appropriate structure so that the ML resulting from ring-closing of the precursor-ML around the nanotube will have an appropriate number of atoms in its closed-ring structure allowing it to efficiently wrap around the nanotube without being too strained.

Optimal characteristics of the nanotube-ML complex.

Once the closed ring (the ML) has formed around the nanotube, the nanotube-binding moieties of the ML will be non-covalently bound to the surface of the nanotube most of the time, because of the high local concentration of the binding moiety of the ML around the nanotube – where the high local concentration results from the fact that the ML is mechanically bound to the nanotube and therefore constantly held in the vicinity of the nanotube. The smaller the closed ring (i.e. the fewer the atoms in the closed ring), the higher the local concentration of the binding moieties of the ML, and the larger the fraction of the

time the ML will be non-covalently bound to the nanotube. Hence, the smaller the closed ring of the ML, the more restricted the mobility of the ML along the length of the nanotube will be. Such restricted mobility can result in rigidity of the composite material and is therefore often desired.

However, in some cases an initial strain (flexibility) is desired when stress is applied to the composite material. By using a ML with a relatively large closed ring (a relatively large number of atoms in the closed ring) such an initial flexibility will result, both as result of the mechanical binding (that hinders complete dissociation of the ML and the nanotube in a direction away from and perpendicular to the tube), and as a result of the non-covalent binding being established a smaller fraction of the time because the local concentration is lower as compared to the smaller closed ring described above. As a result, the initial movement will be less restricted initially perpendicular to the ring and will be generally less restricted along the length of the nanotube.

Thus, it is possible to design composite materials of different characteristics depending on the relative size of the nanotube (its circumference) and the closed ring (e.g. its number of atoms in the closed ring), and the pairwise combination of nanotube and ML is therefore an important determinant of composite material characteristics.

In a preferred embodiment, the circumference of the nanotube and the number of atoms in the closed ring of the ML that is complexed to the nanotube, are optimized relative to each other, in order to obtain the desired characteristics of the composite material.

Complexation of a pre-closed-ring molecule to a nanotube.

MLs that are complexed to the nanotube near the ends of the nanotube may migrate along the nanotube and fall off the end. In such cases it is advantageous if the matrix comprises pre-formed closed ring molecules that may slide on to the nanotube to form a mechanical ligand wrapped around the nanotube, in place of the ML that fell off the nanotube.

Typically, the higher the concentration of such pre-formed closed rings in the matrix, the higher the likelihood of closed-ring molecules forming nanotube-ML complexes.

The size of the pre-formed closed-ring molecule is of importance for how efficiently the closed-ring molecule may complex with and wrap around the nanotube terminus. The closed-ring molecule should have a closed-ring circumference significantly larger than the circumference of the nanotube, in order to efficiently complex and wrap around the nanotube.

From the above considerations it is clear that the relative sizes of the nanotube's circumference (which is linearly correlated with its outer diameter) and the length of the closed ring of the ML mechanically bound to the nanotube (as measured by the number of atoms in the closed ring) may determine the characteristics of the composite material that the ML-nanotube complex is a part of.

Thus, in a preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 0,3 and 0,6 nm, and the covalently closed ring of the ML bound to said nanotube comprises 10-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 0,6 and 0,7 nm, and the covalently closed ring of the ML bound to said nanotube comprises 15-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 0,7 and 0,8 nm, and the covalently closed ring of the ML bound to said nanotube comprises 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 0,8 and 0,9 nm, and the covalently closed ring of the ML bound to said nanotube comprises 25-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 1 and 1,2 nm, and the covalently closed ring of the ML bound to said nanotube comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 1,2 and 1,4 nm, and the covalently closed ring of the ML bound to said nanotube comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 1,4 and 1,7 nm, and the covalently closed ring of the ML bound to said nanotube comprises 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 1,7 and 2 nm, and the covalently closed ring of the ML bound to said nanotube comprises 50-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 2 and 2,5 nm, and the covalently closed ring of the ML bound to said nanotube comprises 60-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 2,5 and 3 nm, and the covalently closed ring of the ML bound to said nanotube comprises 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 3 and 5 nm, and the covalently closed ring of the ML bound to said nanotube comprises 80-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 5 and 10 nm, and the covalently closed ring of the ML bound to said nanotube comprises 100-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 10 and 20 nm, and the covalently closed ring of the ML bound to said nanotube comprises 100-300 atoms, or 301-500 atoms, or 501-2000 atoms, or 2001-10000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 20 and 40 nm, and the covalently closed ring of the ML bound to said nanotube comprises 301-500 atoms, or 501-2000 atoms, or 2001-10000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 40 and 400 nm, and the covalently closed ring of the ML bound to said nanotube comprises 500-2000 atoms, or 2001-10000 atoms.

From the above consideration it is also clear that in order for a closed ring molecule to associate and bind to a nanotube in a way so that it forms a mechanical bond with the nanotube, and for the resulting ML-nanotube complex to provide the desired characteristics of the composite material within which it resides, the relative sizes of the closed ring and the circumference of the nanotube are important.

From the above considerations it is clear that the relative sizes of the nanotube's circumference (which is linearly correlated with its outer diameter) and the length of the closed ring (as measured by the number of atoms in the closed ring) may determine the characteristics of the composite material that the closed ring and the nanotube is a part of.

Thus, in a preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 0,3 and 0,6 nm,

and the closed ring molecule comprises 10-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 0,6 and 0,7 nm, and the closed ring molecule comprises 15-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 0,7 and 0,8 nm, and the closed ring molecule comprises 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 0,8 and 0,9 nm, and the closed ring molecule comprises 25-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 1 and 1,2 nm, and the closed ring molecule comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 1,2 and 1,4 nm, and the closed ring molecule comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 1,4 and 1,7 nm, and the closed ring molecule comprises 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 1,7 and 2 nm, and the closed ring molecule comprises 50-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 2 and 2,5 nm,

and the closed ring molecule comprises 60-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 2,5 and 3 nm, and the closed ring molecule comprises 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 3 and 5 nm, and the closed ring molecule comprises 80-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 5 and 10 nm, and the closed ring molecule comprises 100-150 atoms, or 151-500 atoms, or 501-5000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 10 and 20 nm, and the closed ring molecule comprises 100-300 atoms, or 301-500 atoms, or 501-2000 atoms, or 2001-10000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 20 and 40 nm, and the closed ring molecule comprises 301-500 atoms, or 501-2000 atoms, or 2001-10000 atoms.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 40 and 400 nm, and the closed ring molecule comprises 500-2000 atoms, or 2001-10000 atoms.

For industrial applications it is often preferred that the composite comprises a polymer, metal, or a ceramic.

Thus, in a preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 0,2 and 0,6 nm, and the covalently closed ring of the ML bound to said nanotube comprises 7-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA,

Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 0,6 and 0,7 nm, and the covalently closed ring of the ML bound to said nanotube comprises 15-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 0,7 and 0,8 nm, and the covalently closed ring of the ML bound to said nanotube comprises 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 0,8 and 0,9 nm, and the covalently closed ring of the ML bound to said nanotube comprises 25-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI),

Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 1 and 1,2 nm, and the covalently closed ring of the ML bound to said nanotube comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 1,2 and 1,4 nm, and the covalently closed ring of the ML bound to said nanotube comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 1,4 and 1,7 nm, and the covalently closed ring of the ML bound to said nanotube comprises 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA,

Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 1,7 and 2 nm, and the covalently closed ring of the ML bound to said nanotube comprises 50-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 2 and 2,5 nm, and the covalently closed ring of the ML bound to said nanotube comprises 60-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 2,5 and 3 nm, and the covalently closed ring of the ML bound to said nanotube comprises 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS),

Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 3 and 5 nm, and the covalently closed ring of the ML bound to said nanotube comprises 80-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 5 and 10 nm, and the covalently closed ring of the ML bound to said nanotube comprises 100-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 10 and 20 nm, and the covalently closed ring of the ML bound to said nanotube comprises 100-300 atoms, or 301-500 atoms, or 501-2000 atoms, or 2001-10000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE),

Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 20 and 40 nm, and the covalently closed ring of the ML bound to said nanotube comprises 301-500 atoms, or 501-2000 atoms, or 2001-10000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube-ML complex where the outer diameter of the nanotube is between 40 and 400 nm, and the covalently closed ring of the ML bound to said nanotube comprises 500-2000 atoms, or 2001-10000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

From the above consideration it is also clear that in order for a closed ring molecule to associate and bind to a nanotube in a way so that it forms a mechanical bond with the nanotube, and for the resulting ML-nanotube complex to provide the desired characteristics of the composite material within which it resides, the relative sizes of the closed ring and the circumference of the nanotube are important, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

From the above considerations it is clear that the relative sizes of the nanotube's circumference (which is linearly correlated with its outer diameter) and the length of the closed ring (as measured by the number of atoms in the closed ring) may determine the characteristics of the composite material that the closed ring and the nanotube is a part of, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

Thus, in a preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 0,2 and 0,6 nm, and the closed ring molecule comprises 7-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 0,6 and 0,7 nm, and the closed ring molecule comprises 15-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 0,7 and 0,8 nm, and the closed ring molecule comprises 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 0,8 and 0,9 nm, and the closed ring molecule comprises 25-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 1 and 1,2 nm, and the closed ring molecule comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide

(PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 1,2 and 1,4 nm, and the closed ring molecule comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 1,4 and 1,7 nm, and the closed ring molecule comprises 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 1,7 and 2 nm, and the closed ring molecule comprises 50-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA,

Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 2 and 2,5 nm, and the closed ring molecule comprises 60-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 2,5 and 3 nm, and the closed ring molecule comprises 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 3 and 5 nm, and the closed ring molecule comprises 80-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 5 and 10 nm, and the closed ring molecule comprises 100-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 10 and 20 nm, and the closed ring molecule comprises 100-300 atoms, or 301-500 atoms, or 501-2000 atoms, or 2001-10000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 20 and 40 nm, and the closed ring molecule comprises 301-500 atoms, or 501-2000 atoms, or 2001-10000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 40 and 400 nm, and the closed ring molecule comprises 500-2000 atoms, or 2001-10000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal,

or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

For high-strength applications, carbon nanotubes are particularly preferred nanotubes.

Thus, in a preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 0,2 and 0,6 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 7-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 0,6 and 0,7 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 15-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 0,7 and 0,8 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 0,8 and 0,9 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 25-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 1 and 1,2 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA,

Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 1,2 and 1,4 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 1,4 and 1,7 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 1,7 and 2 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 50-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone

(PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 2 and 2,5 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 60-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 2,5 and 3 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 3 and 5 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 80-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA,

Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 5 and 10 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 100-150 atoms, or 151-500 atoms, or 501-5000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 10 and 20 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 100-300 atoms, or 301-500 atoms, or 501-2000 atoms, or 2001-10000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 20 and 40 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 301-500 atoms, or 501-2000 atoms, or 2001-10000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

In another preferred embodiment of the invention, a composite comprises a carbon nanotube-ML complex where the outer diameter of the carbon nanotube is between 40 and 400 nm, and the covalently closed ring of the ML bound to said carbon nanotube comprises 500-2000 atoms, or 2001-10000 atoms, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

From the above consideration it is also clear that in order for a closed ring molecule to associate and bind to a carbon nanotube in a way so that it forms a mechanical bond with the carbon nanotube, and for the resulting ML-carbon nanotube complex to provide the desired characteristics of the composite material within which it resides, the relative sizes of the closed ring and the circumference of the carbon nanotube are important, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

From the above considerations it is clear that the relative sizes of the carbon nanotube's circumference (which is linearly correlated with its outer diameter) and the length of the closed ring (as measured by the number of atoms in the closed ring) may determine the characteristics of the composite material that the closed ring and the carbon nanotube is a part of, and where the composite further comprises a polymer, metal, or a ceramic, where said polymer, metal, or ceramic is optionally non-covalently or covalently or mechanically linked to the closed ring, and where the polymer optionally is chosen from the following list of polymers: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

DEMANDE OU BREVET VOLUMINEUX

LA PRÉSENTE PARTIE DE CETTE DEMANDE OU CE BREVET COMPREND PLUS D'UN TOME.

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CLAIMS

1. A composite material comprising nanotubes, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 1 mm.

2. The composite material according to claim 1, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 1 mm, such as larger than 0.1 mm, such as larger than 0.01 mm, such as larger than 1 µm, such as larger than 0.1 µm, such as larger than 0.01 µm, such as larger than 2 nm.

3. The composite material according to any one of the preceding claims, having a volume of more than 50 nm^3 and comprising more than 0.01 w/w % nanotubes.

4. The composite material according to any one of the preceding claims, having a volume of more than 50 nm^3 and comprising more than 0.01 w/w % nanotubes, such as 0.01-0.1 w/w%, or 0.1-1 w/w%, or 2-3 w/w%, or 4-5 w/w%, or 5-10 w/w%, or 10-15 w/w%, or 15-20 w/w%, or 20-25 w/w%, or 25-30 w/w%, or 30-35 w/w%, or 35-40 w/w%, or 40-50 w/w%, or 50-60 w/w%, or 60-70 w/w%, or 60-80 w/w%, or 80-99.99 w/w%.

5. The composite material according to any of the preceding claims, wherein the composite material has a mass of more than 10^{-15} g, such as more than 10^{-14} g, such as more than 10^{-13} g, such as more than 10^{-11} g, such as more than 10^{-10} g, such as more than 10^{-9} g, such as more than 10^{-8} g, such as more than 10^{-7} g, such as more than 10^{-6} g, such as more than 10^{-5} g, such as more than 10^{-4} g, such as more than 10^{-3} g, such as more than 10^{-2} g, such as more than 0.1 g, such as more than 1 g, such as more than 10 g, such as more than 100 g, such as more than 1 kg, such as more than 10 kg, such as more than 100 kg, such as more than 1000 kg, such as more than 10,000 kg; and/or

   wherein the nanotube concentration is 0.01-0.1 w/w%, or 0.1-1 w/w%, or 2-3 w/w%, or 4-5 w/w%, or 5-10 w/w%, or 10-15 w/w%, or 15-20 w/w%, or 20-25 w/w%, or 25-30 w/w%, or 30-35 w/w%, or 35-40 w/w%, or 40-50 w/w%, or 50-60 w/w%, or 60-70 w/w%, or 60-80 w/w%, or 80-99.99 w/w%; and/or

   where the nanotubes have an average length of at least 10 nm, such as at least 20 nm, such as at least 50 nm, such as at least 100 nm, such as at least 300 nm, such as at least 500 nm, such as at least 1 µm, or such as at least 20 µm.

6. The composite material according to any one of the preceding claims, having a volume of at least 100 nm^3, such as at least 300 nm^3, such as at least 1000 nm^3, such as at least 10000 nm^3, such as at least 100000 nm^3, such as at least 100000 nm^3, such as at least 1000000 nm^3, such as at least 10000000 nm^3, such as at least 100000000 nm^3, such as at least 1000000000 nm^3, such as at least 10 μm^3, such as at least 100 μm^3, such as at least 1000 μm^3, such as at least 10000 μm^3, such as at

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least 100000 μm^3, such as at least 1000000 μm^3, such as at least 10000000 μm^3, such as at least 100000000 μm^3, such as at least 1 mm^3, or such as at least 10 mm^3.

7. The composite material according to any one of the preceding claims, said composite material comprising at least a first and at least a second carbon nanotube,

   where the outer diameter of the second nanotube is more than 0.1 nm greater than the outer diameter of the first nanotube,

   and wherein said first and said second nanotubes are each complexed with mechanical ligands.

8. The composite material according to claim 7, said composite material further comprising at least a third carbon nanotube,

   where the outer diameter of the third nanotube is more than 0.1 nm greater than the outer diameter of the second nanotube,

   and wherein said first, second and said third nanotubes are each complexed with mechanical ligands.

9. The composite material according to claim 8, said composite material further comprising at least a fourth carbon nanotube,

   where the outer diameter of the fourth nanotube is more than 0.1 nm greater than the outer diameter of the third nanotube,

   and wherein said first, second, third and fourth nanotubes are complexed with mechanical ligands.

10. The composite material according to claim 9, said composite material further comprising at least a fifth carbon nanotube,

    where the outer diameter of the fifth nanotube is more than 0.1 nm greater than the outer diameter of the fourth nanotube,

    and wherein said first, second, third, fourth and fifth nanotubes are complexed with mechanical ligands.

11. The composite material according to claim 10, said composite material further comprising at least a sixth carbon nanotube,

    where the outer diameter of the sixth nanotube is more than 0.1 nm greater than the outer diameter of the fifth nanotube,

    and wherein said first, second, third, fourth, fifth and sixth nanotubes are complexed with mechanical ligands.

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12. The composite material according to claim 11, said composite material further comprising at least a seventh carbon nanotube,

    where the outer diameter of the seventh nanotube is more than 0.1 nm greater than the outer diameter of the sixth nanotube,

    and wherein said first, second, third, fourth, fifth, sixth and seventh nanotubes are complexed with mechanical ligands.

13. The composite material according to claim 12, said composite material further comprising at least a eighth carbon nanotube,

    where the outer diameter of the eighth nanotube is more than 0.1 nm greater than the outer diameter of the seventh nanotube,

    and wherein said first, second, third, fourth, fifth, sixth, seventh and eighth nanotubes are complexed with mechanical ligands.

14. The composite material according to claim 13, said composite material further comprising at least a ninth carbon nanotube,

    where the outer diameter of the ninth nanotube is more than 0.1 nm greater than the outer diameter of the eighth nanotube,

    and wherein said first, second, third, fourth, fifth, sixth, seventh, eighth and ninth nanotubes are complexed with mechanical ligands.

15. The composite material according to claim 14, said composite material further comprising at least a tenth carbon nanotube,

    where the outer diameter of the tenth nanotube is more than 0.1 nm greater than the outer diameter of the ninth nanotube,

    and wherein said first, second, third, fourth, fifth, sixth, seventh, eighth, ninth and tenth nanotubes are complexed with mechanical ligands.

16. The composite material according to any one of the preceding claims, wherein a nanotube is complexed to a mechanical ligand that is a closed ring structure, and where the mechanical ligand comprises any of the following chemical moieties: hydroxyl, thiol, phenyl or other aromatic moiety.

17. The composite material according to any one of the preceding claims, comprising a nanotube and a closed ring molecule where the outer diameter of the nanotube is between 0.3 and 0.6 nm, and the closed ring molecule comprises 10-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

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where the outer diameter of the nanotube is between 0.6 and 0.7 nm, and the closed ring molecule comprises 15-20 atoms, or 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 0.7 and 0.8 nm, and the closed ring molecule comprises 21-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 0.8 and 0.9 nm, and the closed ring molecule comprises 25-30 atoms, or 31-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 1.0 and 1.2 nm, and the closed ring molecule comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 1.2 and 1.4 nm, and the closed ring molecule comprises 30-40 atoms, or 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 1.4 and 1.7 nm, and the closed ring molecule comprises 41-50 atoms, or 51-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 1.7 and 2.0 nm, and the closed ring molecule comprises 50-60 atoms, or 61-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms; or

where the outer diameter of the nanotube is between 2.0 and 2.5 nm, and the closed ring molecule comprises 60-70 atoms, or 71-80 atoms, or 81-90 atoms, or 91-100 atoms, 101-150 atoms, or 151-500 atoms, or 501-5000 atoms.

18. The composite material according to any one of the preceding claims, wherein the composite material additionally comprises a polymer chosen from: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide

(PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

19. The composite material according to claim 18, wherein at least one of said one or more mechanical ligands is bonded to a polymer chain, preferably a polymer chosen from: PE, LDPE, HDPE, Polypropylene, PVC, PS, EPS, PPS, PU, PUR, Polyamide, Nylon, Epoxy, Polyester, ABS, ASA, SAN, PBS, PBT, PET, PA, Polycarbonate, PU, PUR, UPR, Polymethylpentene (PMP), Polybutene-1 (PB-1), polyisobutylene (PIB), Ethylene propylene rubber (EPR), Vinyl ester, PMMA, Phenolic (PH), Polyphenylene sulfide (PPS), Polyetherimide (PEI), Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK), CA, Cyanate ester (CE), Bismaleimide (BMI), Polyimide (PI), TPE, PBAT, PTT, PHA, PEF, EPDM, PLA, or Ethylene propylene diene monomer (M-class) rubber.

20. The composite material according to any one of the preceding claims, wherein the nanotubes are selected from carbon nanotube, multiwall, single-wall, or double-wall nanotubes, or mixtures thereof.

21. The composite material according to any one of the preceding claims, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 10-15 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

22. The composite material according to any one of the preceding claims, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 15-25 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

23. The composite material according to any one of the preceding claims, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 25-40 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

24. The composite material according to any one of the preceding claims, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 40-70 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

25. The composite material according to any one of the preceding claims, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 70-99,99 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

26. The composite material according to any one of the preceding claims, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 10-25 w/w%; and wherein the composite material has a volume of at least 1 μm^3.

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27. The composite material according to any one of the preceding claims, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 10-25 w/w%; and wherein the composite material has a volume of at least 10 μm^3.

28. The composite material according to any one of the preceding claims, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.1 µm, wherein the nanotube concentration is 10-25 w/w%; and wherein the composite material has a volume of at least 100 μm^3.

29. The composite material according to any one of the preceding claims, wherein said composite material does not comprise any nanotube aggregates having a smallest dimension larger than 0.01 µm, wherein the nanotube concentration is 10-25 w/w%; and wherein the composite material has a volume of at least 10 μm^3.

30. A ML-nanotube complex, comprising at least two mechanical ligands (ML) complexed to a single nanotube, and wherein said at least two mechanical ligands are covalently linked to one another.

31. A material comprising a filler and at least one byproduct.

32. The material according to claim 31, wherein the filler is selected from the group consisting of a nanotube, a carbon nanotube, a multi-wall nanotube, a multi-wall carbon nanotube, a single-wall nanotube, a single-wall carbon nanotube, graphene, a carbon fibre, a carbon nanofibre, a carbon nanothread, nanowire, a ceramic material, a fullerene, graphane, graphene oxide, graphite, graphyne, a COOH-functionalized carbon nanotube, a OH-functionalized carbon nanotube, an NH2-functionalized carbon nanotube, an SH-functionalized carbon nanotube, COOH-functionalized graphene, NH2-functionalized graphene, OH-functionalized graphene, thiol-functionalized graphene, a glass fibre, preferably selected from nanotube, a carbon nanotube, a single-wall carbon nanotube, graphene, and graphene oxide.

33. The material according to any one of claims 31 or 32, wherein the byproduct is selected from H2O, HCl, NaCl, N2, CO2, biphenyl, NC-C(CH3)2-C(CH3)2-CN, NC-C(CH3)(CH2-CH3)-C(CH3)(CH2-CH3)-CN, NC-C(CH3)(CH2-C(CH3)2-O-CH3)-C(CH3)(CH2-C(CH3)2-O-CH3)-CN, preferably selected from H2O, HCl, NaCl, N2, CO2, biphenyl, and NC-C(CH3)2-C(CH3)2-CN.

34. The material according to any one of claims 31 to 33, further comprising a polymer such as polyester, polyamide, polyurethane, polystyrene, polymethyl methacrylate, polyacrylate, polyacrylonitrile.

35. A method for preparing a composite material, said method comprising:
    a) Provide a SE1;
    b) Provide a precursor-ML;
    c) Optionally, provide a catalyst;
    to generate a SE1-ML structure;

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wherein steps a) to c) may be performed in any order.

36. The method according to claim 35, further comprising:
d) Provide a SE2
To generate a SE1-ML-SE2 structure:
Wherein steps a) to d) may be performed in any order.

37. The method according to claim 36, the method comprising:
i) Provide a precursor-ML;
ii) Provide a SE1, to form a SE1-precursor ML complex;
iii) The precursor-ML is turned into a ML, mechanically bound to the SE1, optionally by the addition of catalyst and/or reagent(s);
iv) Provide a SE2 and covalently or non-covalently link it to the ML, optionally by the addition of catalyst and/or reagent(s);
to form a SE1-ML-SE2 structure.

38. The method according to claim 36, the method comprising:
i) Provide a precursor-ML;
ii) Provide a SE2, and attach one or more precursor-ML to SE2;
iii) Provide a SE1, and allow complexation to form a SE1-precursor-ML-SE2 complex;
iv) Convert the precursor-ML to a ML, mechanically bound to SE1;
to form a SE1-ML-SE2 complex.

39. The method according to claim 36, the method comprising:
i) Provide a precursor-ML and a portion of SE2, and associate or react said two components to form a precursor-ML-portion of SE2 structure;
ii) Provide a SE1 and allow SE1-precursor-ML complex formation;
iii) Turn the precursor-ML into a ML, to form a SE1-ML-portion of SE2 structure;
iv) Allow reaction of the portions of SE2 with each other;
to form a SE1-ML-SE2 structure.

40. The method according to claim 36, the method comprising:
i) Provide a precursor-ML and a portion of SE2, and associate or react said two components to form a precursor-ML-portion of SE2 structure;
ii) Provide a SE1 and allow SE1-precursor-ML-portion of SE2 complex formation;
iii) Allow reaction between portions of SE2, attached to precursor-MLs, to form the SE1-precursor-ML-SE2 structure;
iv) Convert the precursor-ML into a ML;
to form a SE1-ML-SE2 complex.

41. The method according to claim 36, the method comprising:
i) Provide a precursor-ML and a portion of SE2, and associate or react said two components to form a precursor-ML-portion of SE2 structure;
ii) Provide a SE1 and allow SE1-precursor-ML-portion of SE2 complex formation;
iii) Allow conversion of the precursor-ML to a ML and formation of a SE2 from portions of SE2;
to form a SE1-ML-SE2 complex.

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42. The method according to claim 36, the method comprising:
i) Provide a SE1, a precursor-ML carrying a polymerization terminator (PT), and optionally a catalyst capable of mediating the conversion of precursor-ML into ML, and a monomer, leading to formation of the SE1-ML complex, where the ML carries a polymerization terminator (PT).
ii) Optionally, provide a catalyst;
iii) Polymerization proceeds to form a polymer in solution;
iv) The growing polymer eventually terminates its polymerization on the polymerization terminator, thereby forming a SE1-ML-SE2 structure in which one ML is attached to one polymer.

43. The method according to claim 36, the method comprising:
i) Provide a SE1, a precursor-ML carrying a first reactive group, and optionally a catalyst capable of mediating the conversion of precursor-ML into ML, and monomers, leading to formation of the SE1-ML complex, where the ML carries the first reactive group.
ii) Optionally, provide a catalyst;
iii) Polymerization proceeds to form a polymer in solution, where the polymer carries a second reactive group capable of reacting with the first reactive group;
iv) Optionally, provide a catalyst and/or reagent(s);
v) The second reactive group of the polymer is brought to react with the first reactive group of the ML;
to form a SE1-ML-SE2 structure.

44. The method according to any one of claims 35 to 43, the method further comprising an additional step of dissociating the SE1-ML complex into a SE1 and a ML;
to obtain a composite material comprising ML, non-ML-complexed SE1 and, if applicable, SE2.

45. The method according to any one of claim 35-44, wherein SE1 is selected from the group consisting of nanotube, a carbon nanotube, a multi-wall nanotube, a multi-wall carbon nanotube, a single-wall nanotube, a single-wall carbon nanotube, graphene, a carbon fibre, a carbon nanofibre, a carbon nanothread, nanowire, a ceramic material, a fullerene, graphane, graphene oxide, graphite, graphyne, a COOH-functionalized carbon nanotube, a OH-functionalized carbon nanotube, an NH2-functionalized carbon nanotube, an SH-functionalized carbon nanotube, COOH-functionalized graphene, NH2-functionalized graphene, OH-functionalized graphene, thiol-functionalized graphene, a glass fibre, preferably selected from nanotube, a carbon nanotube, a single-wall carbon nanotube, graphene, and graphene oxide.

46. The method according to any one of claim 35-45, wherein precursor-ML is selected from the group consisting of a chemical structure comprising one or two or more chemical moieties with affinity for the SE1, such as a Ushape or another chemical entity comprising at least one ligand moiety with affinity for the SE1.

47. The method according to any one of claim 36-46, wherein SE2 is selected from the group consisting of polyester, polyamide, polyurethane, polystyrene, polymethyl methacrylate, polyacrylate, polyacrylonitrile.

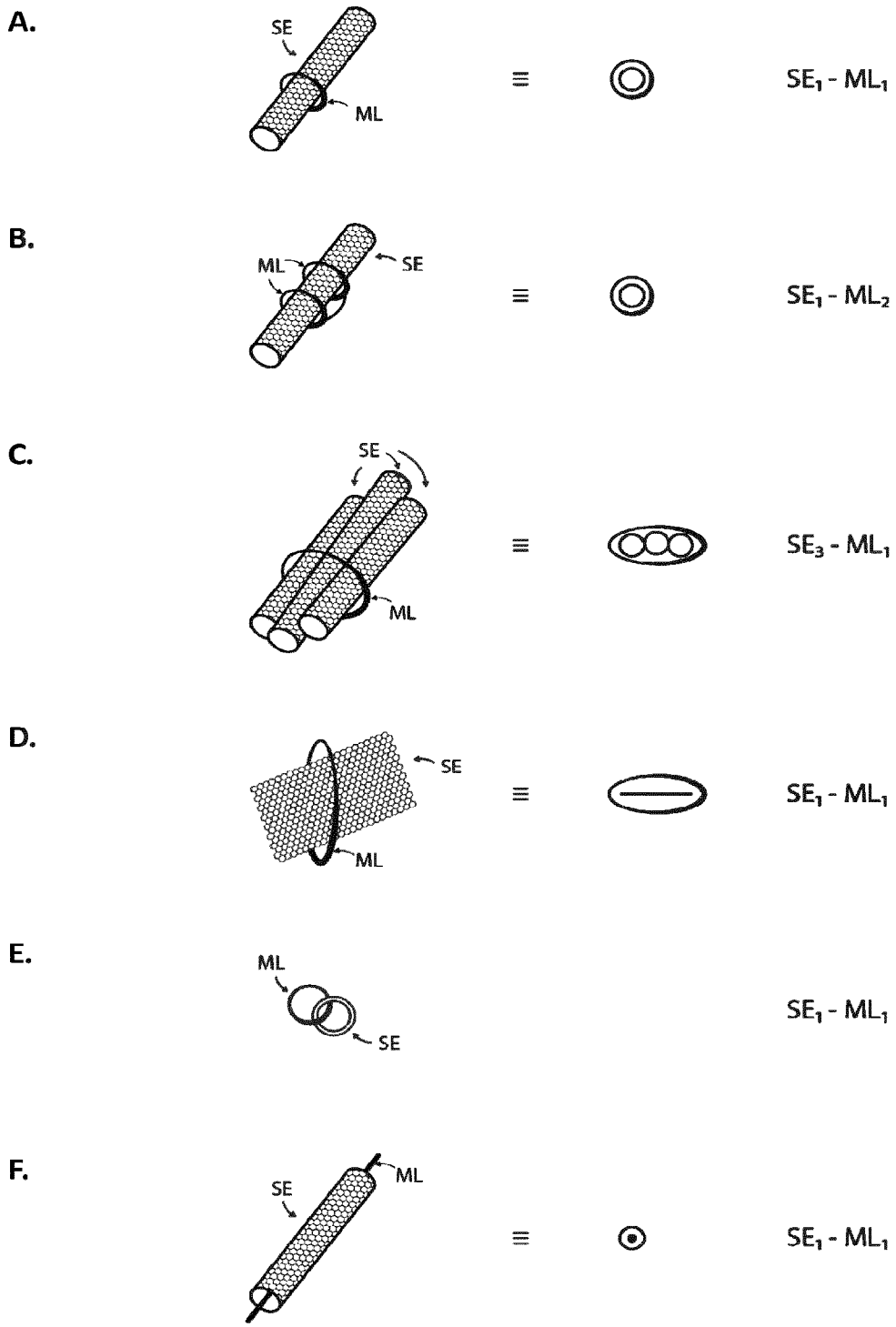
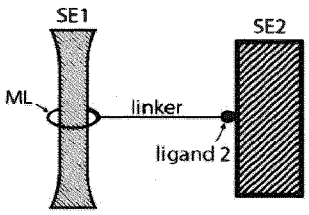
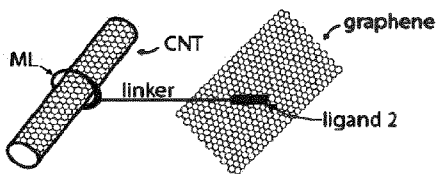

A.
SE
ML
≡
SE1 - ML1
B.
ML
SE
≡
SE1 - ML2
C.
SE
ML
≡
SE3 - ML1
D.
SE
ML
≡
SE1 - ML1
E.
ML
SE
SE1 - ML1
F.
SE
ML
≡
SE1 - ML1

Fig. 1

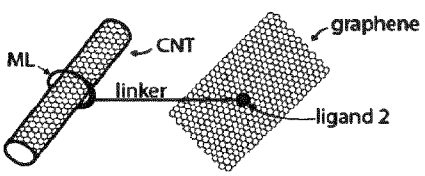
A.


SE1
SE2
ML
linker
ligand 2

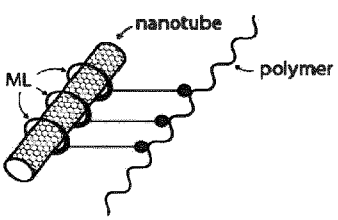
B.


ML
CNT
graphene
linker
ligand 2

C.


ML
CNT
graphene
linker
ligand 2

D.


nanotube
ML
polymer

E.

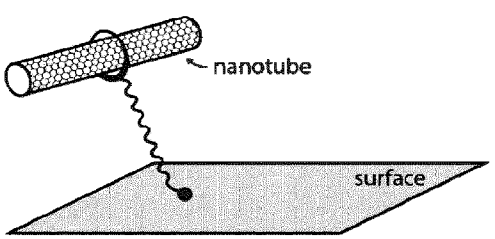

nanotube
surface

Fig. 2

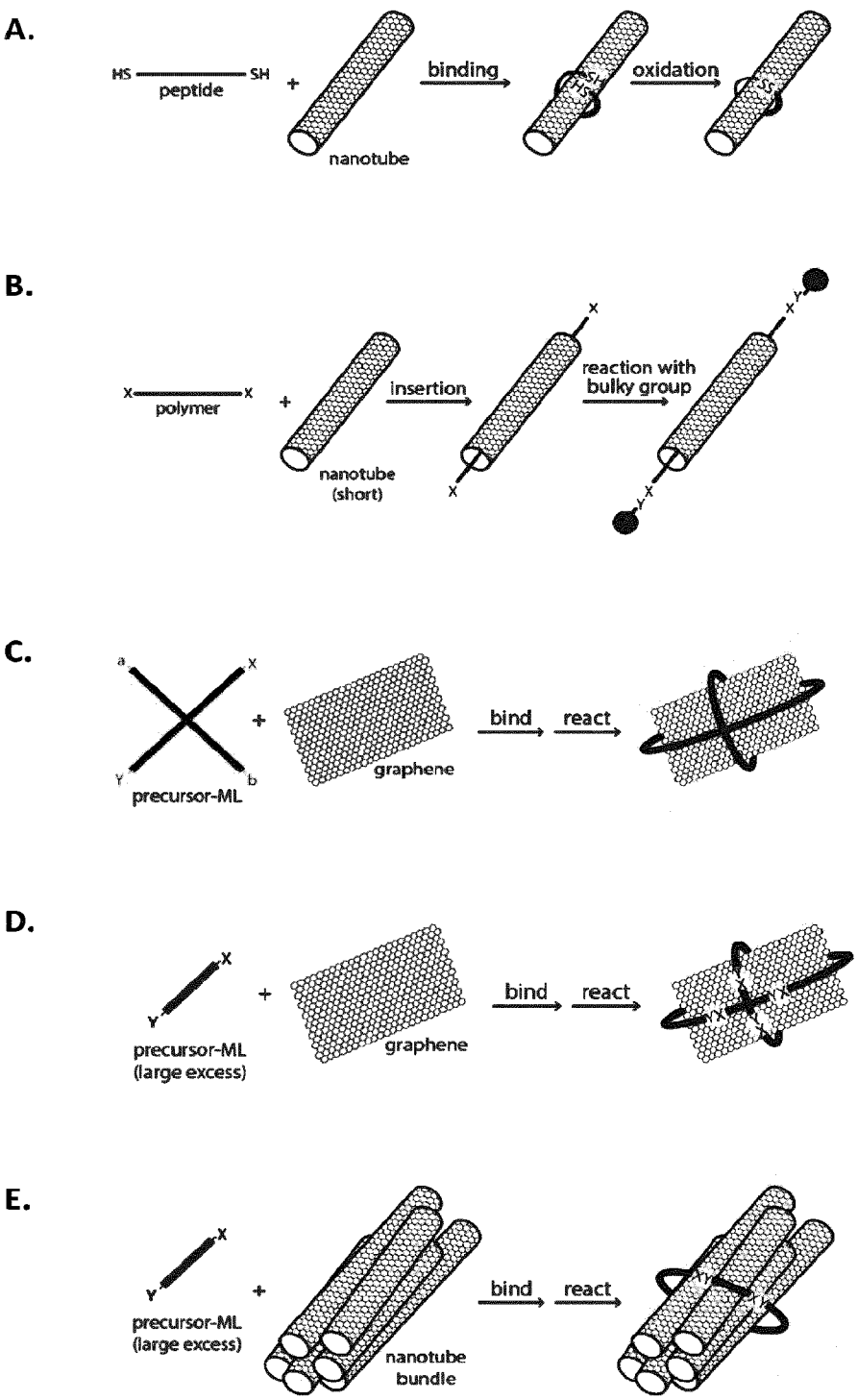

A.
HS
SH
peptide
nanotube
binding
oxidation
B.
X
X
polymer
nanotube
(short)
insertion
reaction with
bulky group
C.
a
X
Y
b
precursor-ML
graphene
bind
react
D.
X
Y
precursor-ML
(large excess)
graphene
bind
react
E.
X
Y
precursor-ML
(large excess)
nanotube
bundle
bind
react

Fig. 3

ROMP synthesis of 'Poly[N-(4-Tosylatebutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A1, synthesized in example A1).

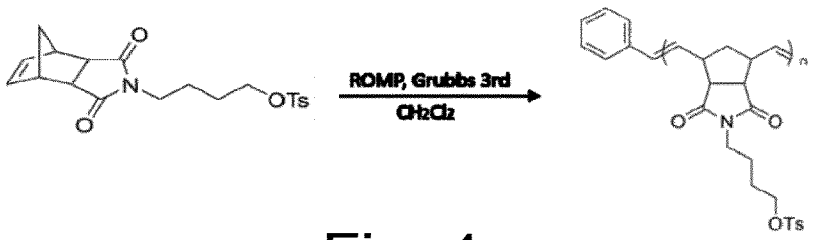


Fig. 4

^{1}H NMR of 'Poly[N-(4-Tosylatebutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A1, synthesized in example A1).

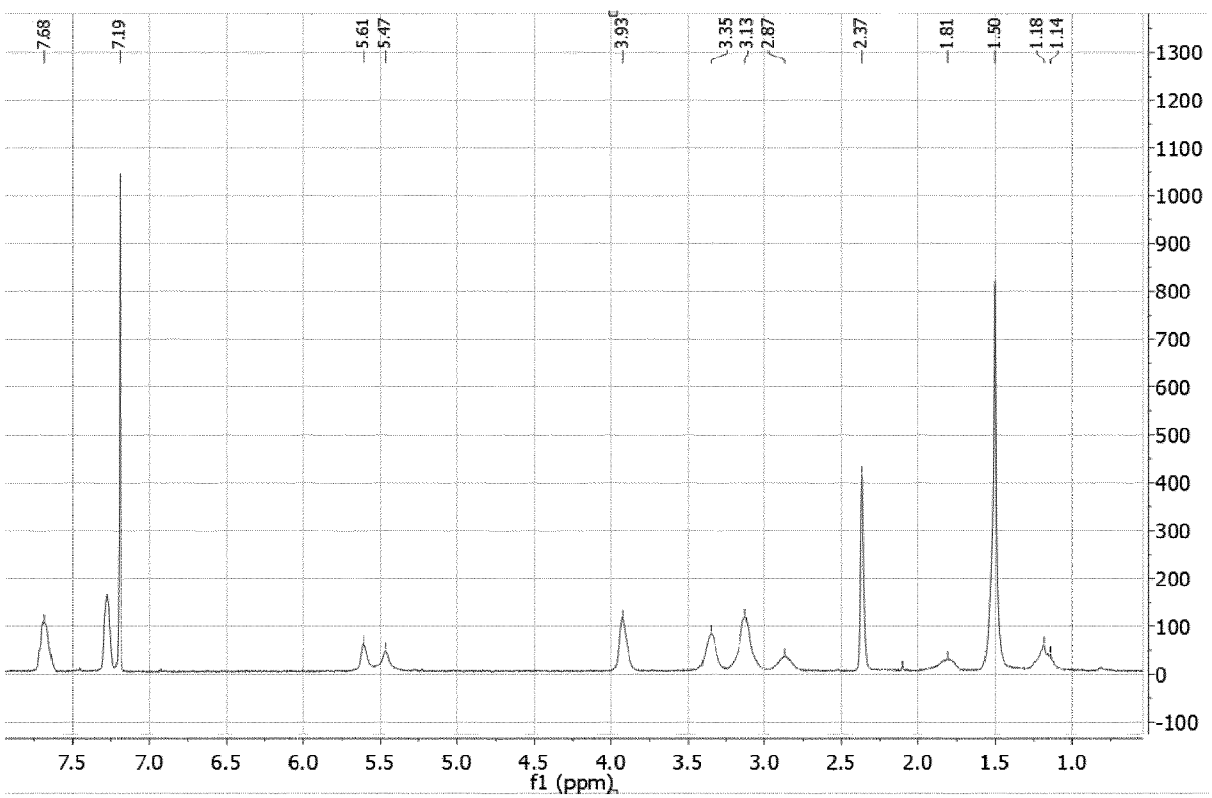


Fig. 5

Synthesis of 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A2, synthesized in example A3).

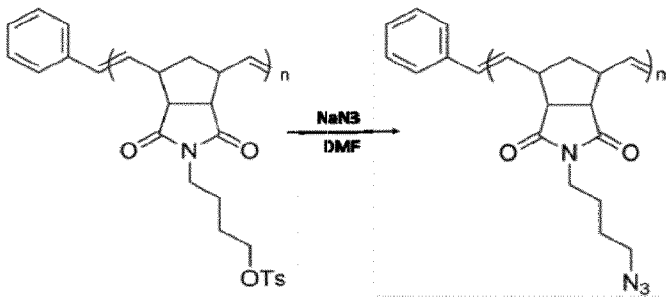


Fig. 6

^{1}H NMR of 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A2, synthesized in example A3).

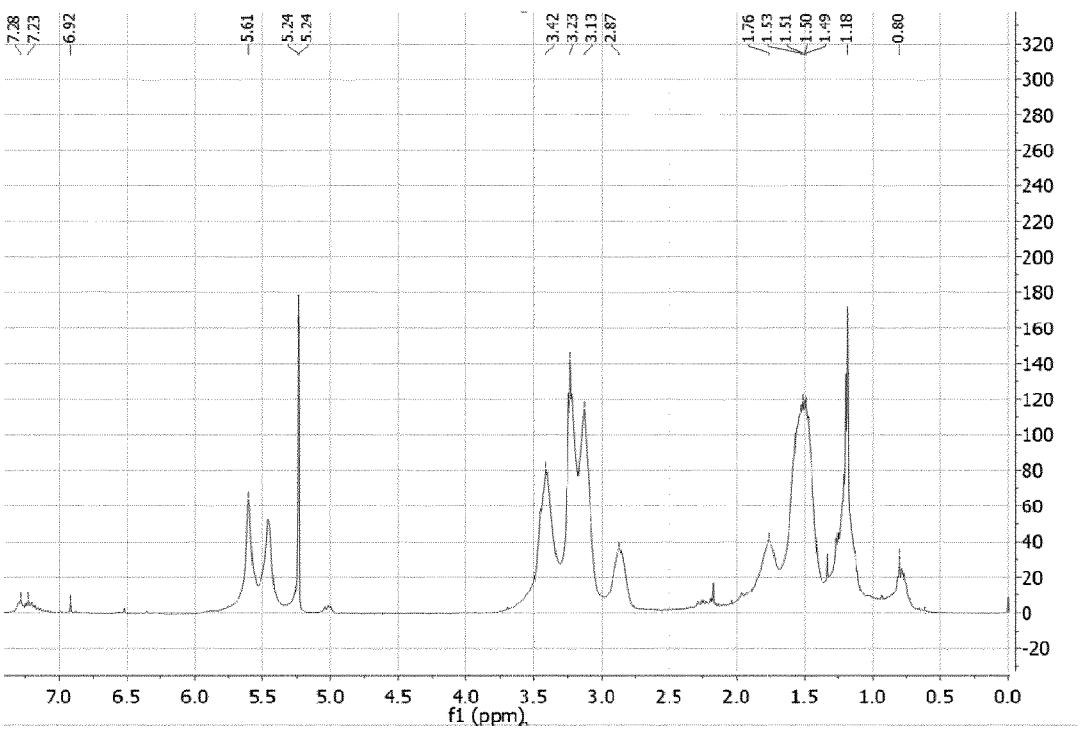


Fig. 7a

FT-IR spectrum of 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A2, synthesized in example A3).

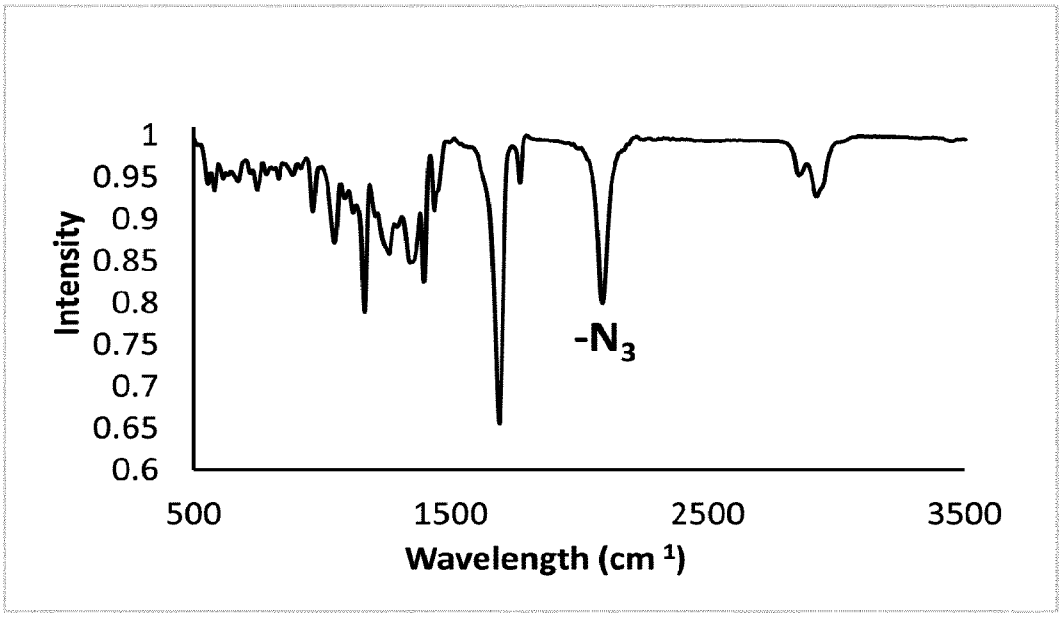


Fig. 7b

End-group (1H NMR) analysis of 'Poly[N-(4-azidobutyl)]-cis-5-norborneneexo-2,3-dicarboximide' (compound A2, synthesized in example A3).

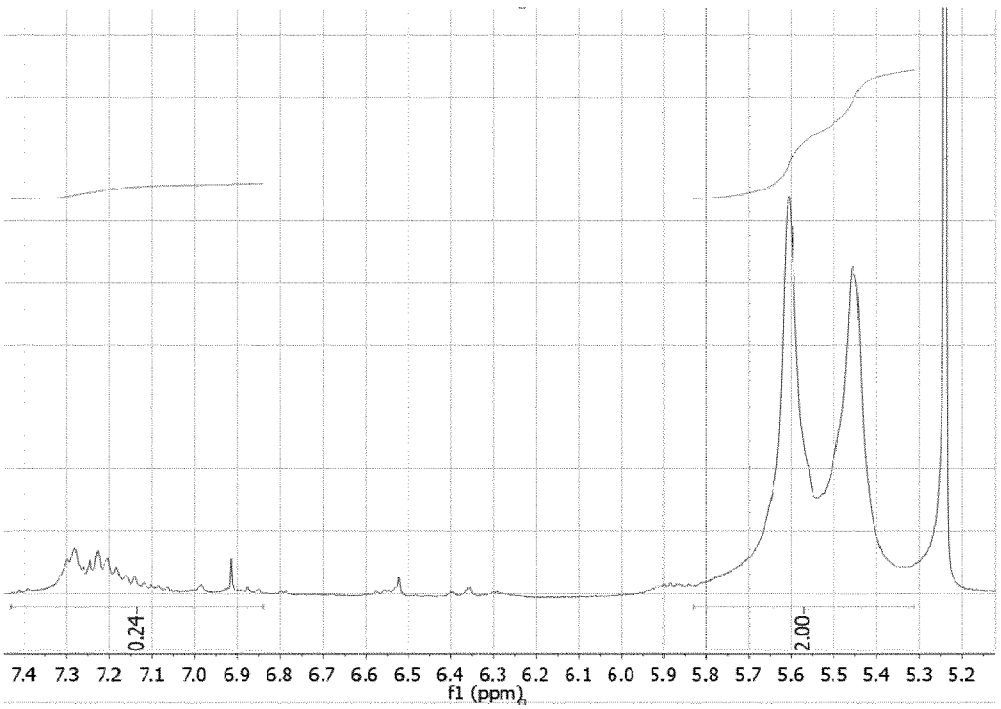


Fig. 8

Synthesis of 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norborneneexo-2,3-dicarboximide' (compound A3, synthesized in example A6).

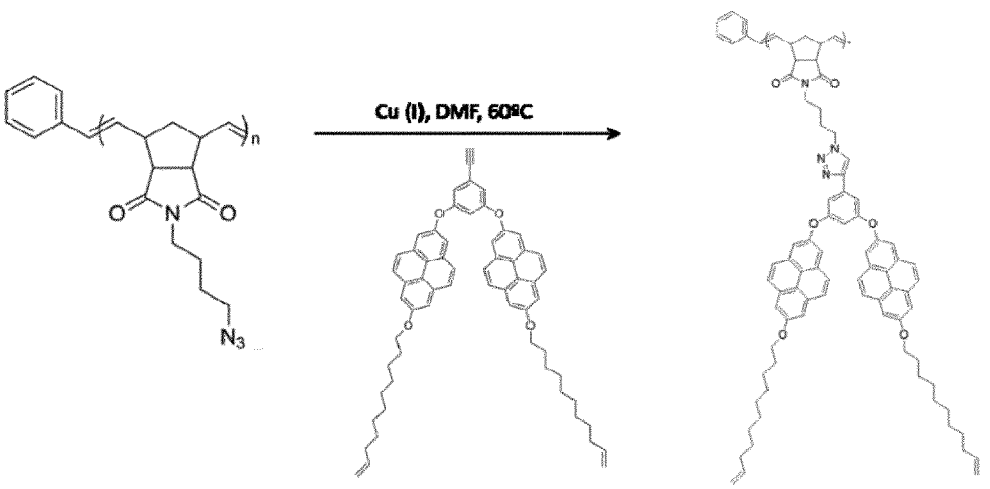


Fig. 9

Comparative Infrared Spectra. Black: Pyrene_Ushape terminal alkyne, blue: 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A2, synthesized in example A3) and red: 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, synthesized in example A6).

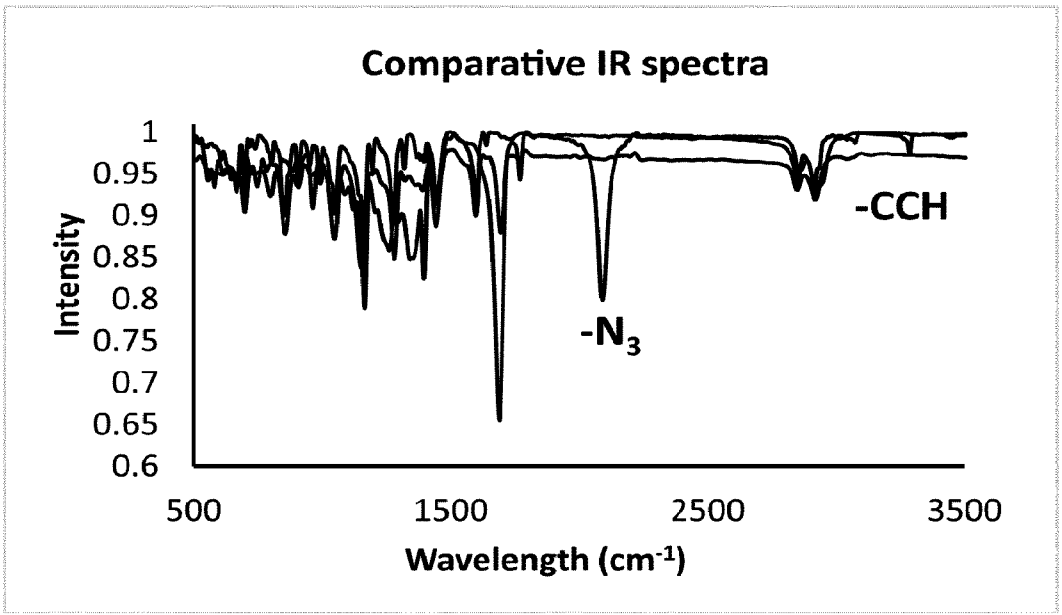


Fig. 10

^{1}H NMR of 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, synthesized in example A6).

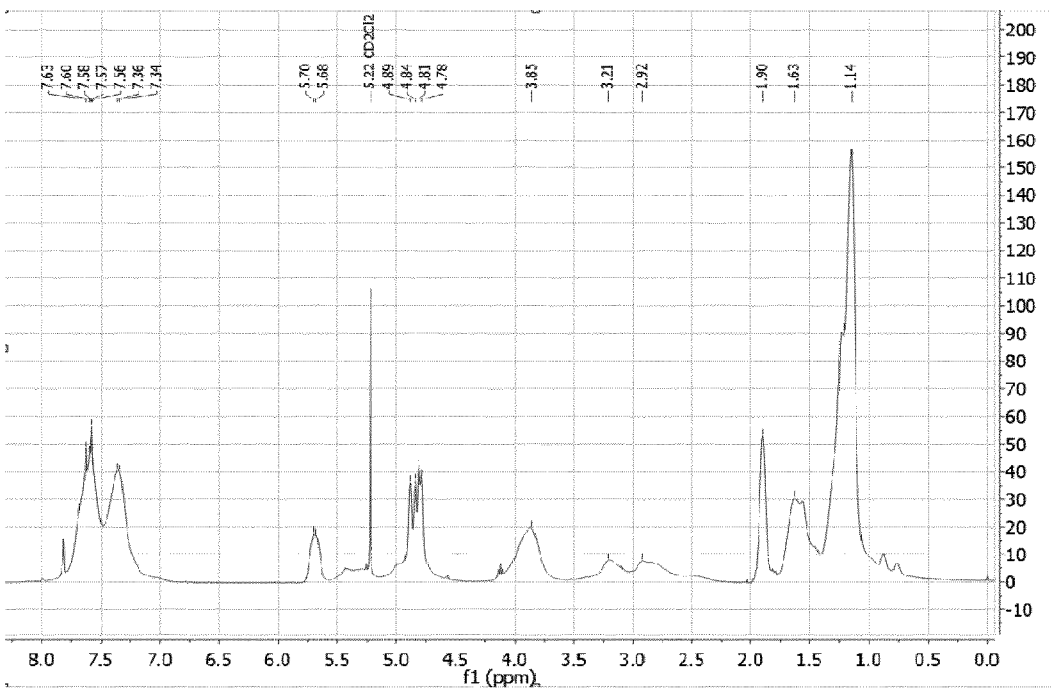


Fig. 11a

UV-Vis. spectrum of 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, synthesized in example A6).

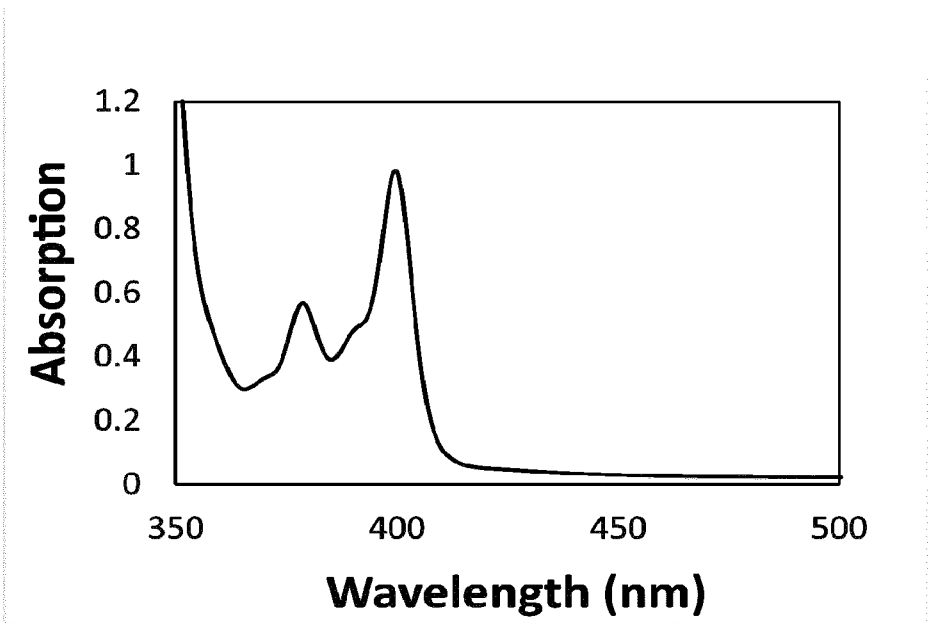
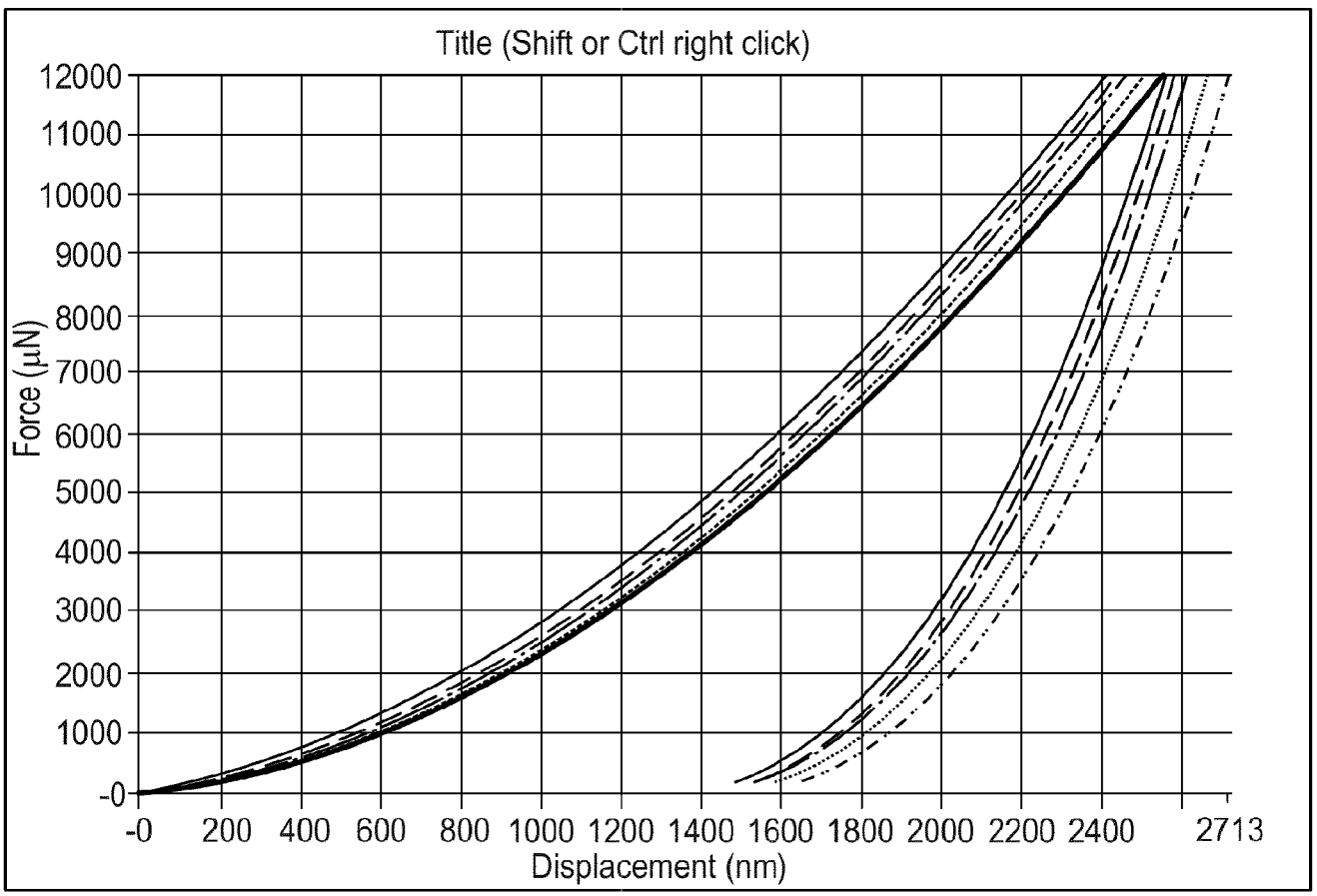


Fig. 11b

TGA spectrum of **'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide'** (compound **A3**, synthesized in example **A6**).

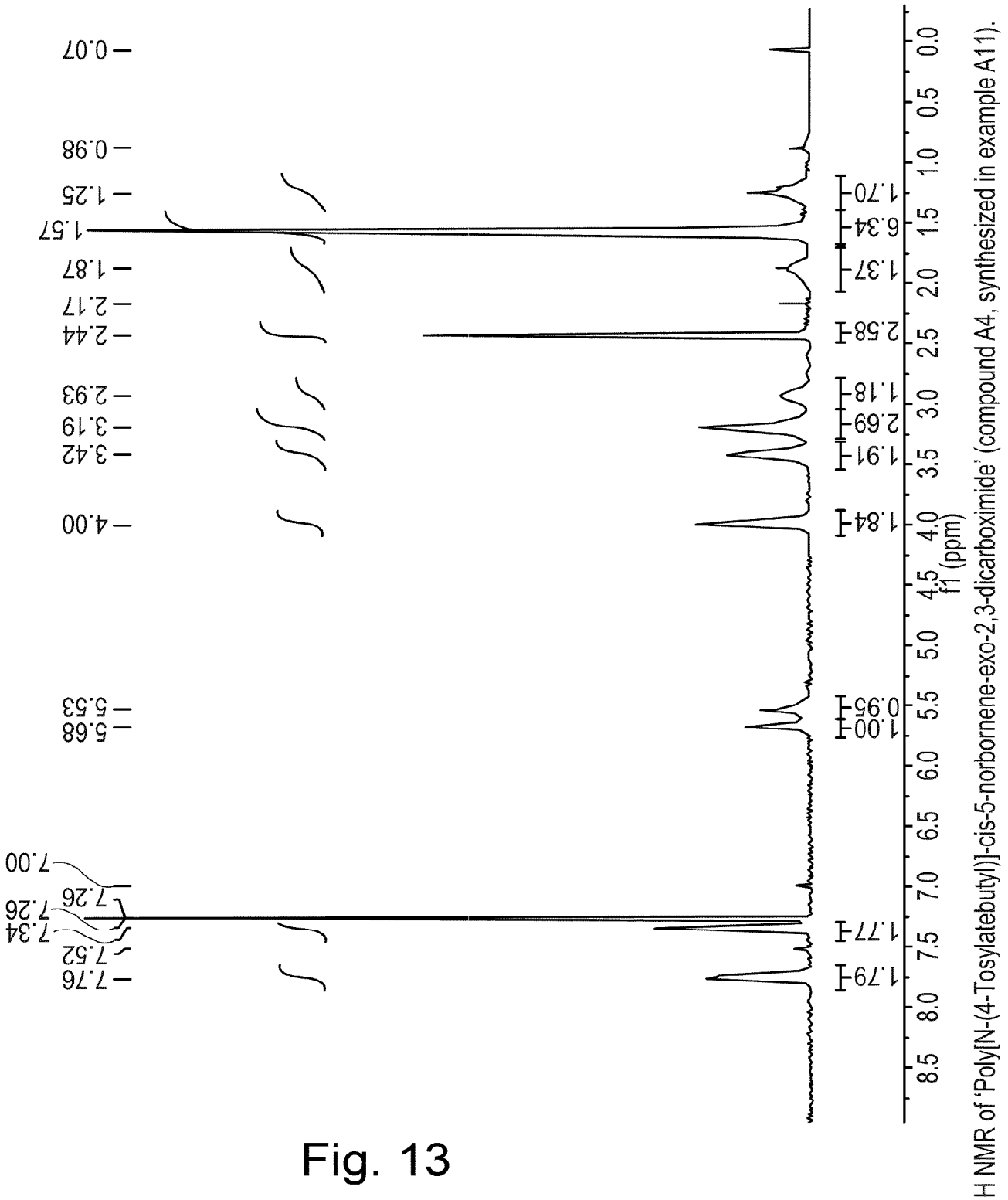
Fig. 11c

Nanoidentation measurement of 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, synthesized in example A6).



Hardnesss (GPa)	STDEV Hardness Reduced Modulus (GPa)	Er (GPa)	STDEV Er (GPa)
0.119	0.003	1.867	0.026

Fig. 12



^{1}H NMR of 'Poly[N-(4-Tosylatebutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A4, synthesized in example A11).

Fig. 13

^{1}H NMR of 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A5, synthesized in example A13).

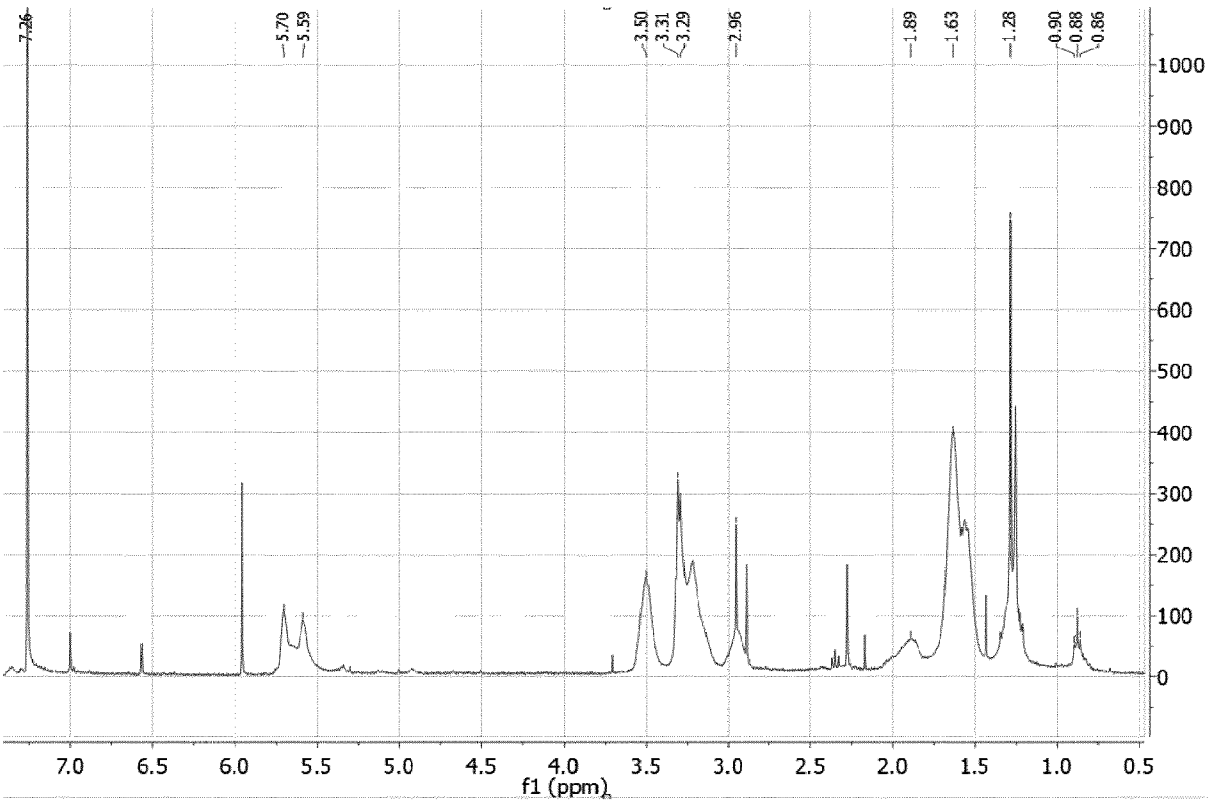


Fig. 14a

FT-IR spectrum of 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A5, synthesized in example A13).

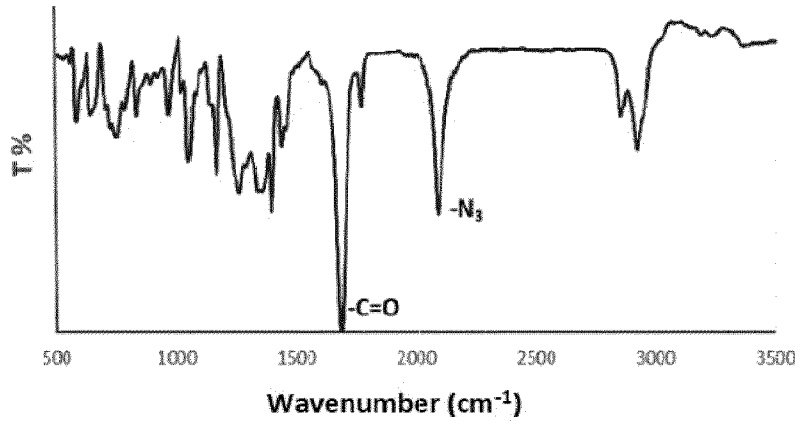


Fig. 14b

End-group (^{1}H NMR) analysis of 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A5, synthesized in example A13).

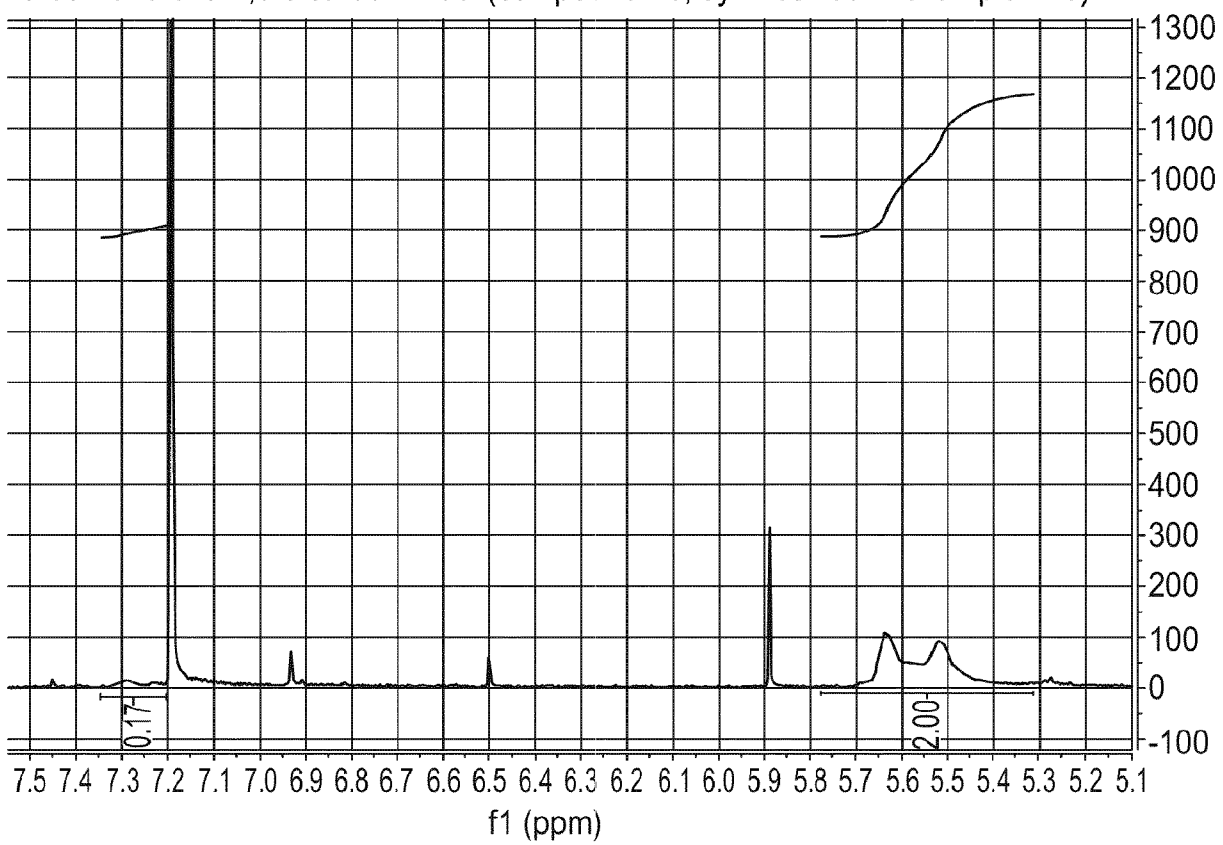


Fig. 15

Comparative Infrared Spectra. Black: Pyrene_Ushape terminal alkyne, blue: 'Poly[N-(4-azidobutyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A5, synthesized in example A13) and red: 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A6, synthesized in example A16).

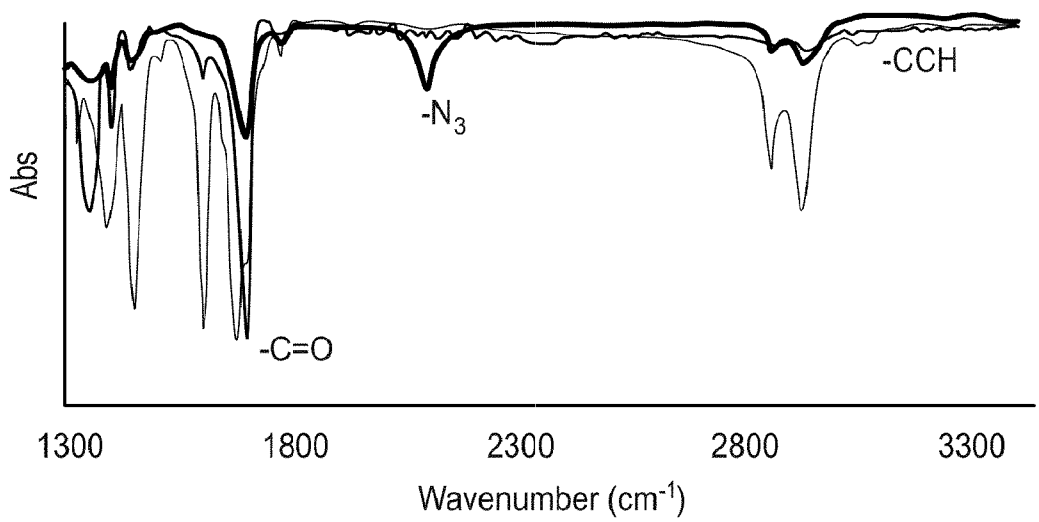


Fig. 16

^{1}H NMR of 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A6, synthesized in example A16).

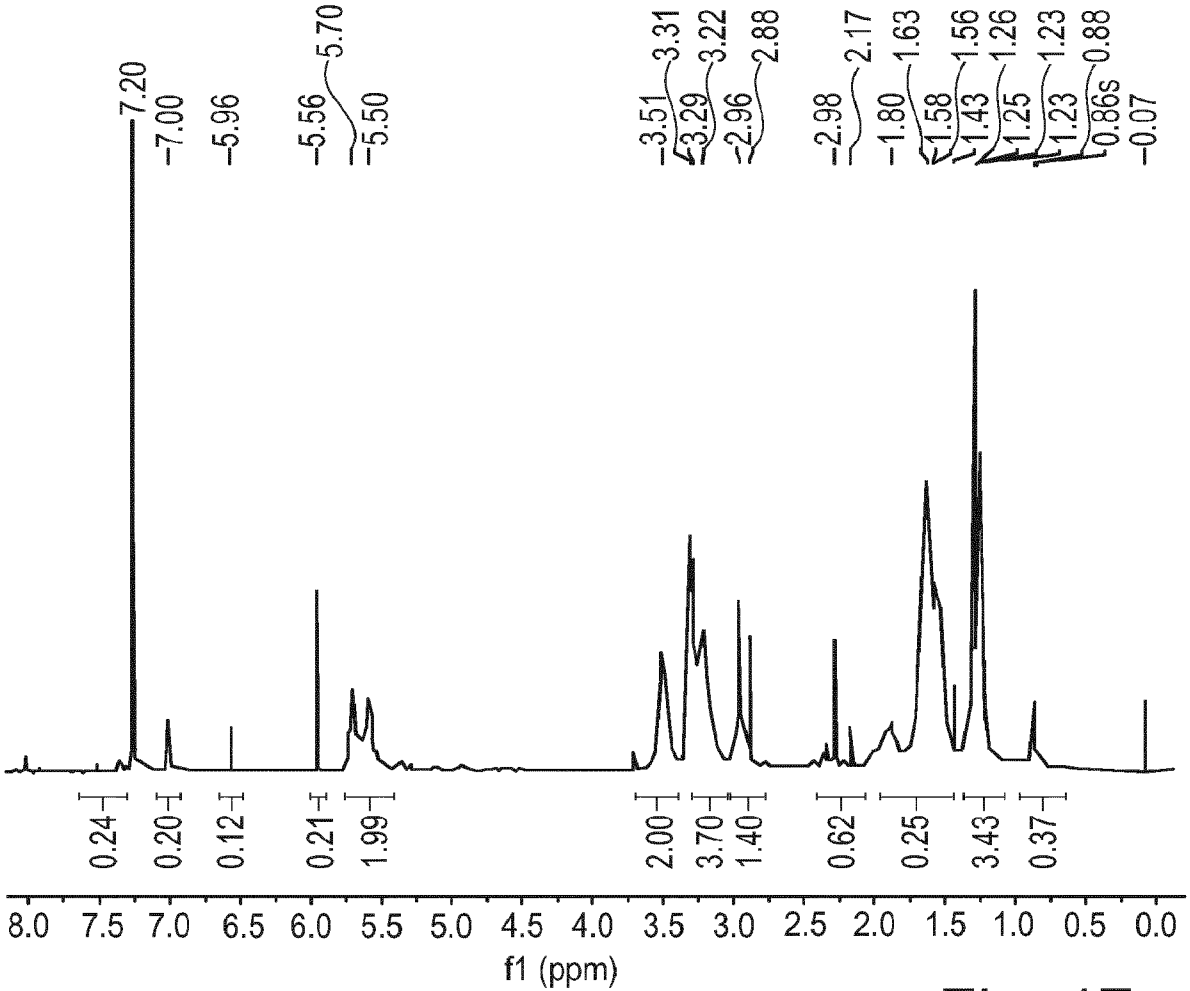
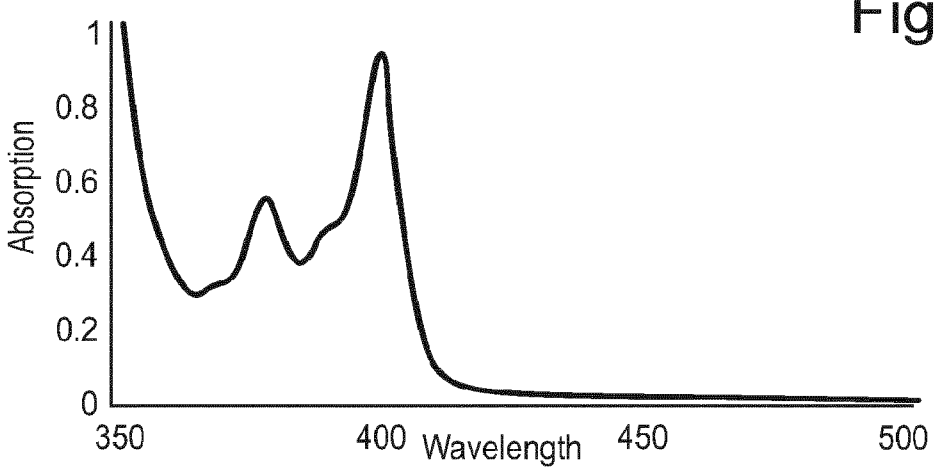


Fig. 17a



UV-Vis. spectrum of 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A6, synthesized in example A16).

Fig. 17b

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TGA spectrum of **'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide'** (compound **A6**, synthesized in example A16).

Fig. 17c

Synthesis of 'SWNT-polyUshape' composite (compound A8) with 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, from example A6).

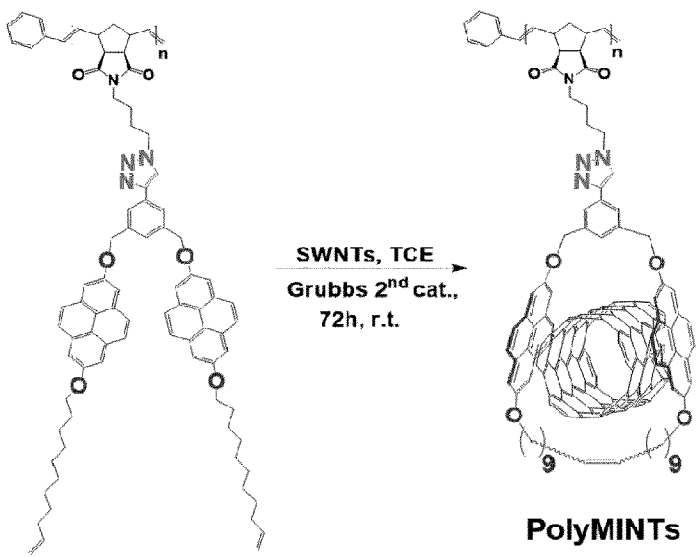


Fig. 18a

Optical Microscopy photo of compound A8

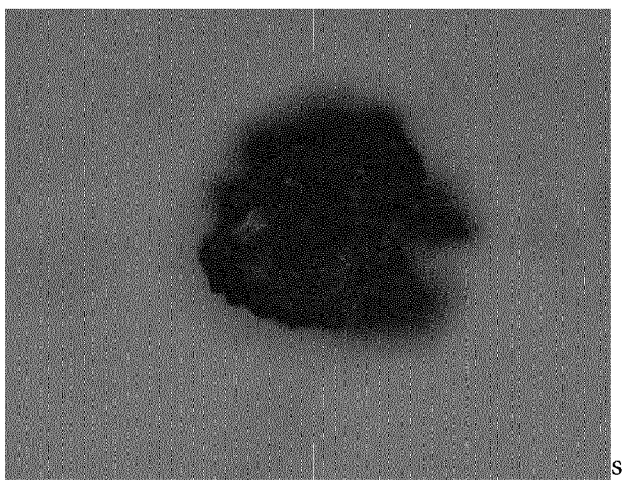


Fig. 18b

Raman spectra of 'SWNT-polyUshape' composite (compound A8), measured at 785 nm and 532 nm.

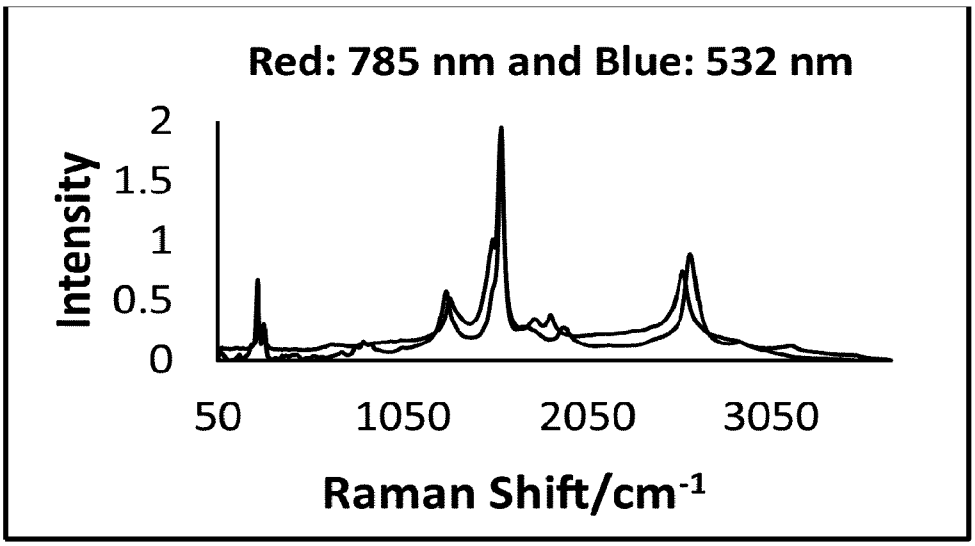


Fig. 19

Raman studies for a '2D versus G band' comparison of 'SWNT-polyUshape' composite (compound A8) and non-modified 6,5_SWNTs (compound A7) from example A19.

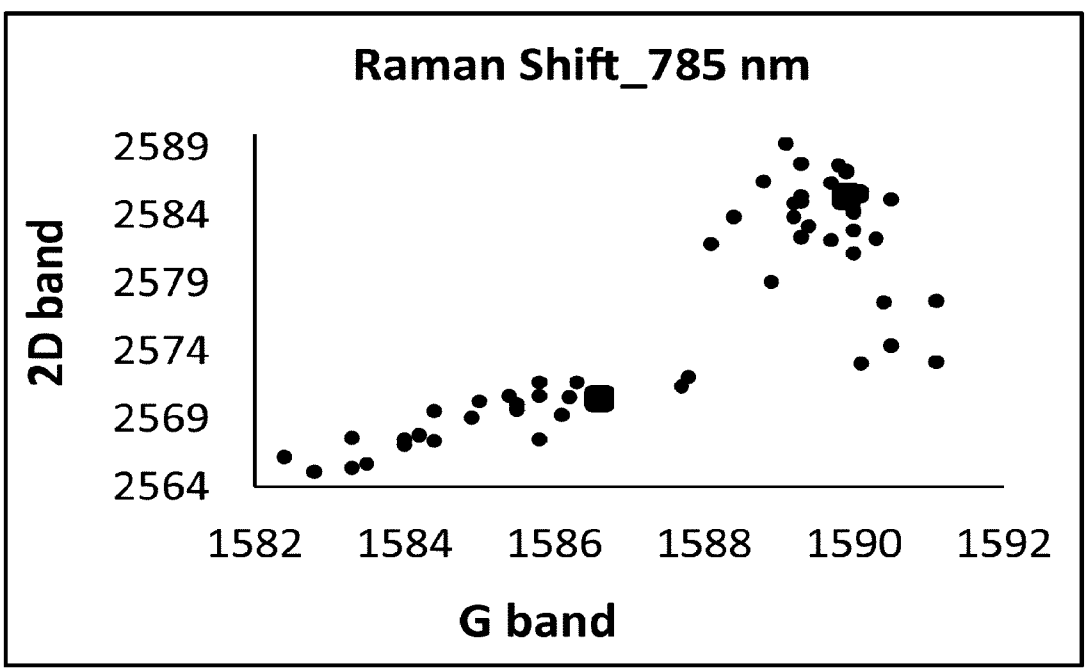
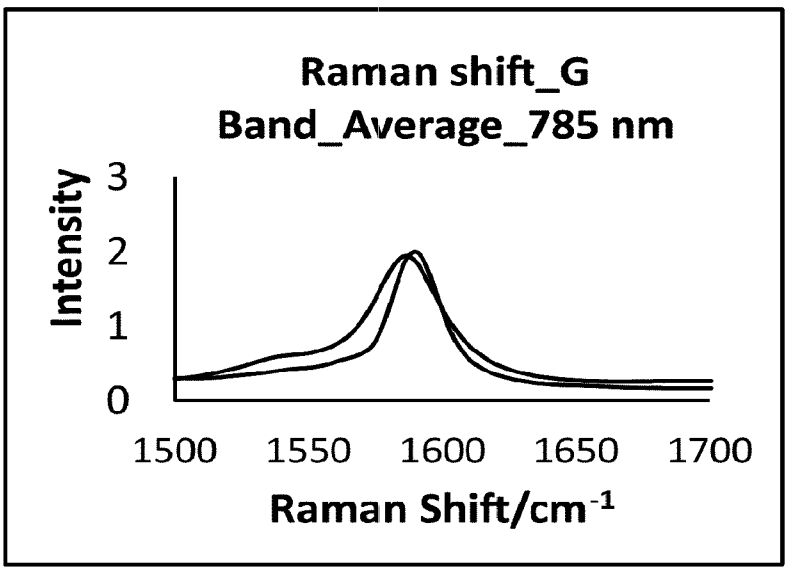


Fig. 20

Average comparison of G and 2D band of 'SWNT-polyUshape' composite (compound A8) and non-modified 6,5_SWNTs (compound A7) from example A19.



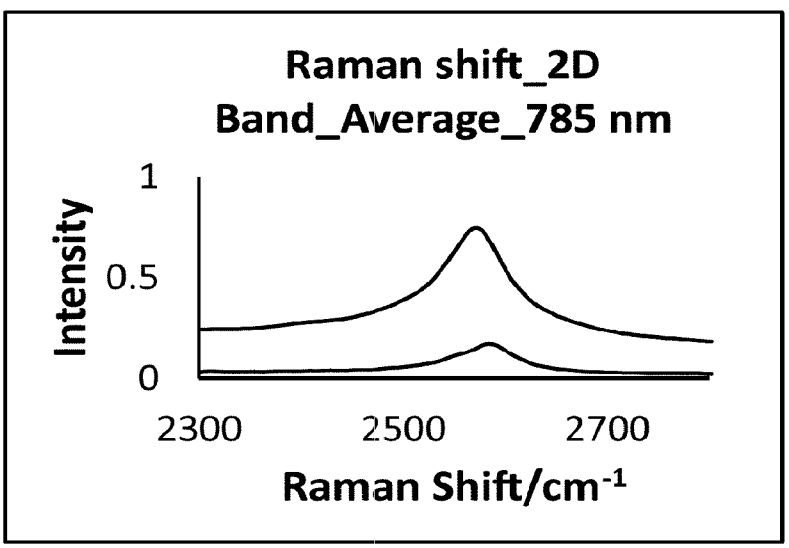


Fig. 21

UV.Vis_NIR spectra (focused in the in the pyrene region) comparison between a) 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, from example A6) in black colour, b) 'SWNT-polyUshape' composite (compound A8) after step 8 in blue colour and c) 'SWNT-polyUshape' composite (compound A8) after step 11 in red colour.

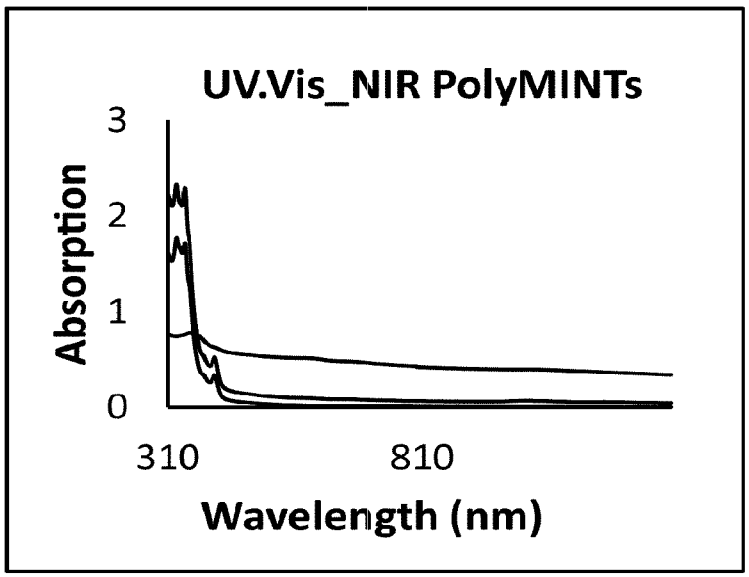


Fig. 22

UV.Vis_NIR spectra (focused in the in the nanotube region) comparison between 'SWNT-polyUshape' composite (compound A8) in red colour and 6,5_SWNTs (compound A7) from example A19 in blue colour.

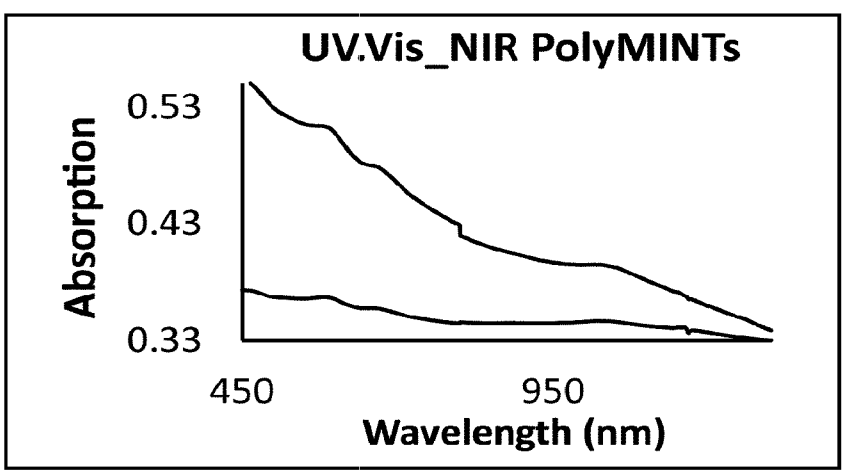
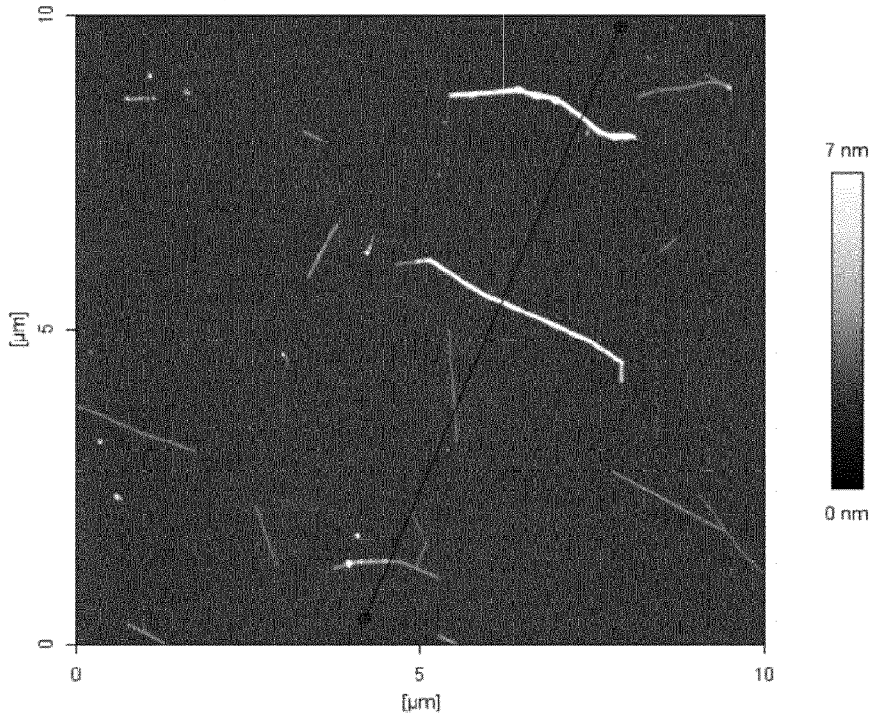


Fig. 23

AFM of 'SWNT-polyUshape' composite (compound A8).
a) Topographic AFM image of compound A8.



b) 'Height measurements' of topographic AFM image from figure A30 (a).

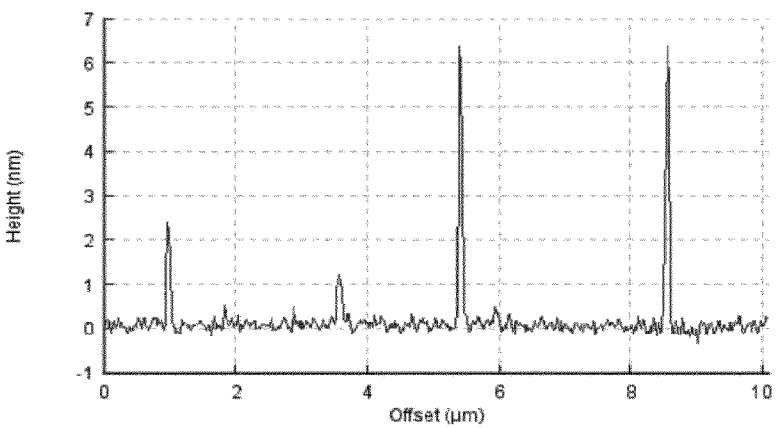
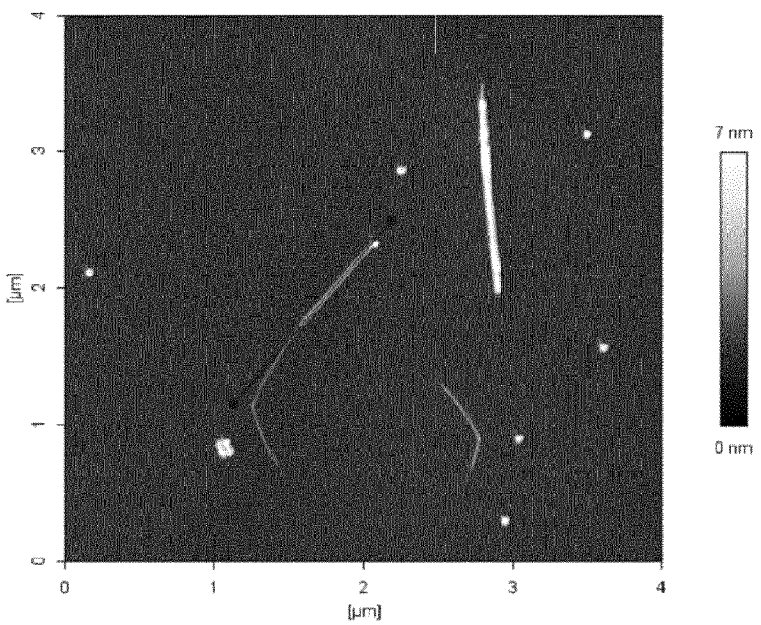


Fig. 24

c) Topographic AFM image of compound A8.



d) 'Height measurements' of topographic AFM image from figure A30 (c).

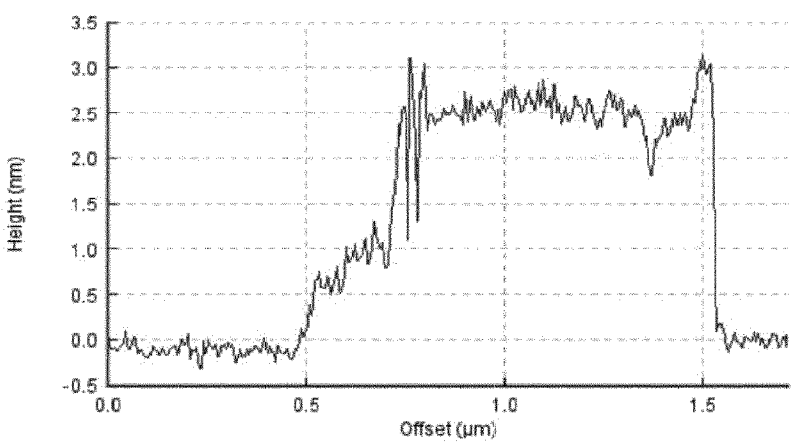


Fig. 24 (Continued)

e) Phase AFM image from figure A30 (c).

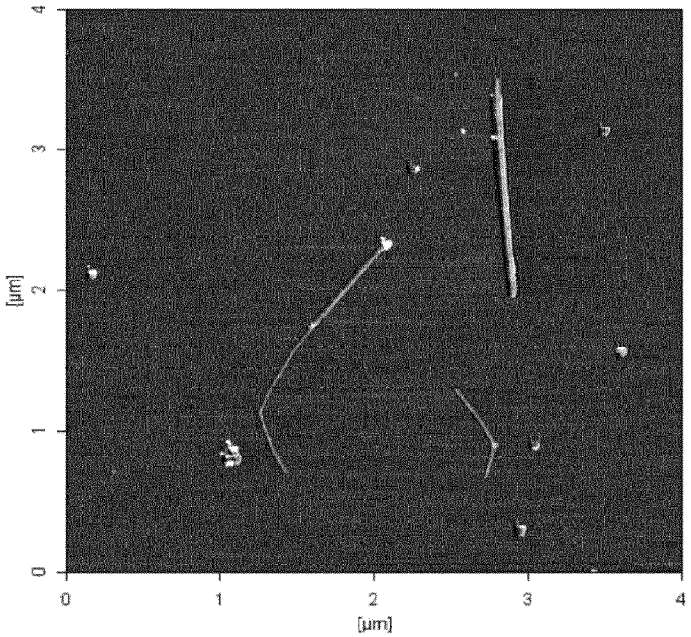


Fig. 24 (Continued)

SEM of 'SWNT-polyUshape' composite (compound A8).

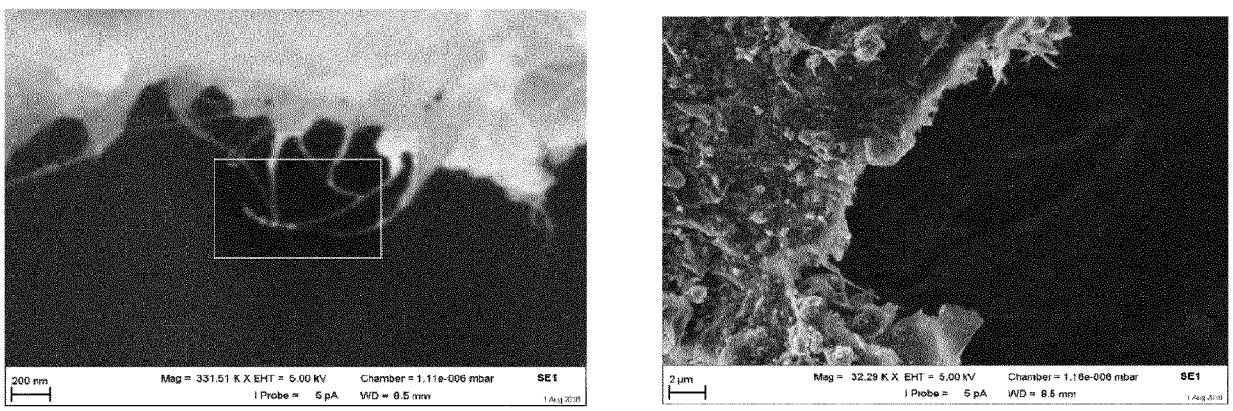


Fig. 25

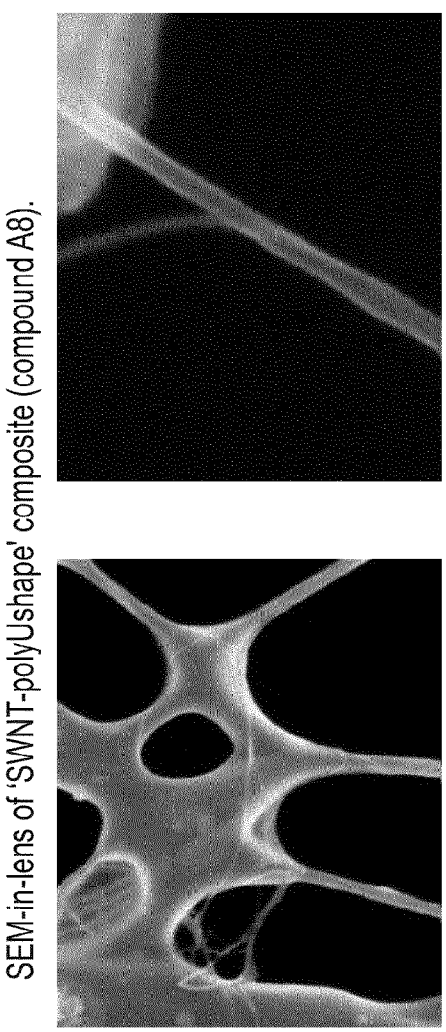

SEM-in-lens of 'SWNT-polyUshape' composite (compound A8).

Fig. 26

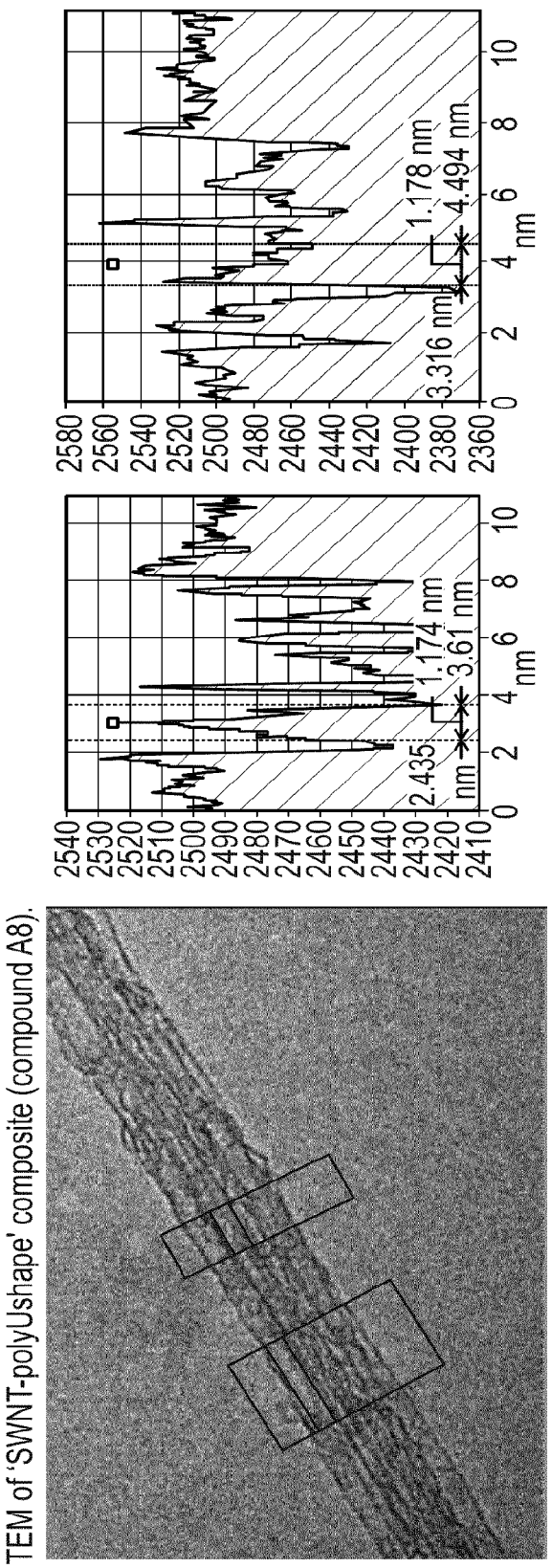

TEM of 'SWNT-polyUshape' composite (compound A8).
2.435 nm
1.174 nm
3.61 nm
3.316 nm
1.178 nm
4.494 nm
nm

Fig. 27

HRTEM of 'SWNT-polyUshape' composite (compound A8).

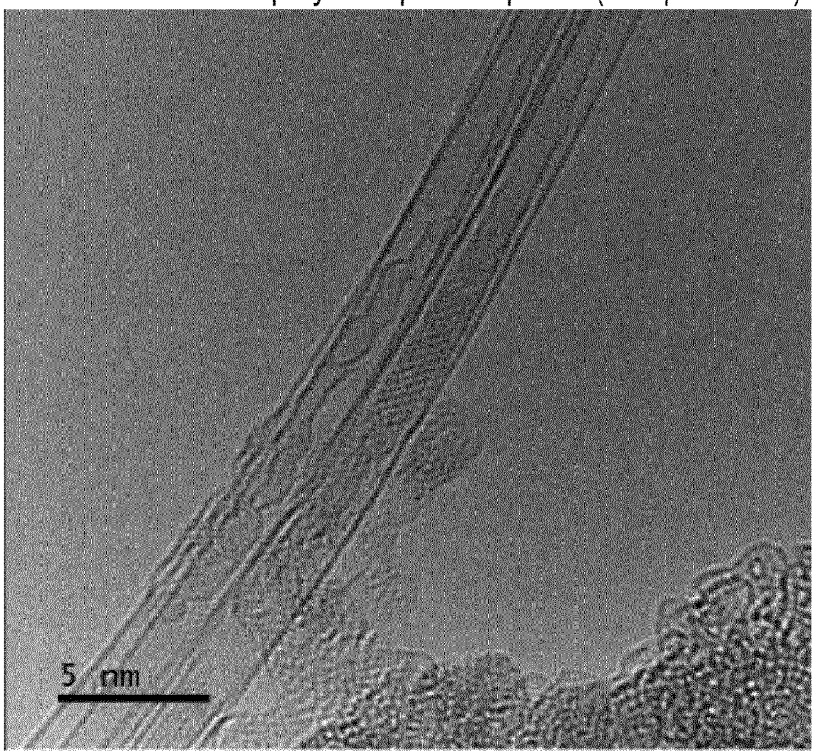


Fig. 28

Raman studies for a '2D versus G band' comparison of composites obtained in examples A20 (compound A8 in red) and A24 (in blue).

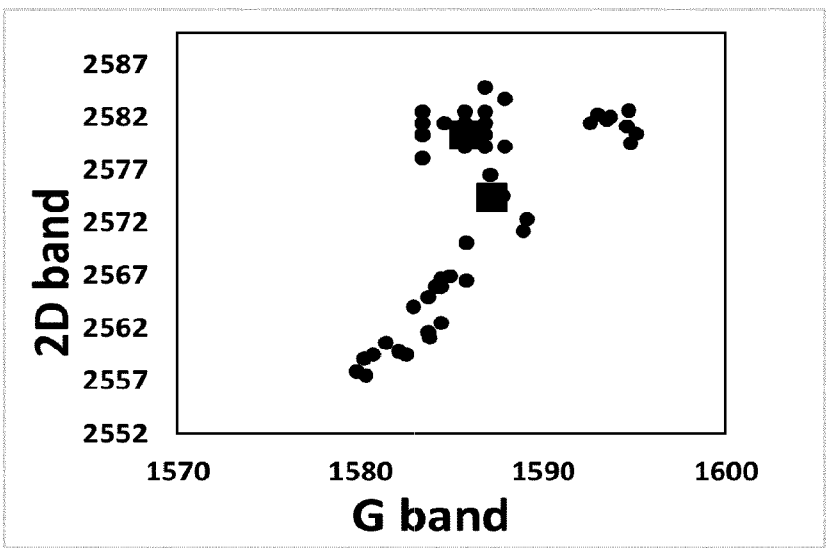


Fig. 29

Raman spectra comparison of a) compound A9 in blue line (example A27), b) compound A8 in red line (example A20) and c) compound A7 in black line (example A19), measured at 785 nm.

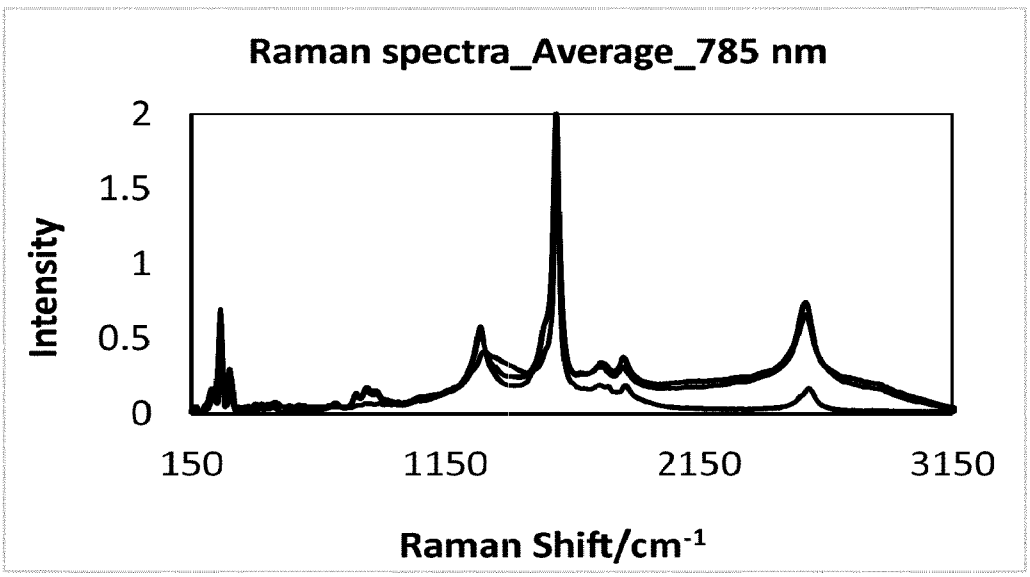


Fig. 30

Raman studies for a '2D versus G band' comparison of a) compound A9 in green (example A27), b) compound A8 in red (example A20), c) compound A7 in orange (example A19) and d) compound obtained from 'control' experiment in blue.

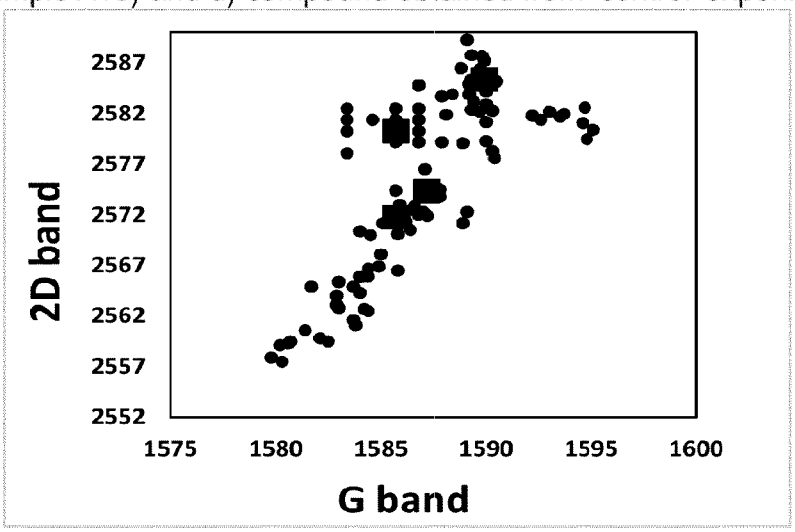


Fig. 31

Average comparison of G and 2D band of a) compound A9 (example A27), b) compound A8 (example A20) and c) compound A7 (example A19), measured at 785 nm.

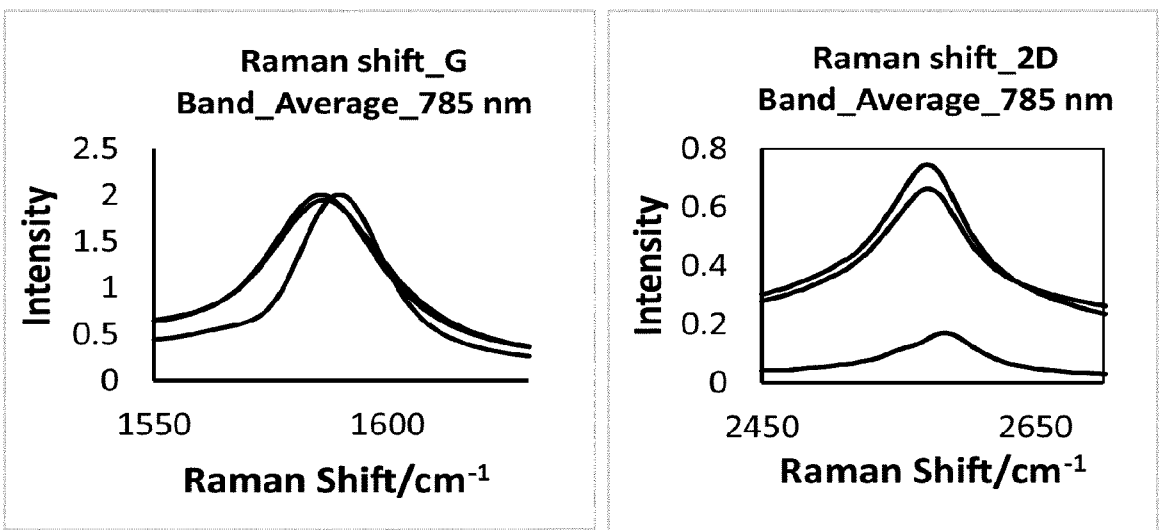
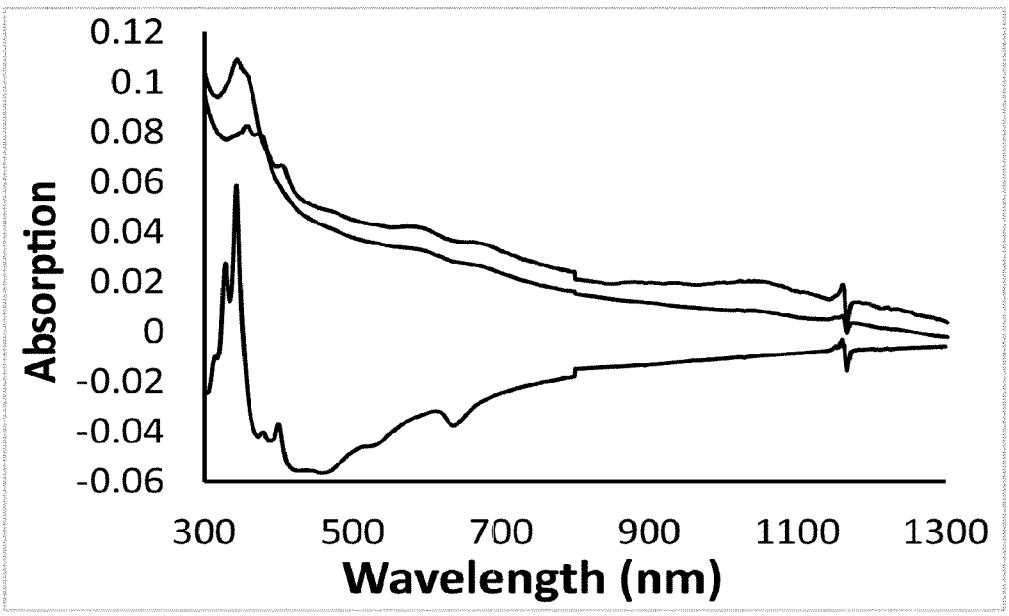
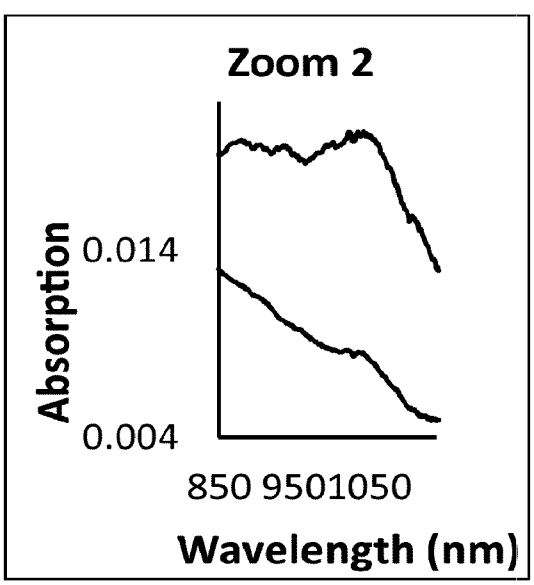


Fig. 32

UV.Vis_NIR comparison spectra of 'SWNT-polyUshape Supramolecular' composite (compound A9) in blue, 'SWNT-polyUshape' composite (compound A8) in red and 'Poly[N-(4-triazole-Pyrene_Ushape-(butyl)]-cis-5-norbornene-exo-2,3-dicarboximide' (compound A3, from example A6) in grey.





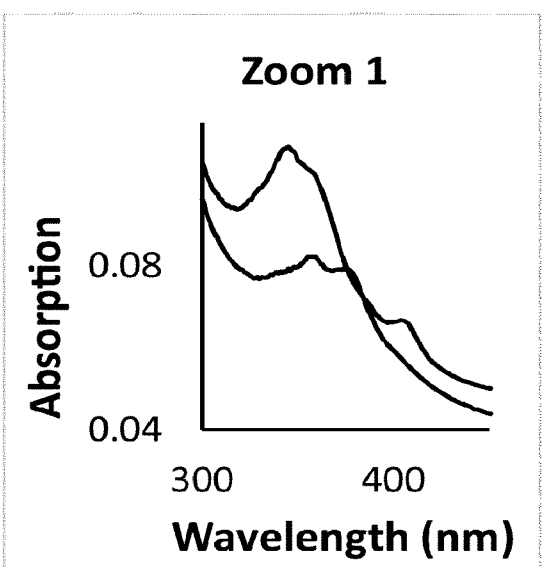


Fig. 33

HRTEM of 'SWNT-polyUshape Supramolecular' composite (compound A9).

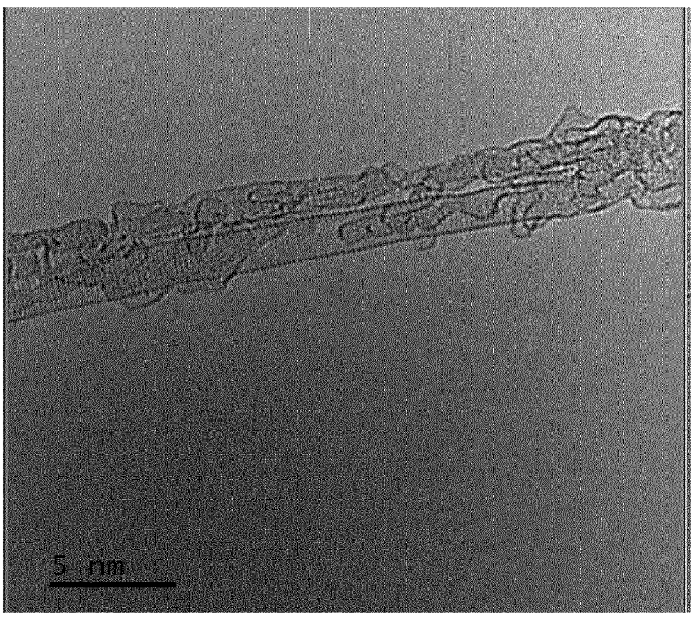


Fig. 34

Raman Spectroscopy of 'SWNT-polyUshape' composite in red line (compound A10) and non-modified 6,5_SWNTs (compound A7) in black line, measured at 785nm. Note: Both spectra are the average from 30 different measurements.

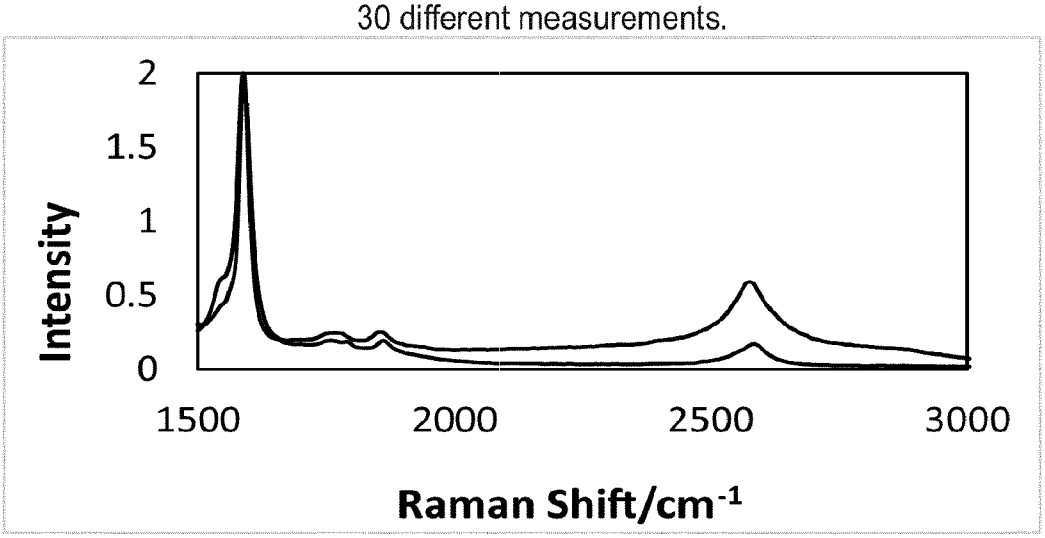


Fig. 35

Raman studies for a '2D versus G band' comparison of 'SWNT-polyUshape' composite (compound A10) and non-modified 6,5_SWNTs (compound A7).

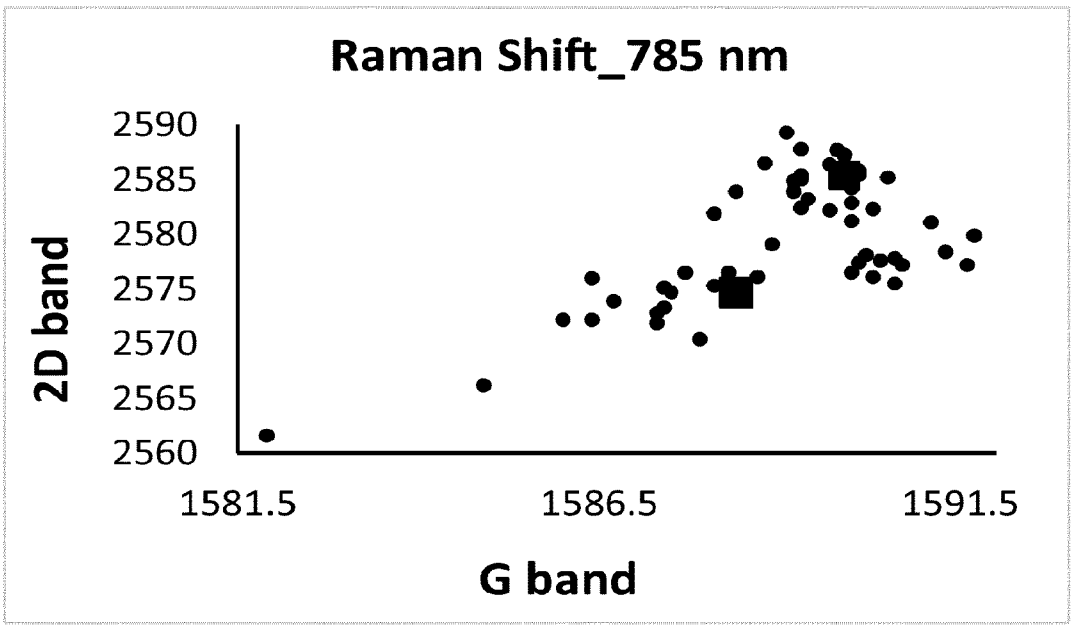


Fig. 36

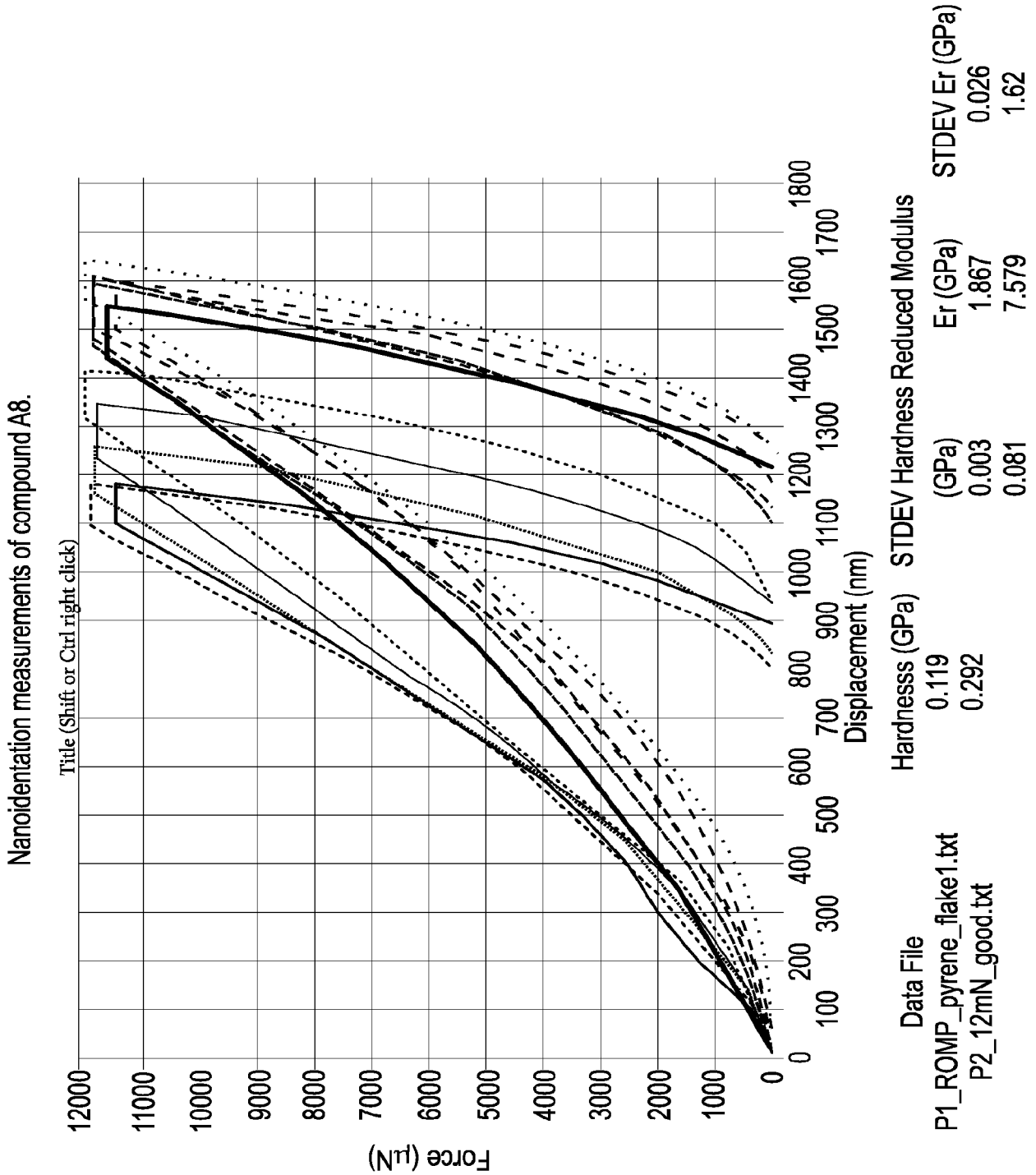

Nanoidentation measurements of compound A8.
Title (Shift or Ctrl right click)
Force (μN)
Displacement (nm)
Data File
Hardness (GPa)
STDEV Hardness (GPa)
Reduced Modulus (GPa)
STDEV Er (GPa)
P1_ROMP_pyrene_flake1.txt 0.119 0.003 1.867 0.026
P2_12mN_good.txt 0.292 0.081 7.579 1.62

Fig. 37

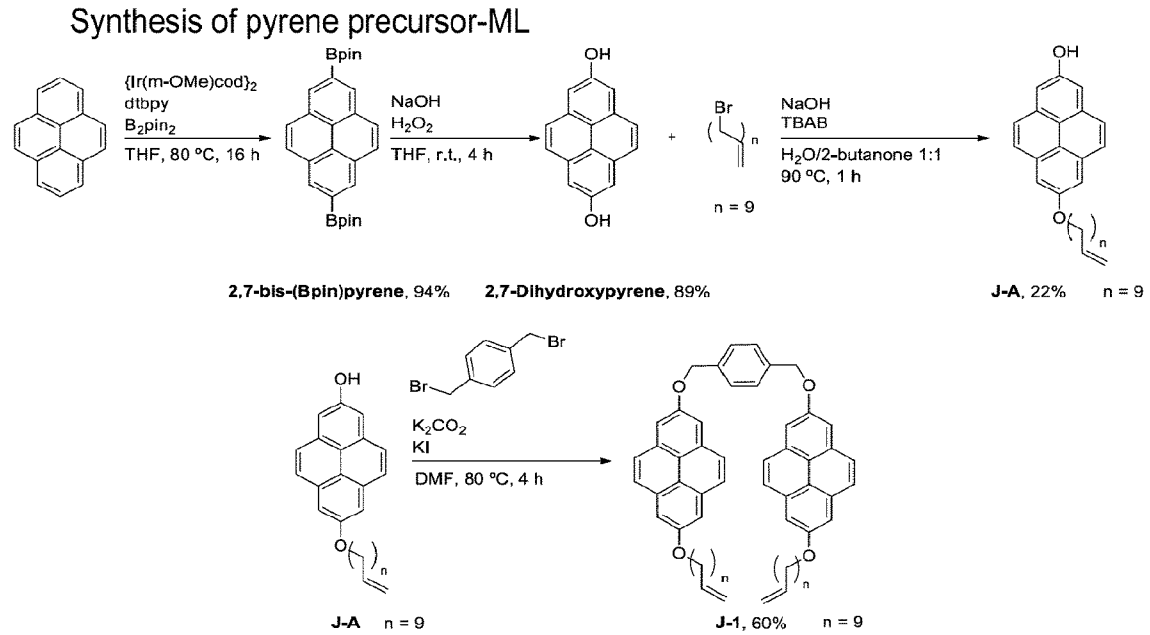


Fig. 38

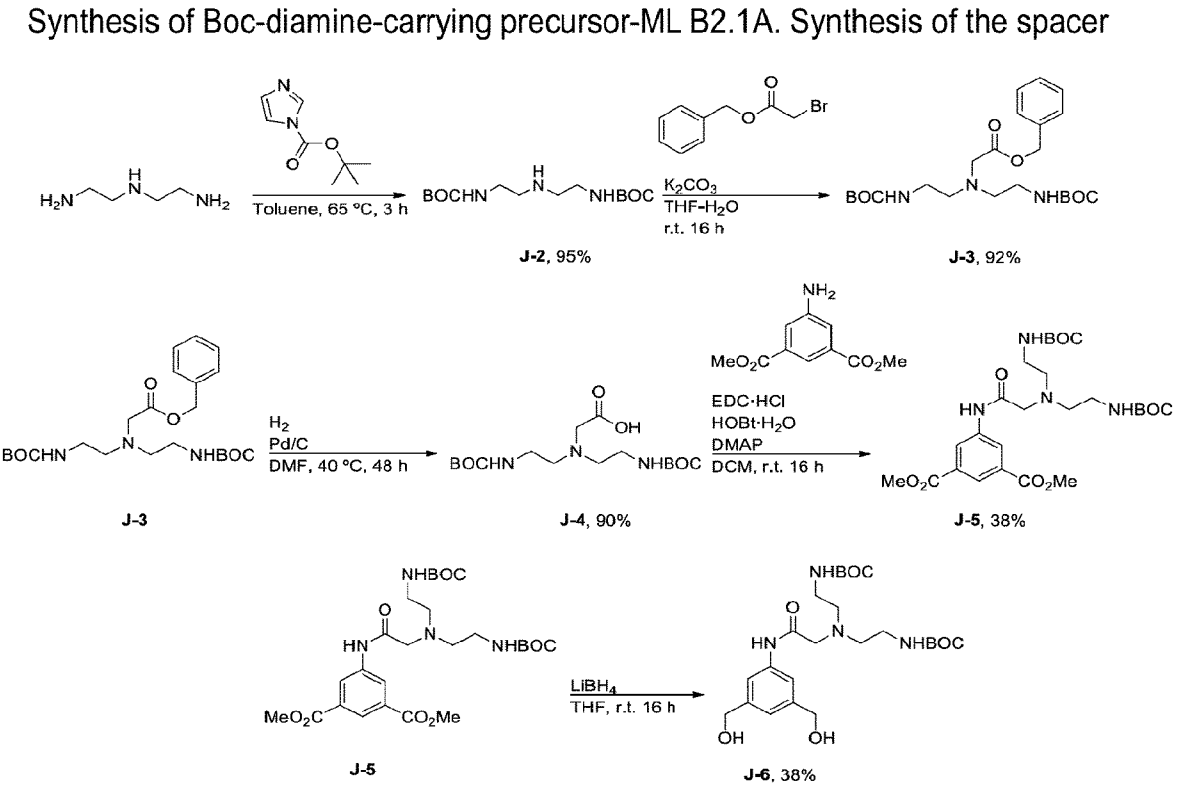


Fig. 39a

Synthesis of the precursor-ML

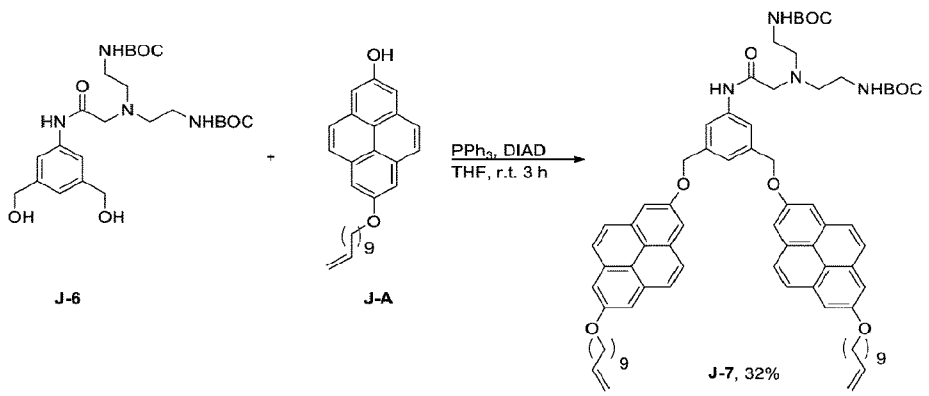
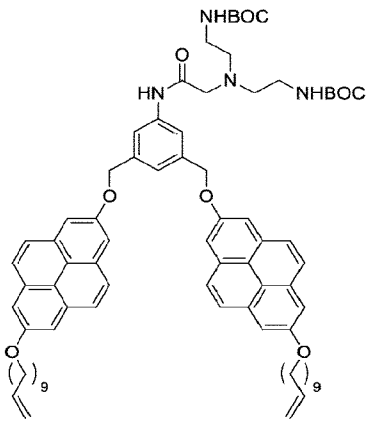


Fig. 39b

Analytical data for "Boc-diamine-carrying precursor-ML of Example B2"
Boc-diamine-carrying precursor-ML of Example B2.
Data for mass spectrometry obtained: HRMS-



MALDI calcd. for $C_{78}H_{96}N_4Na_1O_9$(M+Na)$^+$: 1255.7070 Found: 1255.7062.

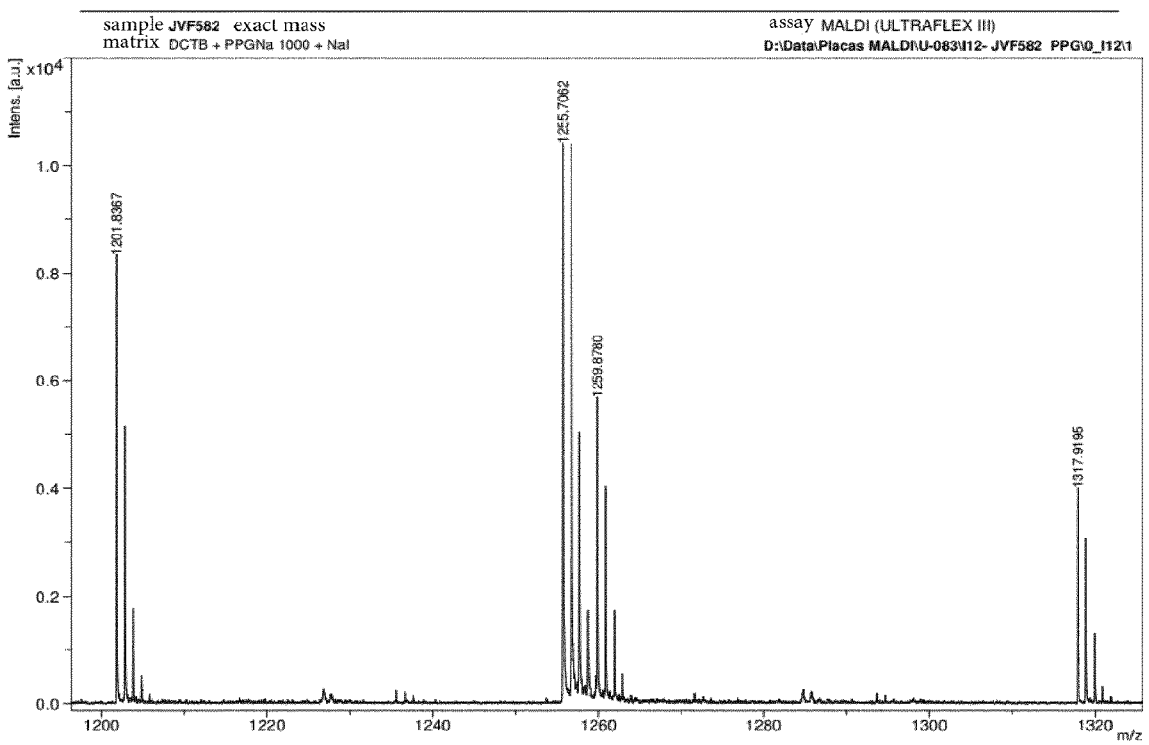


Fig. 39c

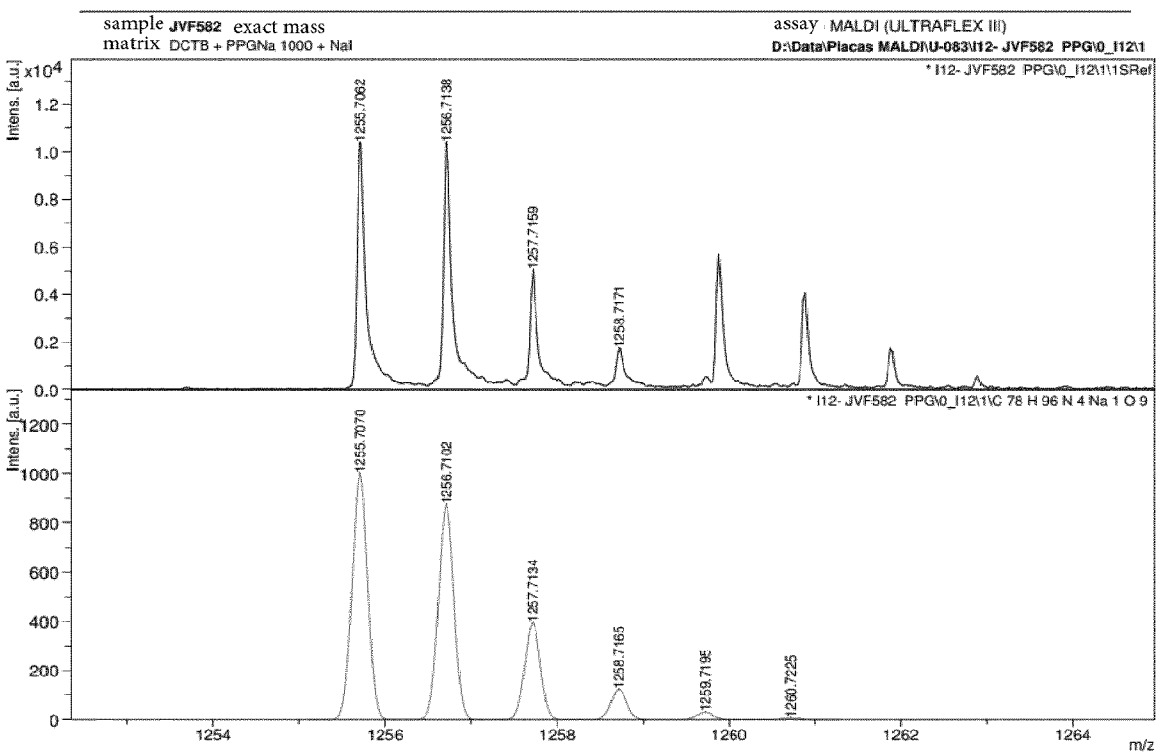
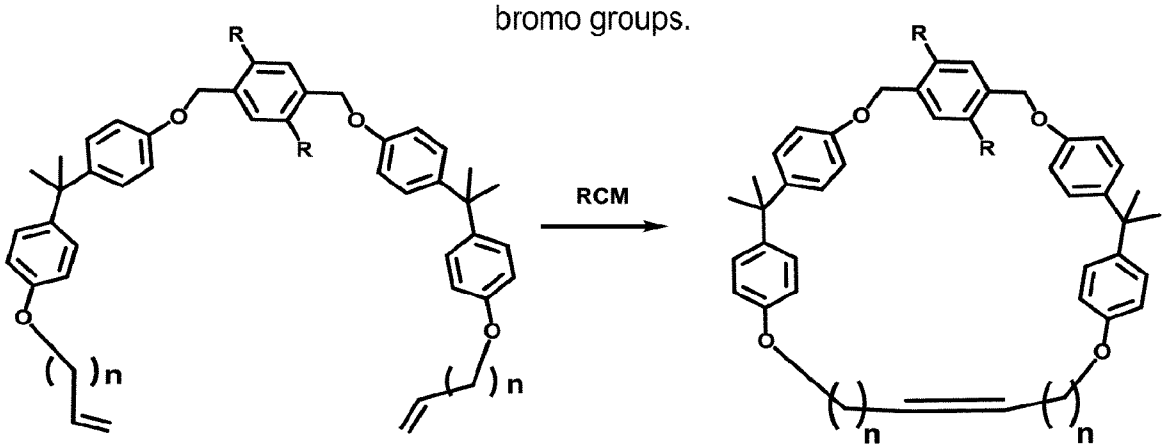


Fig. 39c (Continued)

Preparation of macrocyclic molecule comprising bisphenol A (BPA)-motifs or bromo groups.

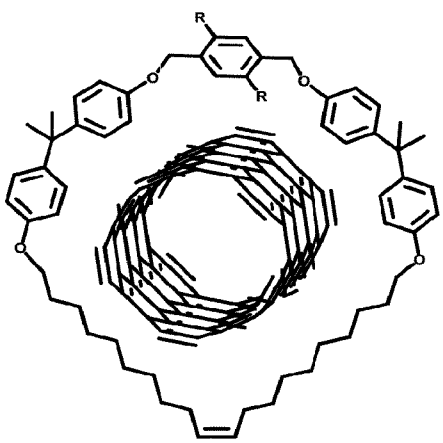


Z-3a, R = H, n = 9
Z-3b, R = Br, n = 9

Z-4a, R = H, n = 9
Z-4b, R = Br, n = 9

Fig. 40a

Structure of macrocyclic molecule around a single-walled carbon nanotube.



R = H or Br, n = 9

Fig. 40b

Synthesis of bisphenol A (BPA) precursor-ML.

Scheme 1

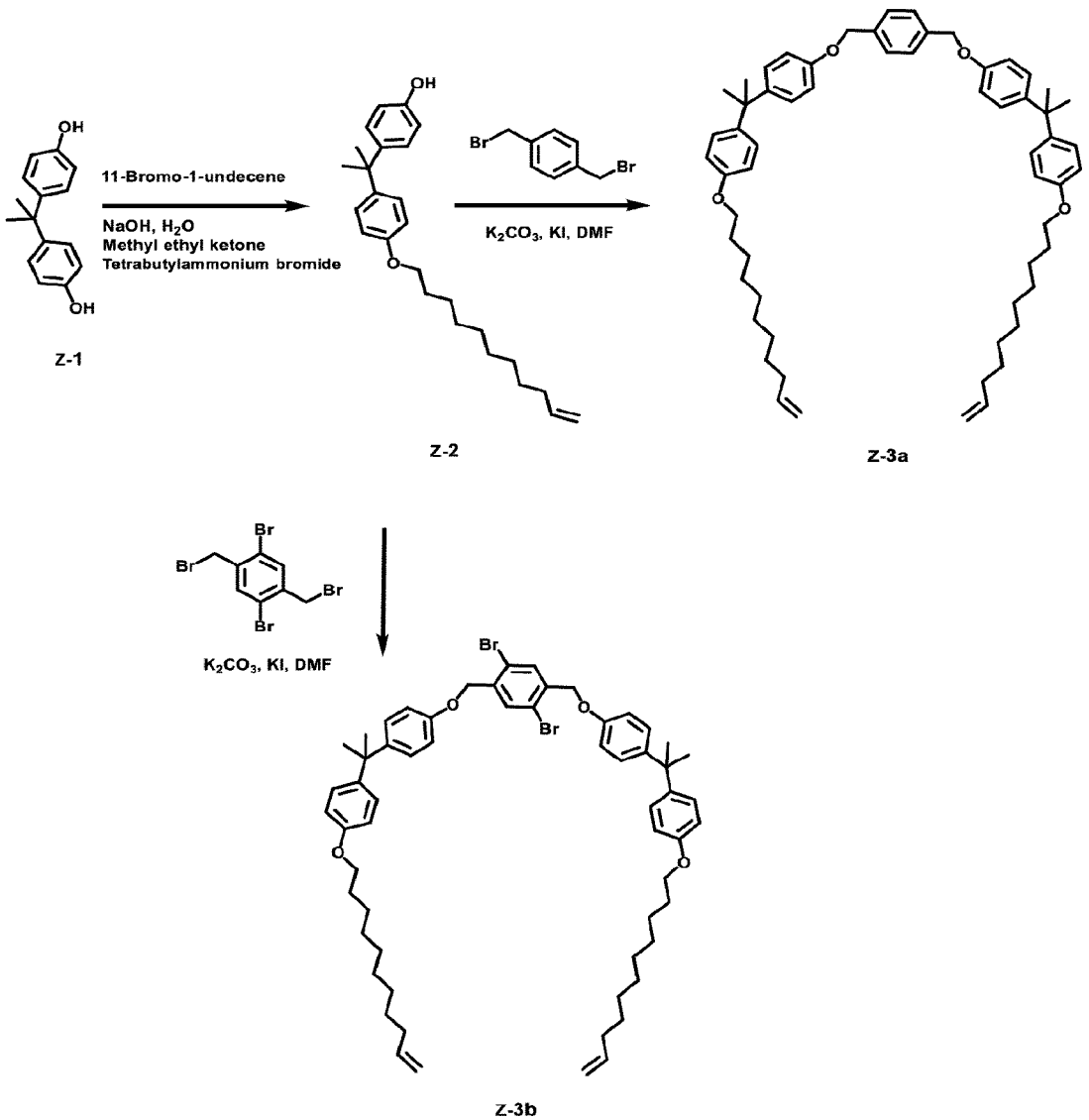
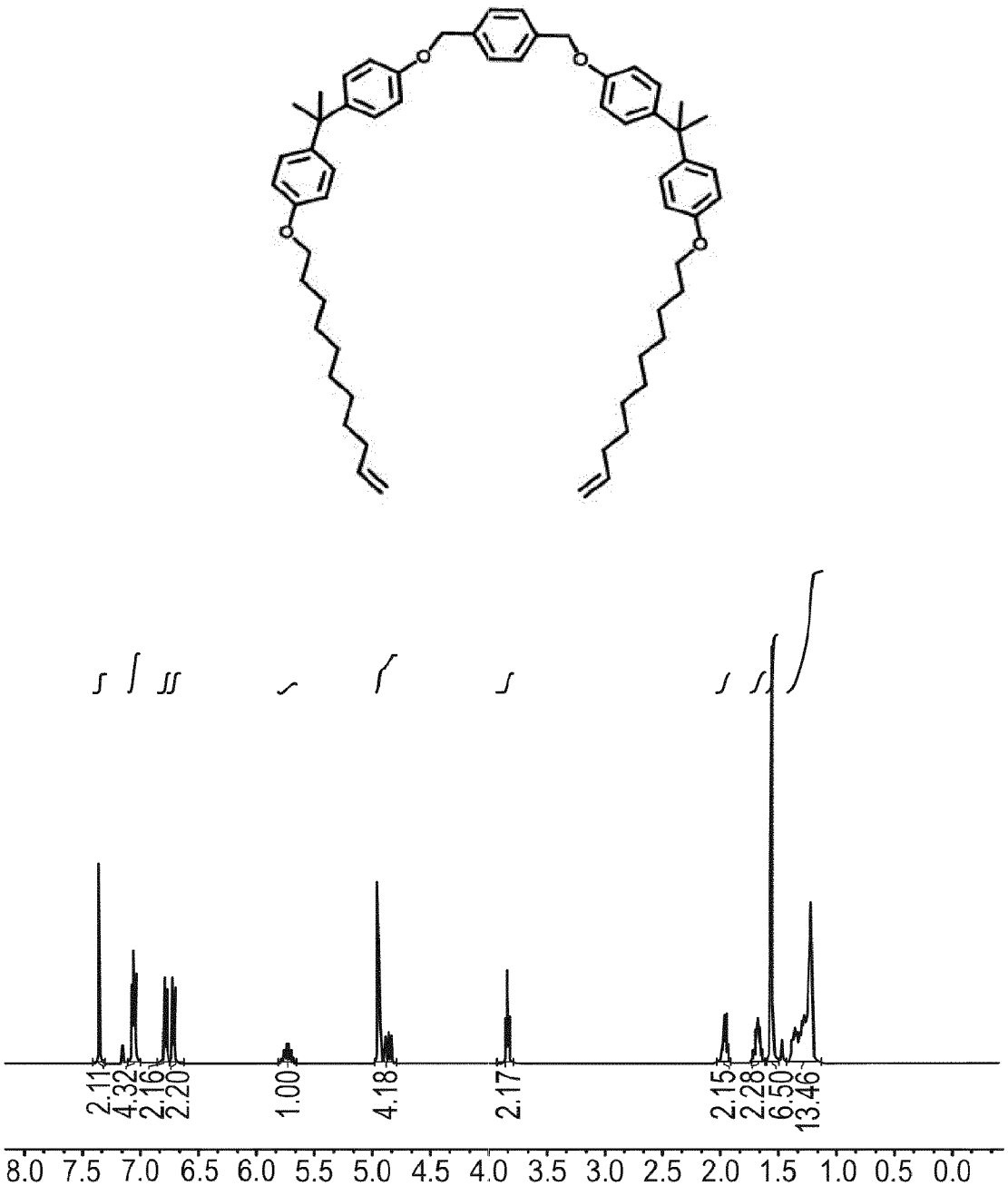


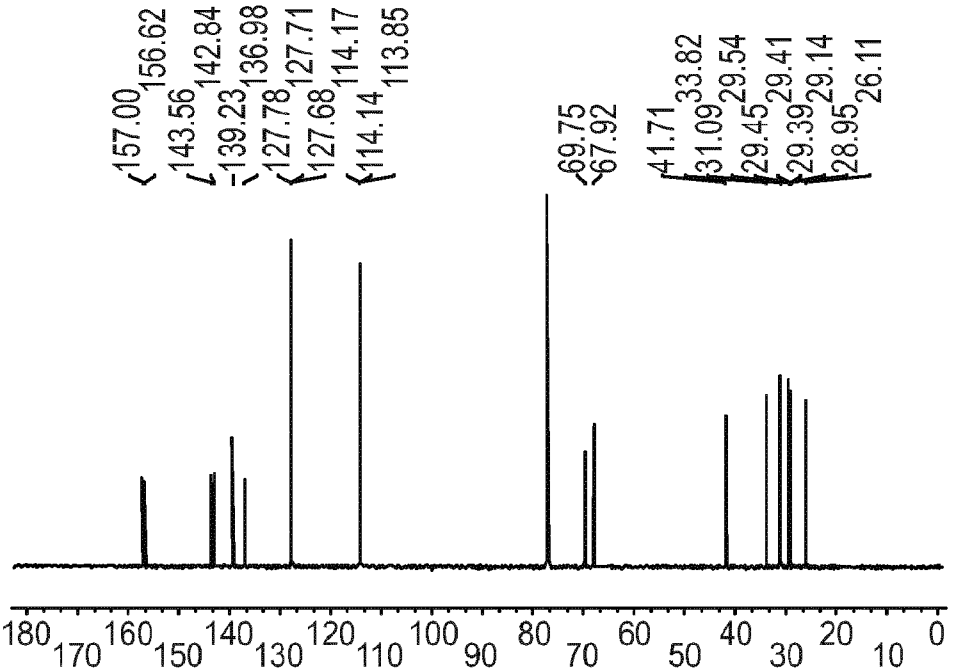
Fig. 40c

Analytical data for bisphenol A (BPA) precursor-ML and macrocyclic molecule.

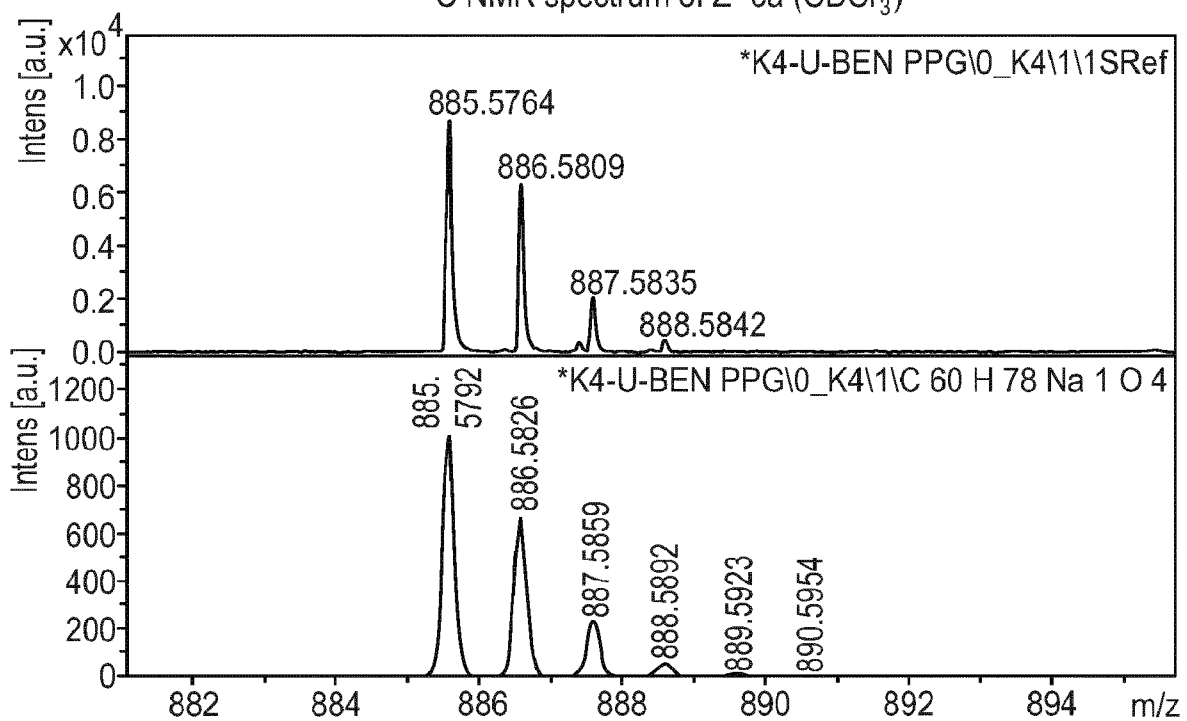


^{1}H NMR spectrum of Z-3a ($CDCl_3$)

Fig. 40d



^{13}C NMR spectrum of Z -3a ($CDCl_3$)



calculated for $C_{60}H_{78}O_4Na$ $[M+Na]^+$ 885.5792, found MALDI 885.5764.

Fig. 40d (Continued)

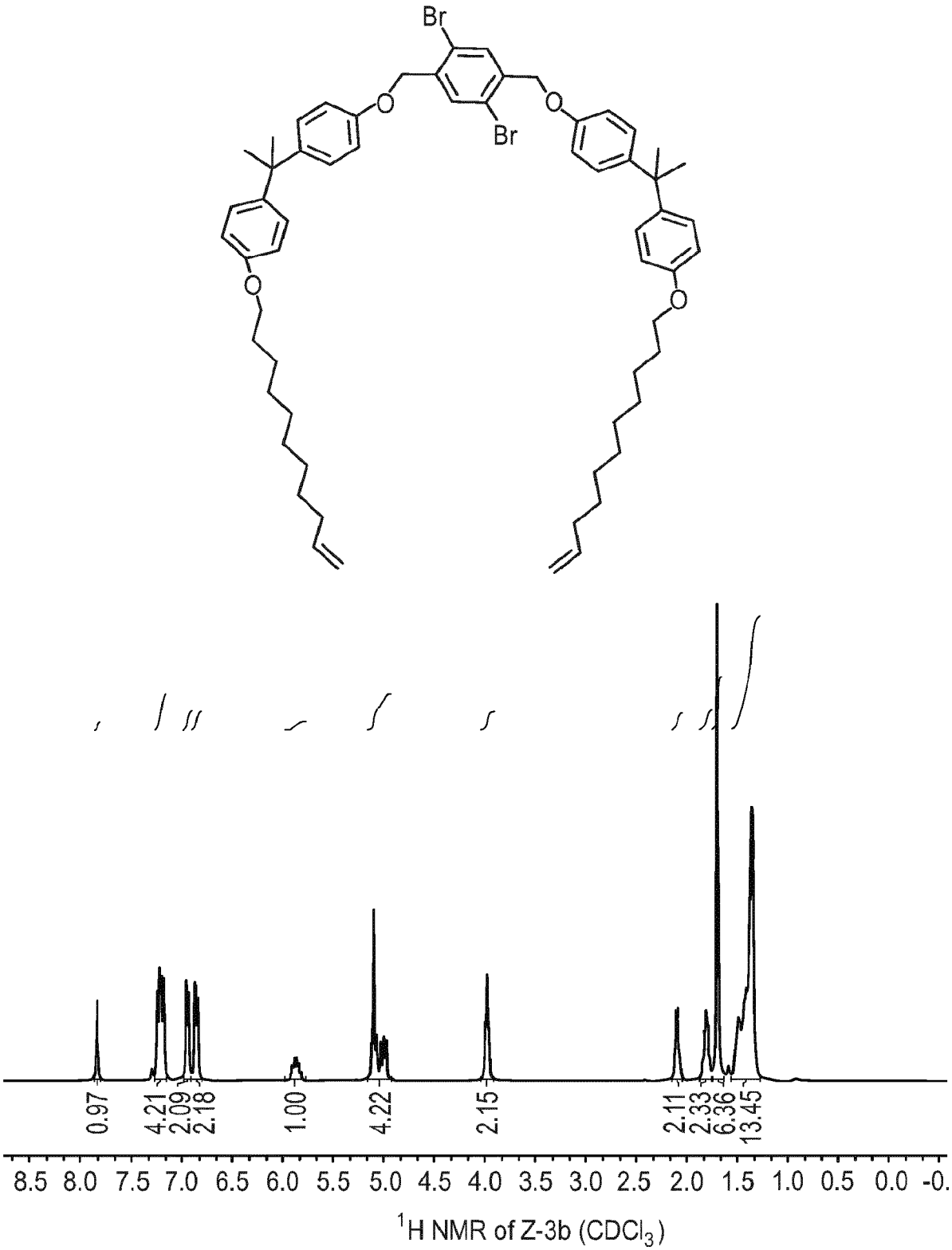
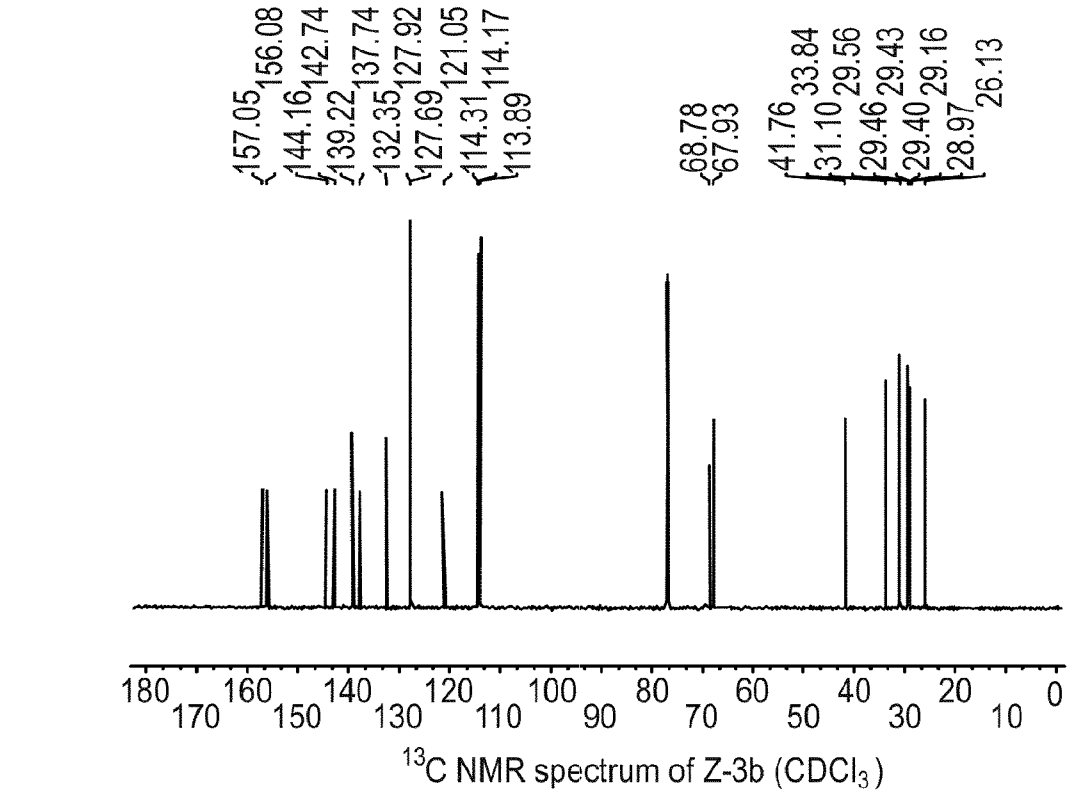


Fig. 40d (Continued)



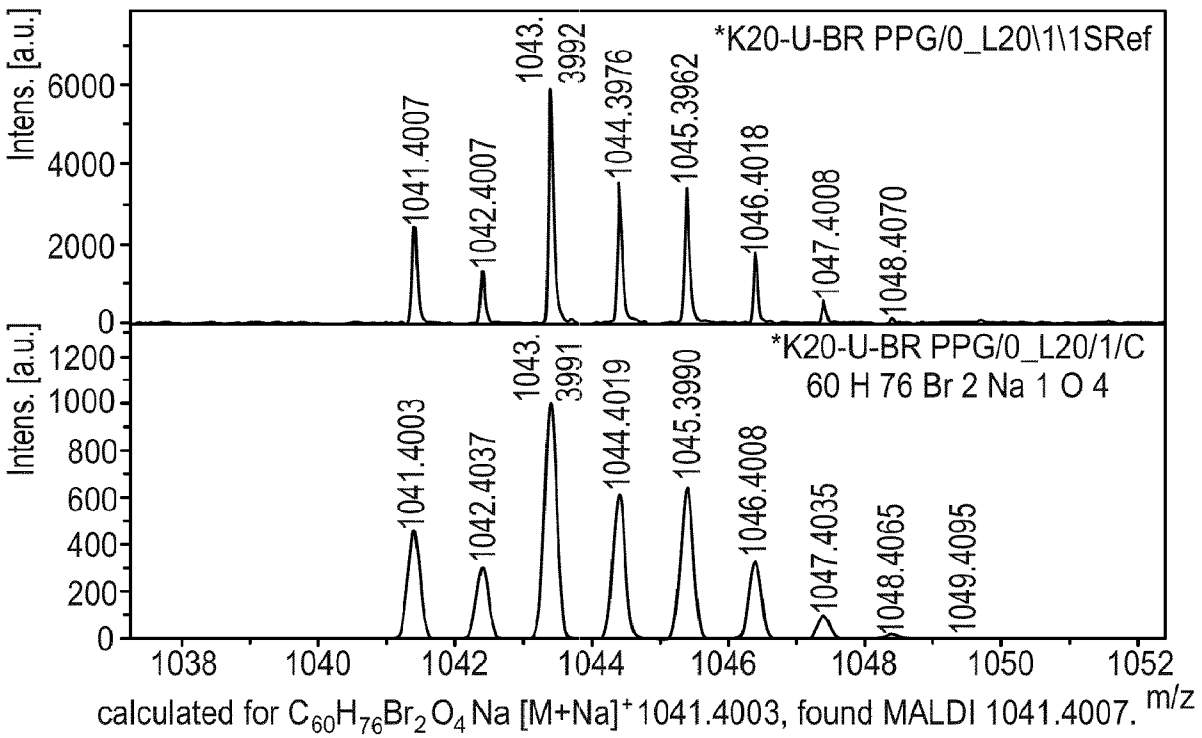
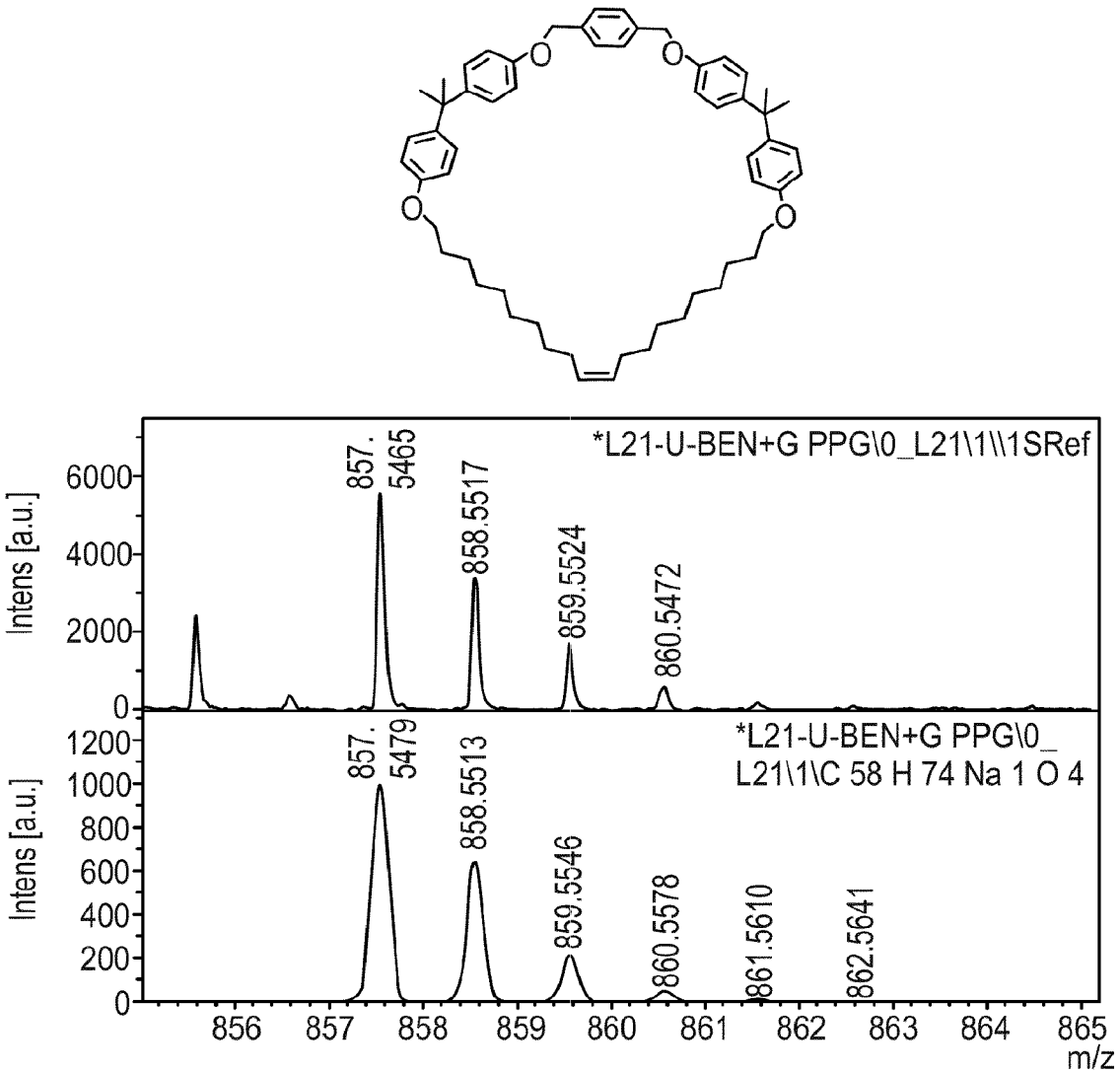


Fig. 40d (Continued)



calculated for $C_{58}H_{74}O_4Na$ $[M+Na]^+$ 857.5749, found MALDI 857.5465.

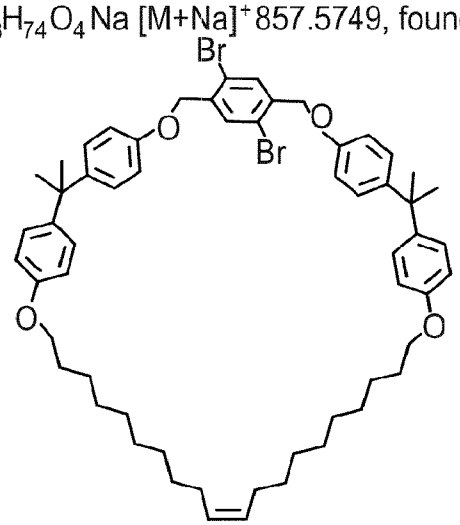
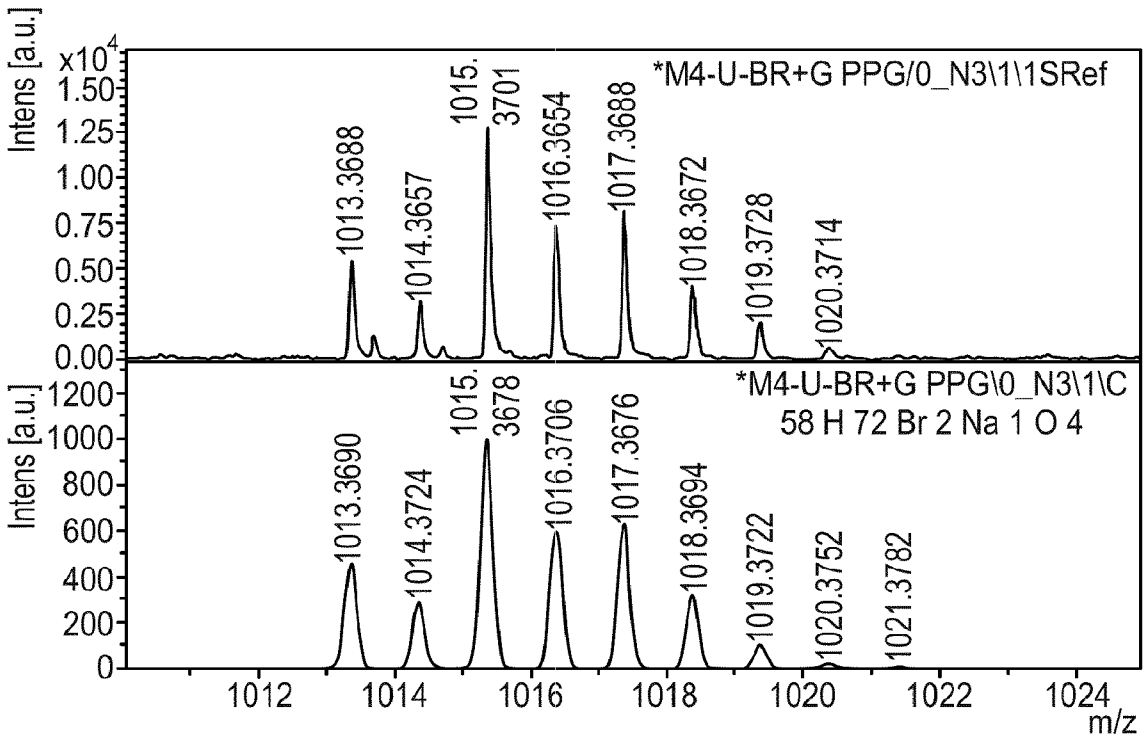


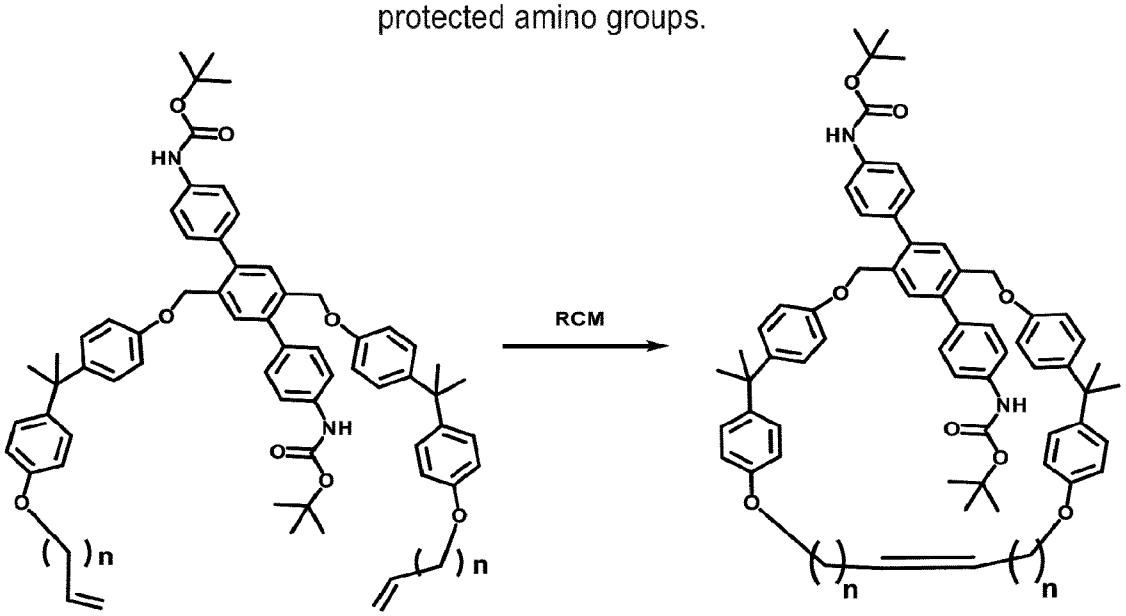
Fig. 40d (Continued)



calculated for $C_{58}H_{72}Br_2O_4Na$ $[M+Na]^+$1013.3690, found MALDI 1015.3688.

Fig. 40d (Continued)

Preparation of macrocyclic molecule comprising tert-butoxycarbonyl (Boc)-protected amino groups.



Z-6 Z-7, n = 9

Fig. 40e

Structure of macrocyclic molecule comprising tert-butoxycarbonyl (Boc)-protected amino groups, wrapped around a single-walled carbon nanotube.

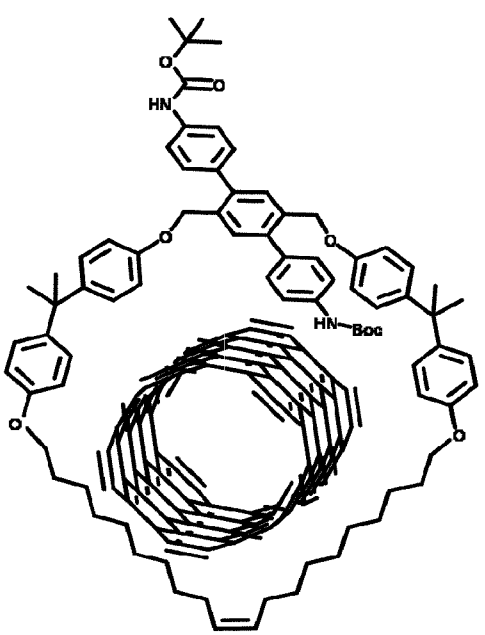
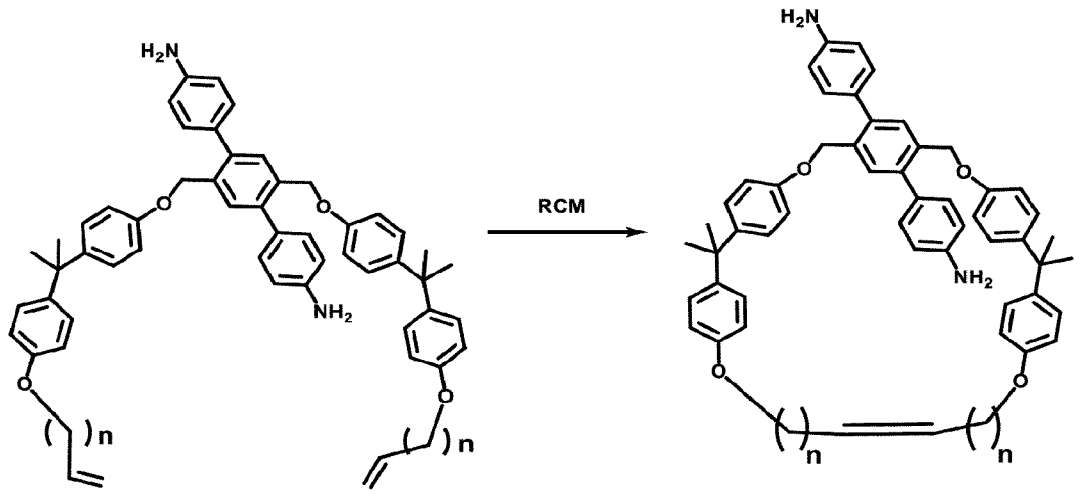


Fig. 40f

Preparation of macrocyclic molecule comprising amino groups.



Z-5 Z-8, n = 9

Fig. 40g

Structure of macrocyclic molecule comprising amino groups, wrapped around a single-walled carbon nanotube.

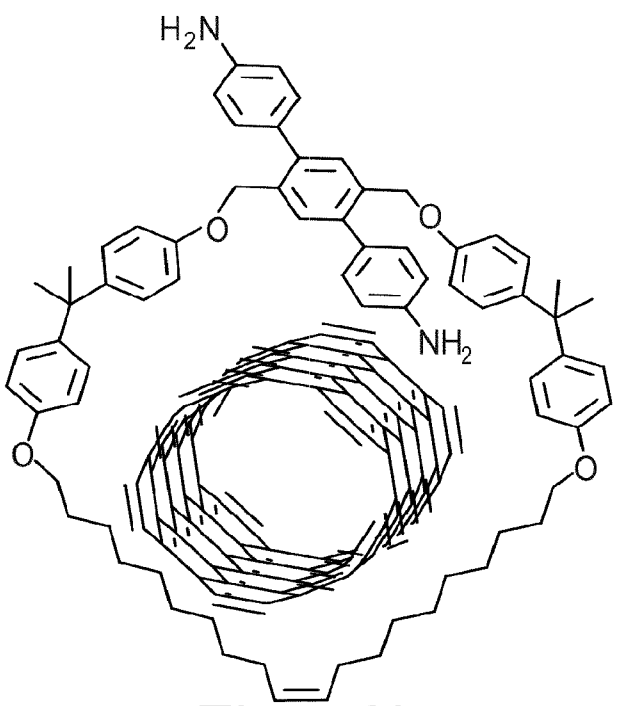


Fig. 40h

Synthesis of bisphenol A (BPA) precursor-ML comprising amino groups.

Scheme 2

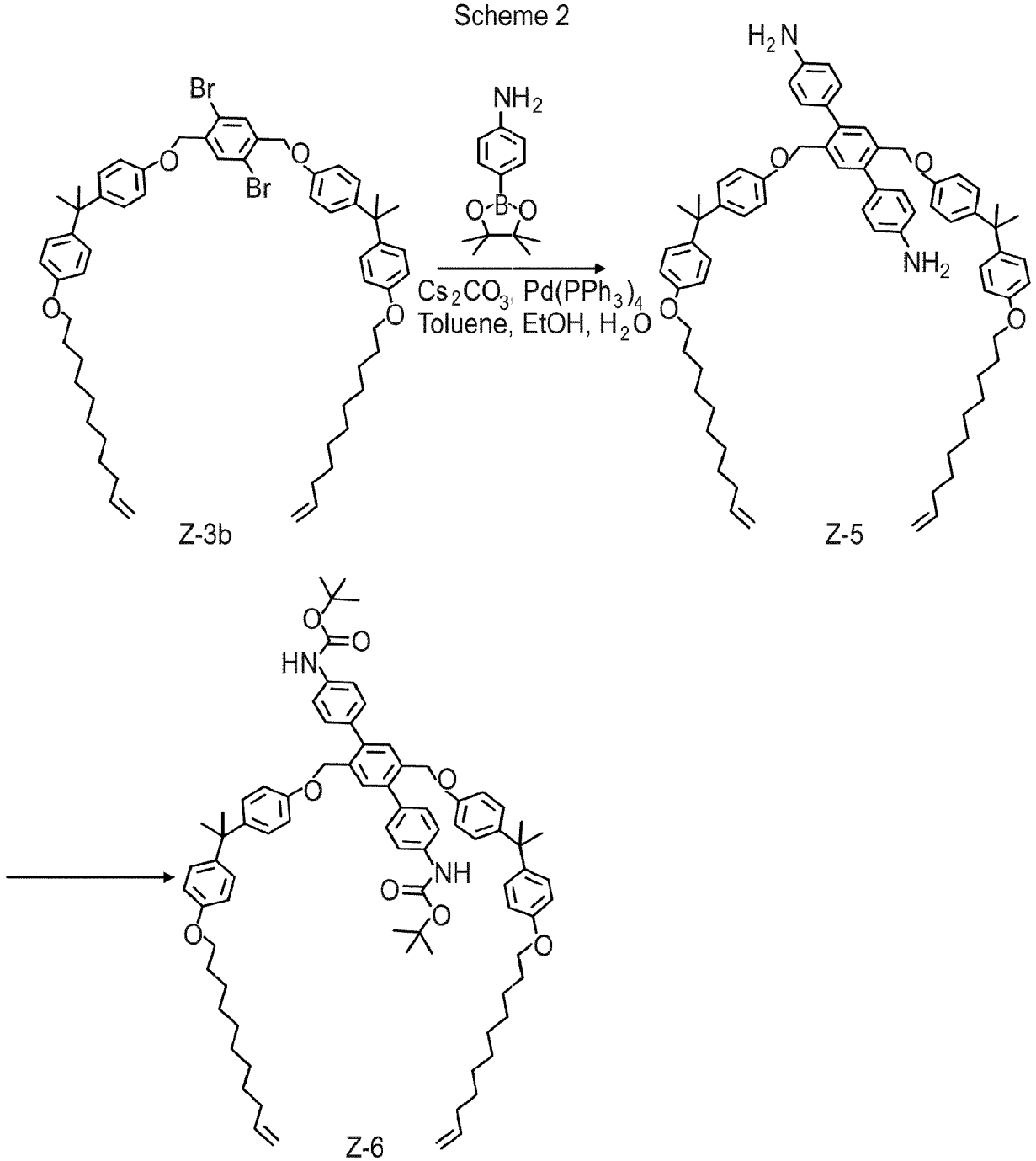
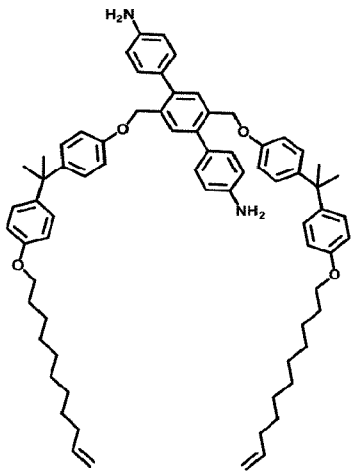
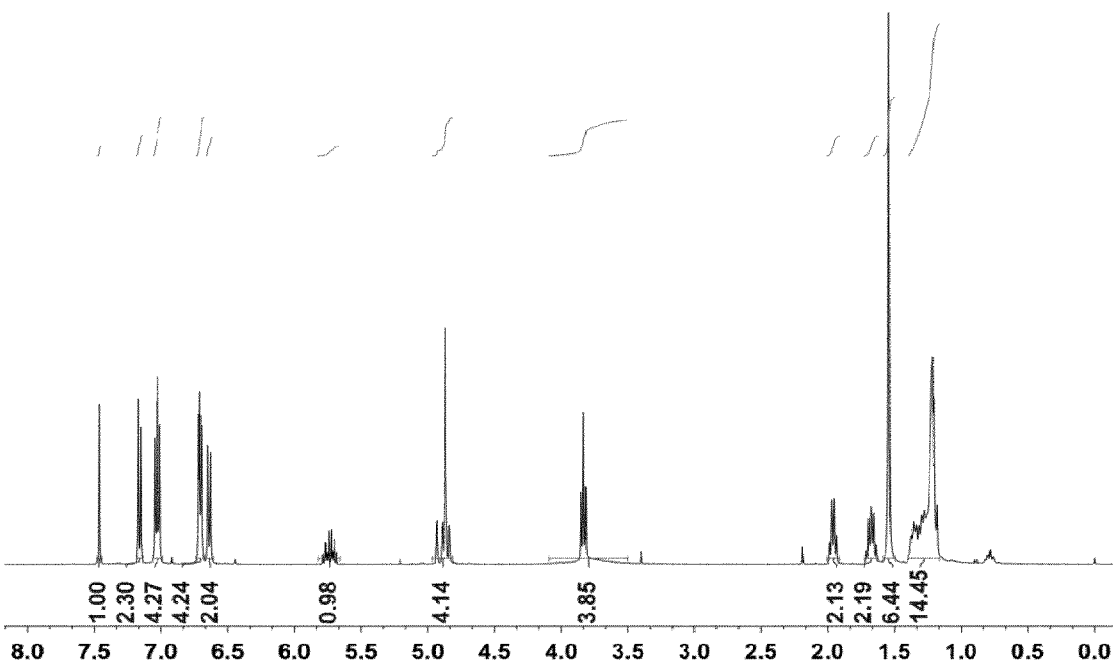


Fig. 40i

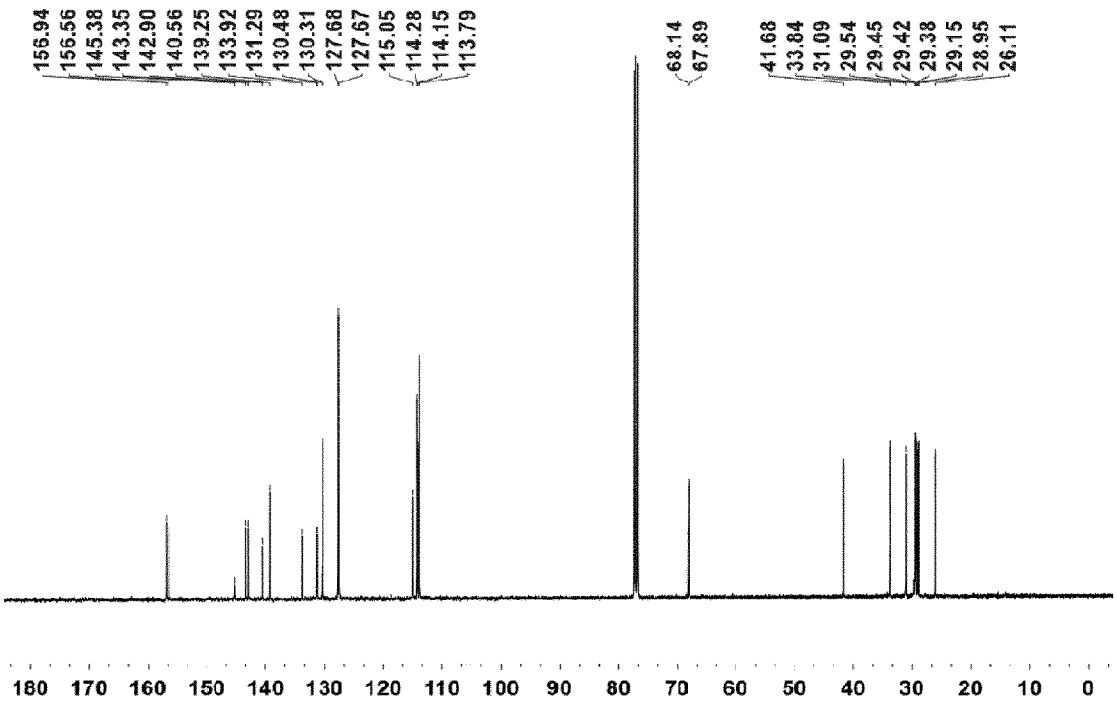
Analytical data for bisphenol A (BPA) precursor-ML and macrocyclic molecule comprising amino groups.



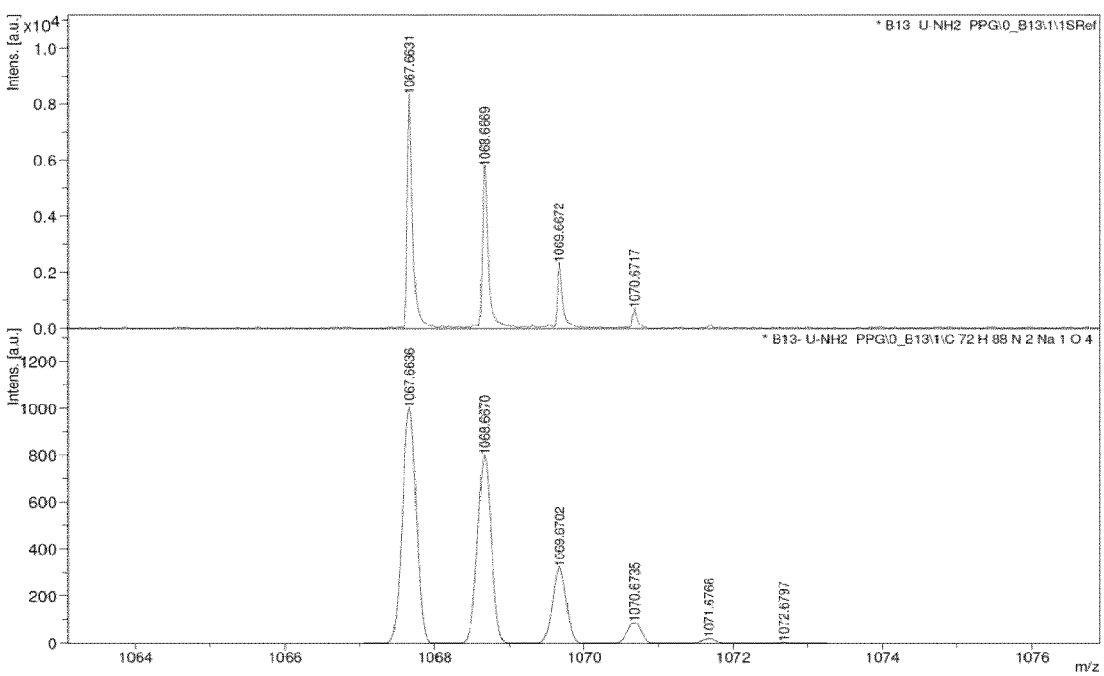


^{1}H NMR spectrum of **Z-5** ($CDCl_3$)

Fig. 40j

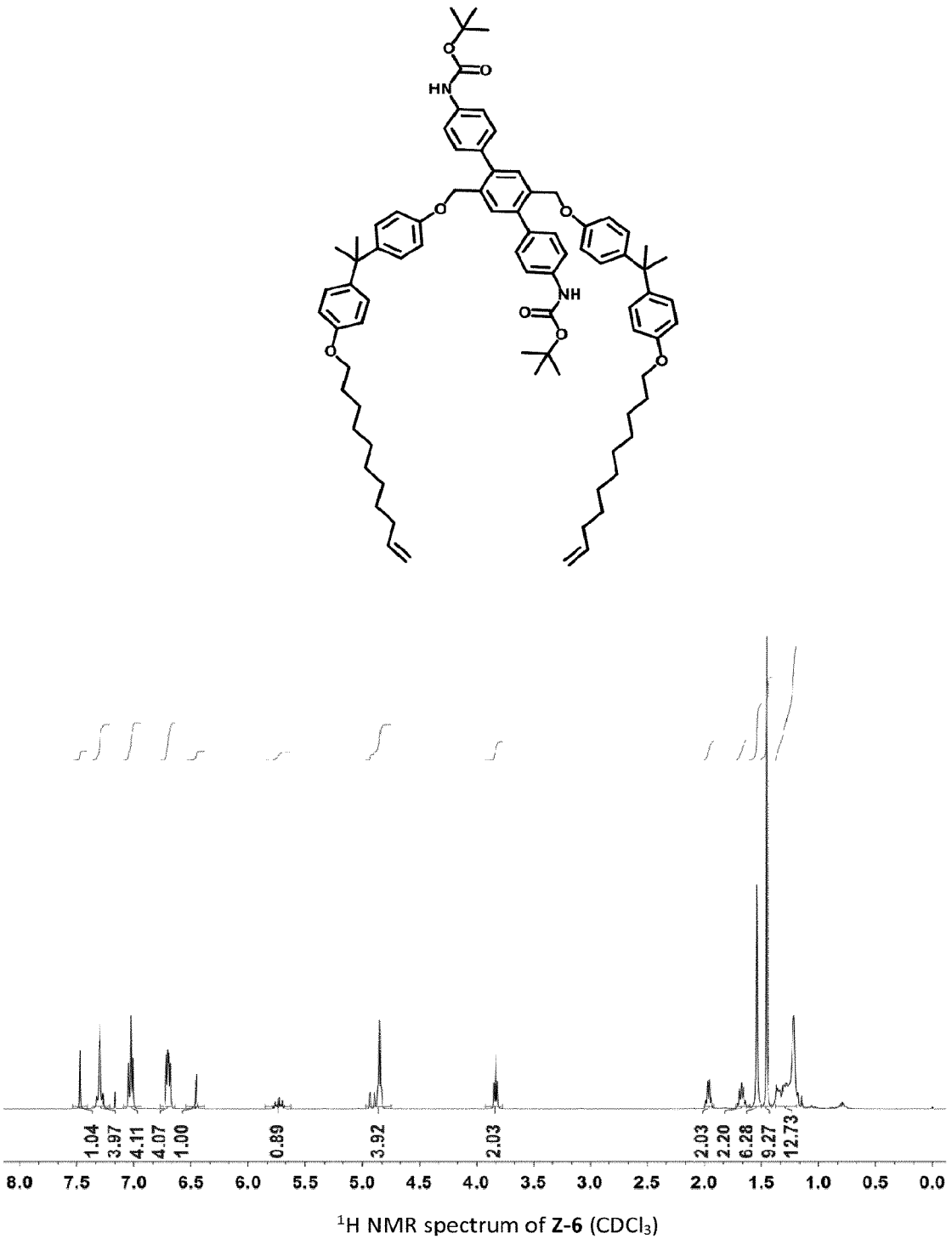


^{13}C NMR spectrum of **Z-5** ($CDCl_3$)



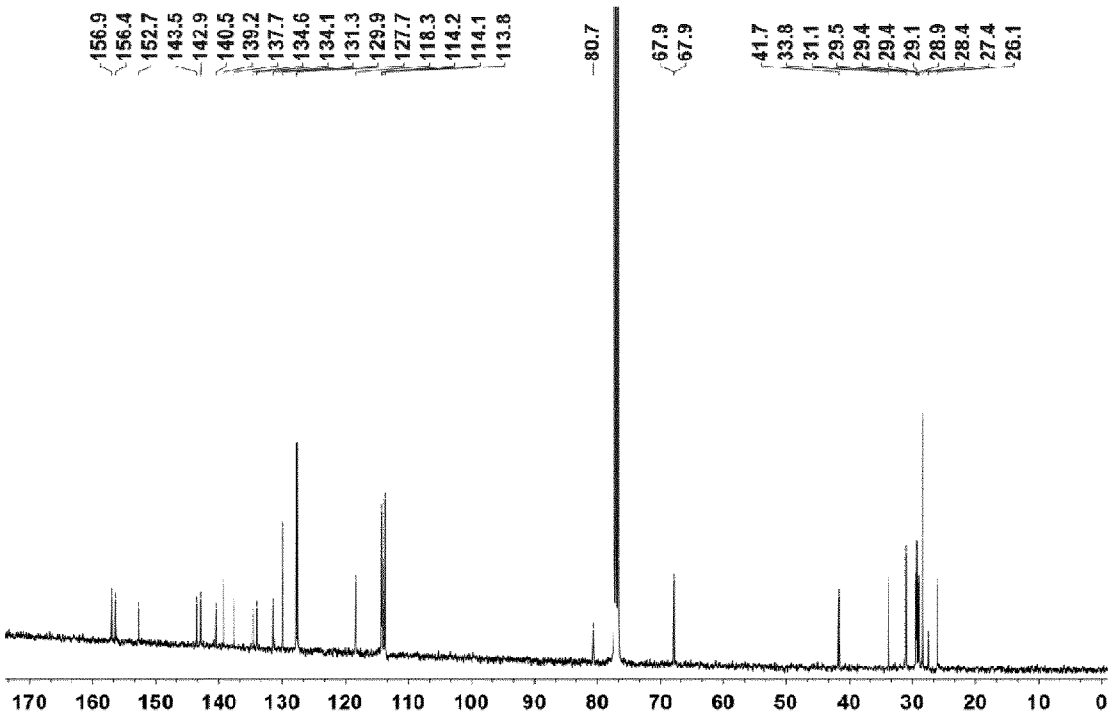
calculated for $C_{72}H_{88}N_2O_4Na$ $[M+Na]^+$ 1067.6636, found MALDI 1067.6631.

Fig. 40j (Continued)

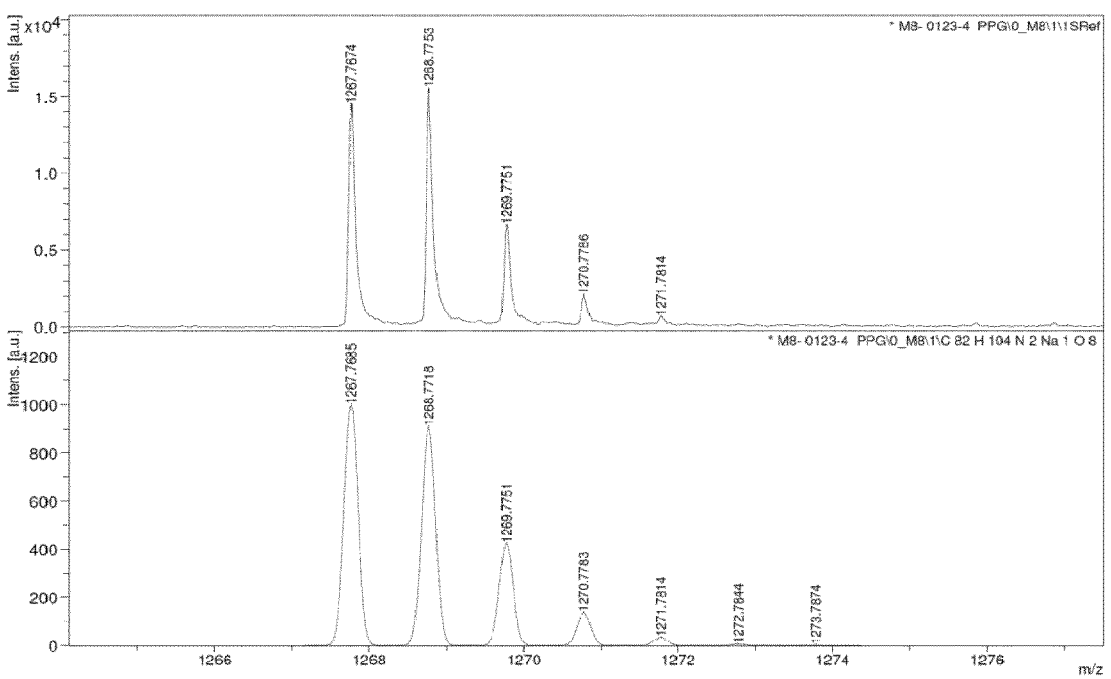


^{1}H NMR spectrum of **Z-6** ($CDCl_3$)

Fig. 40j (Continued)

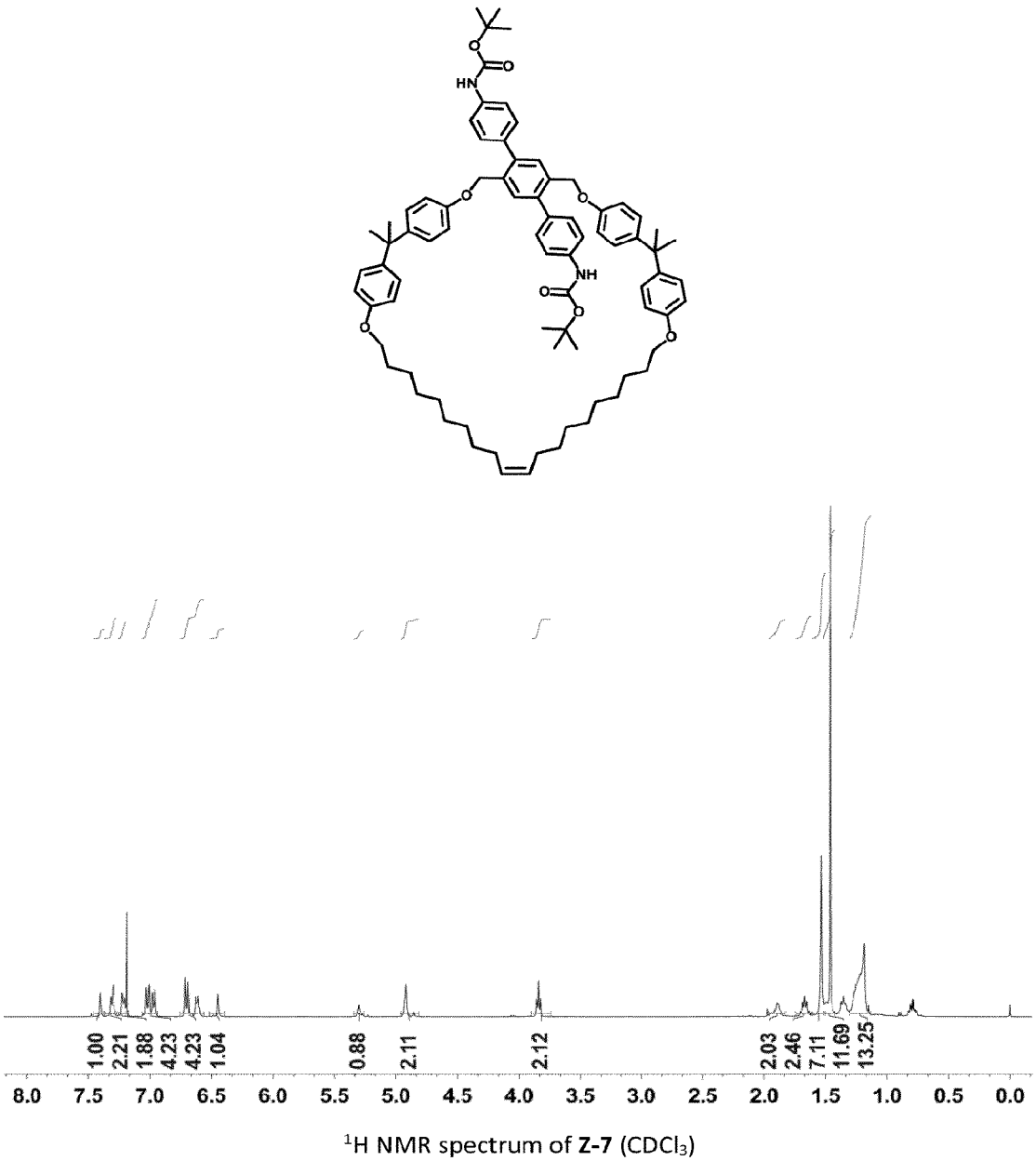


^{13}C NMR spectrum of **Z-6** ($CDCl_3$)



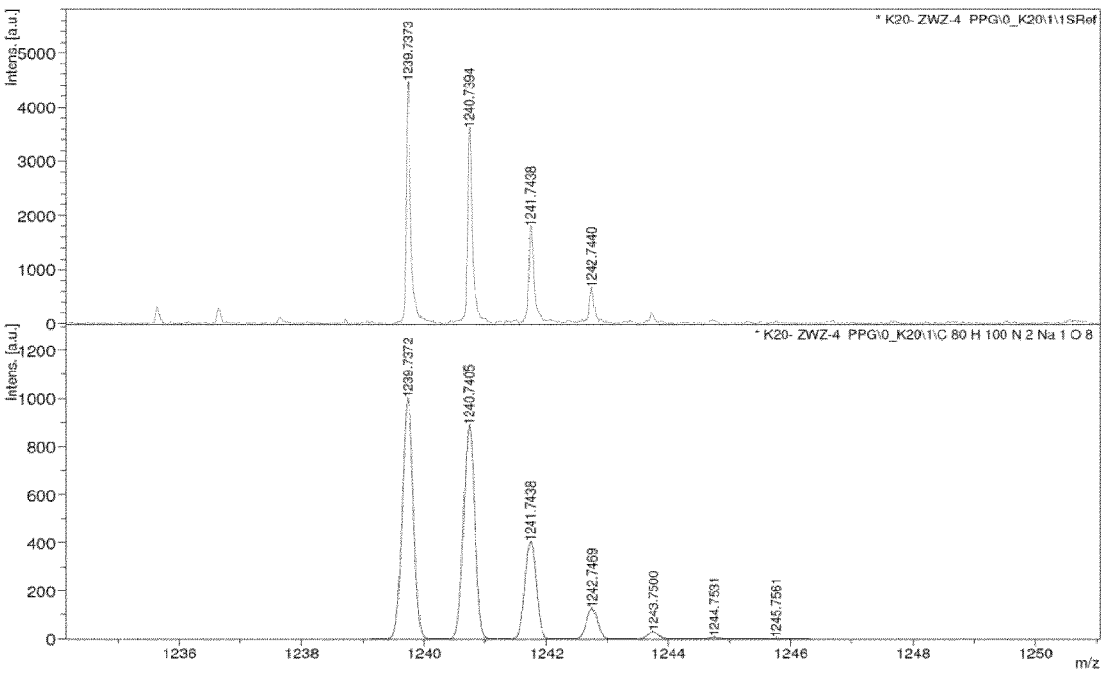
calculated for $C_{82}H_{104}N_2O_8Na$ $[M+Na]^+$ 1267.7685, found MALDI 1267.7674.

Fig. 40j (Continued)



^{1}H NMR spectrum of **Z-7** ($CDCl_3$)

Fig. 40j (Continued)



calculated for C80H100N2O8Na [M+Na]+ 1239.7372, found MALDI 1239.7373.

Fig. 40j (Continued)

Different nanofillers used to prepare viscous suspensions of 10 (w/w) % PMMA polymer.

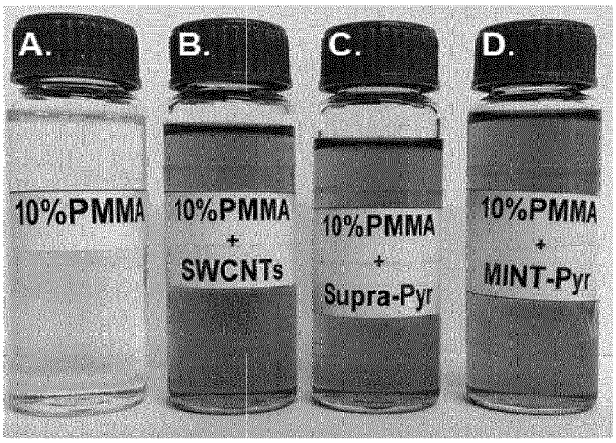


Fig. 41

Electrospun fibers of PMMA polymer (A) and PMMA with different nanofillers based on SWNT (B-D). No Macroscopic differences were observed.

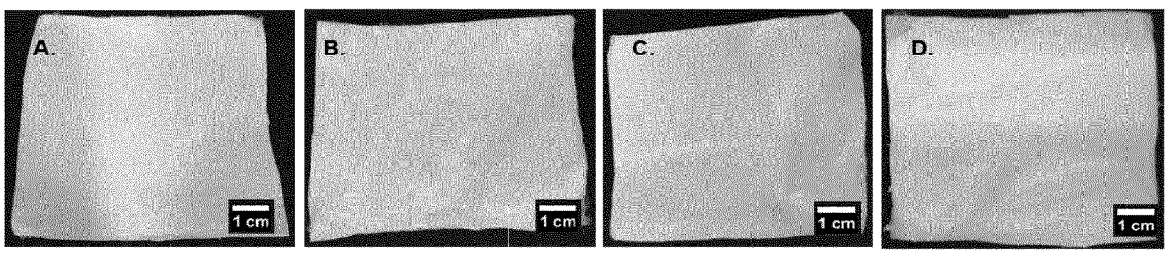


Fig. 42

Rectangular shaped PMMA fibers composite sample of dimensions of 1×4 cm placed at DMA Q800, TA instruments.

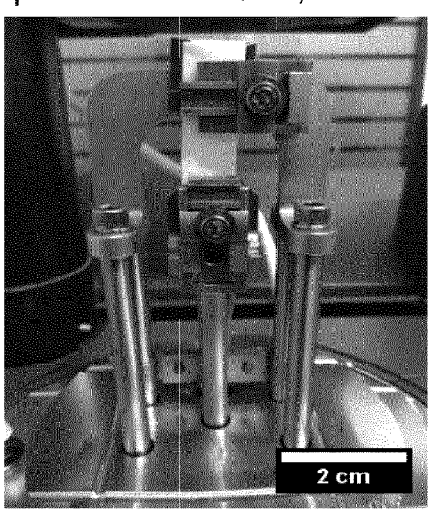


Fig. 43

SEM pictures of PMMA polymer fibers (A) and PMMA with different nanofillers based on SWNT (B-D).

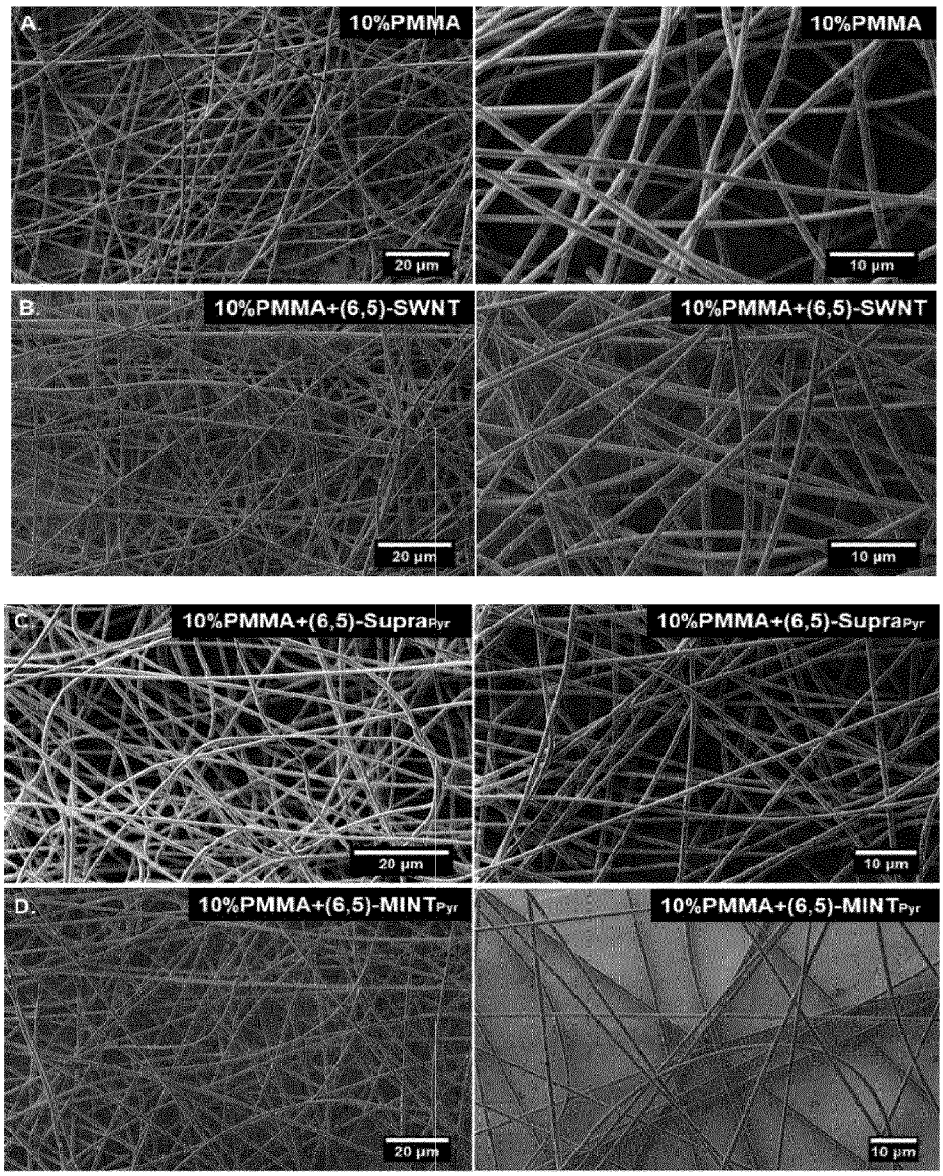


Fig. 44

Diameter distributions for PMMA fibers estimated from SEM pictures.

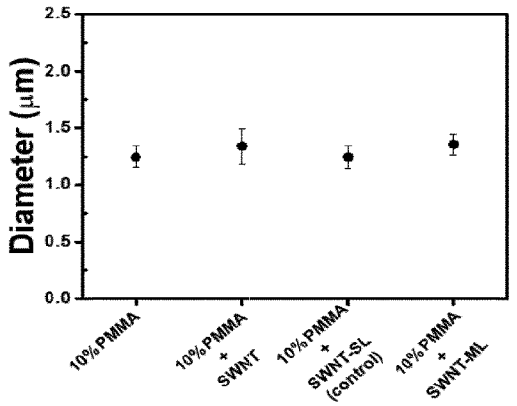


Fig. 45

Fiber area density distribution for PMMA electrospun fibers.

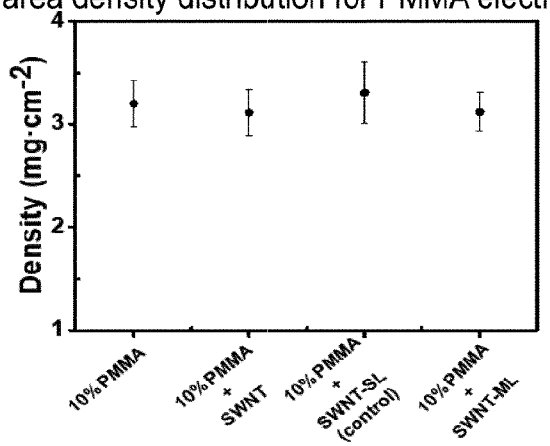


Fig. 46

Representative stress/strain curves of PMMA (grey) and its composites with SWNTs (black), "SWNT-SL of example H1" (blue) and "SWNT-ML of example B4" (red).

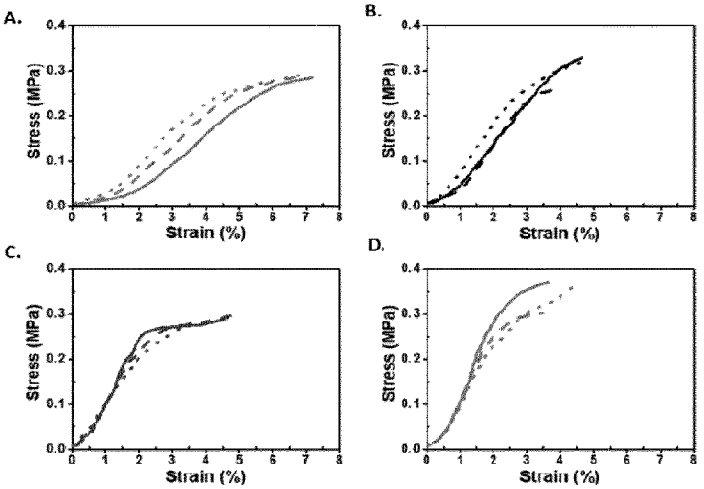


Fig. 47

Representative stress/strain curves of PMMA (grey) and its composites with SWNTs (black), "SWNT-SL of example H1" (blue) and "SWNT-ML of example B4" (red).

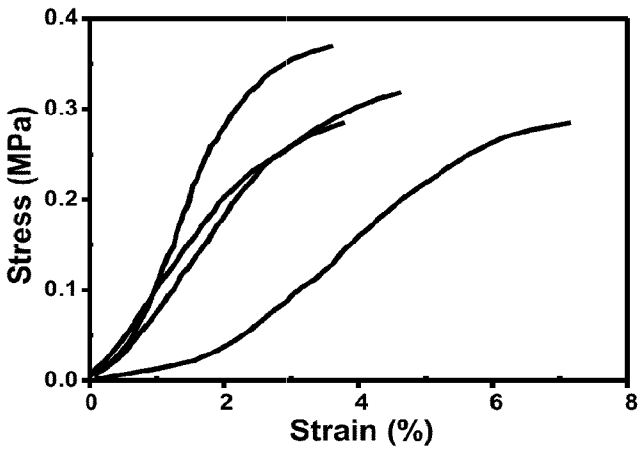


Fig. 48

Measured mechanical properties observed for PMMA polymer fibers and PMMA with different nanofillers based on SWNT. A. Young's Modulus. B. Tensile Strength C. Strain (%).

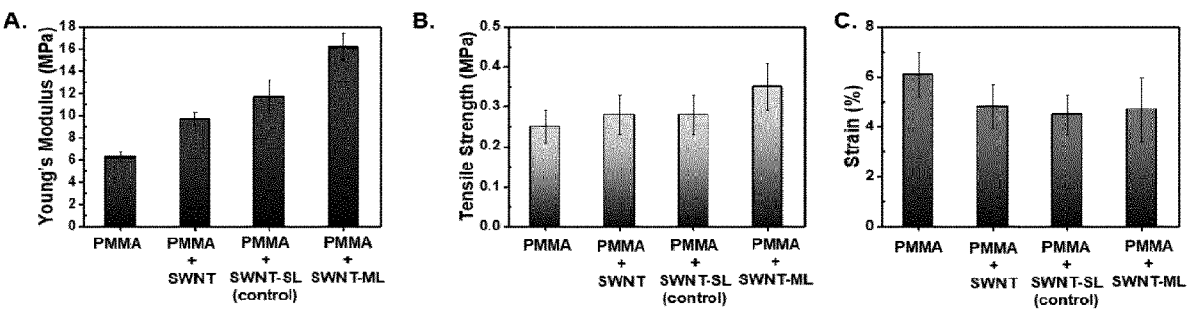


Fig. 49

Different nanofillers used to prepare viscous suspensions of 25 (w/w) % PSU polymer.

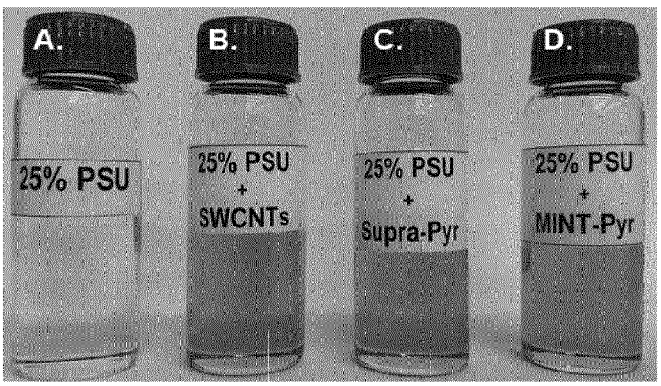


Fig. 50

Electrospun fibers of PSU polymer (A) and PSU with different nanofillers based on SWNT (B-D). No Macroscopic differences were observed.

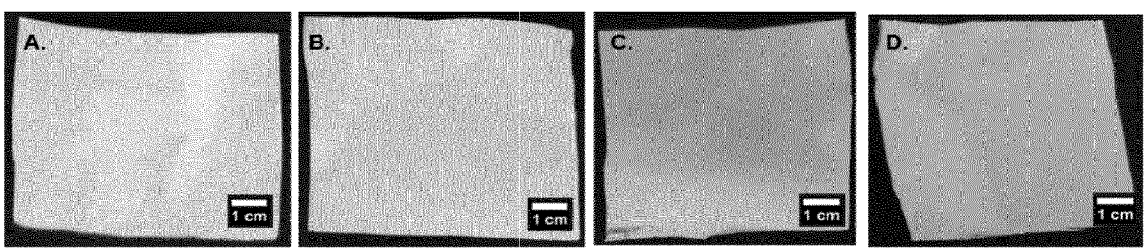


Fig. 51

SEM pictures of PSU polymer fibers (A) and PSU with different nanofillers based on SWNT (B-D).

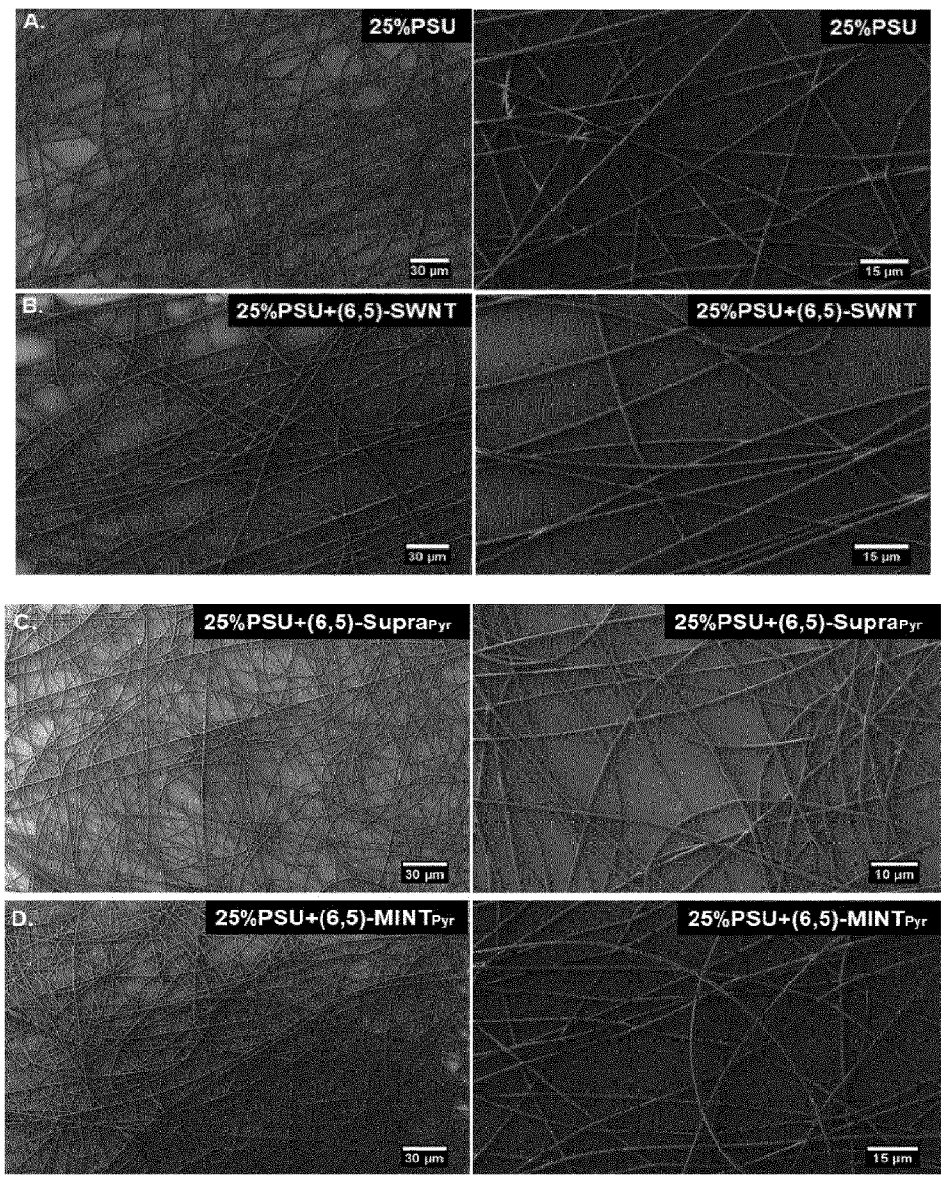


Fig. 52

Diameter distributions for PSU fibers estimated from SEM pictures.

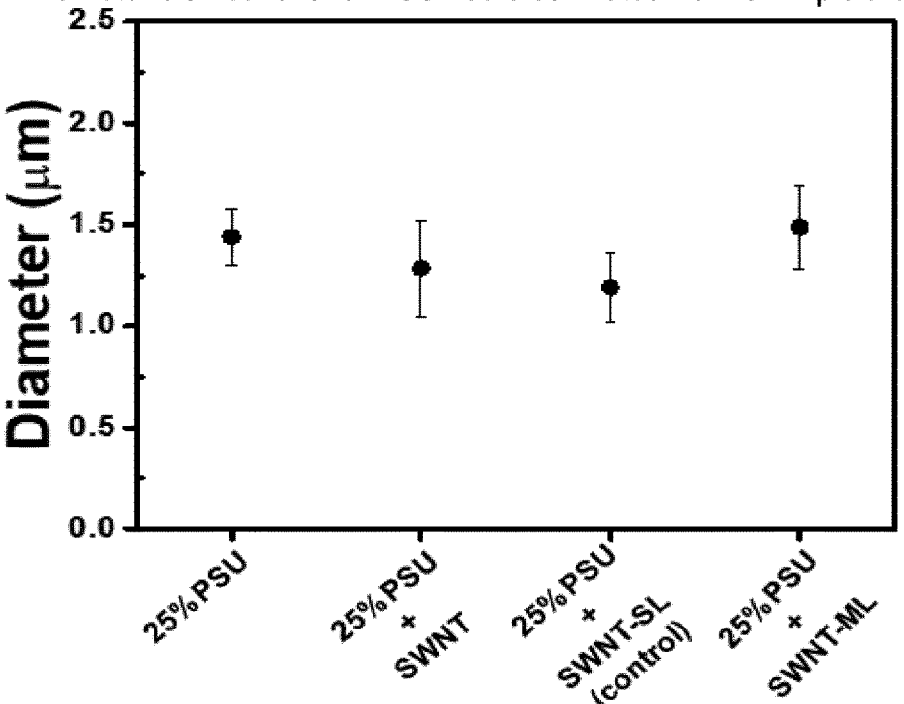


Fig. 53

Fiber area density distribution for PSU electrospun fibers.

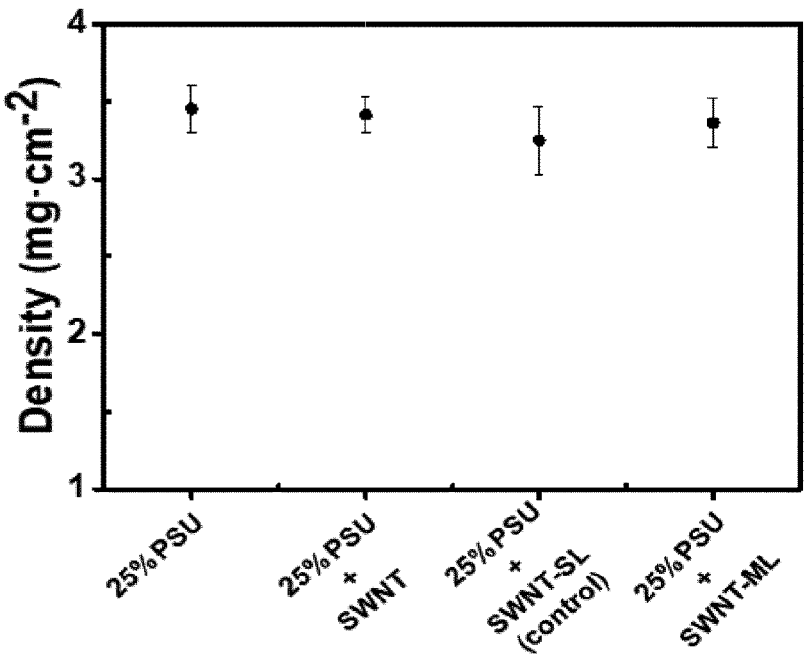


Fig. 54

Representative Stress-Strain curves of PSU (grey) and its composites with SWNTs (black), "SWNT-SL of example H1" (blue); "SWNT-ML of example B4" (red).

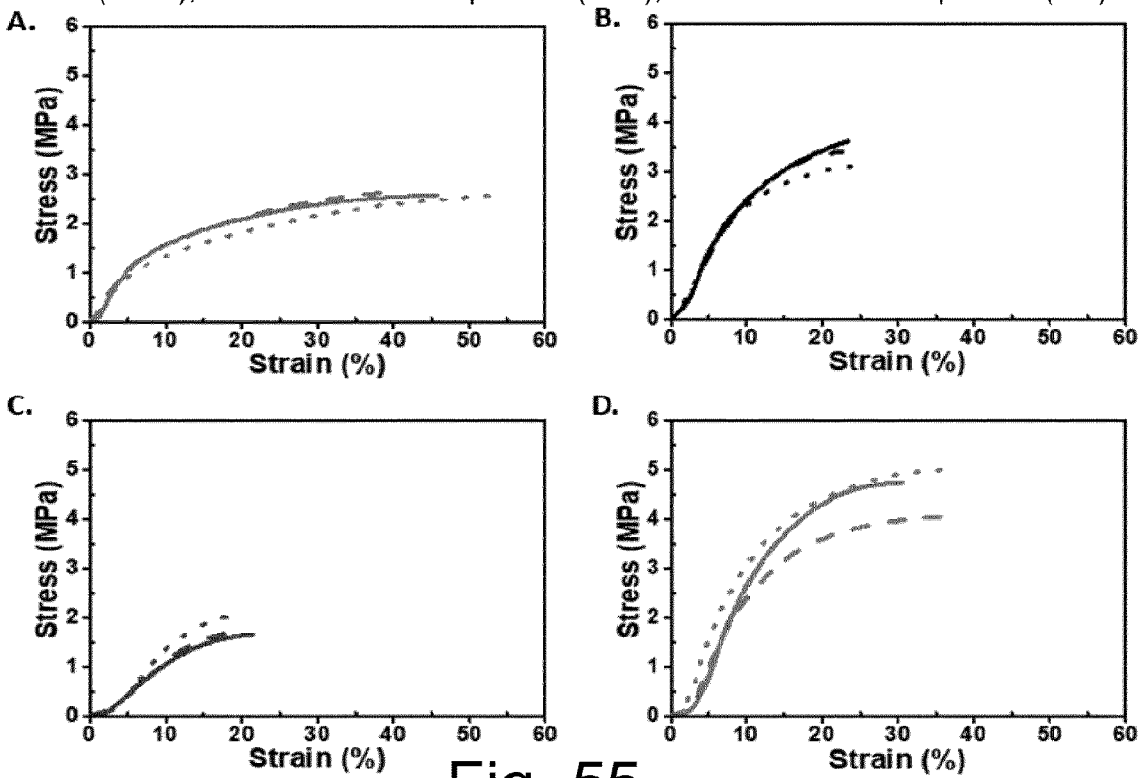


Fig. 55

Representative stress/strain curves of PSU (grey) and its composites with SWNTs (black), "SWNT-SL of example H1" (blue); "SWNT-ML of example B4" (red).

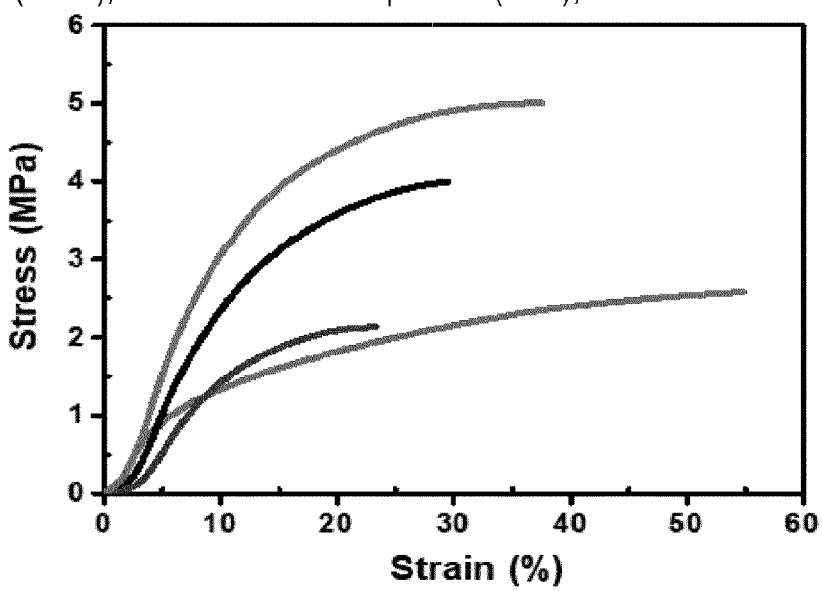


Fig. 56

Measured mechanical properties observed for PSU polymer fibers and PSU with different nanofillers based on SWNT (B-D). A. Young's Modulus. B. Tensile Strength C. Strain (%).

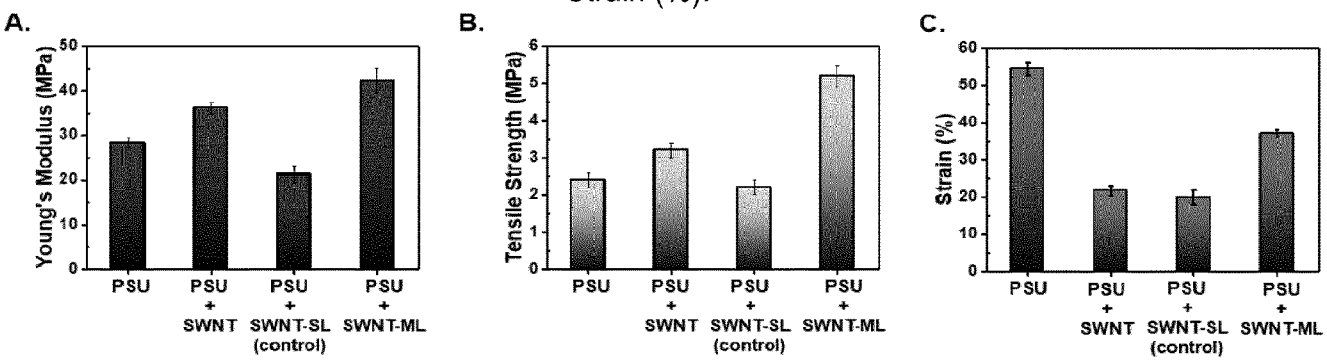


Fig. 57

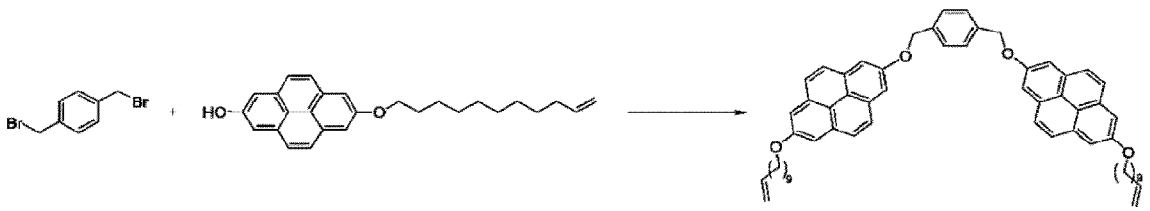


Fig. 58

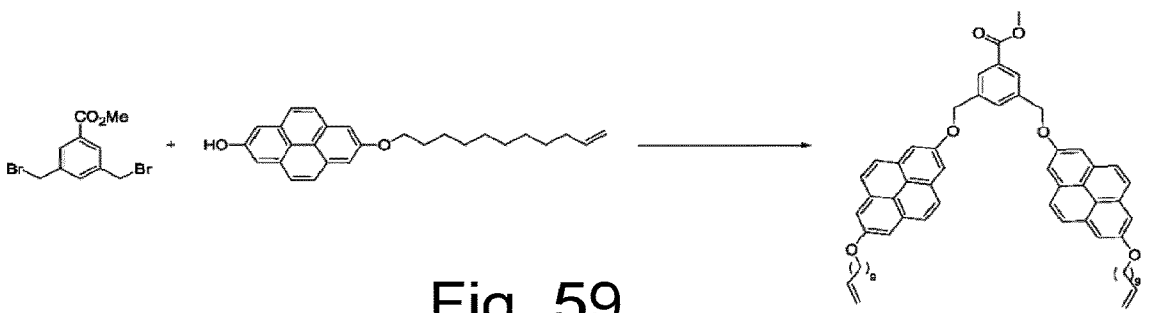


Fig. 59

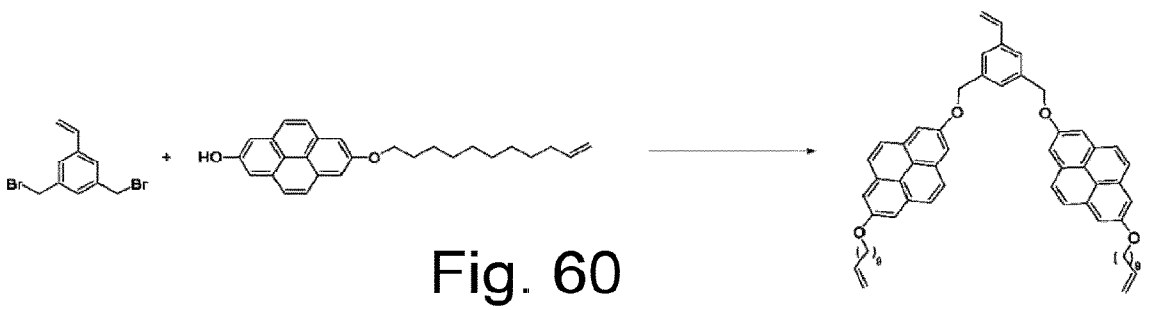


Fig. 60

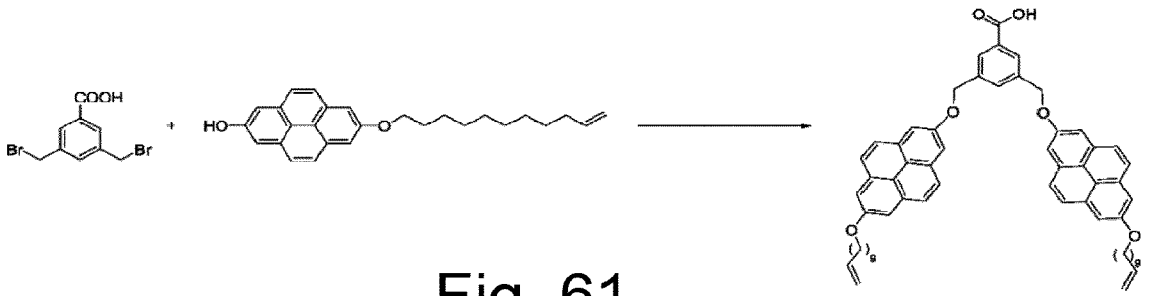


Fig. 61

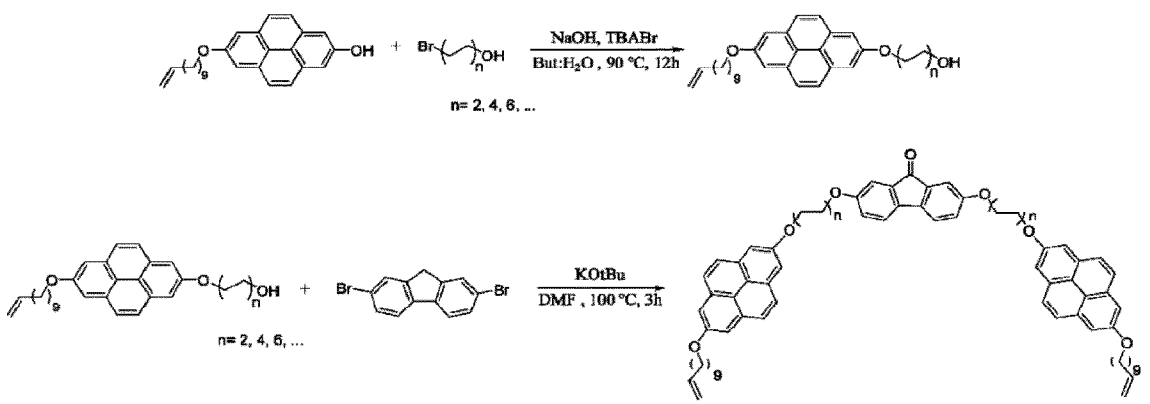


Fig. 62

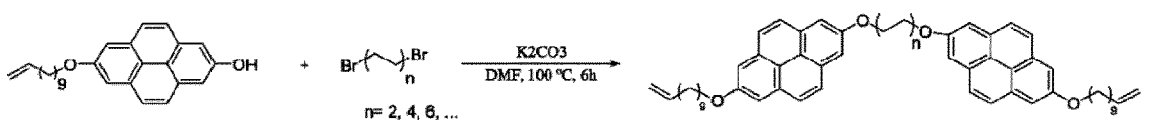


Fig. 63

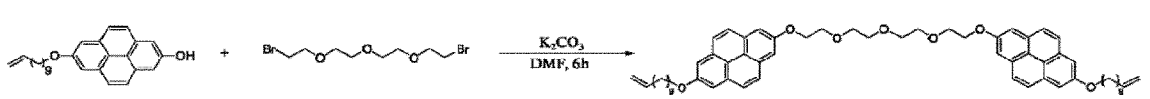


Fig. 64

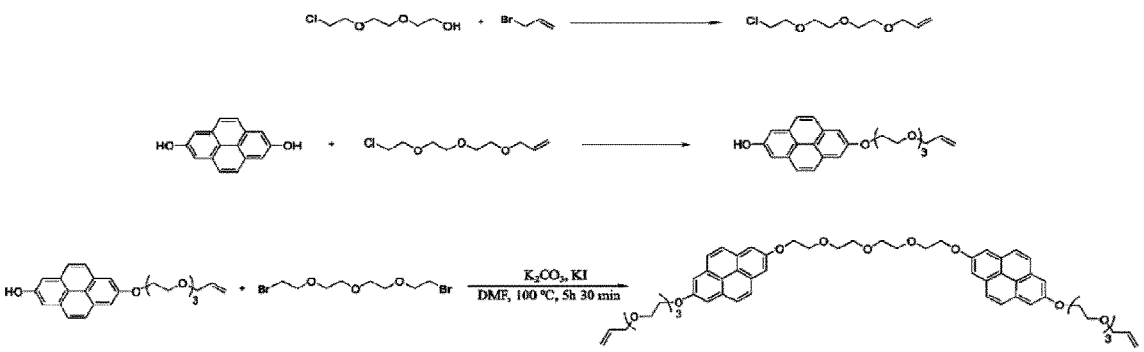


Fig. 65

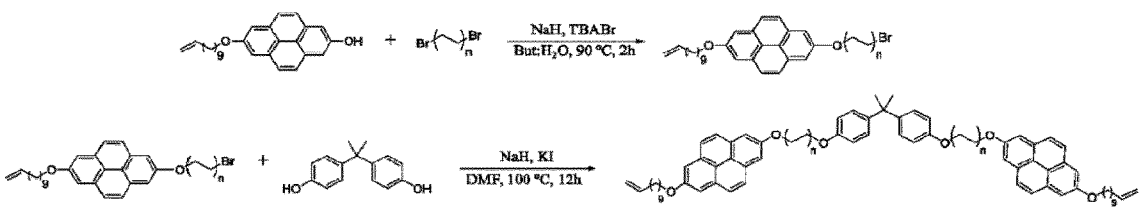


Fig. 66

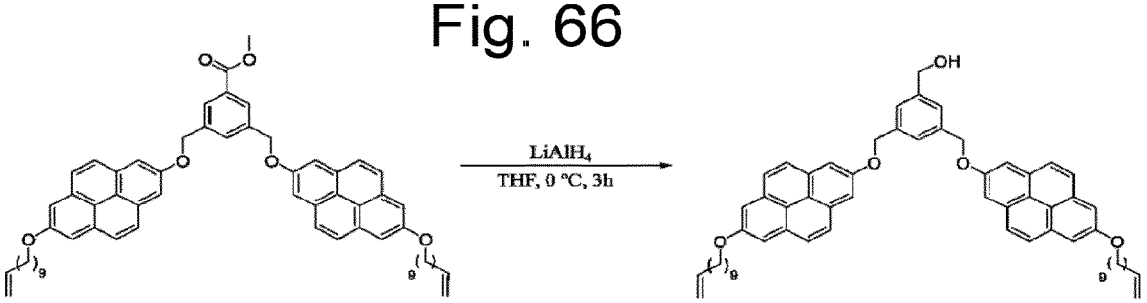


Fig. 67

Sample	Young's Modulus (MPa)	Standard deviation
Neat_PMMA	2360.97	107.05
PMMA_Tuball_0.1	2665.69	418.4
PMMA_Tuball_1.0	1860.08	238.14
PMMA_Chain_0.1	3732.77	1115.97
PMMA_Chain_1.0	3423.32	277.7
PMMA_Glycol_0.1	2910.89	140.35
PMMA_Glycol_1.0	2868.87	503.55

Fig. 68

Sample	Young's Modulus (MPa)	Standard deviation
Neat_PVC	3235.51	-
PVC_Tuball_0.1	3515.42	191.3
PVC_Tuball_1.0	6694.85	236.2
PVC_Chain_0.1	3381.71	100.9
PVC_Chain_1.0	3672.11	31.2
PVC_Glycol_0.1	3970.43	500.7
PVC_Glycol_1.0	4119.14	61.5

Fig. 69

Sample	Young's Modulus (MPa)	Standard deviation
Neat_LDPE	322.18	16.25
LDPE_Tuball_0.1	332.51	36.16
LDPE_Tuball_1.0	343.32	28.75
LDPE_Chain_0.1	350.66	45.82
LDPE_Chain_1.0	342.32	28.75
LDPE_Glycol_0.1	406.44	88.03
LDPE_Glycol_1.0	449.68	91.14

Fig. 70

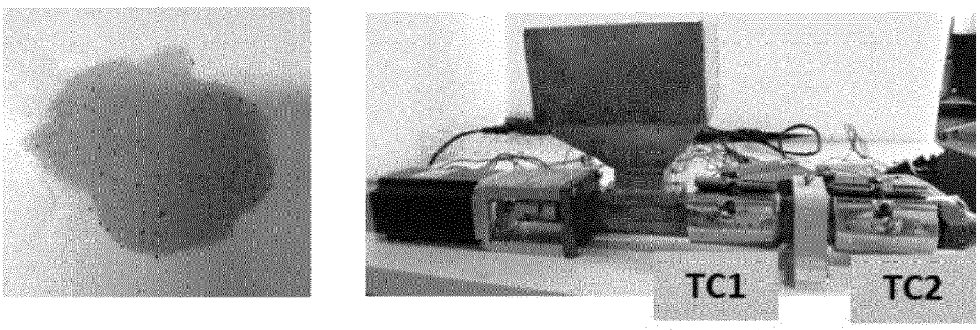


Fig. 71

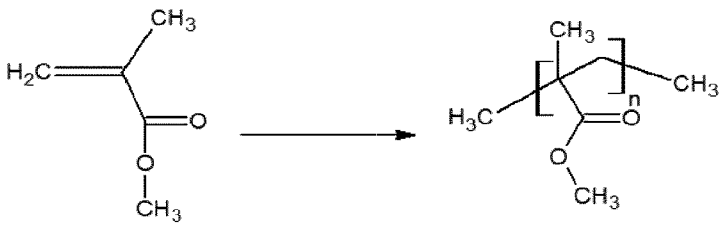


Fig. 72

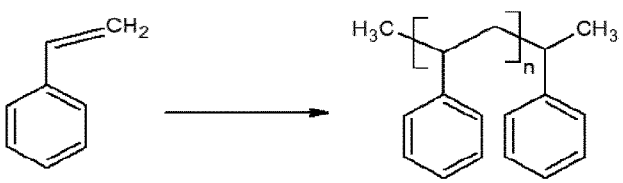


Fig. 73

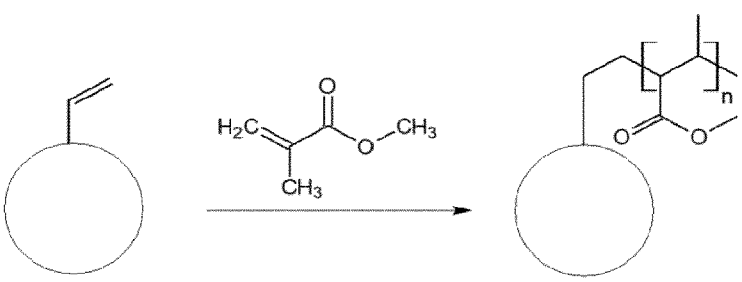


Fig. 74

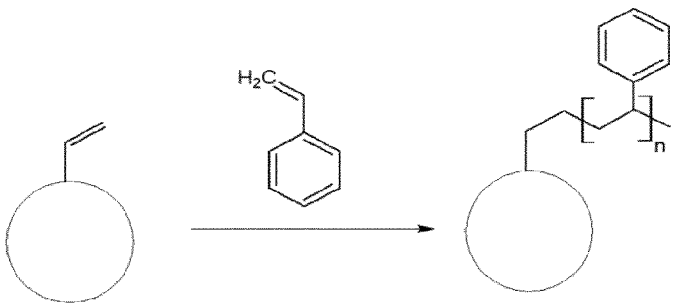


Fig. 75



Fig. 76

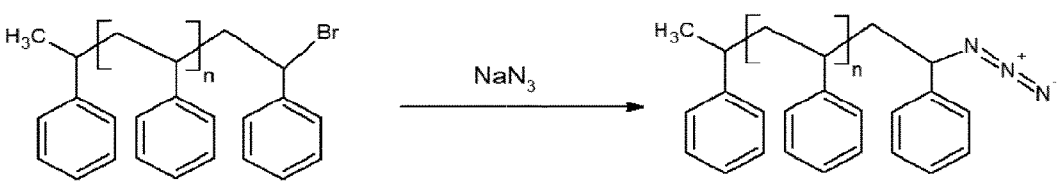


Fig. 77

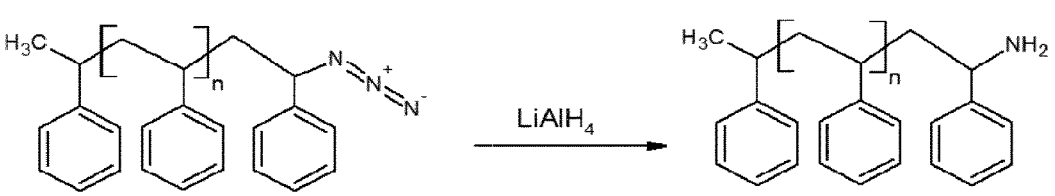


Fig. 78

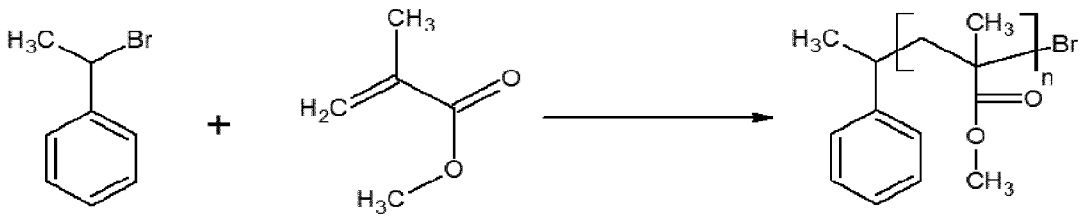


Fig. 79

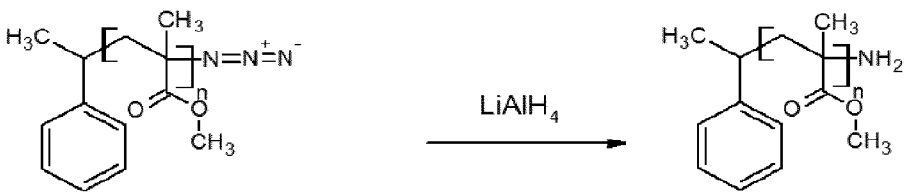


Fig. 80

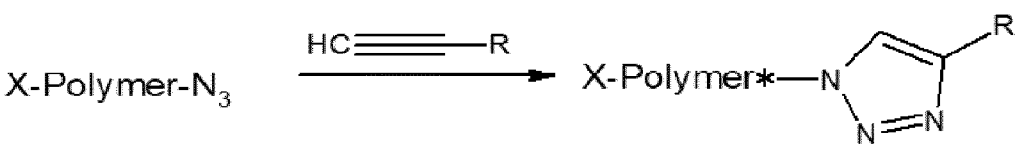


Fig. 81

Figure of "ATRP´s initiator MINTs of Example CC 19"

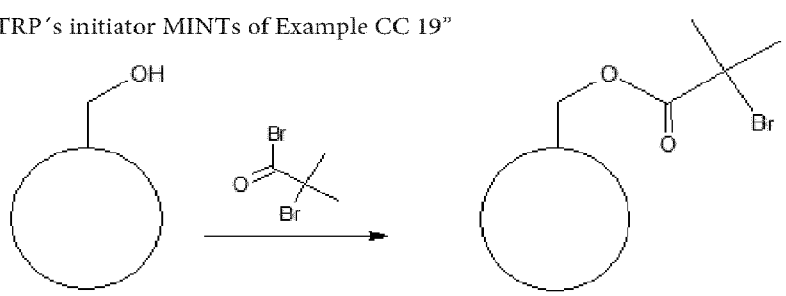


Fig. 82

Figure of "ATRP PS grafting from of example CC 19"

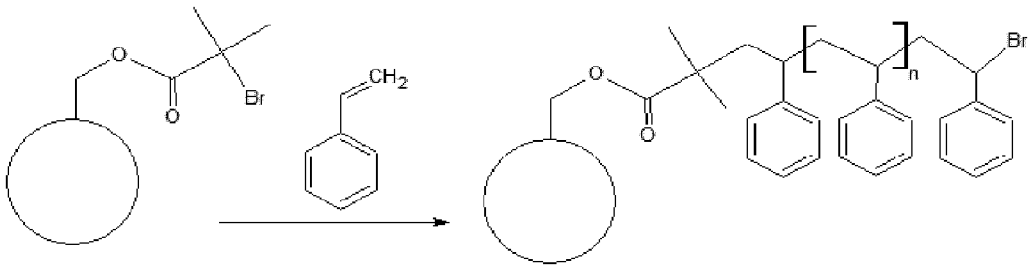


Fig. 83

Figure of "ATRP PMMA grafting from of example CC 20"

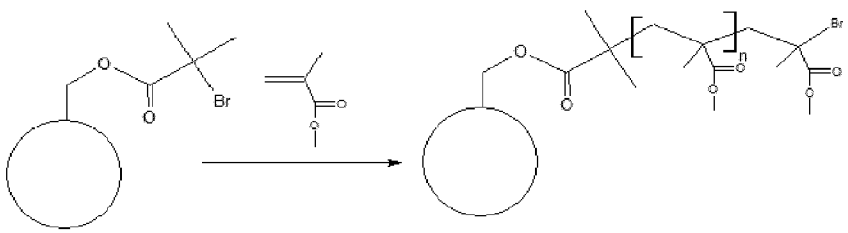


Fig. 84

Figure of "ROP PCL-MINTs composite".

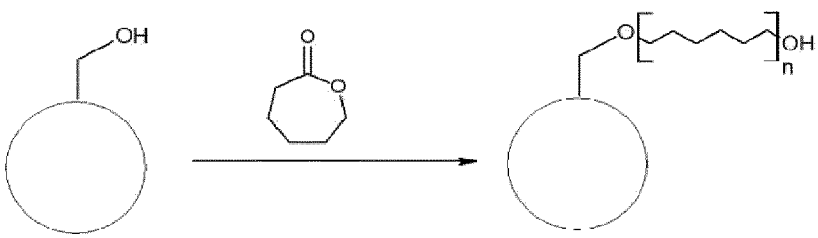


Fig. 85

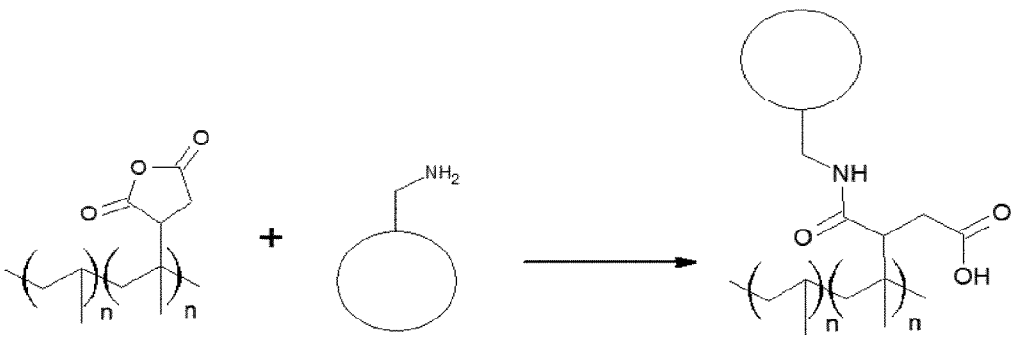
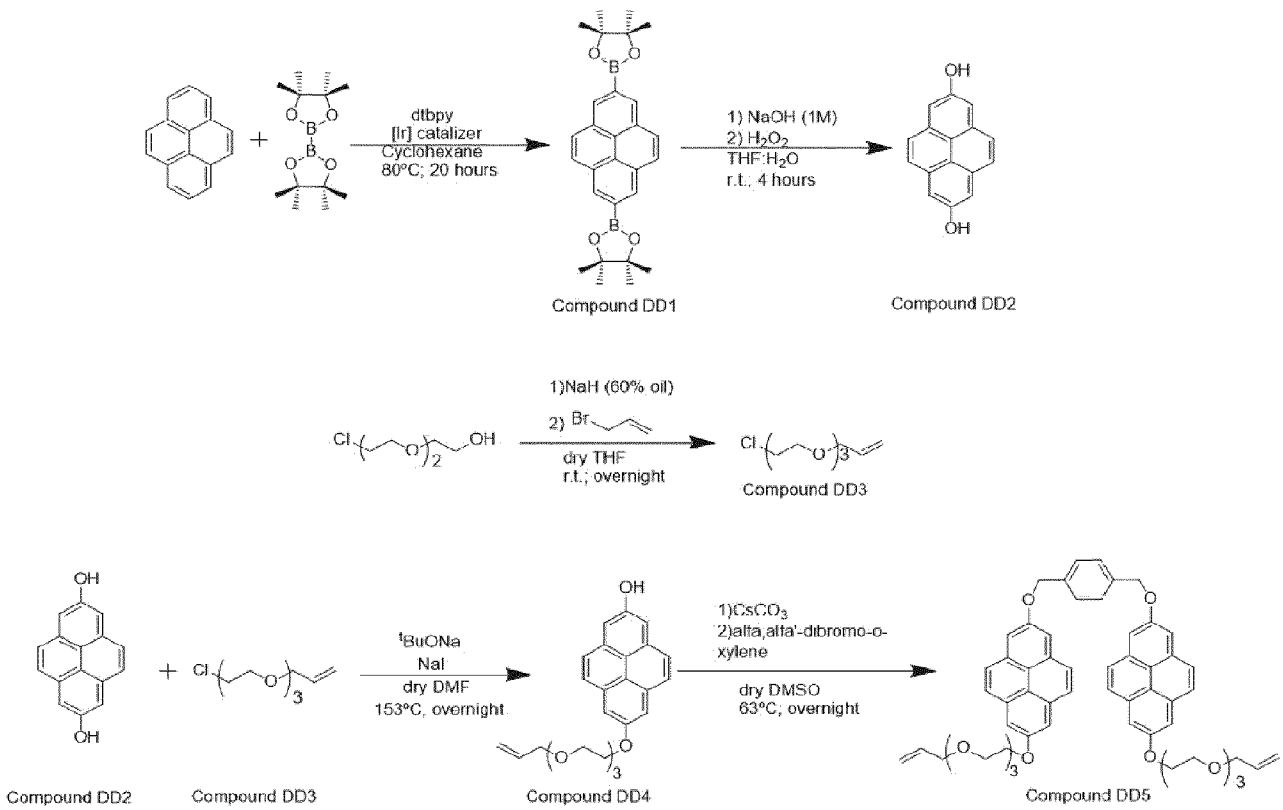
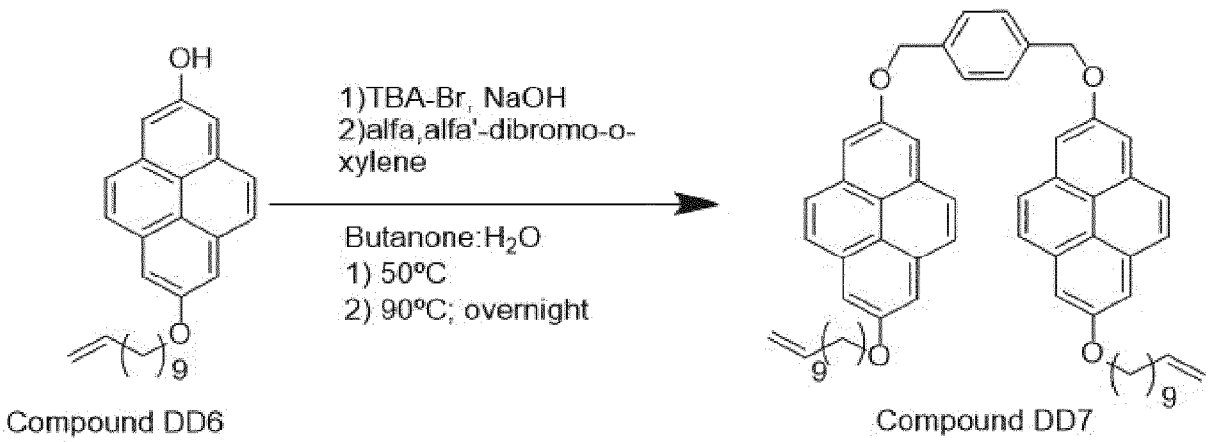


Fig. 86



The figure explains the synthetic route from commercial pyrene until the obtaining "Polyethoxy monoalkylated of Example DD4".

Fig. 87



The figure explains the synthetic route from monoalkylated pyrene until the obtaining "Pyrene U-Shape of Example DD6".

Fig. 88

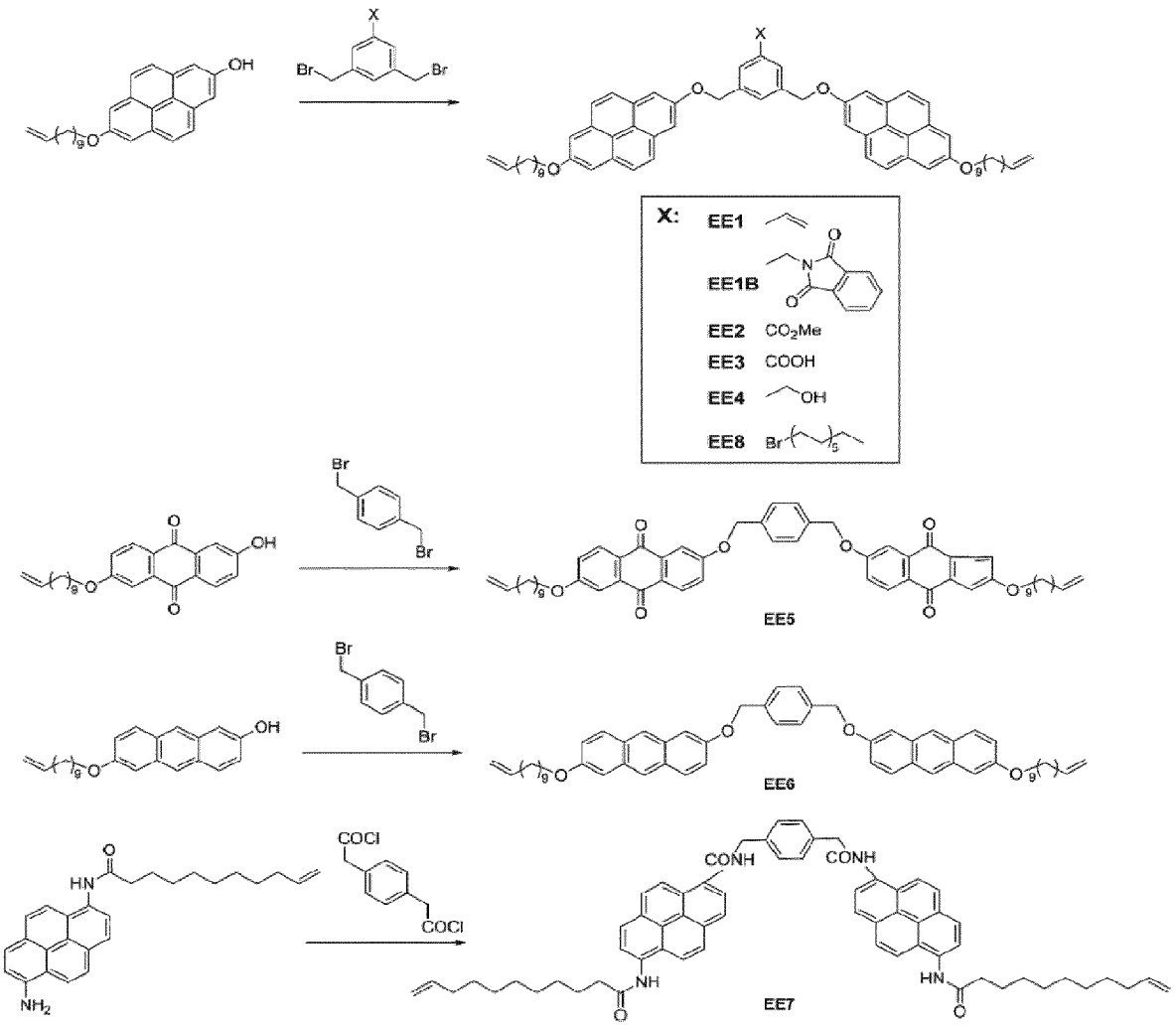

X:
EE1
EE1B
EE2 CO_2Me
EE3 COOH
EE4 OH
EE8
EE5
EE6
EE7
CONH
CONH
COCl
COCl
NH2

Fig. 89

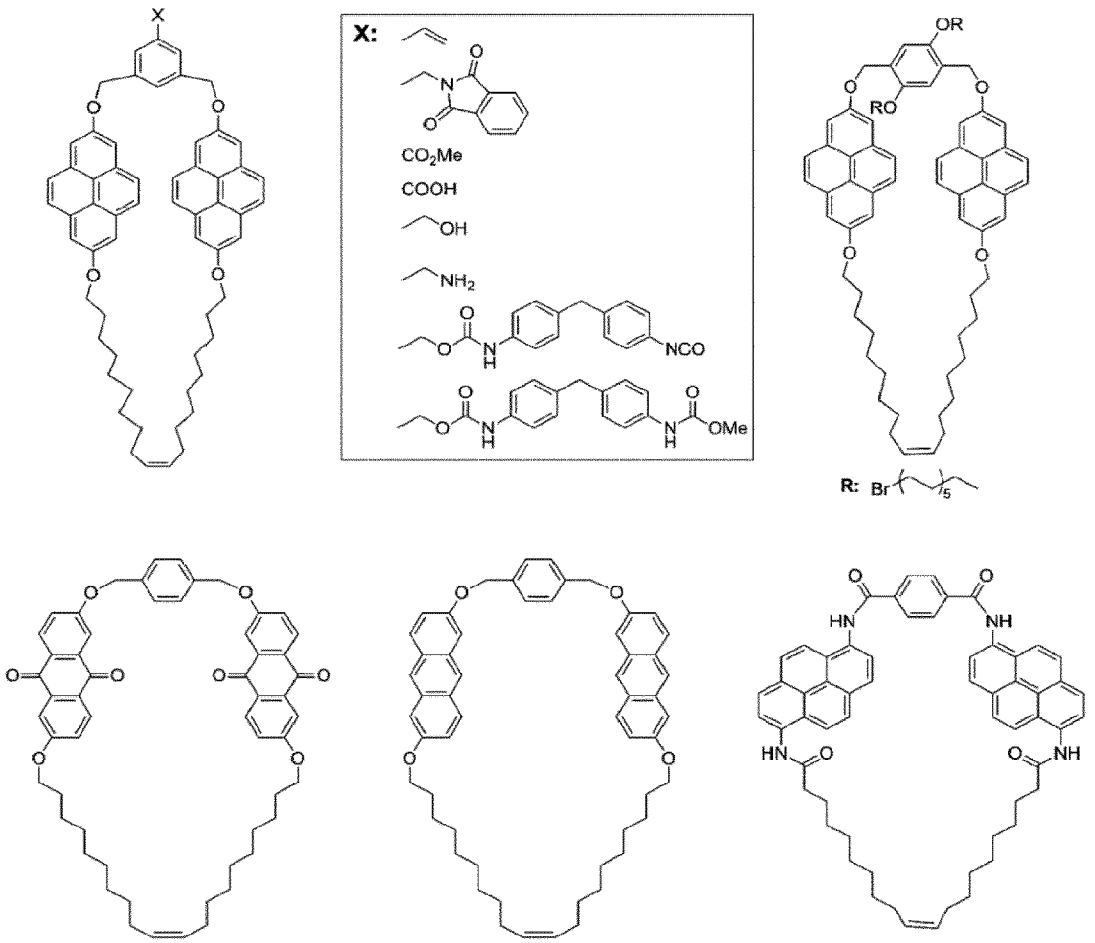

X
X:
CO2Me
COOH
OH
NH2
NCO
OMe
OR
RO
R: Br 5
HN
NH
HN
NH

Fig. 90

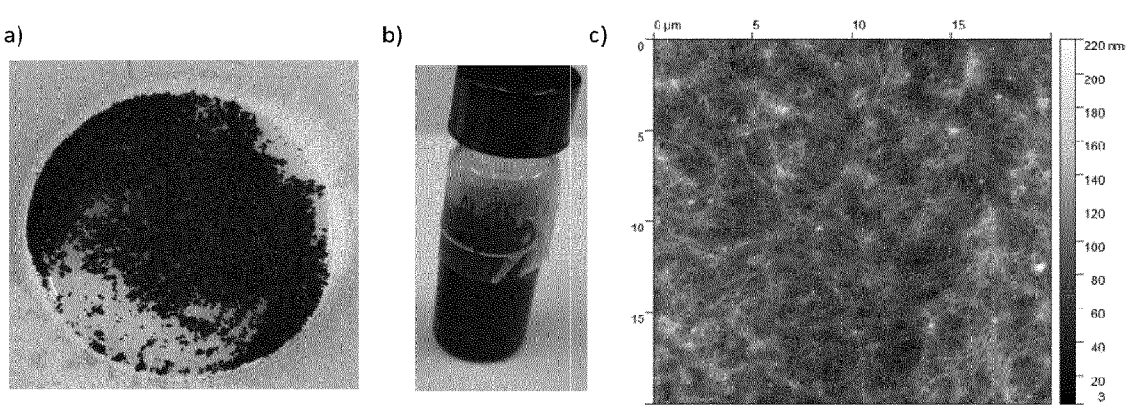

a)
b)
c)
0 µm
5
10
15
220 nm
200
180
160
140
120
100
80
60
40
20
3

Fig. 91

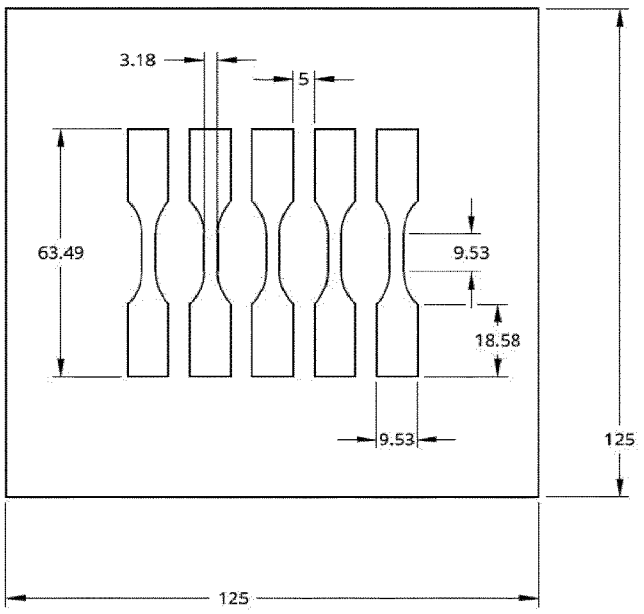

3.18
5
63.49
9.53
18.58
9.53
125
125

Fig. 92

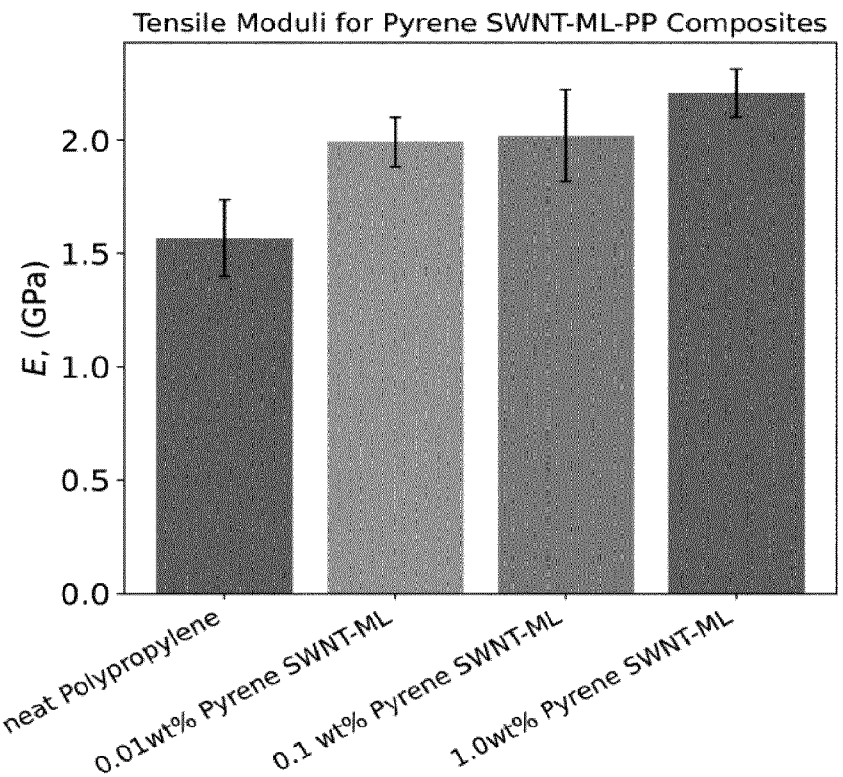

Tensile Moduli for Pyrene SWNT-ML-PP Composites
E, (GPa)
0.0
0.5
1.0
1.5
2.0
neat Polypropylene
0.01wt% Pyrene SWNT-ML
0.1 wt% Pyrene SWNT-ML
1.0wt% Pyrene SWNT-ML

Fig. 93

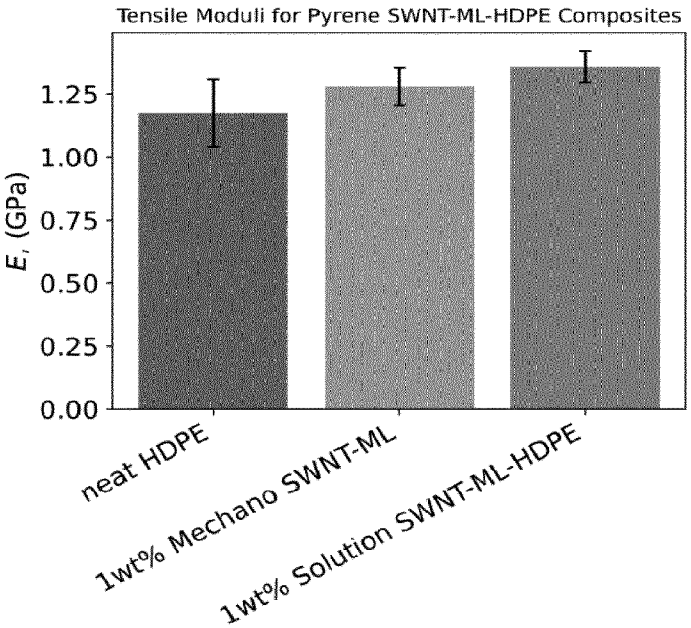

Tensile Moduli for Pyrene SWNT-ML-HDPE Composites
E, (GPa)
0.00
0.25
0.50
0.75
1.00
1.25
neat HDPE
1wt% Mechano SWNT-ML
1wt% Solution SWNT-ML-HDPE

Fig. 94

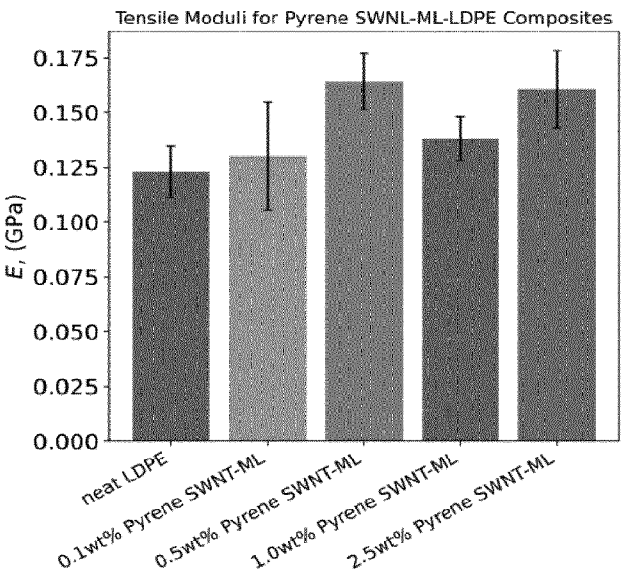

Tensile Moduli for Pyrene SWNL-ML-LDPE Composites
E, (GPa)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
neat LDPE
0.1wt% Pyrene SWNT-ML
0.5wt% Pyrene SWNT-ML
1.0wt% Pyrene SWNT-ML
2.5wt% Pyrene SWNT-ML

Fig. 95

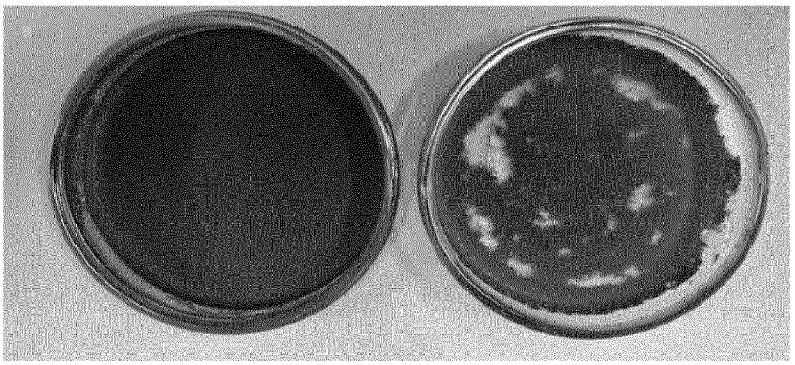


Fig. 96

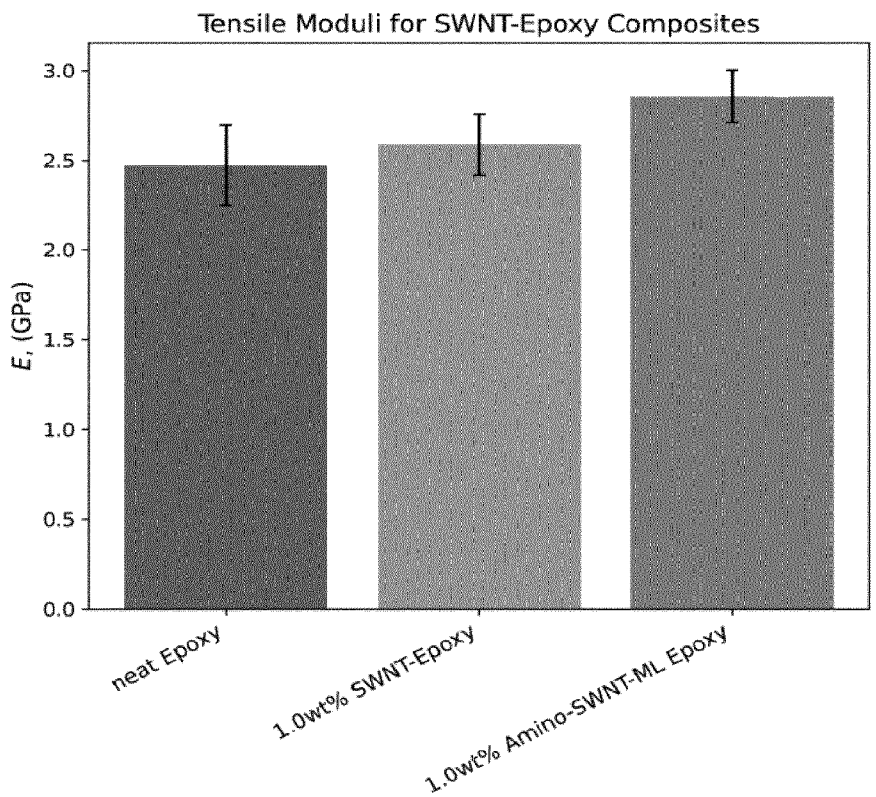

Tensile Moduli for SWNT-Epoxy Composites
E, (GPa)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
neat Epoxy
1.0wt% SWNT-Epoxy
1.0wt% Amino-SWNT-ML Epoxy

Fig. 97

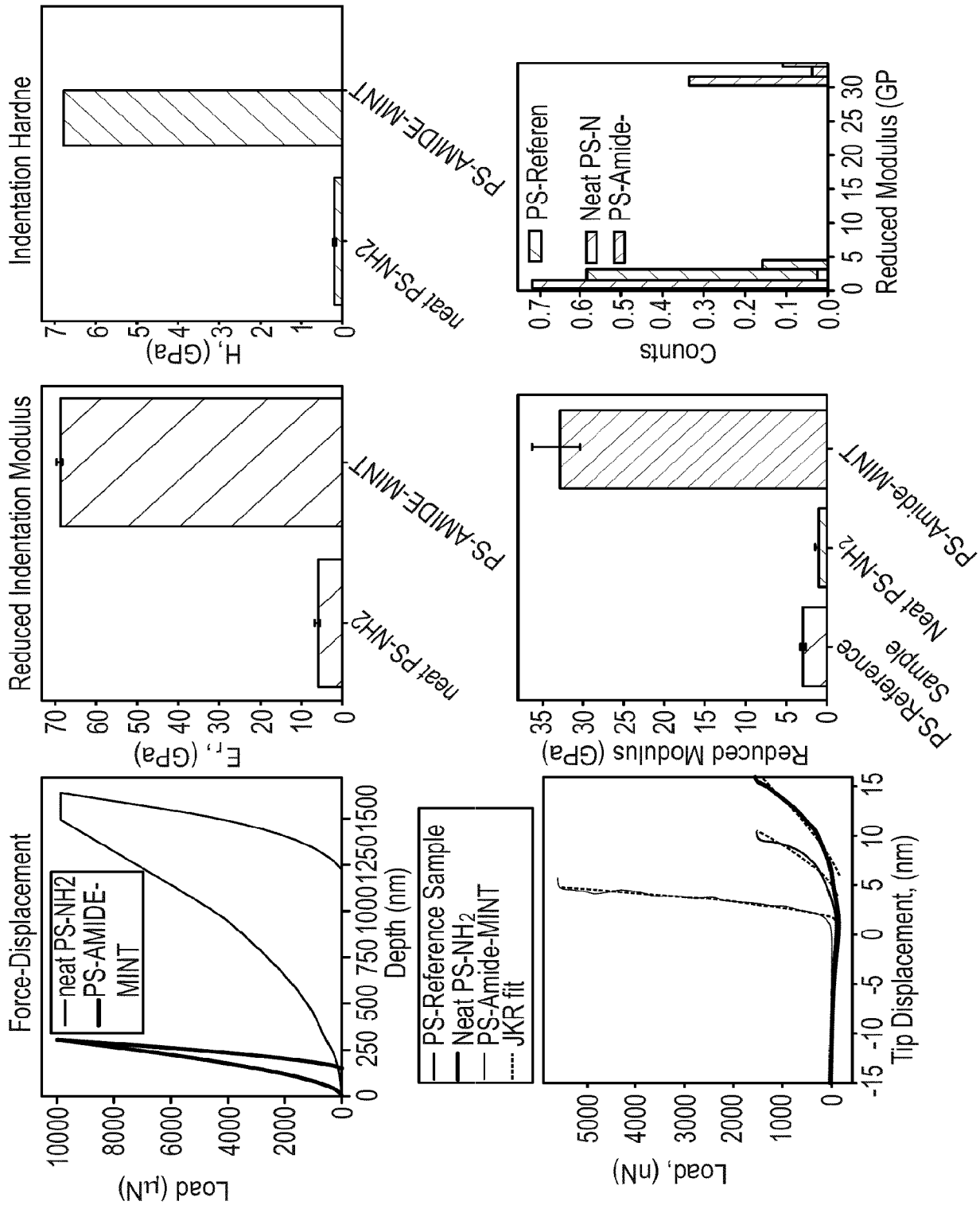

Force-Displacement
neat PS-NH2
PS-AMIDE-MINT
Load (μN)
Depth (nm)
Reduced Indentation Modulus
neat PS-NH2
PS-AMIDE-MINT
Indentation Hardne
neat PS-NH2
PS-AMIDE-MINT
PS-Reference Sample
Neat PS-NH2
PS-Amide-MINT
JKR fit
Load, (nN)
Tip Displacement, (nm)
Reduced Modulus (GPa)
PS-Reference Sample
Neat PS-NH2
PS-Amide-MINT
Counts
PS-Referen
Neat PS-N
PS-Amide-
Reduced Modulus (GP

Fig. 98

Fig. 99

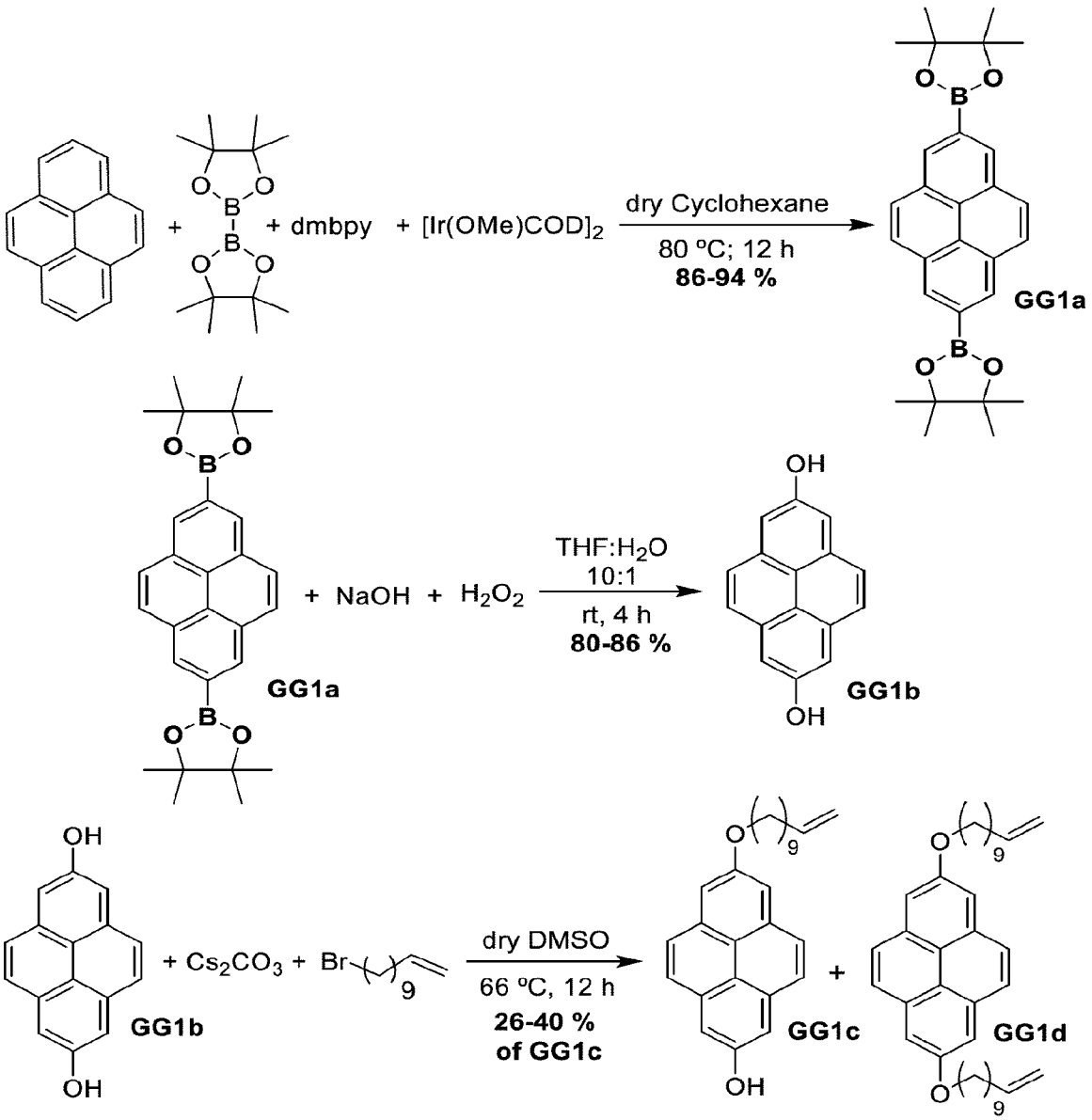

+ dmbpy + [Ir(OMe)COD]2
dry Cyclohexane
80 °C; 12 h
86-94 %
GG1a
+ NaOH + H2O2
THF:H2O
10:1
rt, 4 h
80-86 %
GG1a
GG1b
+ Cs2CO3 + Br
dry DMSO
66 °C, 12 h
26-40 %
of GG1c
GG1b
GG1c
GG1d

Fig. 100

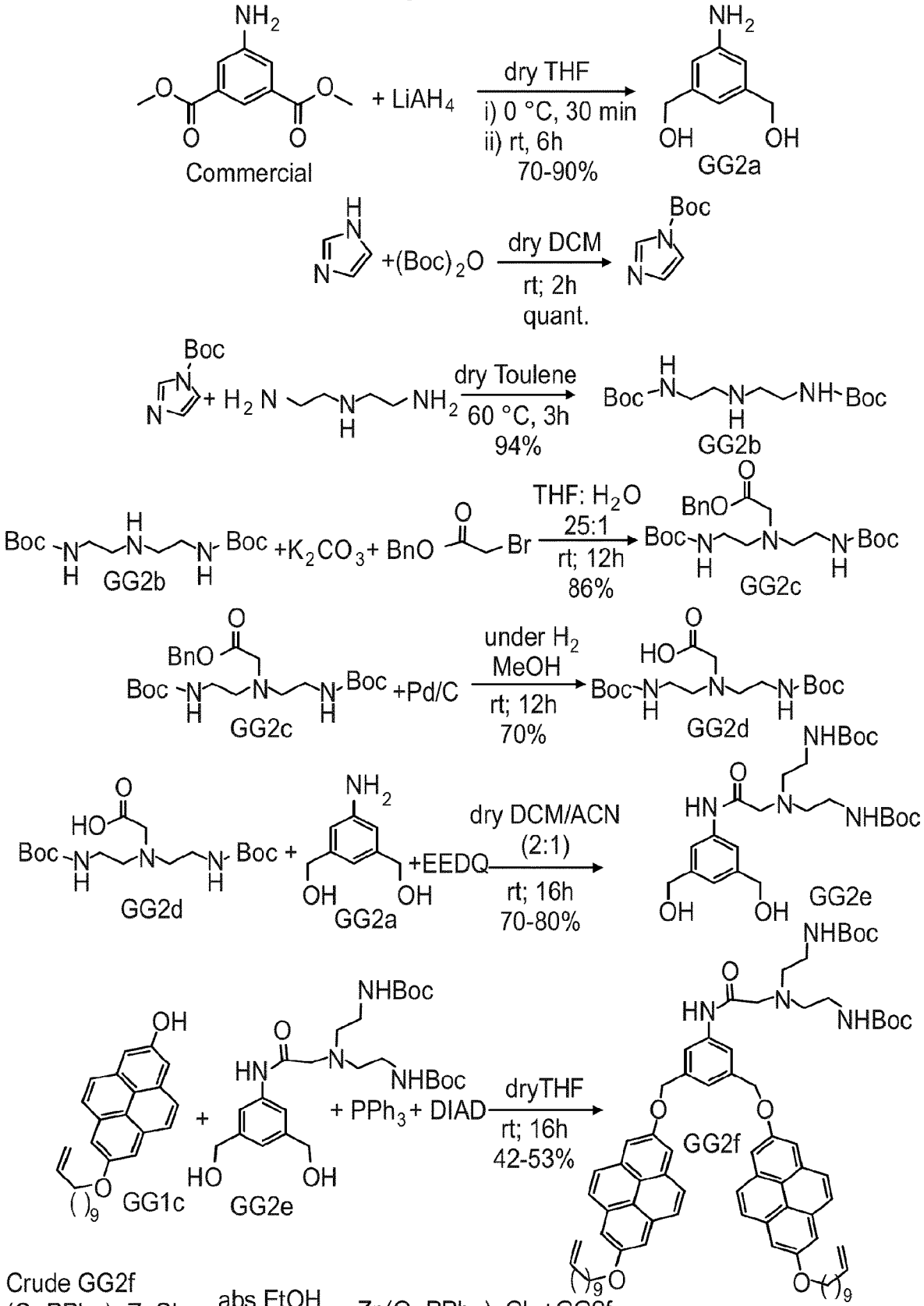
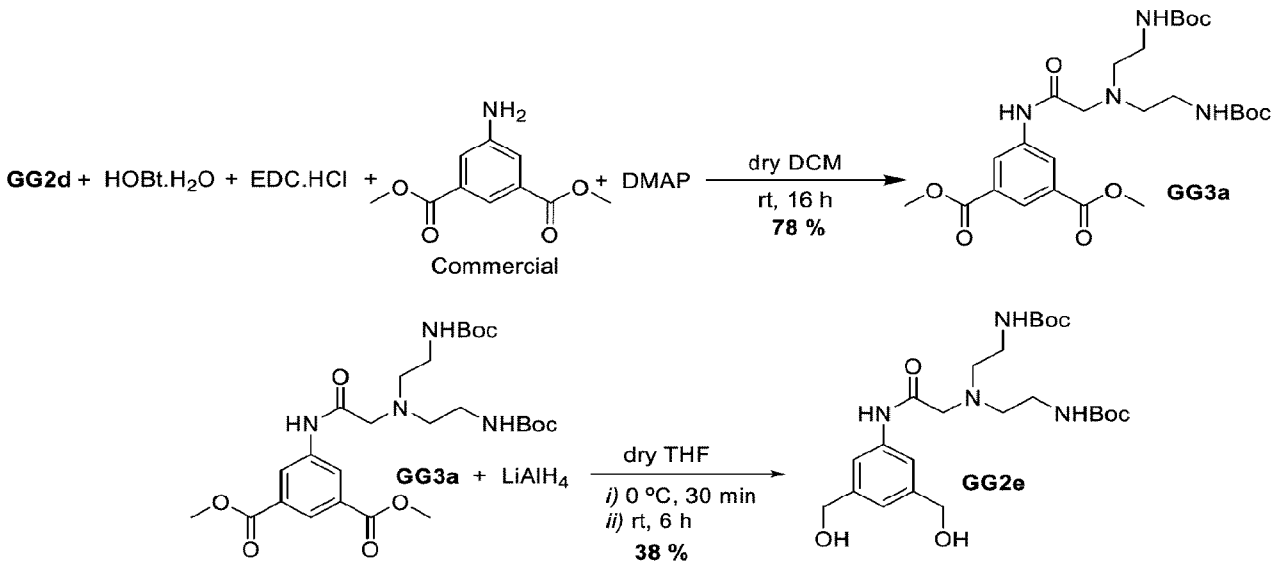

NH2
+ LiAH4
dry THF
i) 0 °C, 30 min
ii) rt, 6h
70-90%
Commercial
GG2a
+(Boc)2O
dry DCM
rt; 2h
quant.
Boc
+ H2 N
dry Toulene
60 °C, 3h
94%
GG2b
+K2CO3+ BnO
Br
THF: H2O
25:1
rt; 12h
86%
GG2c
+Pd/C
under H2
MeOH
rt; 12h
70%
GG2d
+EEDQ
dry DCM/ACN
(2:1)
rt; 16h
70-80%
GG1c
+ PPh3+ DIAD
dryTHF
rt; 16h
42-53%
GG2f
Crude GG2f
(O=PPh3)+ZnCl2
abs EtOH
i) 78 °C, 30 min
ii) rt, overnigth
Zn(O=PPh3)2Cl2+GG2f

Fig. 101

a.


GG2d + HOBt.H2O + EDC.HCl +
Commercial
+ DMAP
dry DCM
rt, 16 h
78 %
GG3a
GG3a + LiAlH4
dry THF
i) 0 °C, 30 min
ii) rt, 6 h
38 %
GG2e
NHBoc
NHBoc
HN
OH
OH

b.

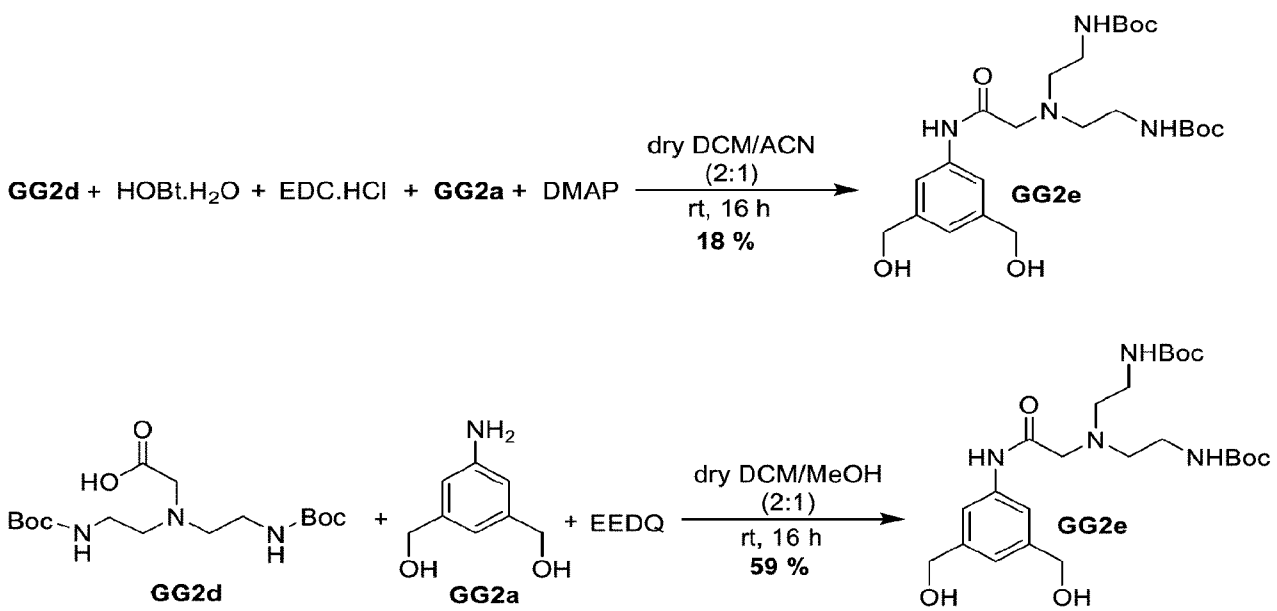

GG2d + HOBt.H2O + EDC.HCl + GG2a + DMAP
dry DCM/ACN
(2:1)
rt, 16 h
18 %
GG2e
+ EEDQ
dry DCM/MeOH
(2:1)
rt, 16 h
59 %
GG2d
GG2a
NHBoc
HN
OH
Boc

Fig. 102

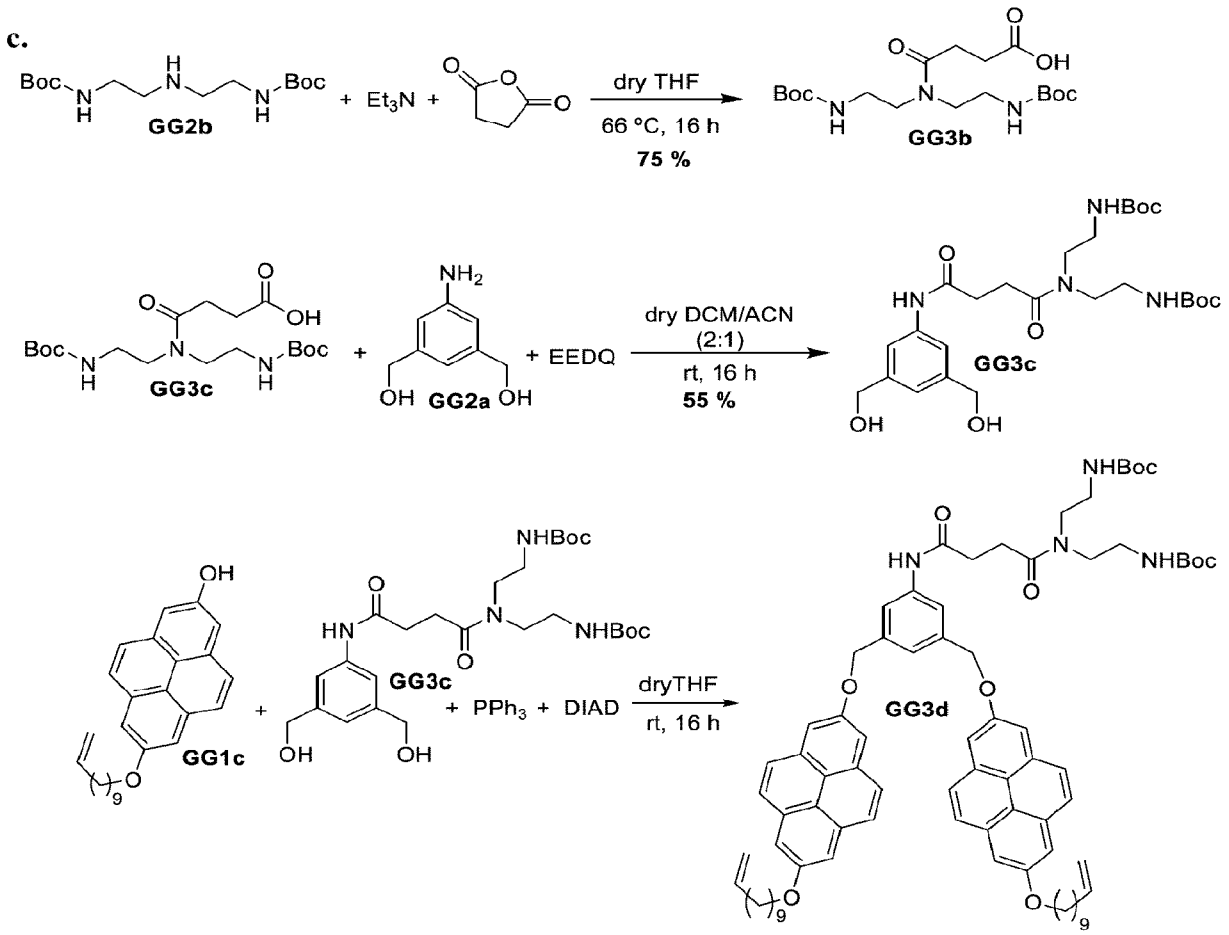


Fig. 102 (Continued)

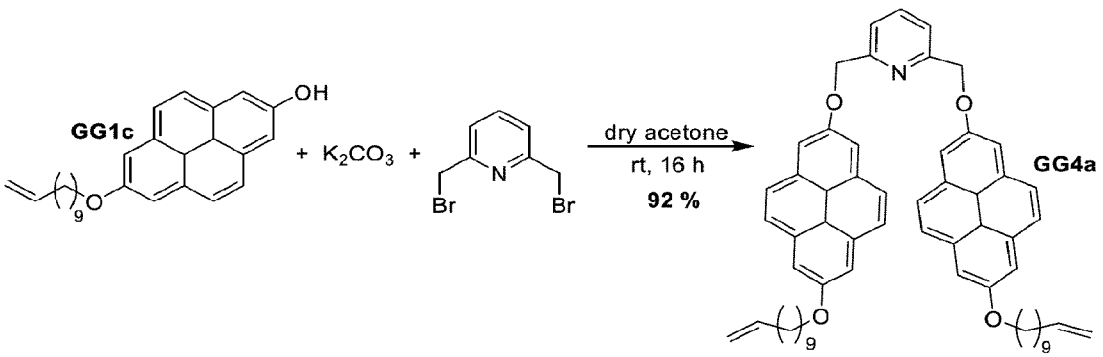


Fig. 103

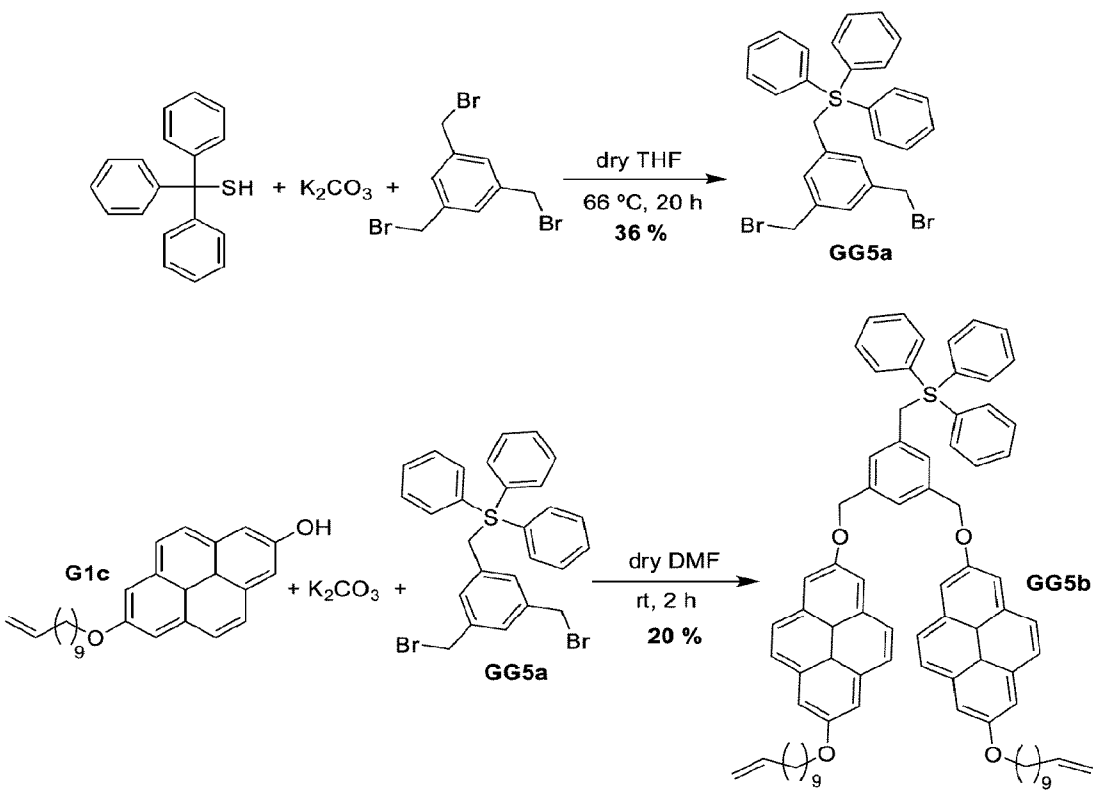


Fig. 104

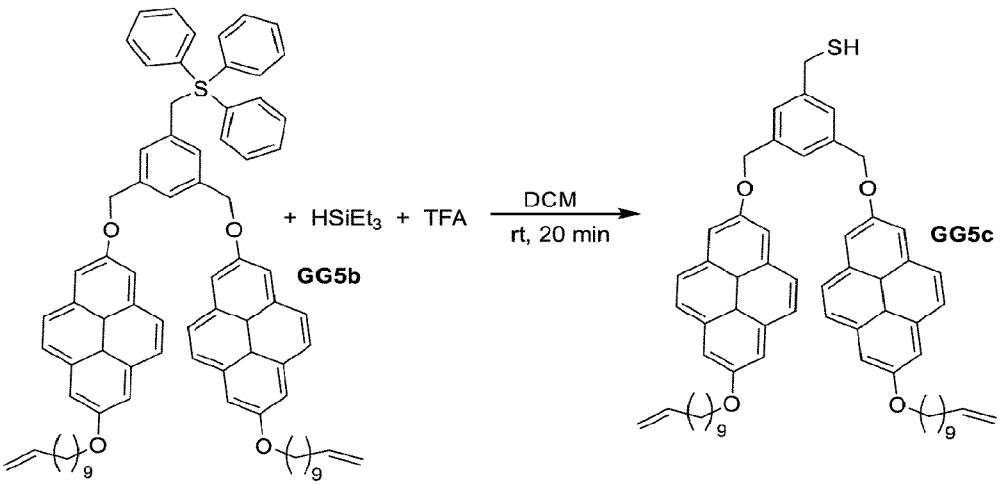


Fig. 104 (Continued)

a.

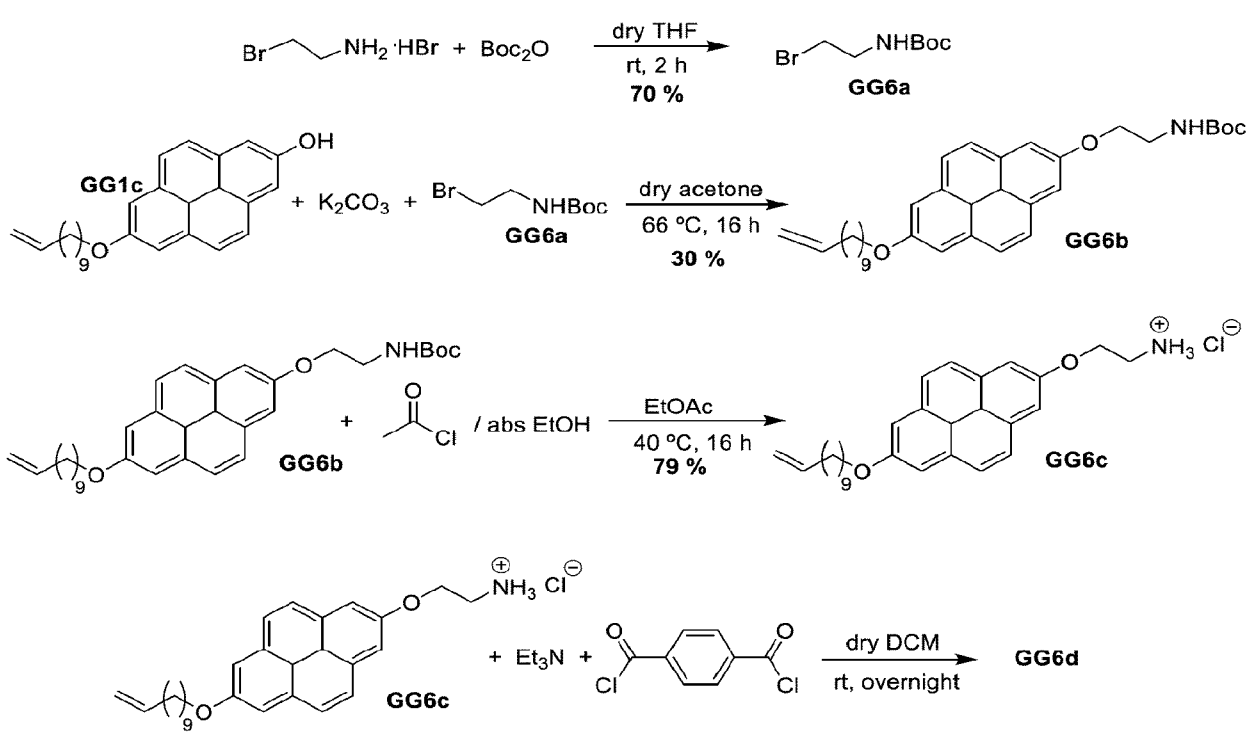
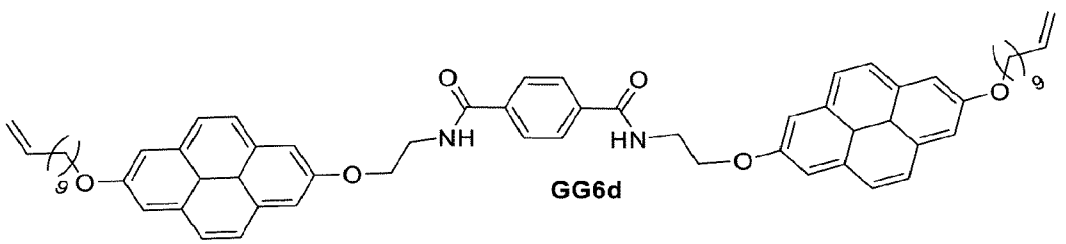


Fig. 105



b.

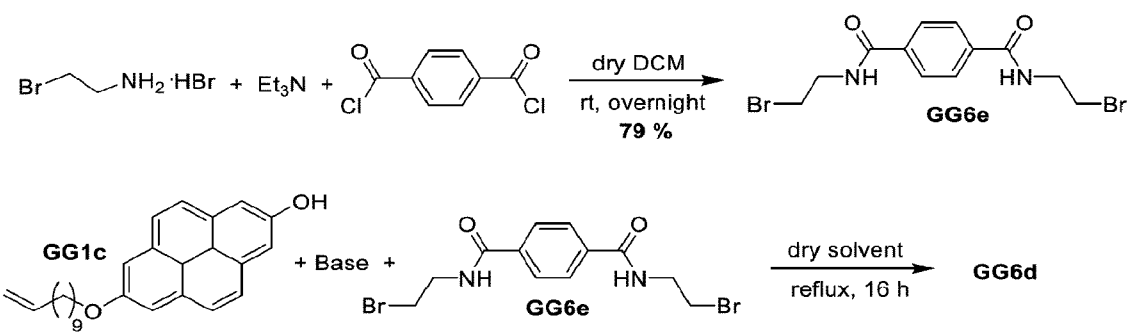


Fig. 105 (Continued)

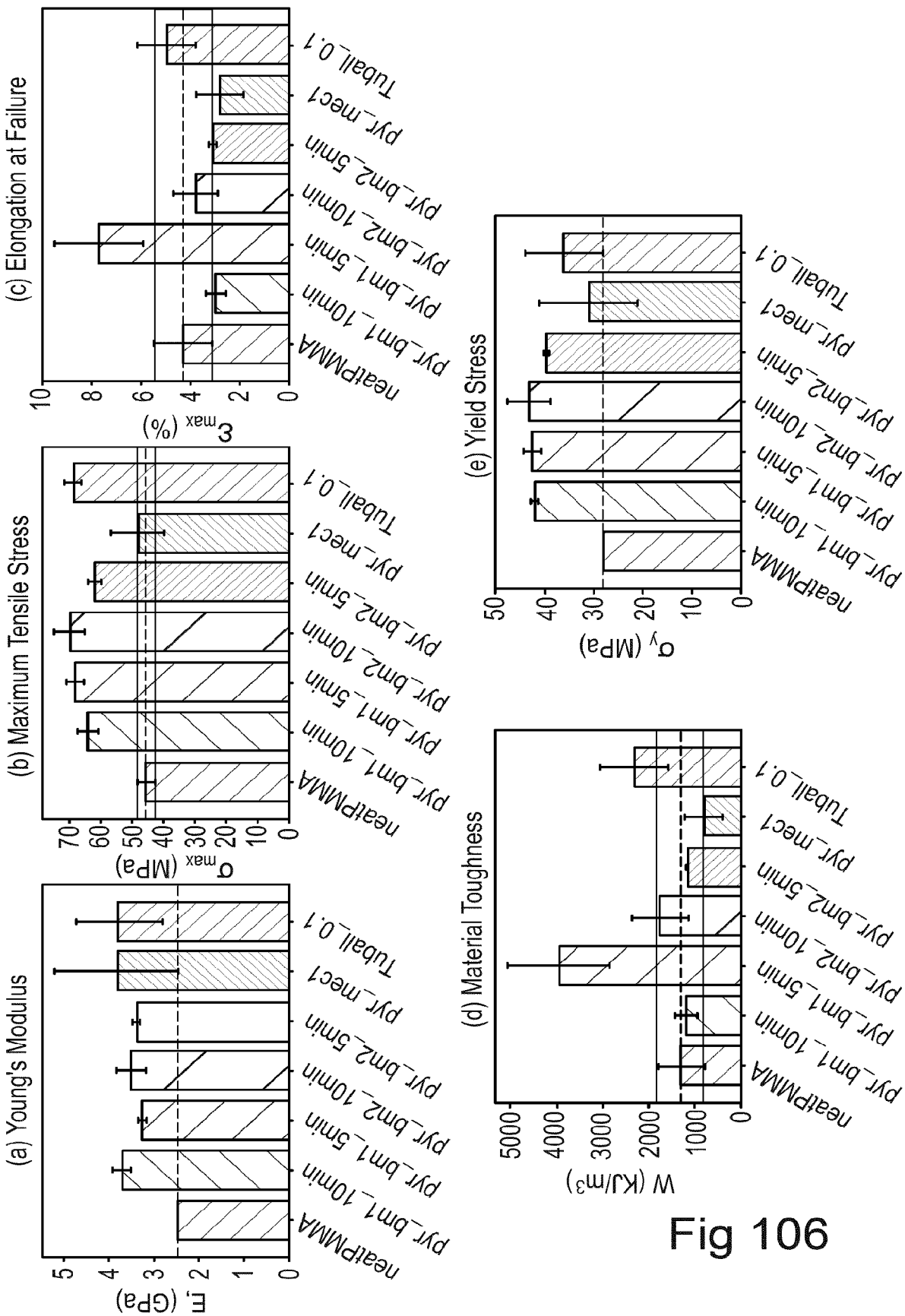

(a) Young's Modulus
E, (GPa)
(b) Maximum Tensile Stress
σmax (MPa)
(c) Elongation at Failure
εmax (%)
(d) Material Toughness
W (kJ/m3)
(e) Yield Stress
σy (MPa)
neatPMMA
pyr_bm1_10min
pyr_bm1_5min
pyr_bm2_10min
pyr_bm2_5min
pyr_mec1
Tuball_0.1

Fig 106

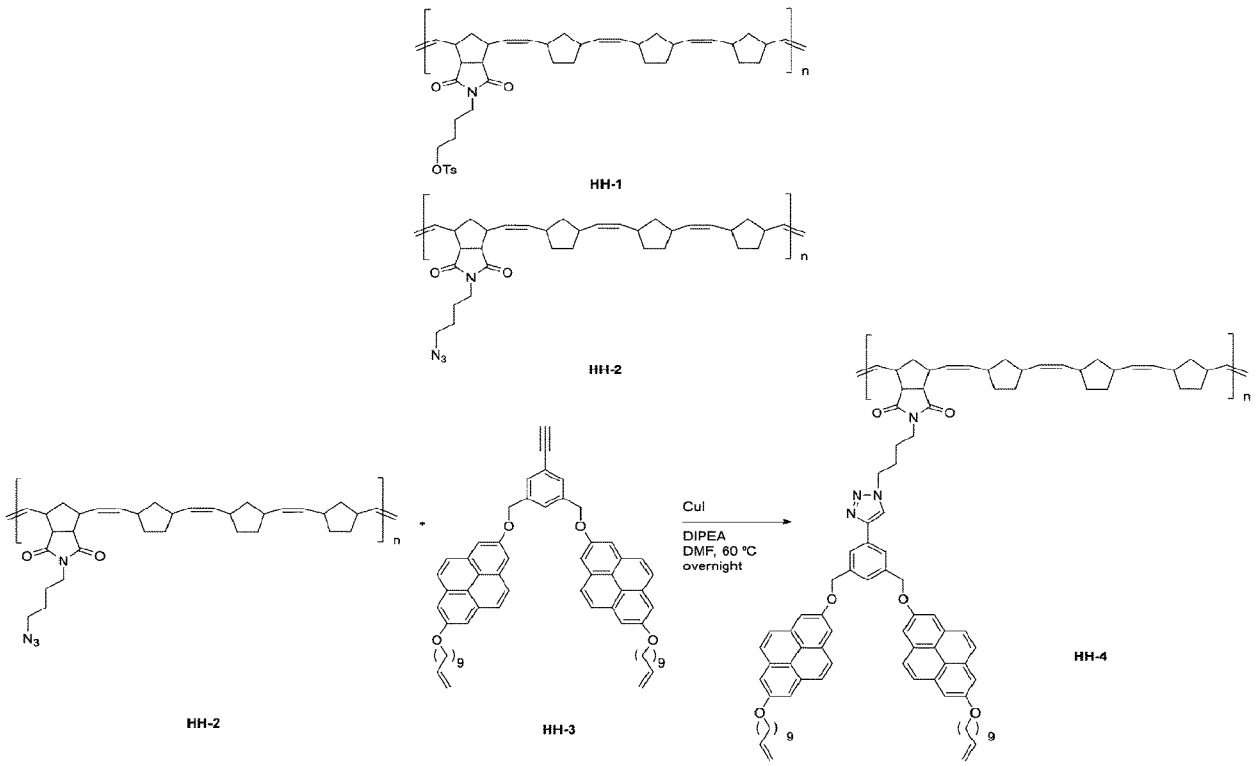
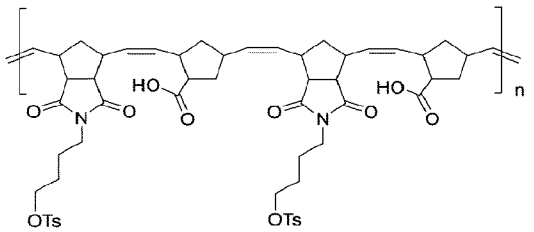
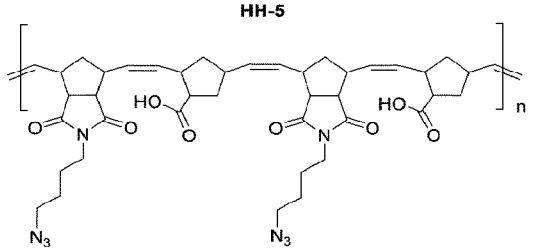


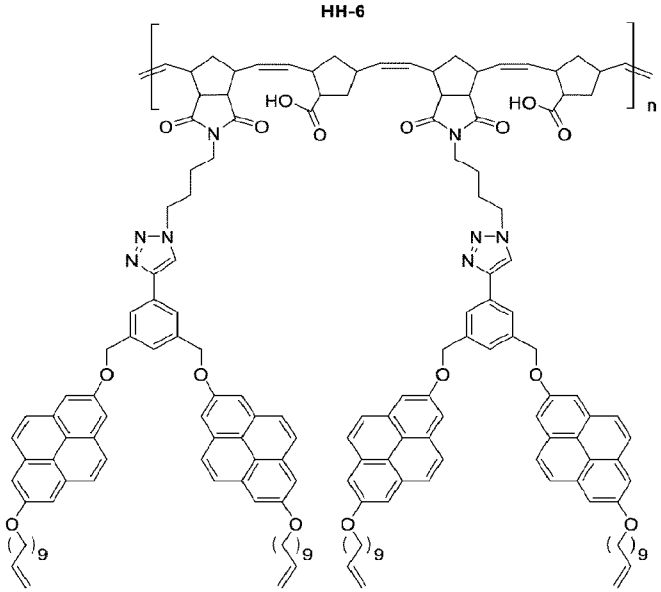
Fig. 107



HH-5



HH-6



HH-7

Fig. 108

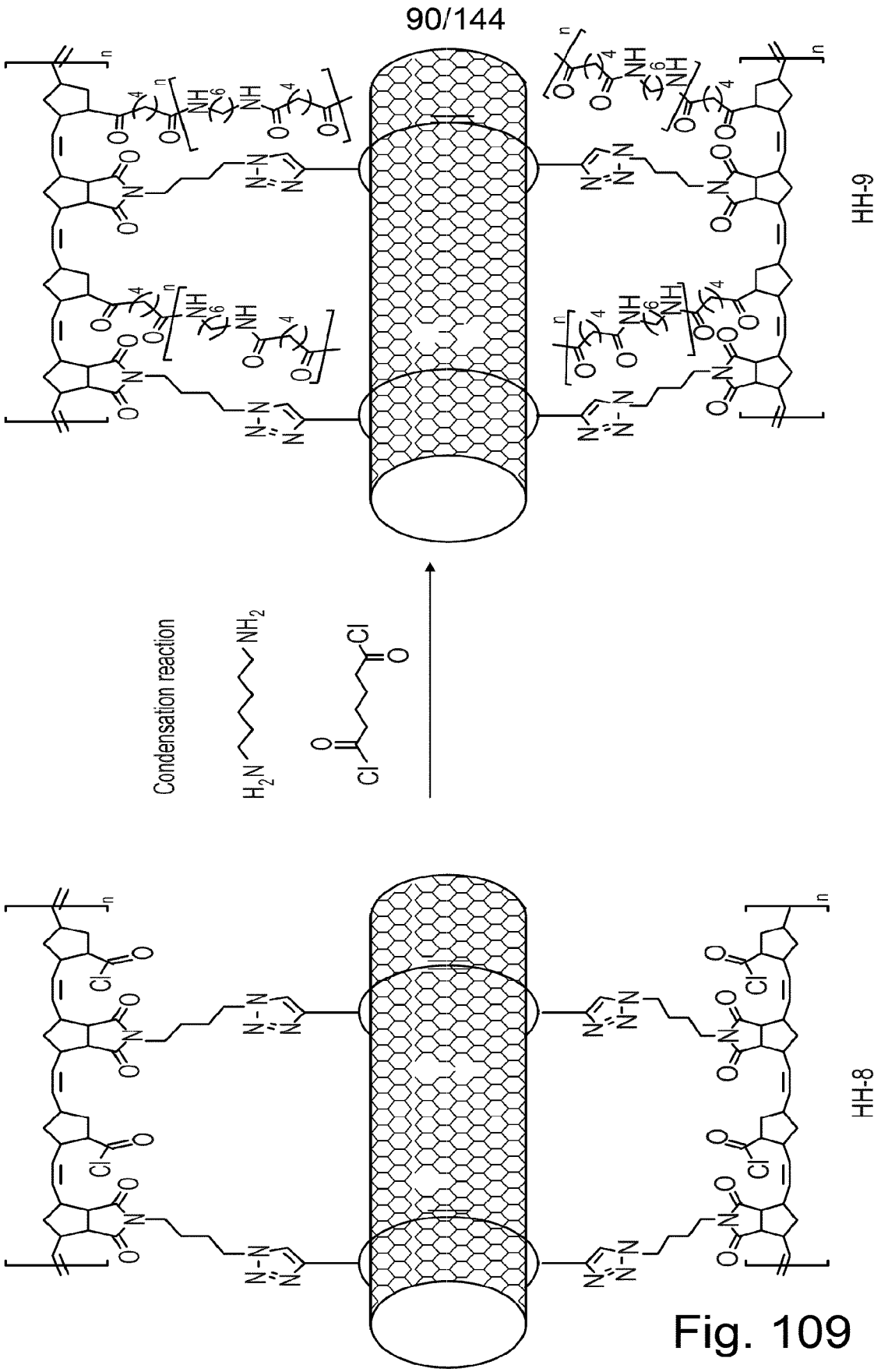
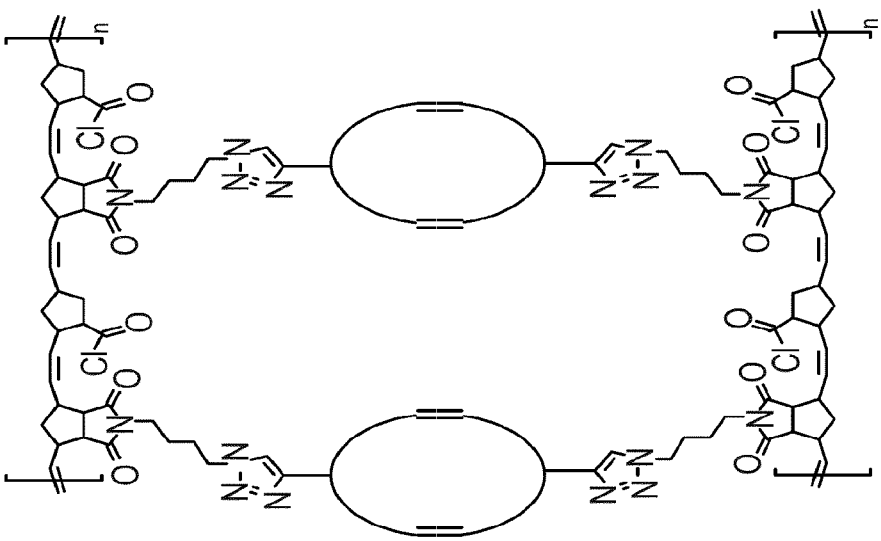
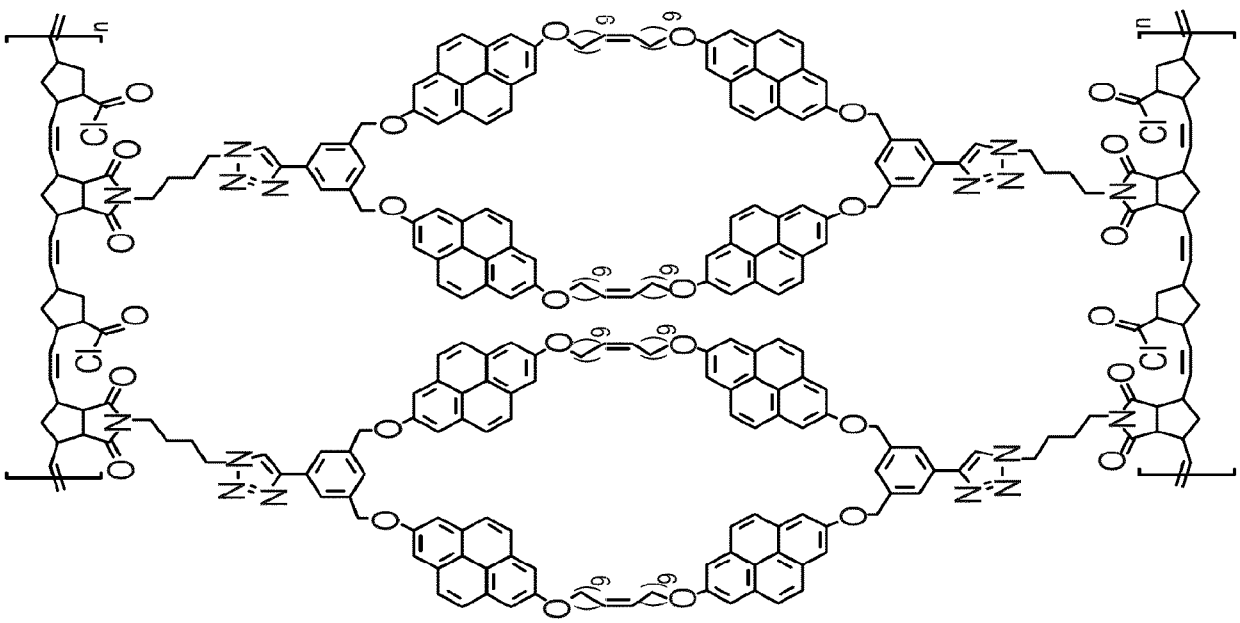


Fig. 109

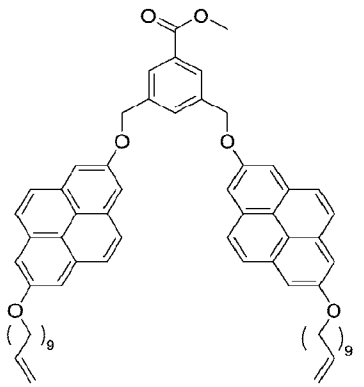


III



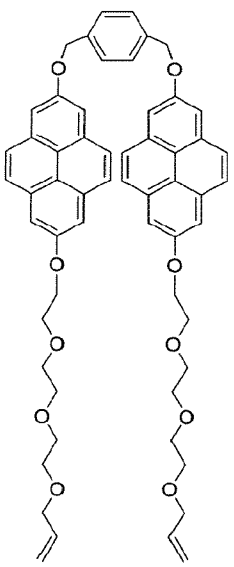
Symbols used:

Fig. 109
(Continued)



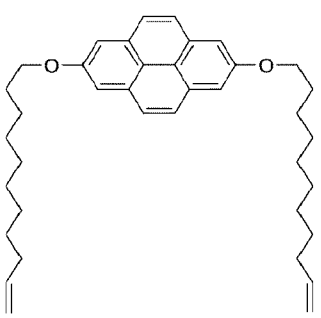
HH-10

Fig. 110



HH-11

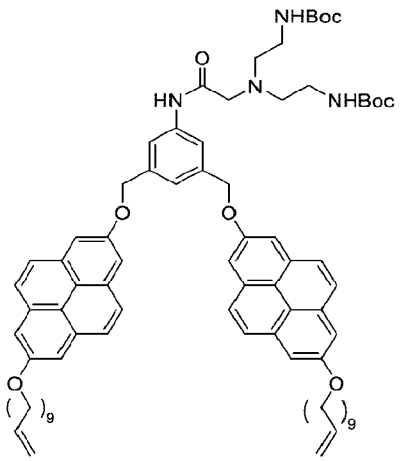
Fig. 111



HH-12

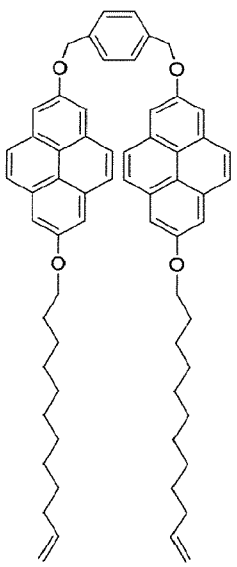
Fig. 112

Figure HH19



HH-13

Fig. 113



HH-14

Fig. 114

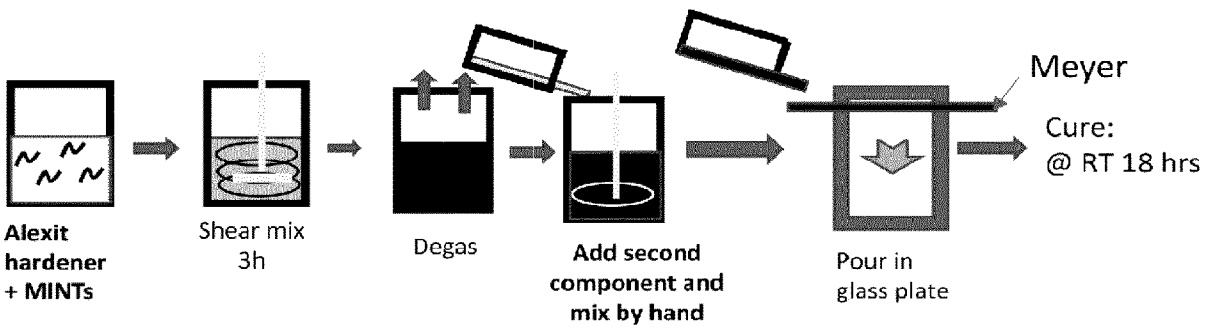


Fig. 115



Fig. 116

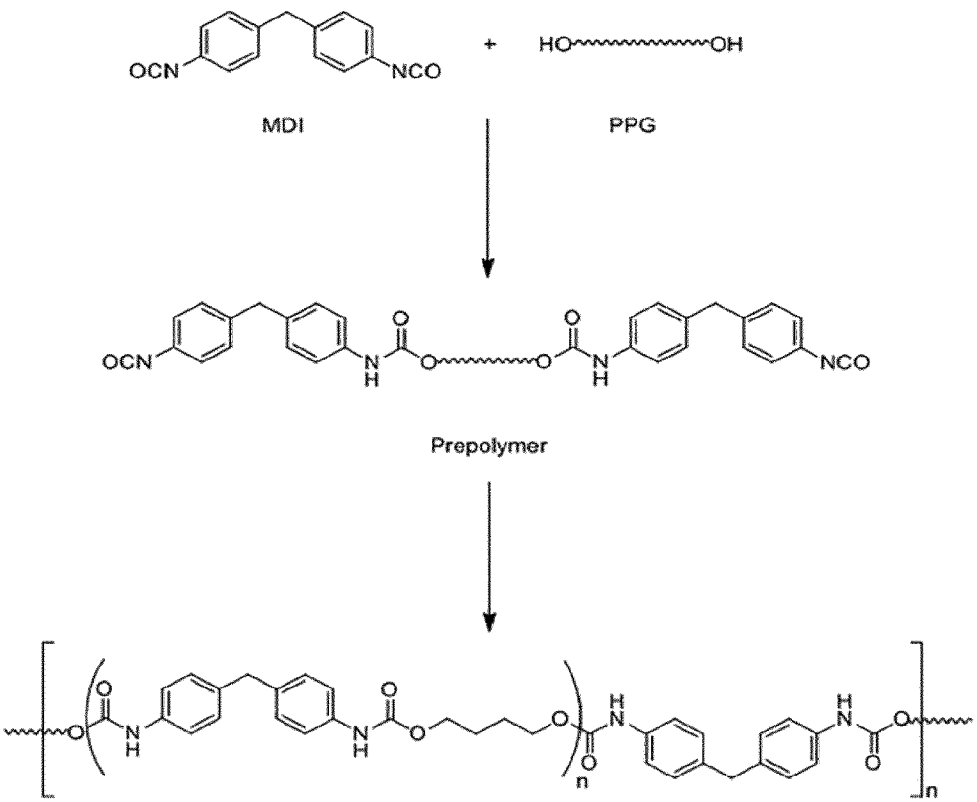


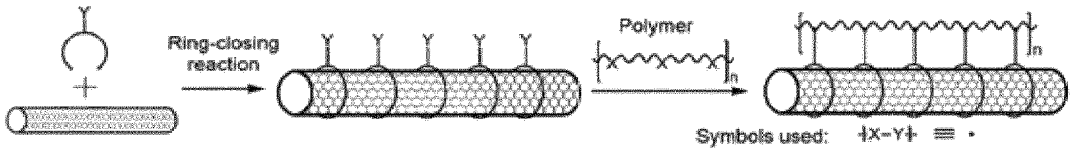
Fig. 117

In situ polyurethane general formulation			OH:NCO Ratio
	mmol	Eq.	
MDI	16	6	
PPG (Mw: 2000)	6	1	1 : 1.07
BD	8	4.6	

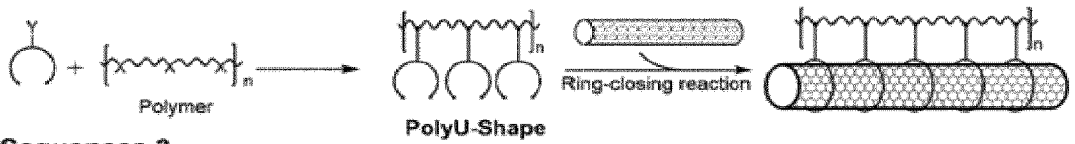
Fig. 118

Different sequences of events leading to polymer composites.

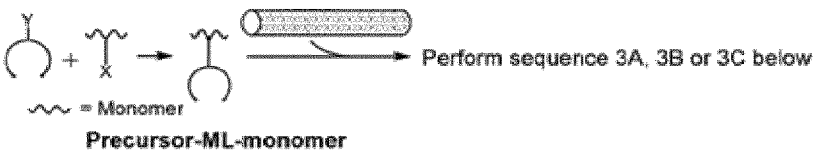
Sequence 1



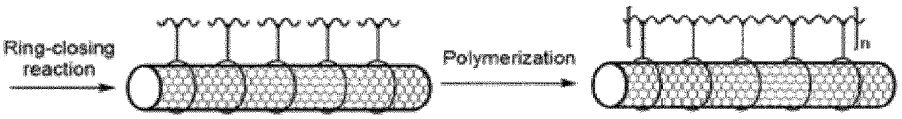
Sequence 2



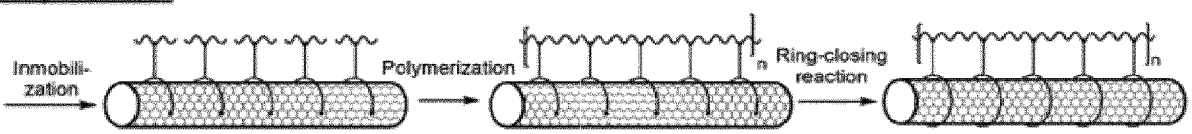
Sequences 3



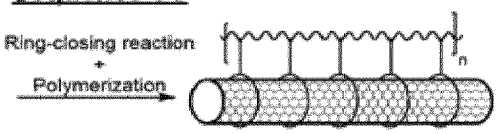
Sequence 3A



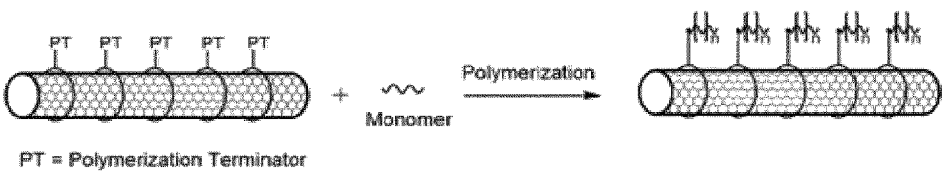
Sequence 3B



Sequence 3C



Sequence 4A



Sequence 4B

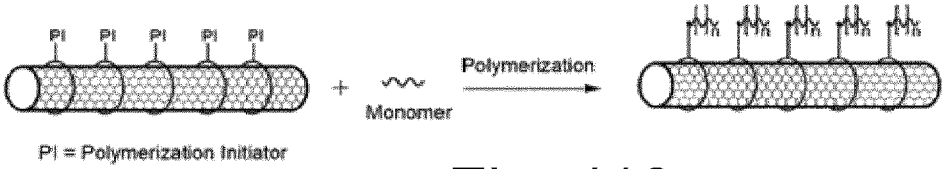
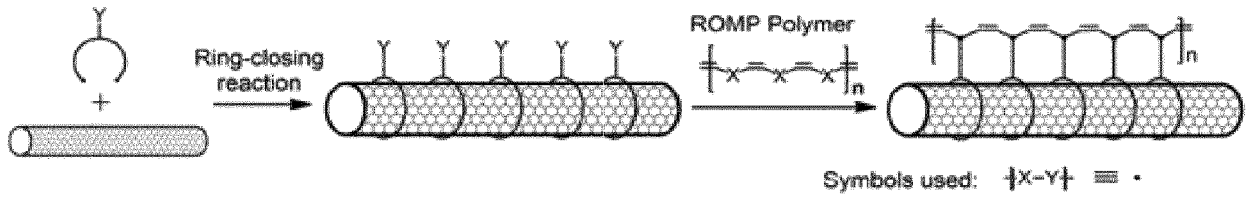


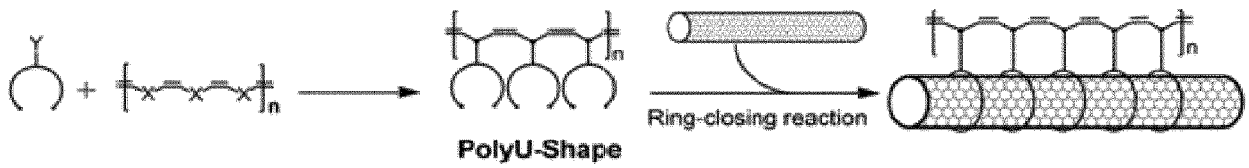
Fig. 119a

Different sequences of events leading to ROMP polymer-carbon nanotube composite materials.

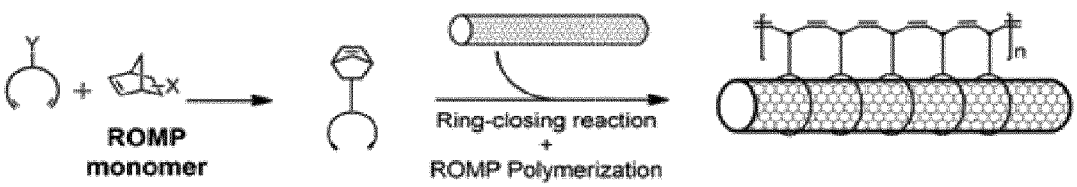
Sequence 1. ROMP Composite



Sequence 2. ROMP Composite

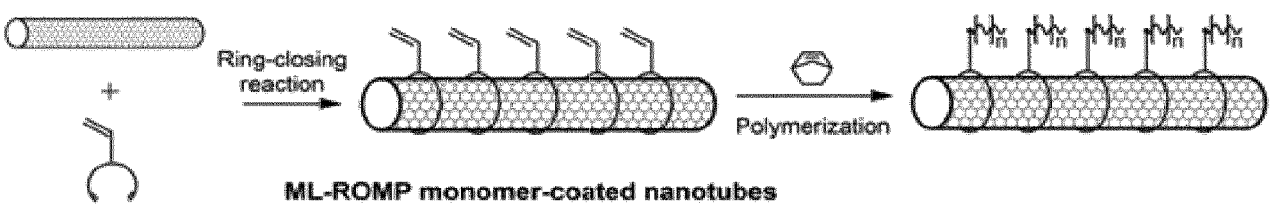


Sequence 3C. ROMP Composite



Precursor-ML-ROMP monomer

Sequence 4. ROMP Composite



ML-ROMP monomer-coated nanotubes

Precursor-ML-ROMP monomer

Fig. 119b

Sequence 1, reaction used to generate polystyrene-coated tuball SWNTs.

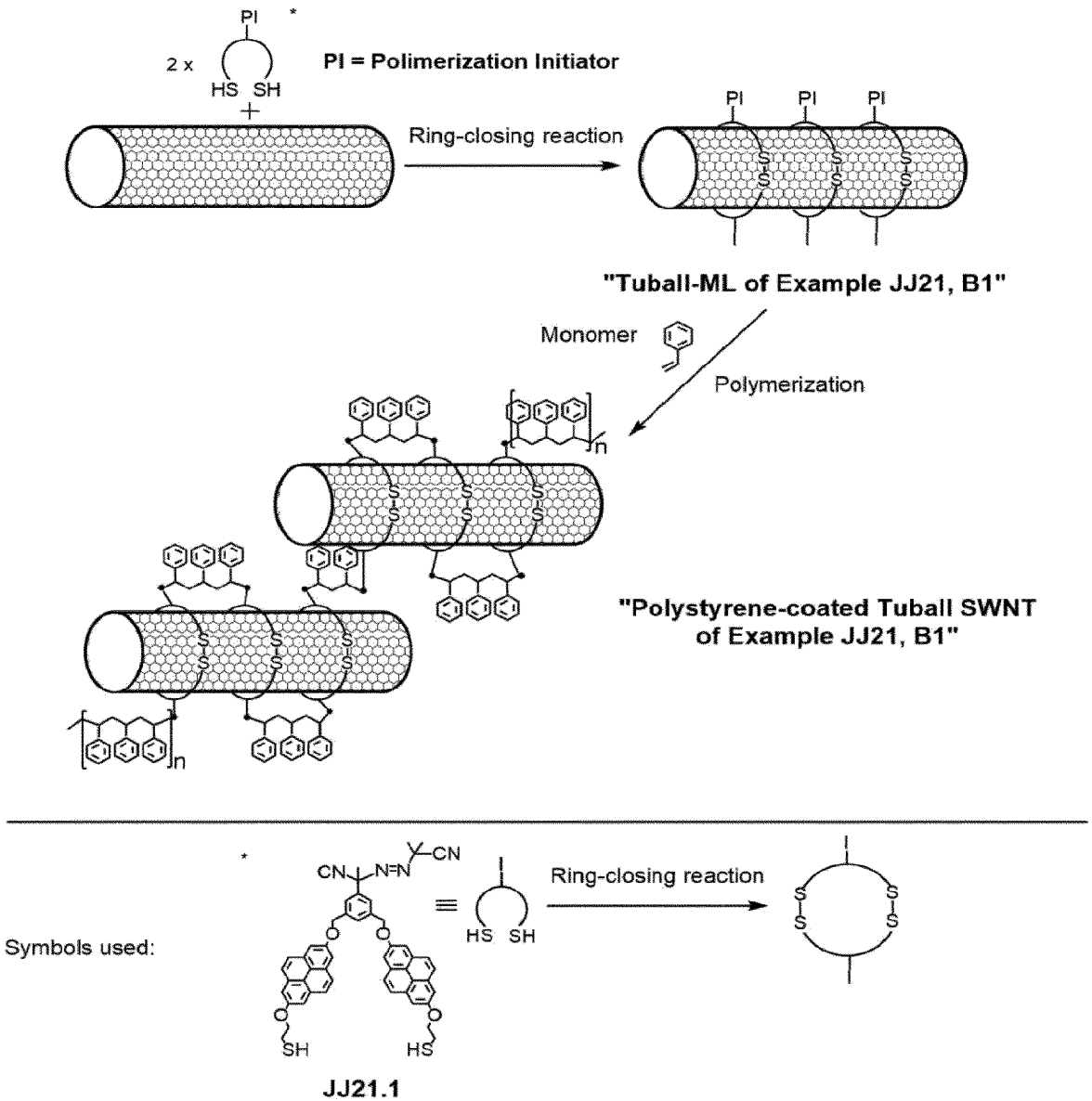


Fig. 119c

Sequence 2, reaction used to generate polyaminoacid-coated SWNTs.

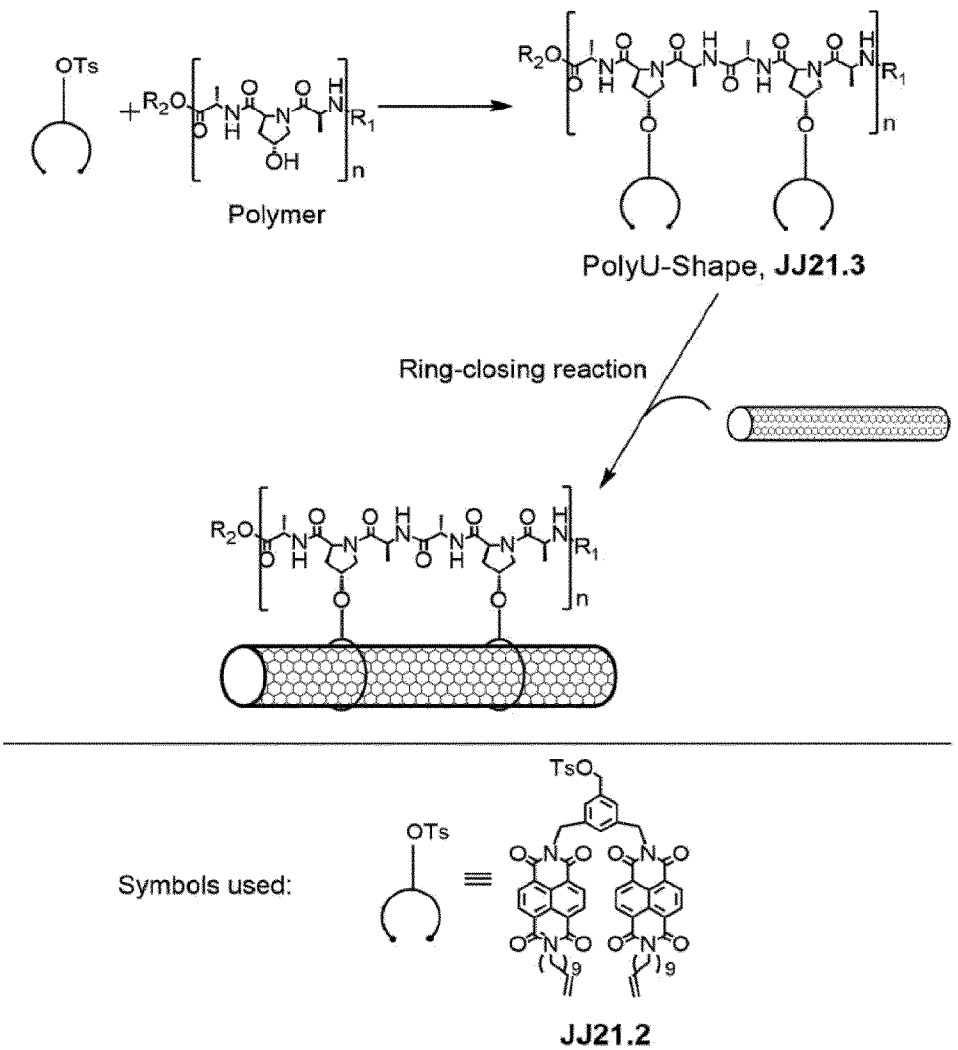


Fig. 119d

Sequence 3A, reaction used to generate polyurethane-coated Tuball SWNTs.

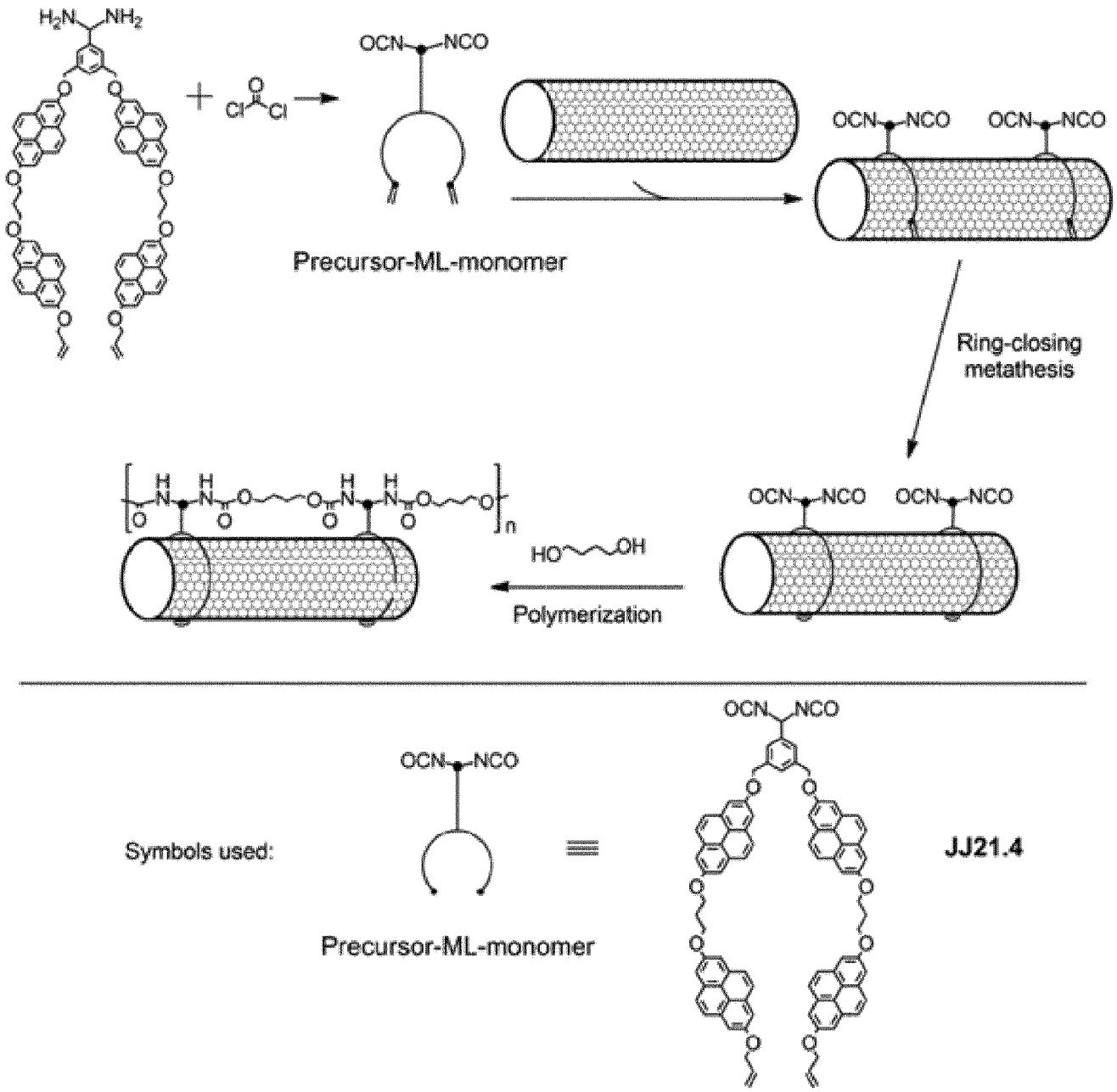
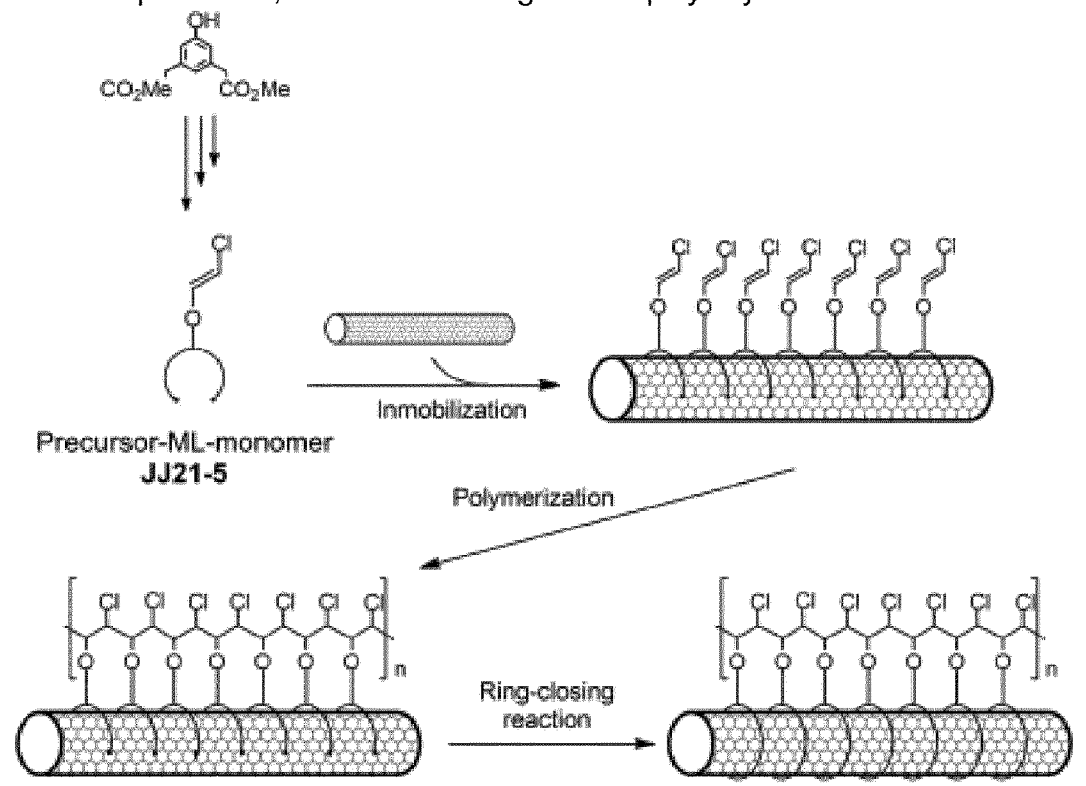


Fig. 119e

Sequence 3B, reaction used to generate polyvinylchloride-coated SWNTs.



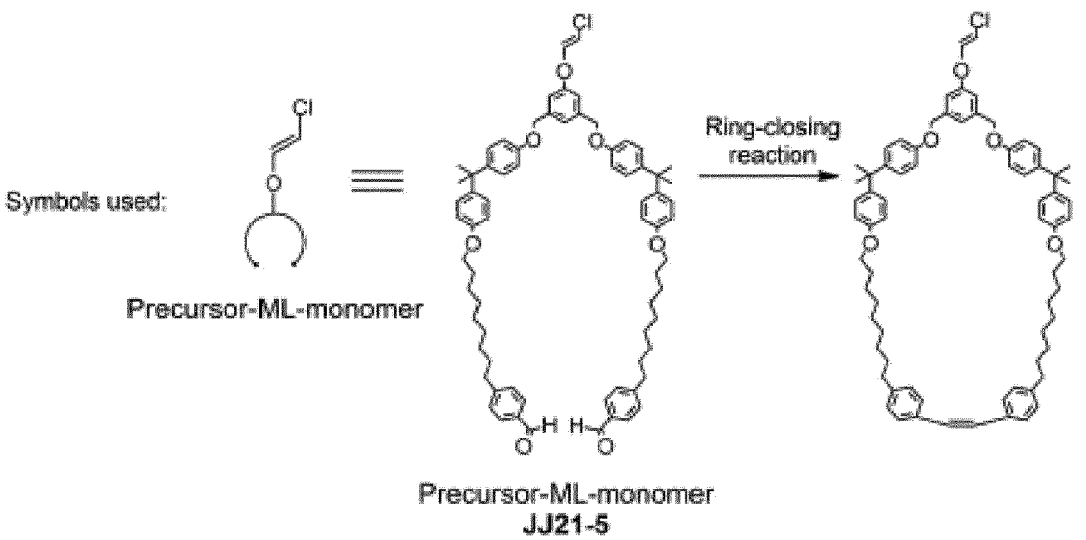


Fig.119f

Sequence 3C, reaction used to generate epoxy-coated DWNTs.

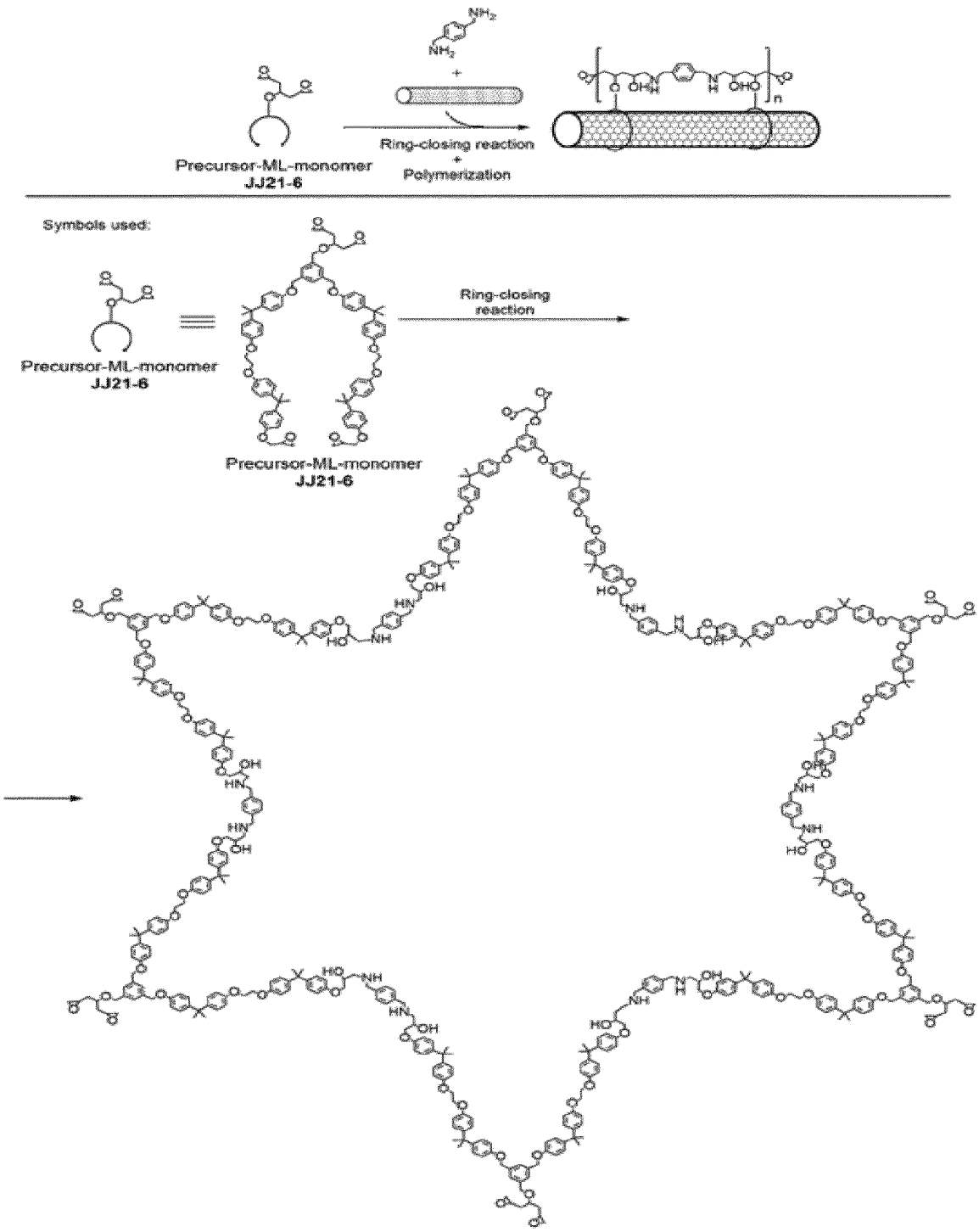
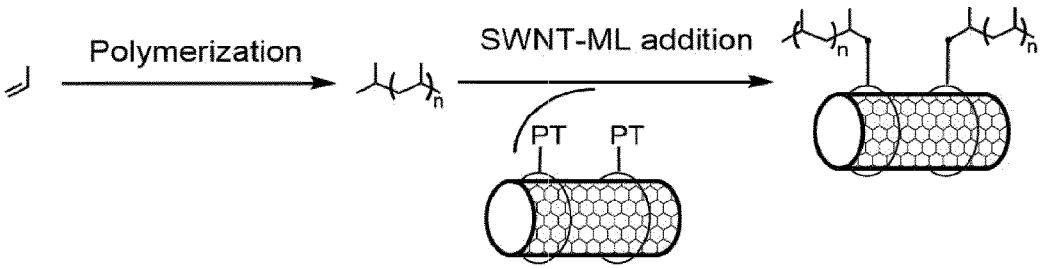
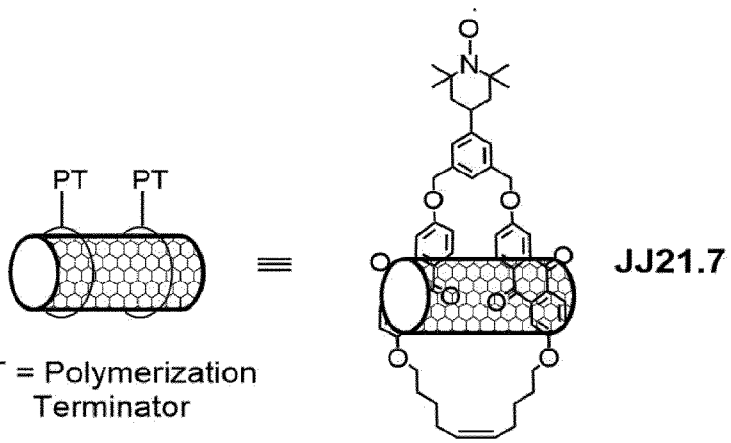


Fig. 119g

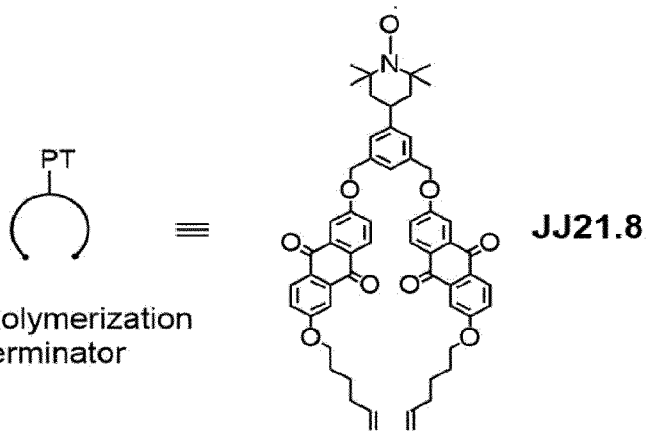
Sequence 4, reaction used to generate polypropylene-coated SWNTs.



Symbols used:



PT = Polymerization Terminator



PT = Polymerization Terminator

Fig. 119h

Connecting polymer and ML by amide-bond formation.

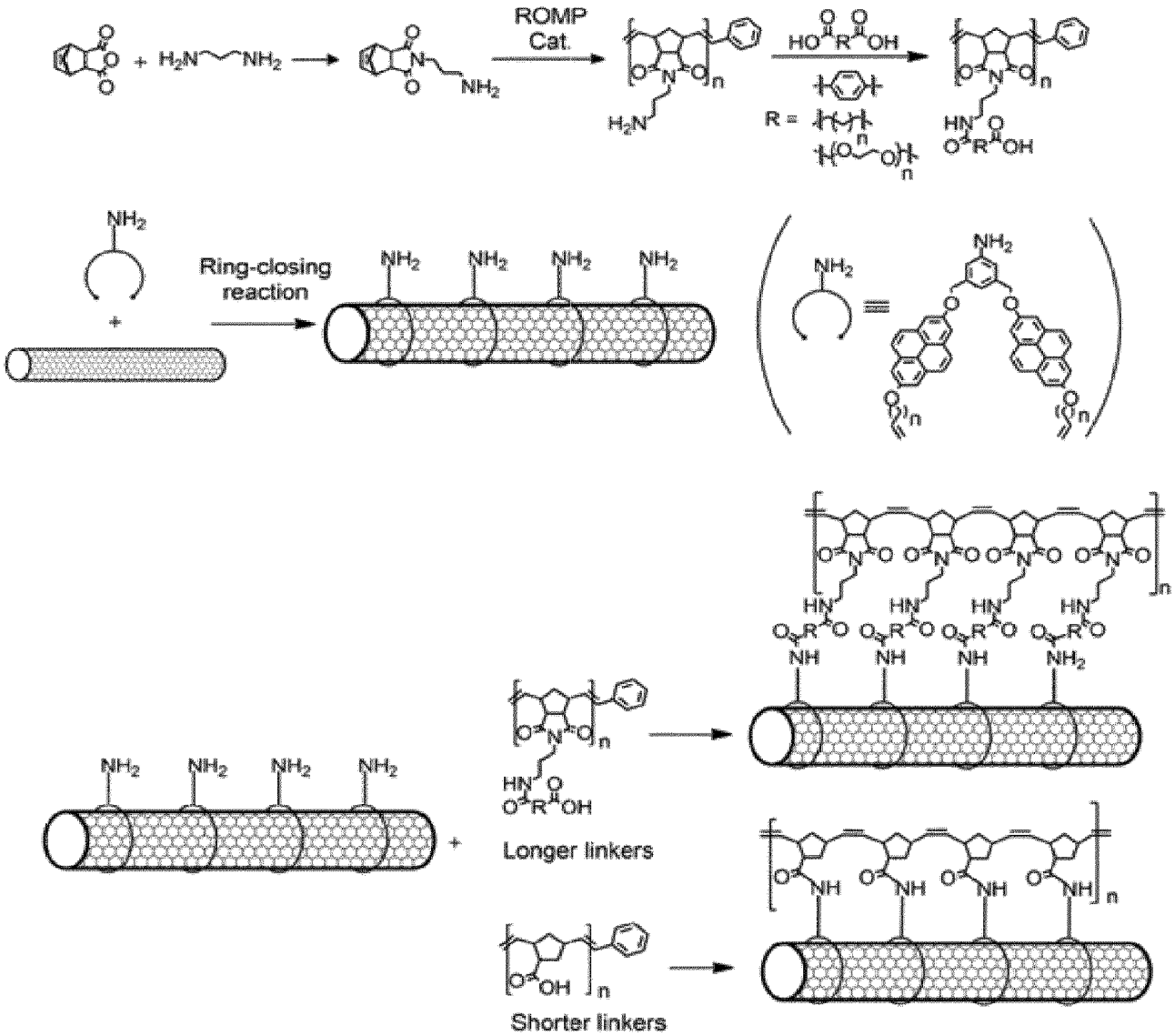


Fig. 120a

Connecting polymer and ML by amide-bond formation.

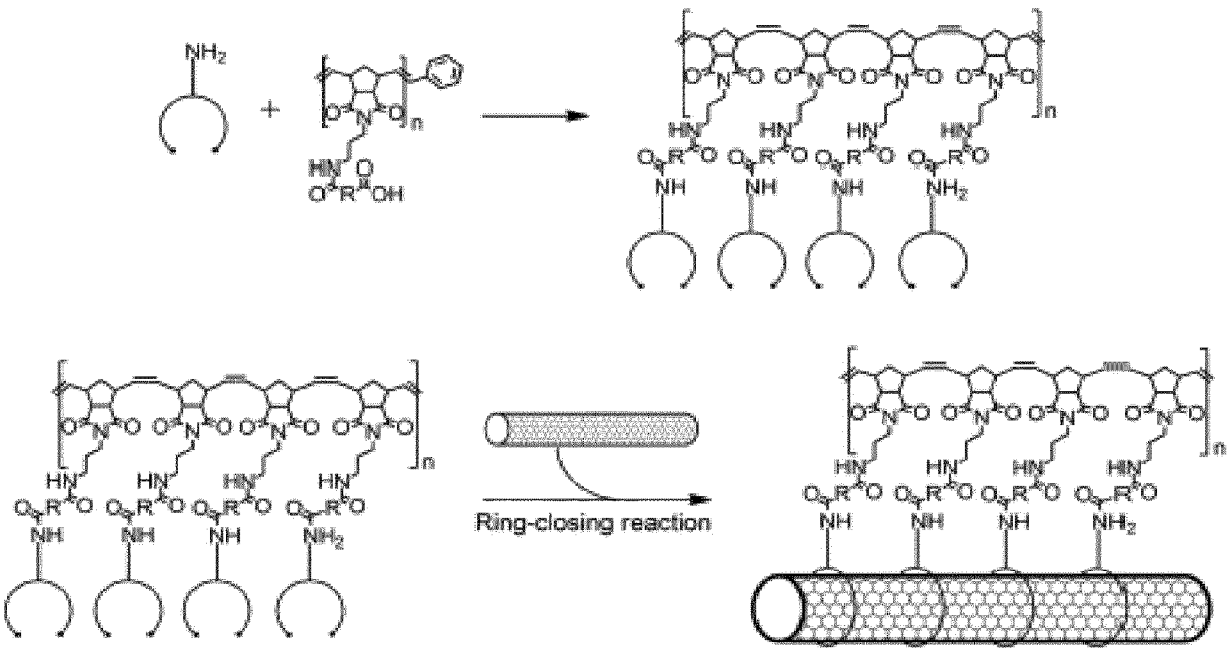


Fig. 120b

Connecting polymer and ML by amide-bond formation.

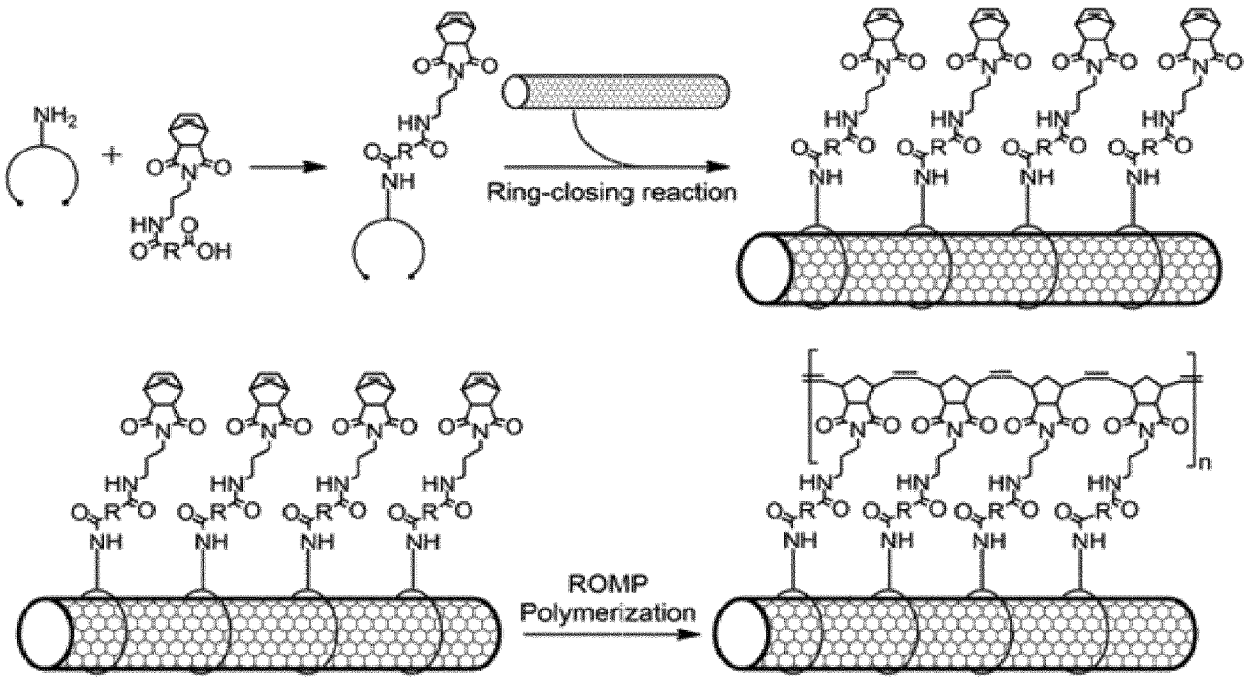


Fig. 120c

Connecting polymer and ML by nucleophilic substitution.

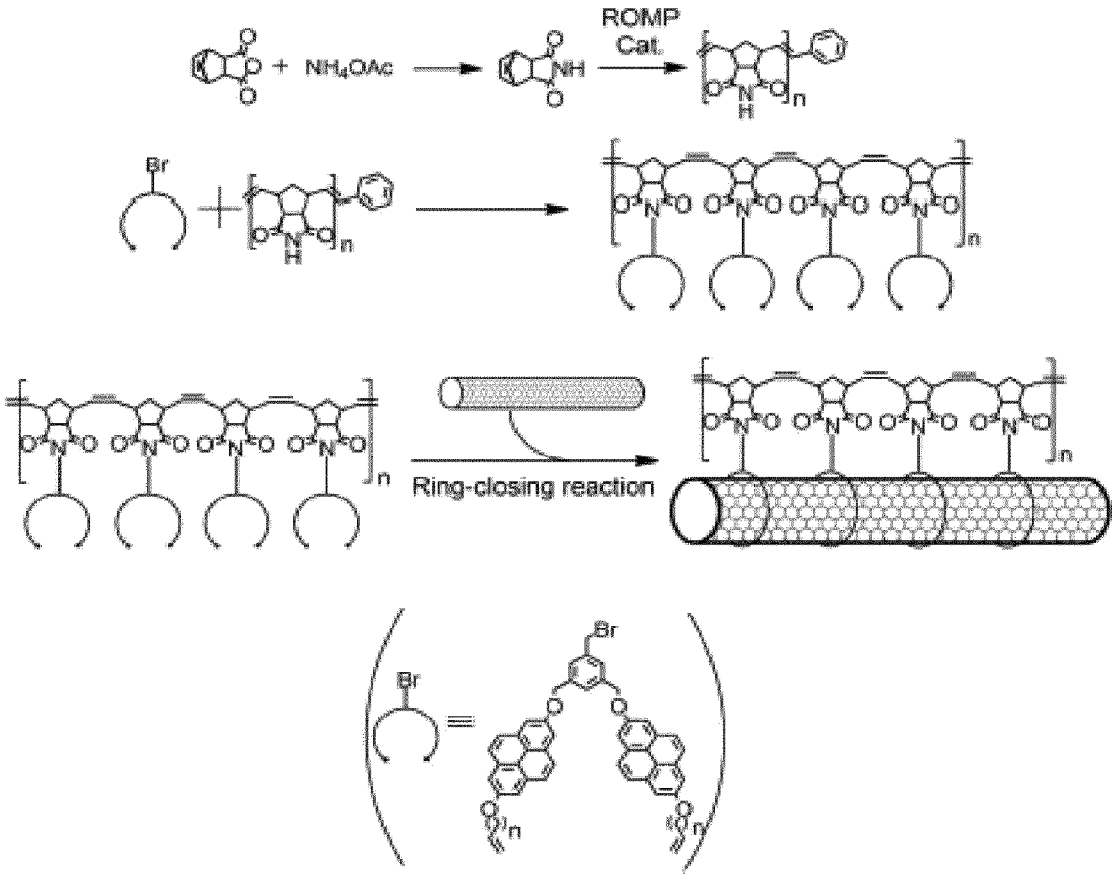


Fig. 121

ROMP polymer-coated SWNT representations

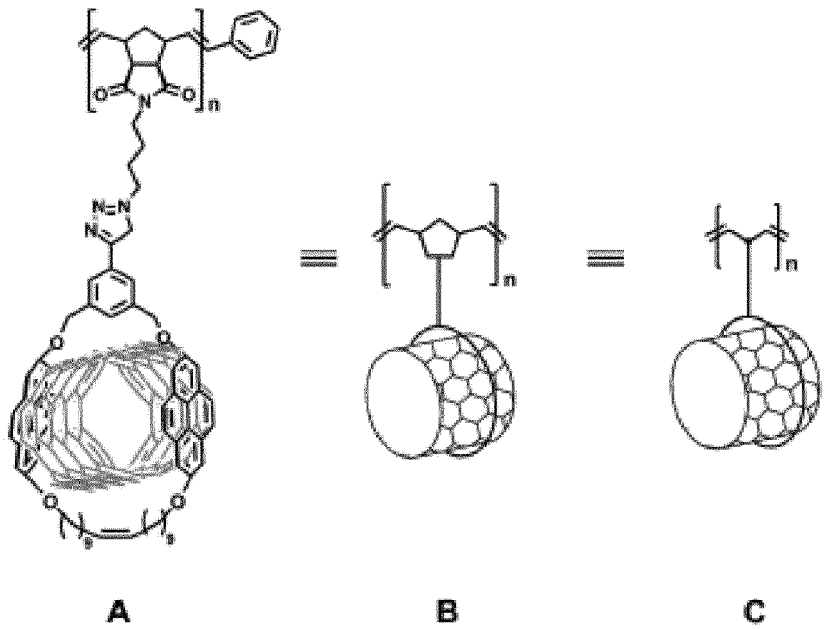


Fig. 122

Metathesis of double bonds, leading to attachment of polymers to the ROMP polymercoated nanotubes or leading to crosslinking of the ROMP polymer-coated nanotubes.

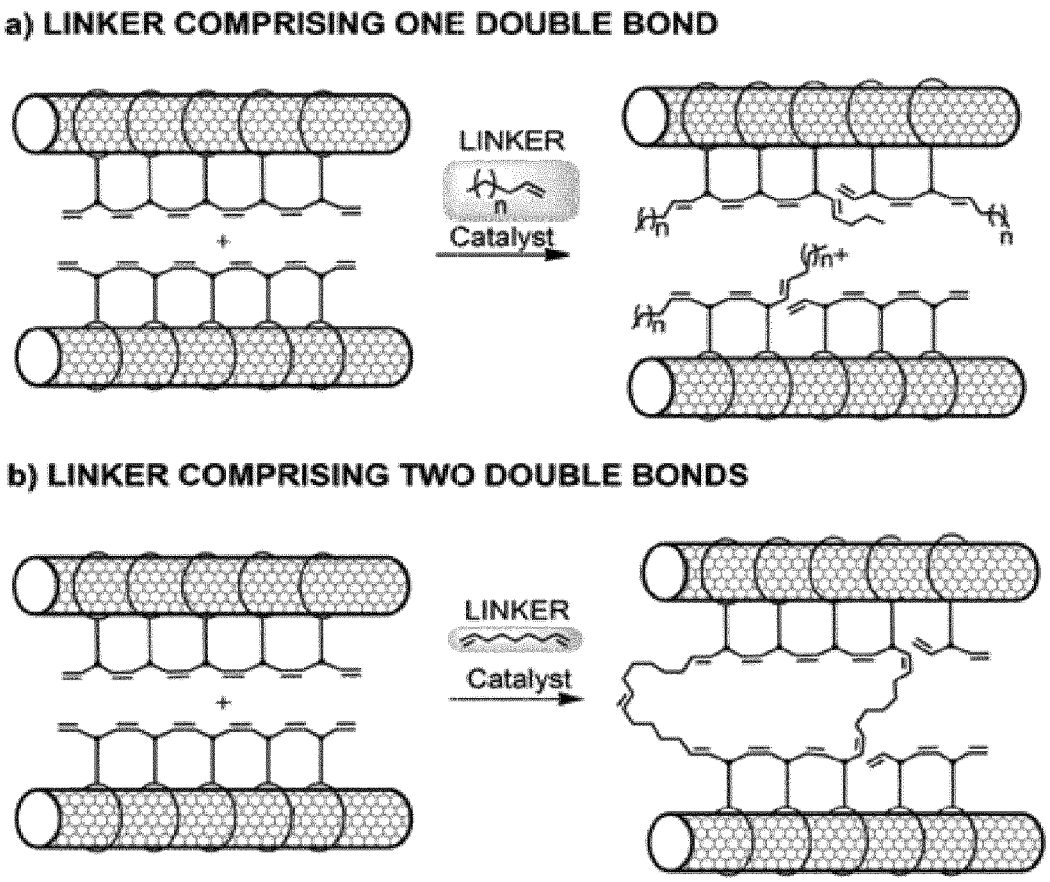


Fig. 123

A fishing rod made from sized SWNTs to which is added linear polyethylene chains comprising at least two double bonds.

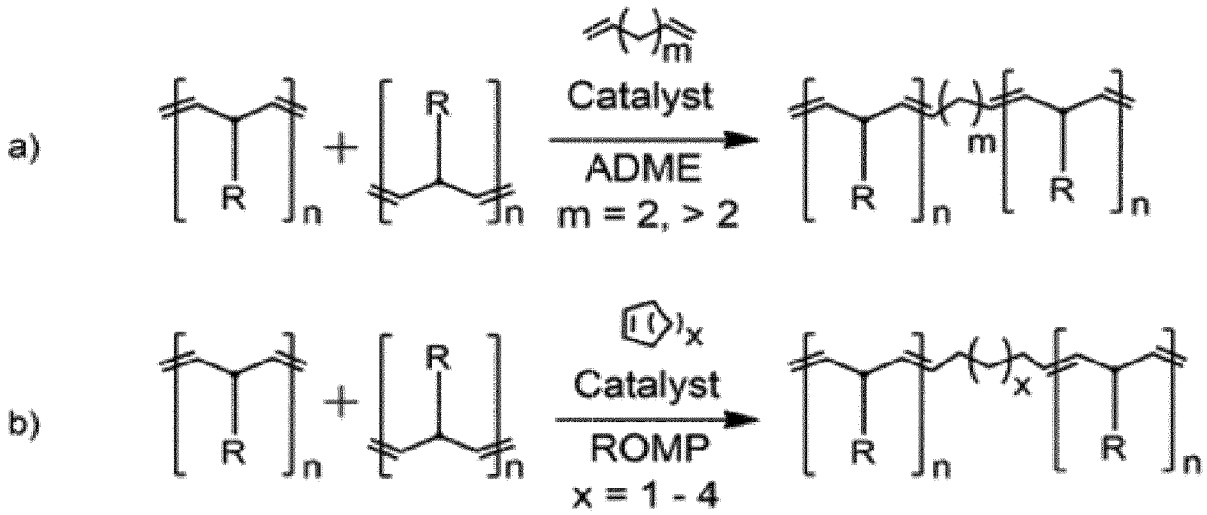
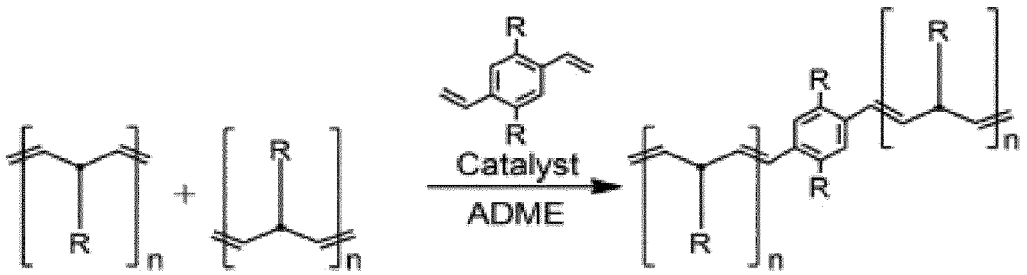


Fig. 124

A gear made from ROMP polymer-coated SWNTs that become cross-linked by linkers comprising aromatic chains and two double bonds.



R = H, OH, OMe, OEt

Fig. 125

A suitcase made from ROMP polymer-coated SWNTs to which is attached polystyrene without crosslinking separate SWNTs.

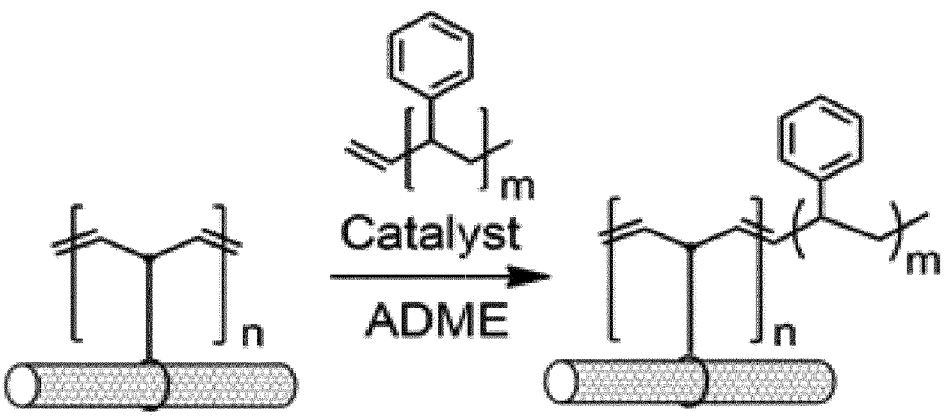


Fig. 126

Introduction of functional groups, by using linkers carrying the desired functionalities.

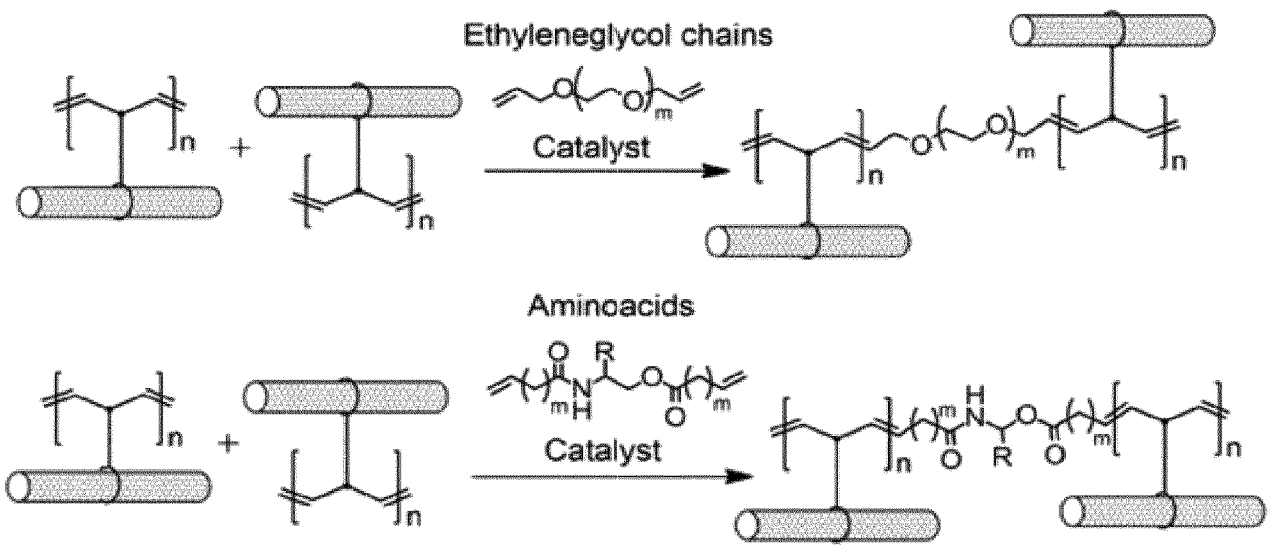


Fig. 127

A roofing membrane made from ROMP polymer-coated SWNTs to which is added polypropylene by a Ziegler-Natta catalytic polymerization.

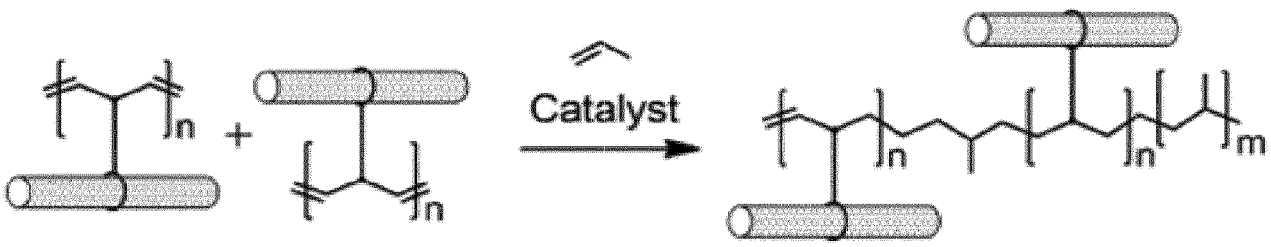


Fig. 128

A fishing line made from sized SWNTs to which is added polystyrene chains comprising one thiol, as well as polystyrene chains not carrying any thiols that can react with double bonds, and where the majority of the polystyrene chains do not become covalently linked to the sized SWNT until after processing (here extrusion).

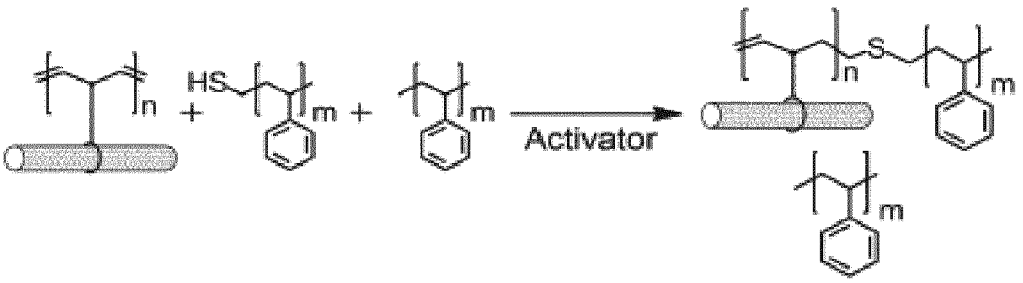


Fig. 129

A tire made from ROMP polymer-coated SWNTs to which is covalently linked cis-1,4-Polybutadiene.

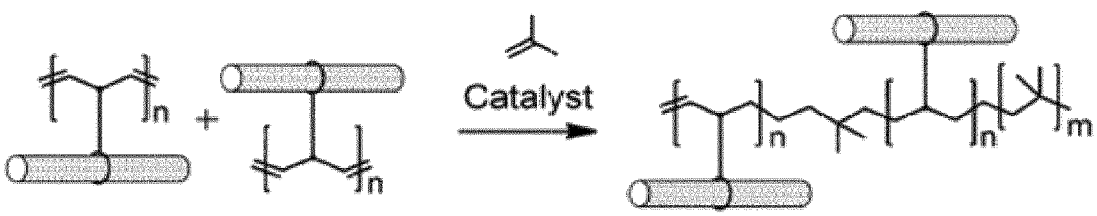


Fig. 130

Vulcanization of modified SWNTs carrying double bonds.

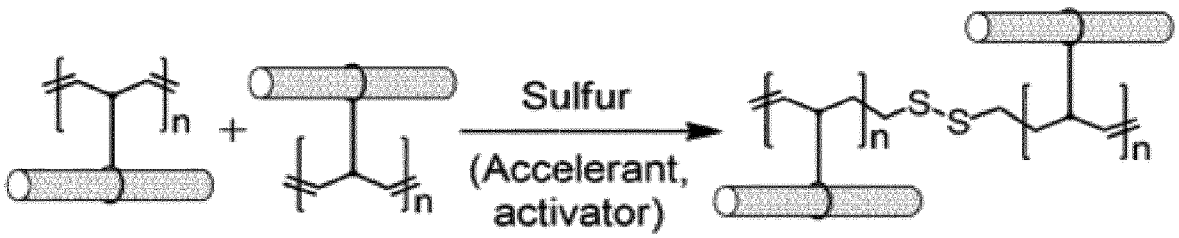


Fig. 131

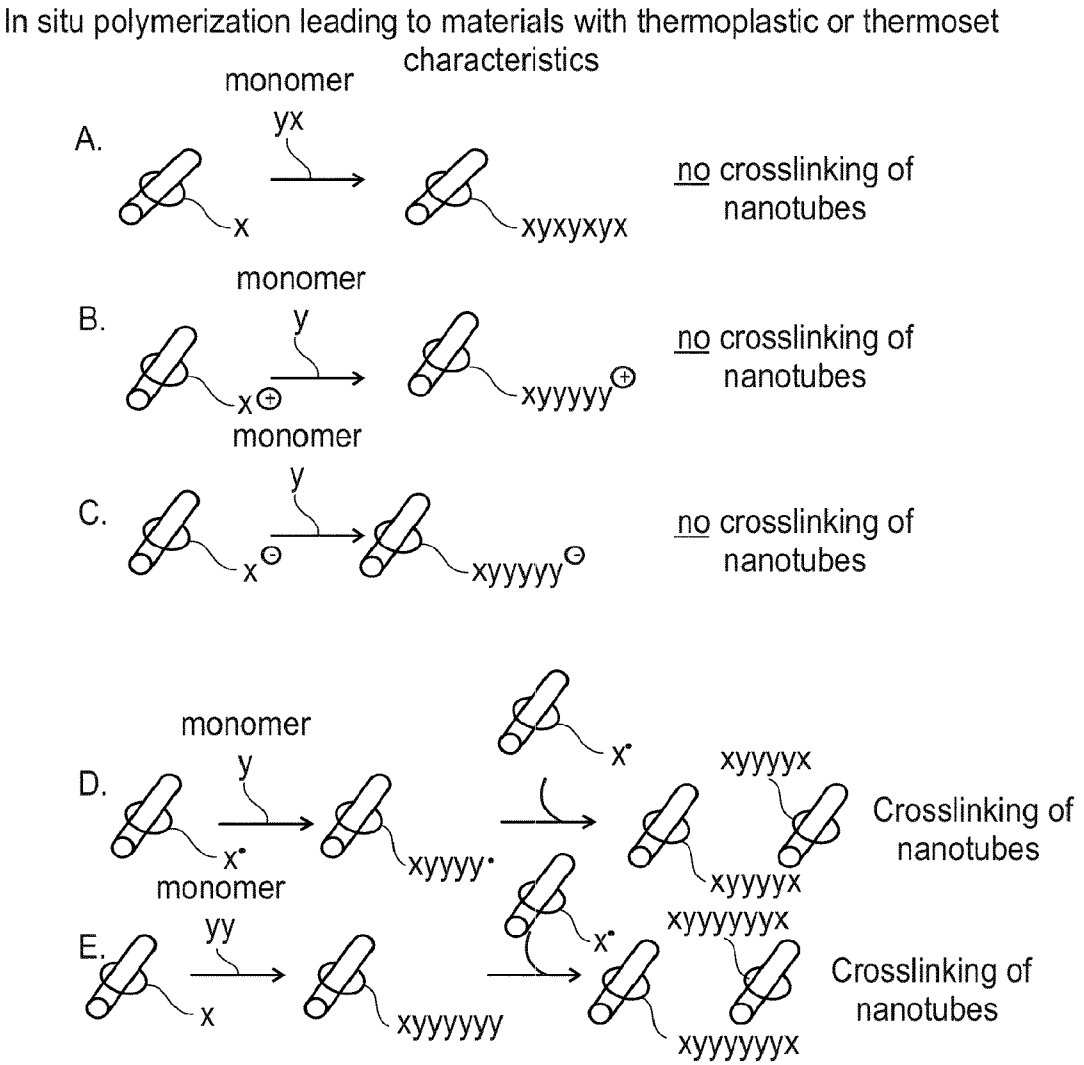
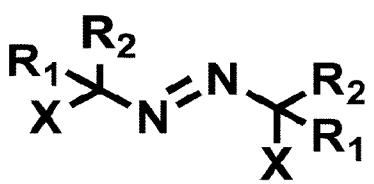


Fig. 132

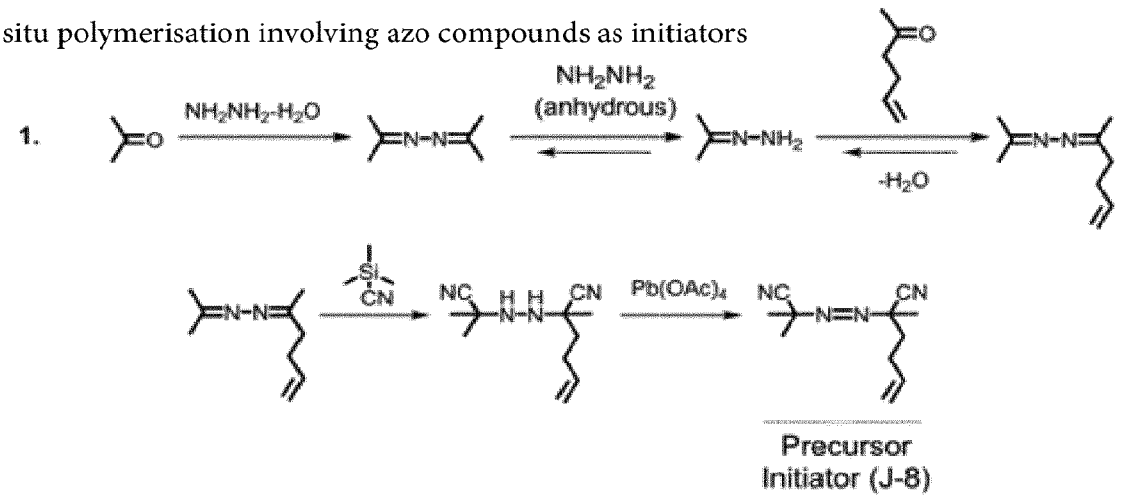


Azo compounds
R=Alkyl group
X =Carboxylic acid derivative (e.g. nitrile, ester, amide)

General structure for azo compounds-based radical initiators

Fig. 133

In situ polymerisation involving azo compounds as initiators



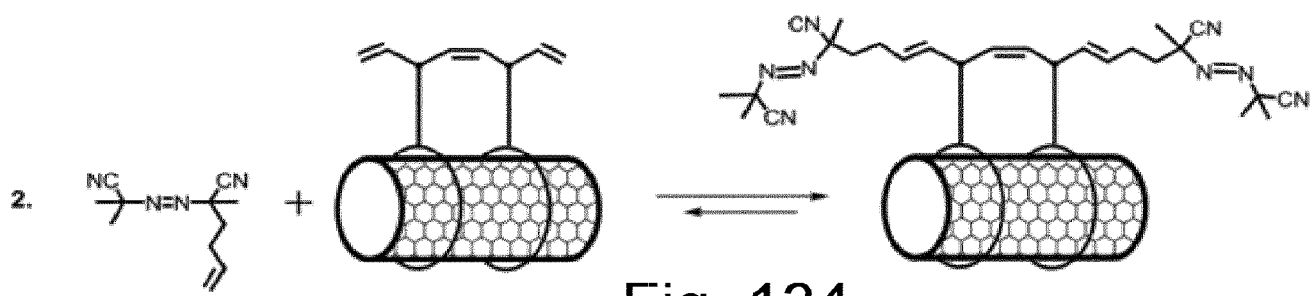
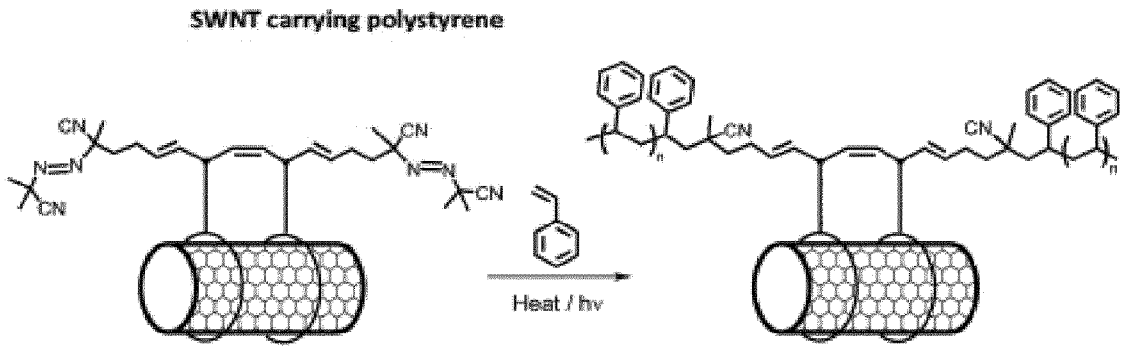


Fig. 134



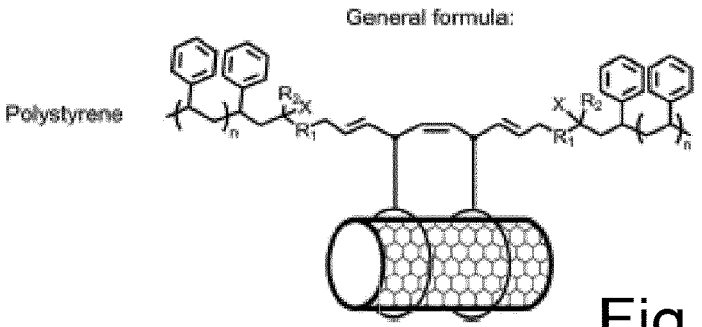


Fig. 135

General structures generated by in situ polymerisation involving azo compounds as initiators.

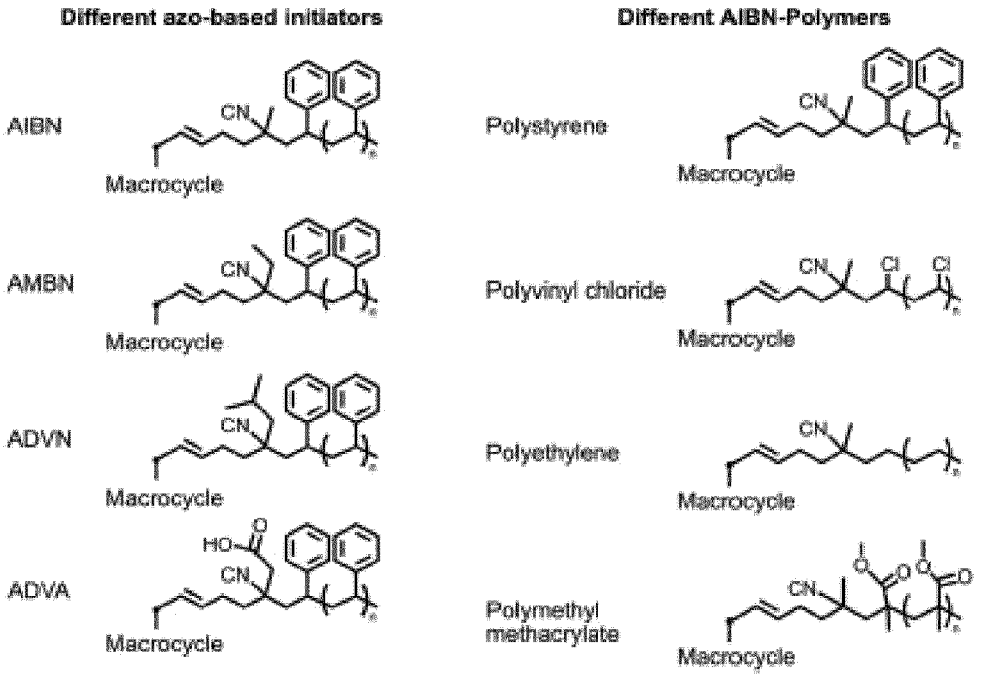


Fig. 136

General structure for alkoxyamine and nitroxide-based radical initiators

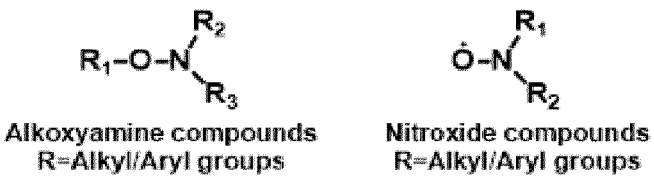


Fig. 137

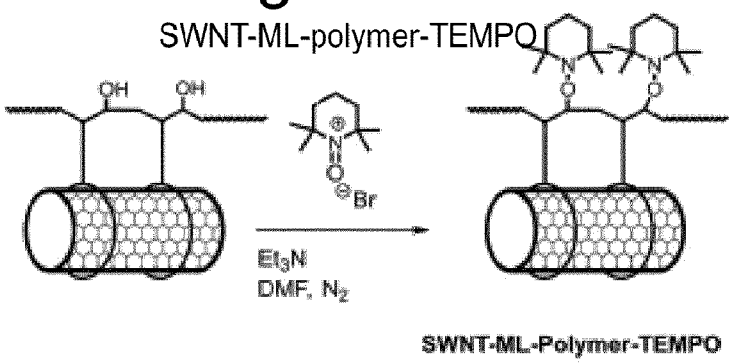
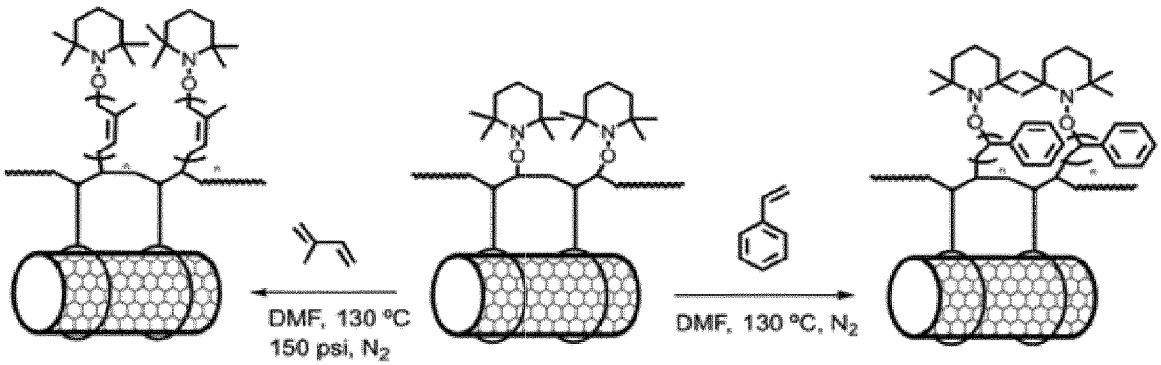


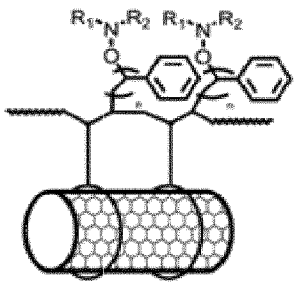
Fig. 138

SWNT-ML-polymer-polystyrene and SWNT-ML-polymer-polyisoprene



SWNT-ML-Polymer-polyisoprene **SWNT-ML-Polymer-polystyrene**

General formula:



Different nitroxide-mediated radical polymerization (NMRP) initiators

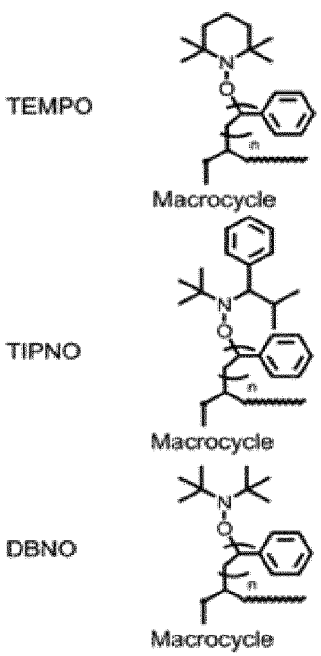


Fig. 139

SWNT-ML-polymer-polystyrene

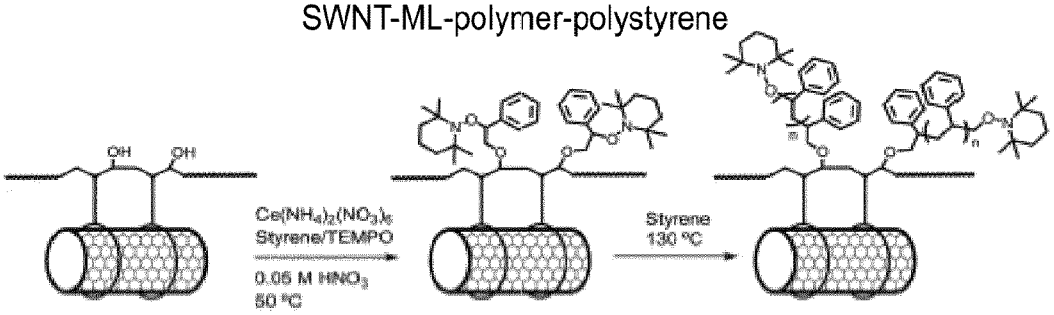
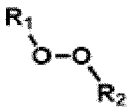


Fig. 140

General structure for organic peroxides-based radical initiators



Organic peroxides
R=Alkyl/Aryl/Carbonyl/H groups

Fig. 141

SWNT carrying polystyrene

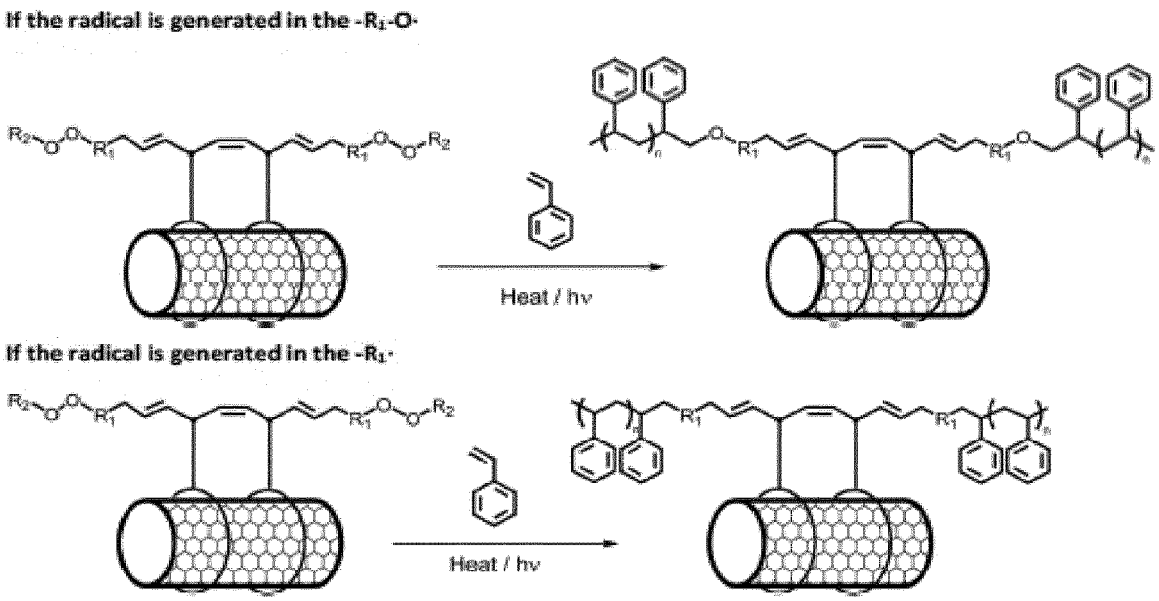


Fig. 142

In situ polymerisation involving ATRP initiators such as alkyl halides, to produce e.g., polystyrene-SWNT composite.

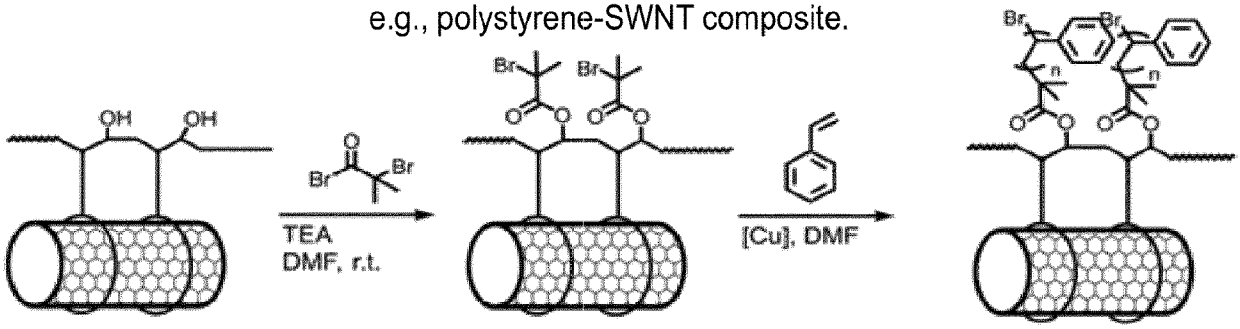


Fig. 143

SWNT-ML-Polymer-polystyrene

General structures generated by in situ polymerisation involving ATRP initiators.

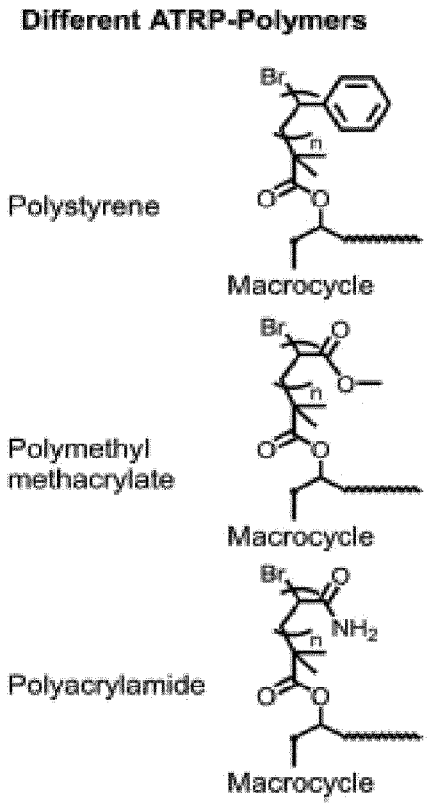


Fig. 144

SWNT-ML-polymer-RAFT initiator

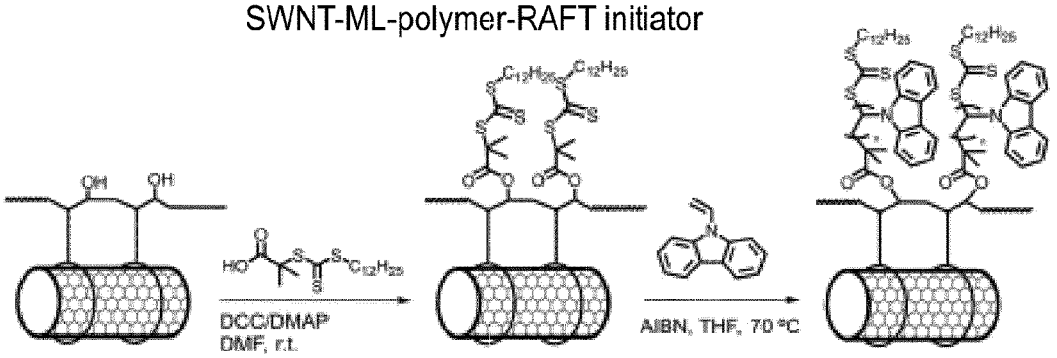


Fig. 145

General structures generated by in situ polymerisation involving RAFT initiators.

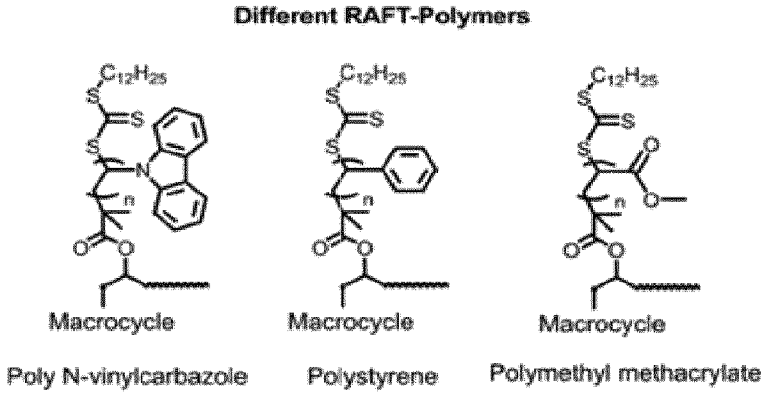


Fig. 146

In situ polymerisation involving organic photoinitiators

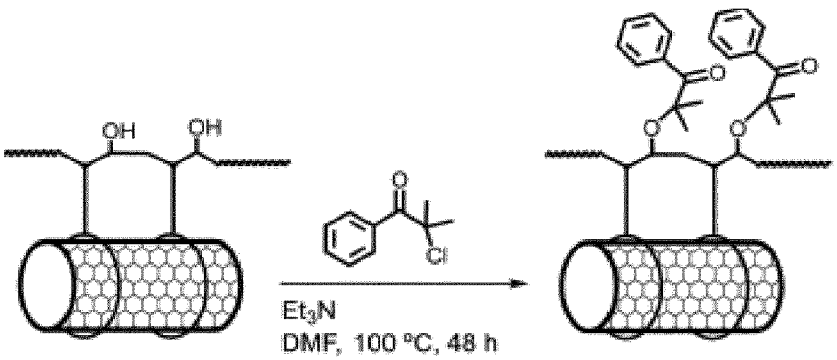
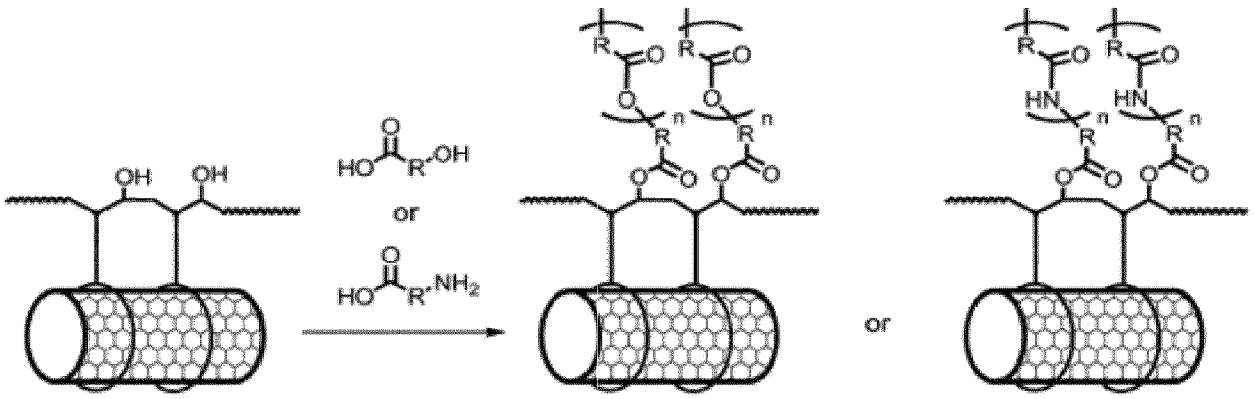


Fig. 147

In situ polymerisation involving initiators that only react with one reactive group of a monomer that is asymmetric in the sense that it comprises two different reactive groups, both of which are involved in the polymerization process.

AB-type polycondensation



AABB-type polycondensation

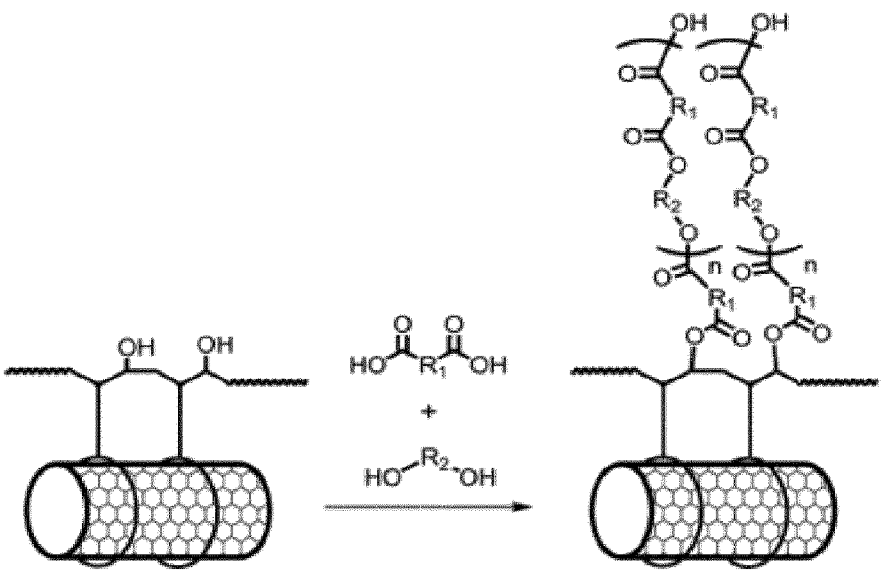
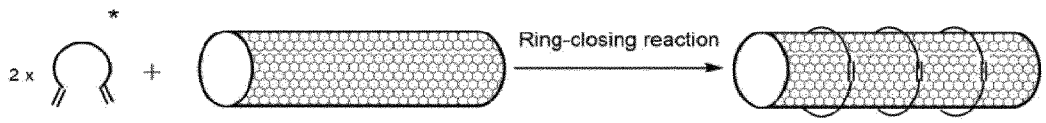
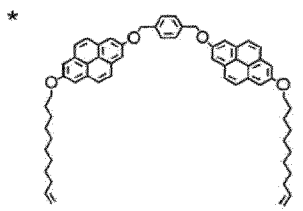


Fig. 148

Ring-closing of a macrocycle around Tuball SWNTs



"SWNT-ML composite of Example JJ36"



JJ36.1

Fig. 149

TGA analysis of "SWNT-ML composite of Example JJ36".

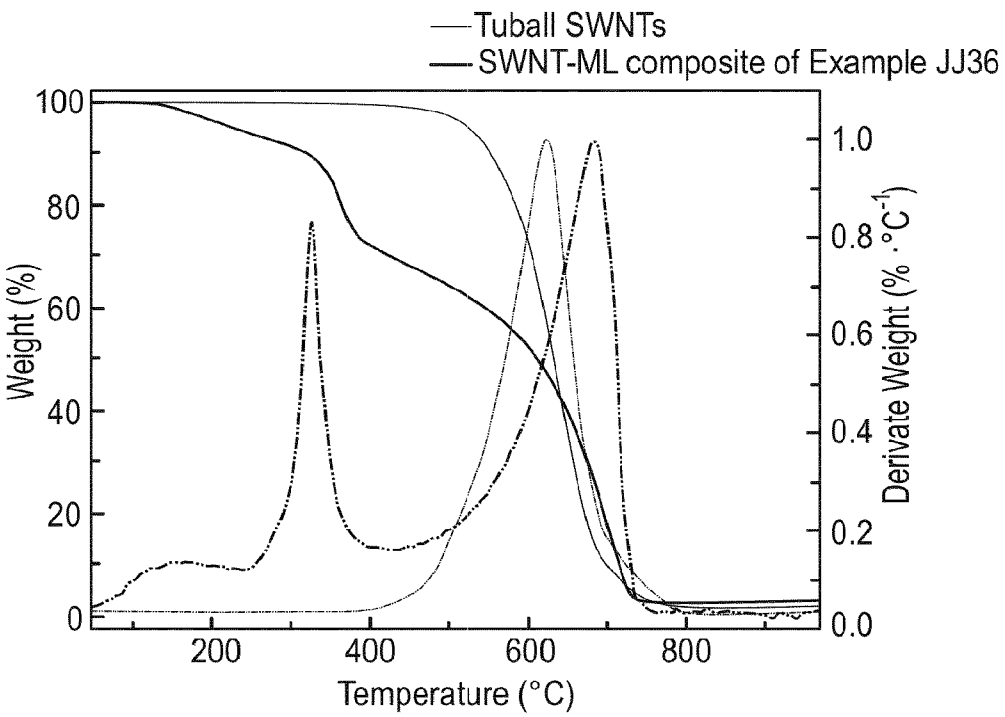


Fig. 150

AC-HRTEM analysis of "SWNT-ML composite of Example JJ36".

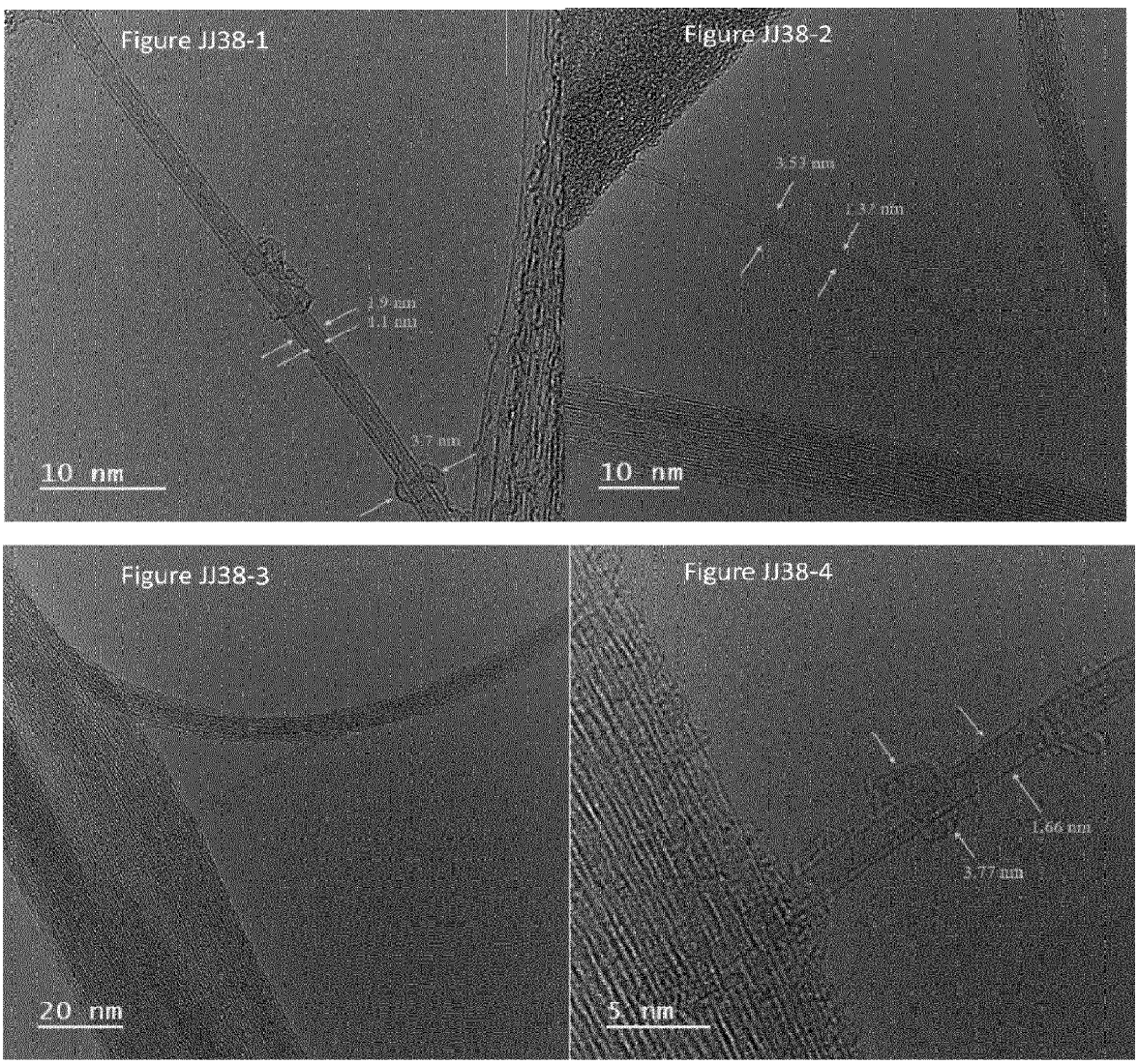


Fig. 151

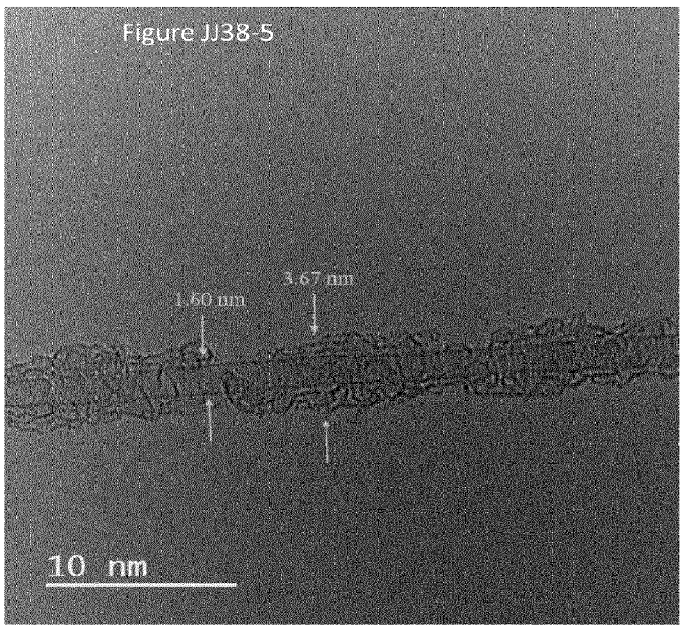


Fig. 151 (Continued)

A.

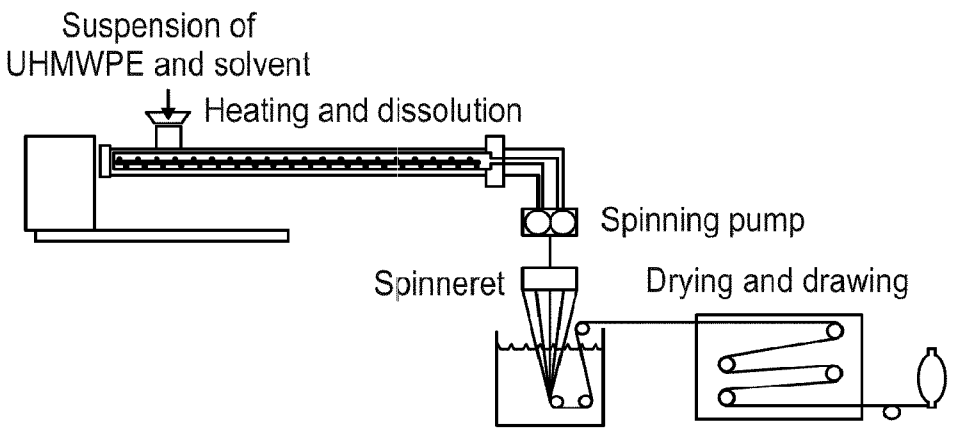

Suspension of
UHMWPE and solvent
Heating and dissolution
Spinning pump
Spinneret
Drying and drawing

Fig. 152

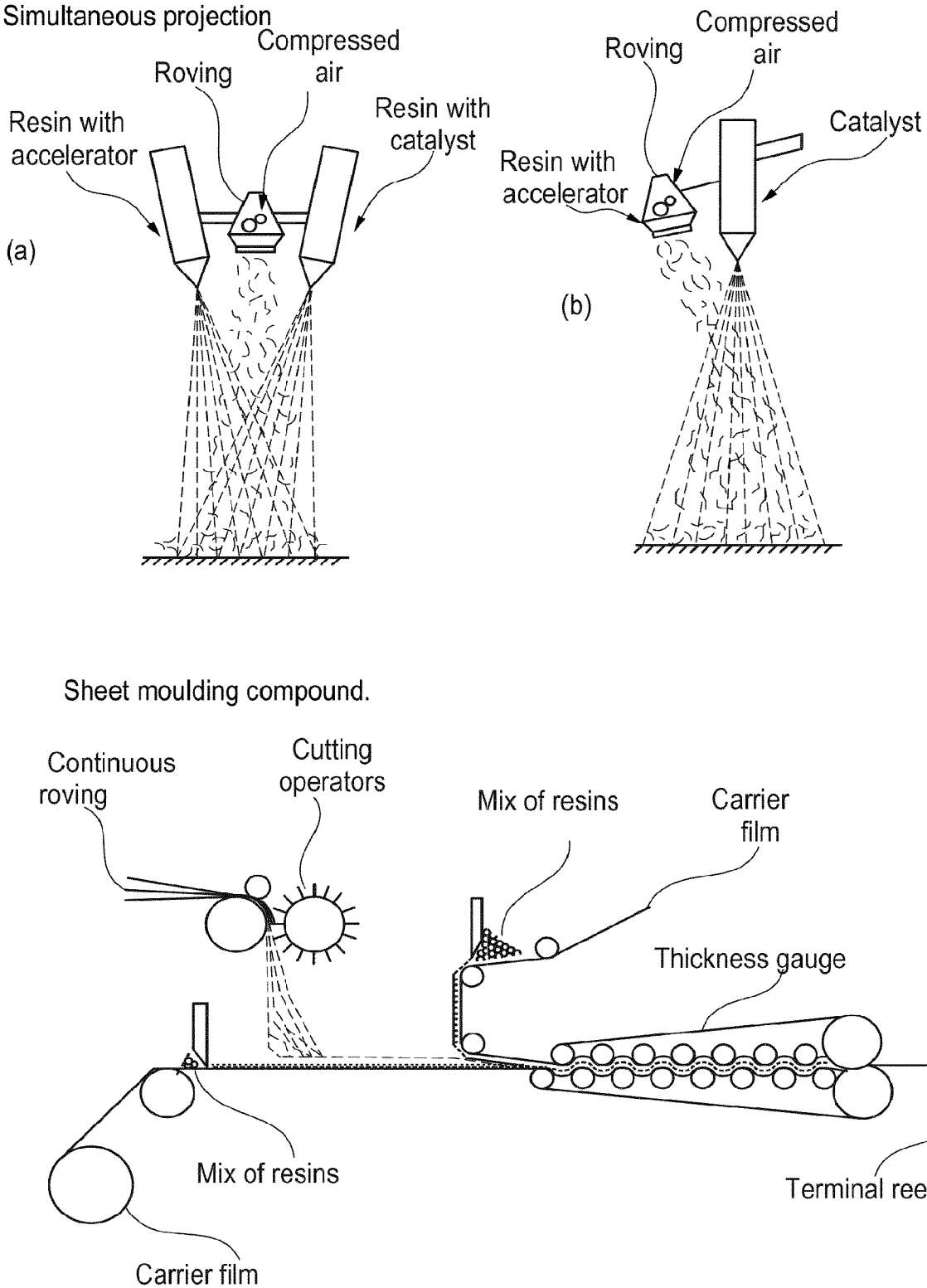
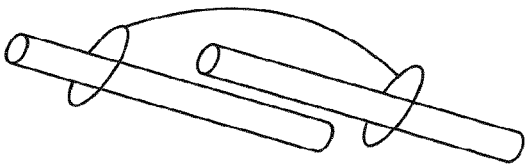


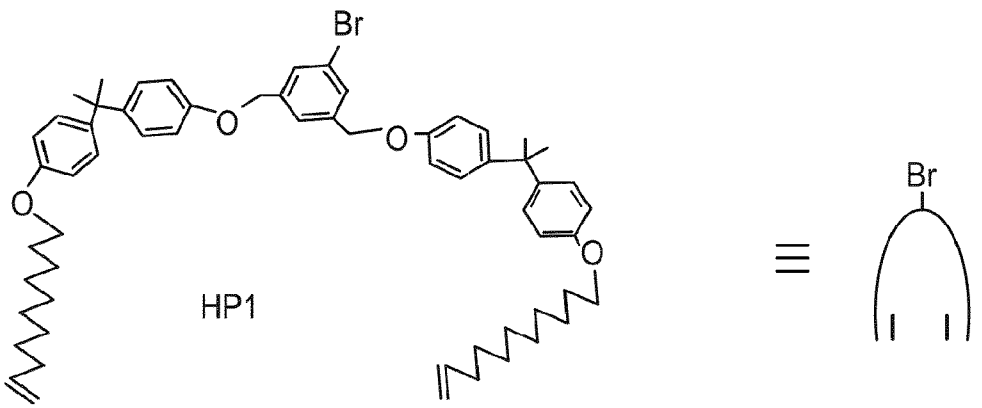
Fig. 152 (Continued)

Bidentate compound carrying two MLs.

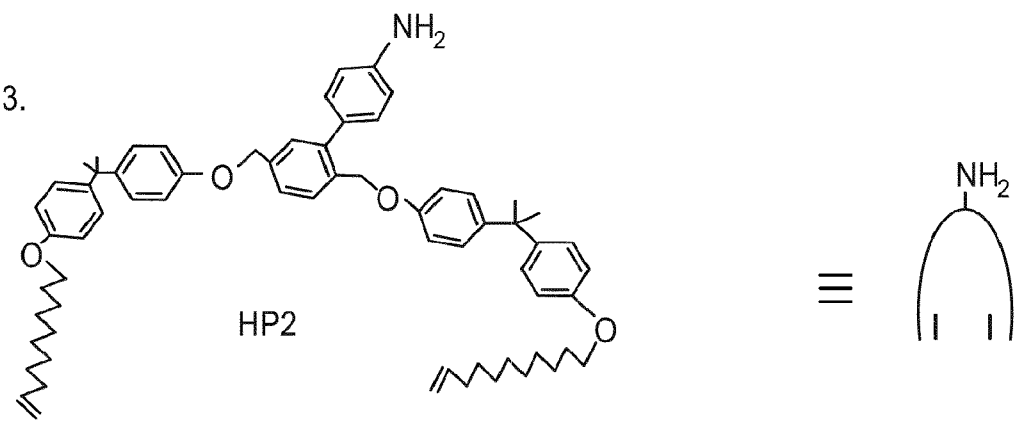
1.



2.



3.



4.

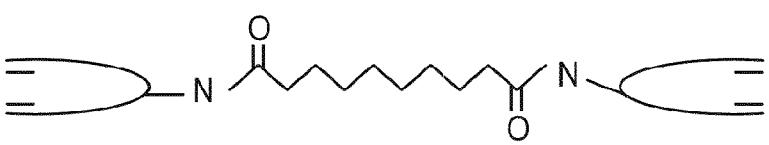
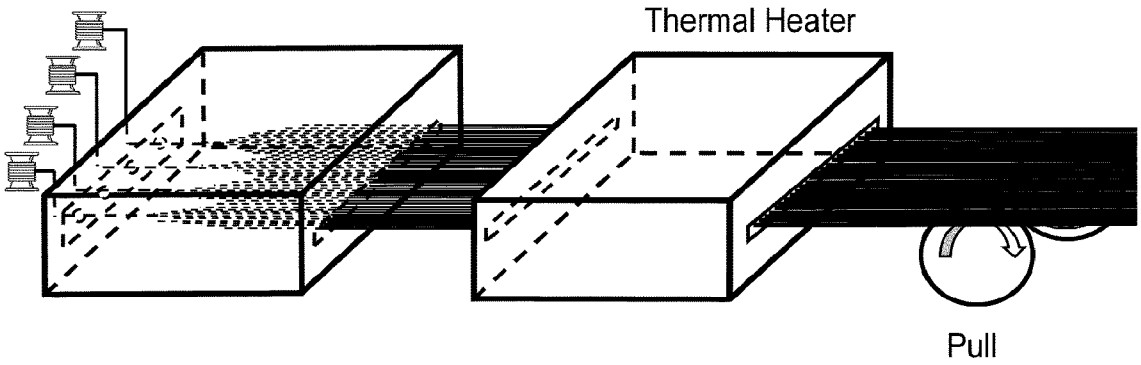
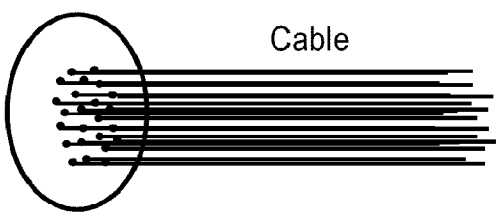
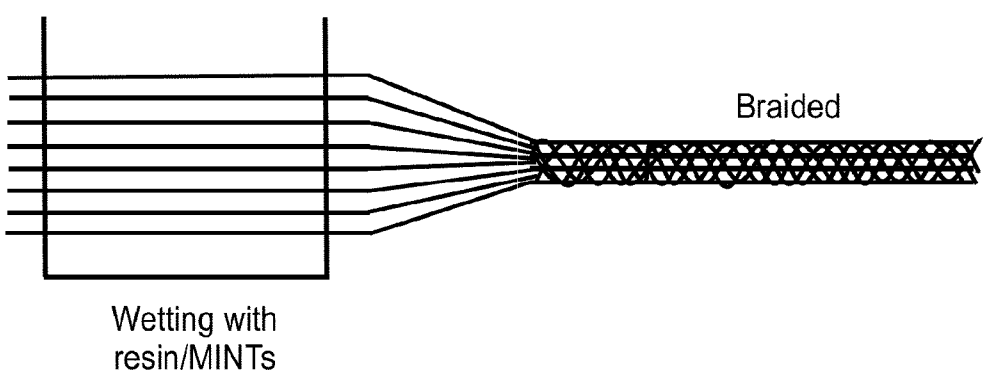


Fig. 153a

Pultrusion using drawn CNT forests, CNT thread or other types of CNT fibers and -lines.







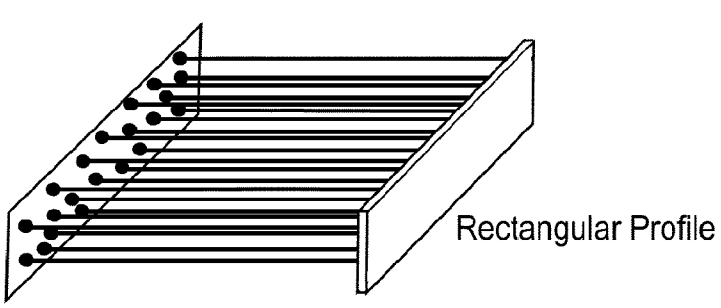


Fig. 153b

Precursor-ML carrying protonated amines, binding to a carbon nanotube.

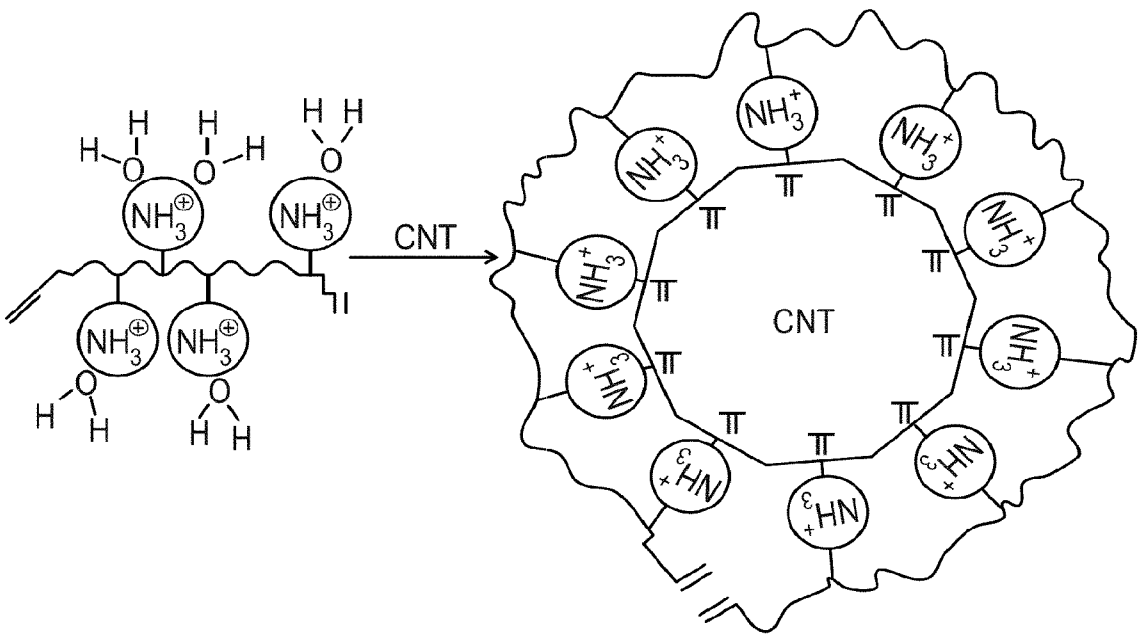


Fig. 154a

Precursor-ML carrying polar groups, binding to a carbon nanotube.

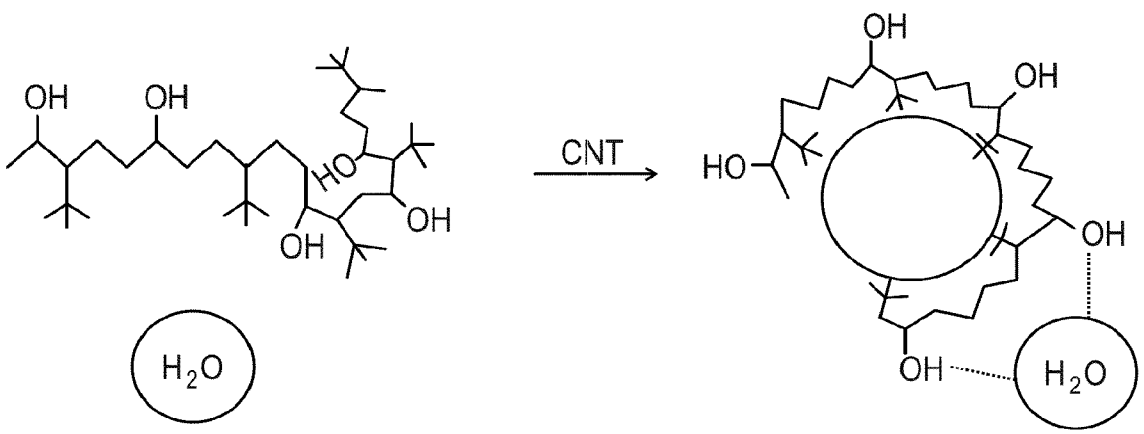


Fig. 154b

Recycling a thermoset-nanotube composite.

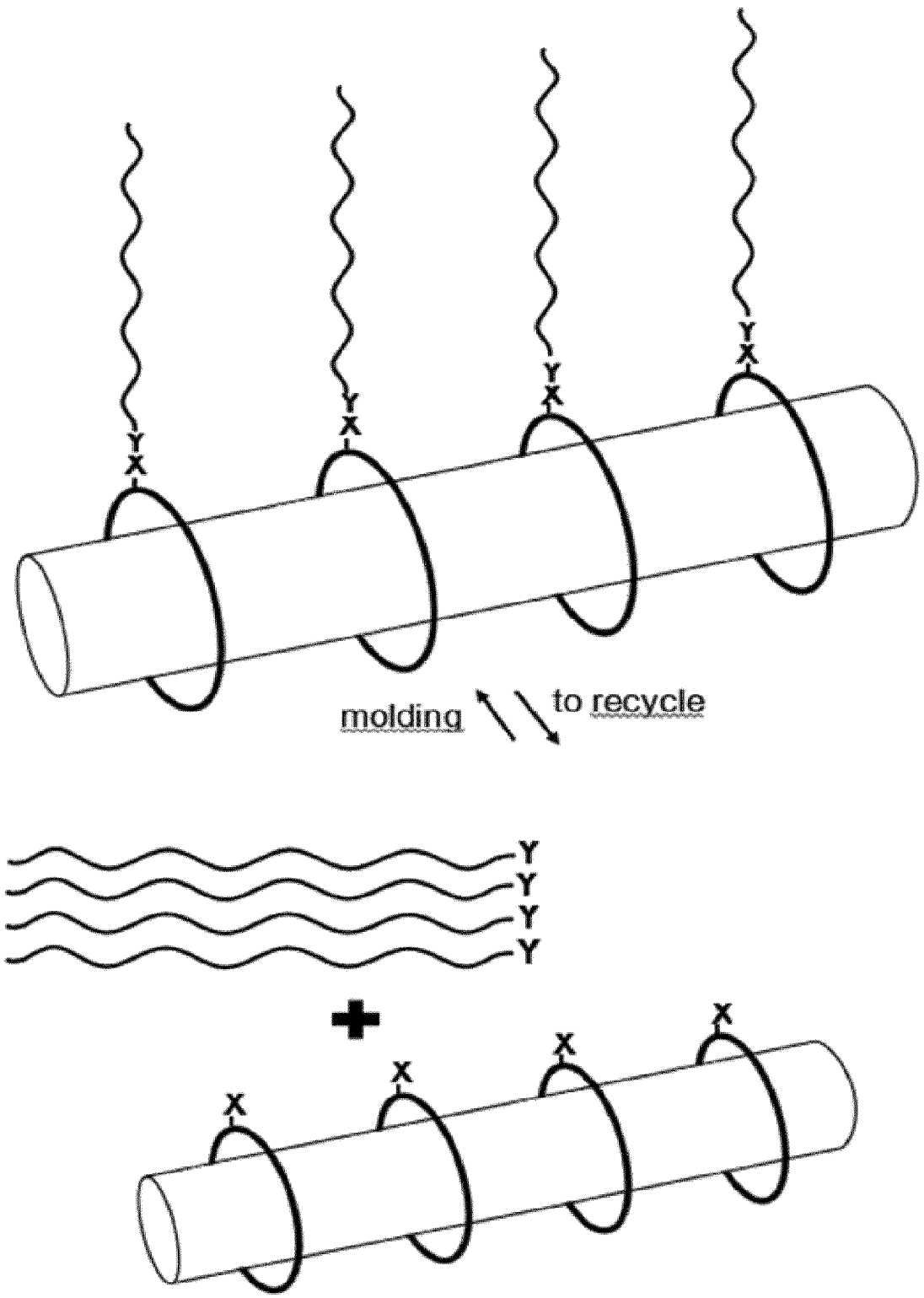


Fig. 155

Two approaches for making CNT-reinforced Kevlar.

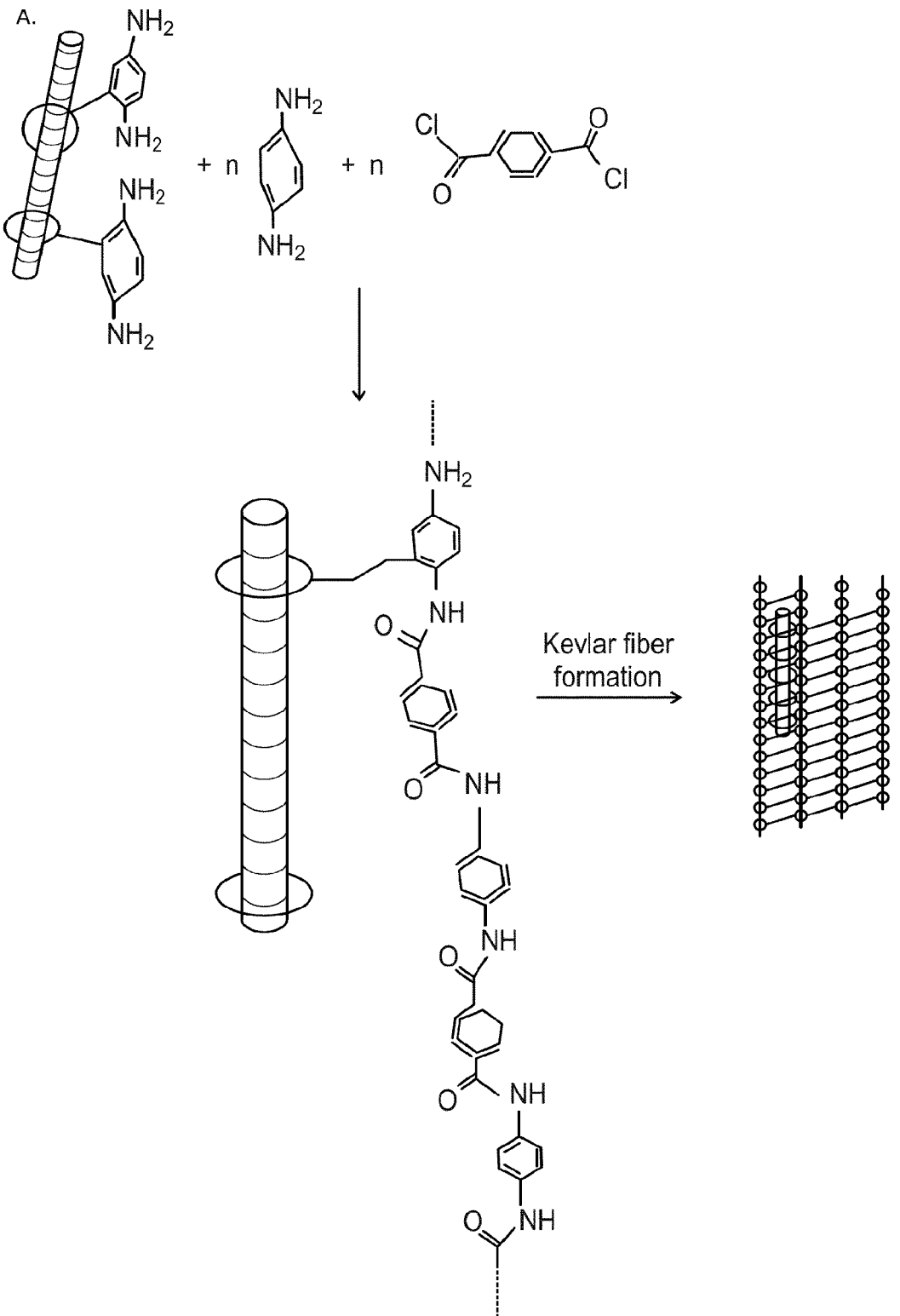


Fig. 156

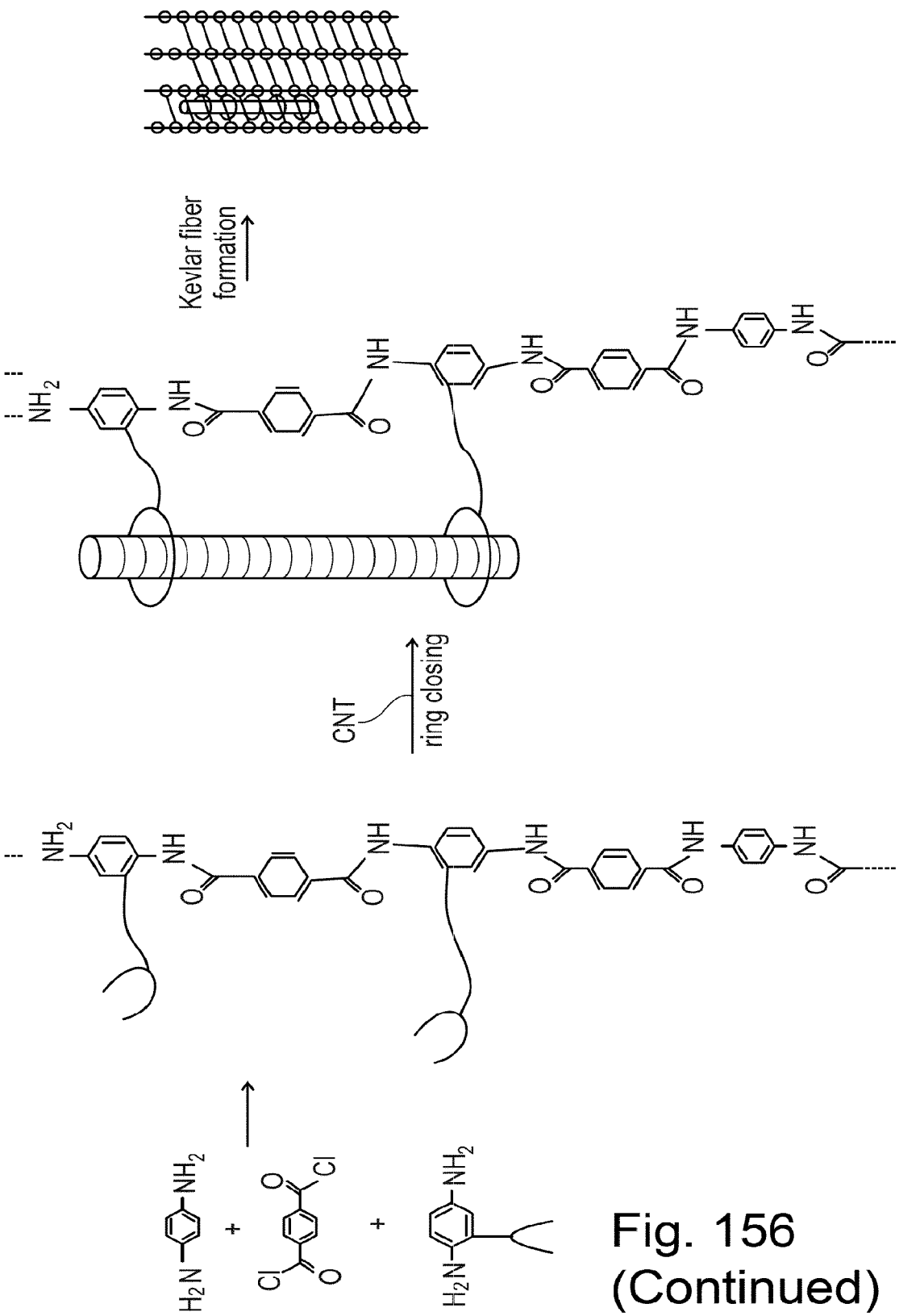


Fig. 156 (Continued)

Scheme 1

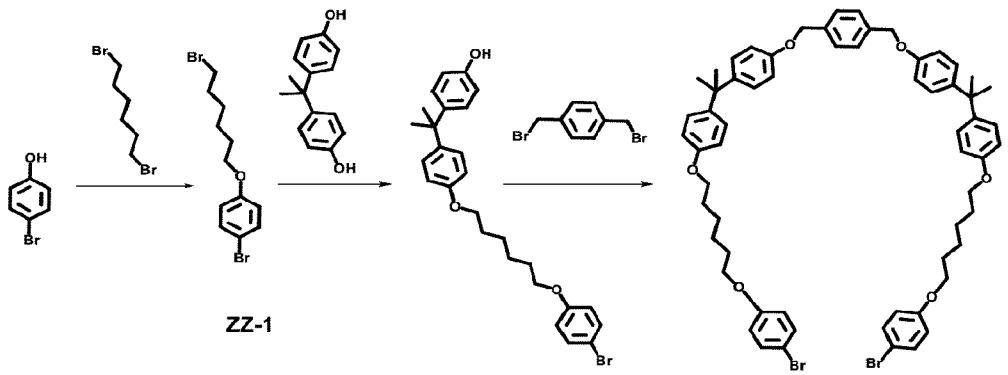


Fig. 157

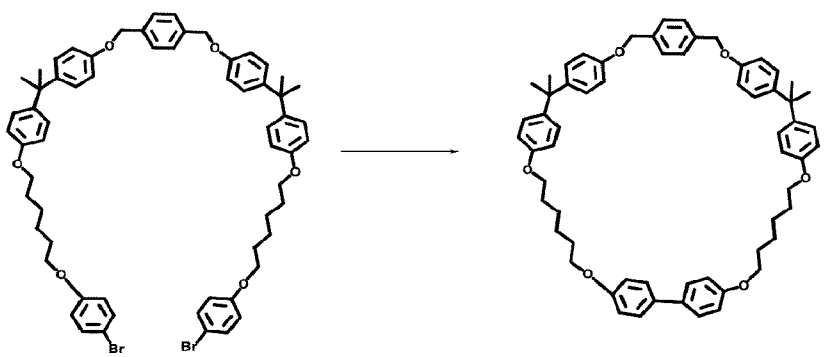


Fig. 158

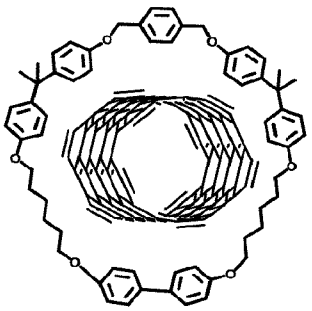


Fig. 159

Scheme 2

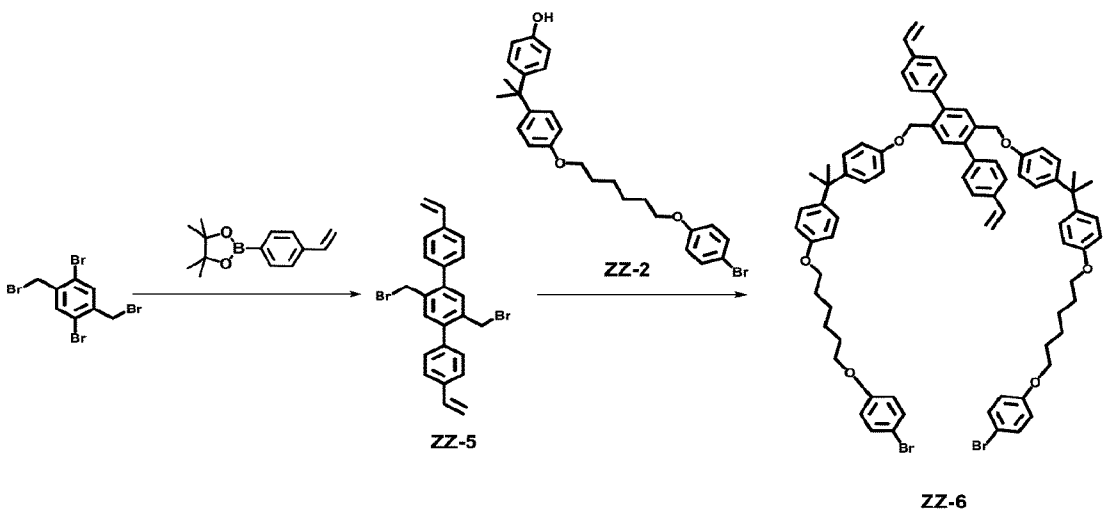
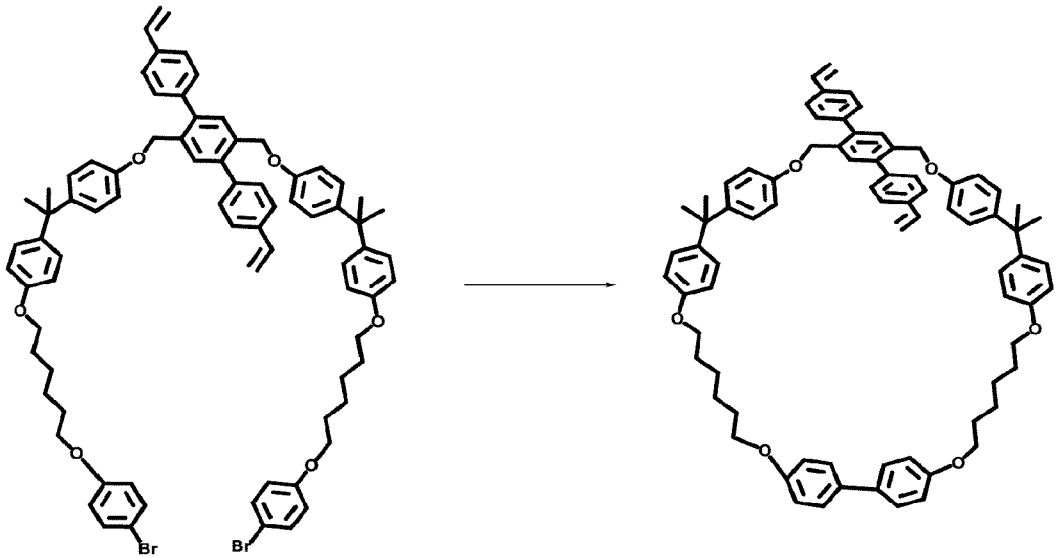


Fig. 160



ZZ-6 ZZ-7

Fig. 161

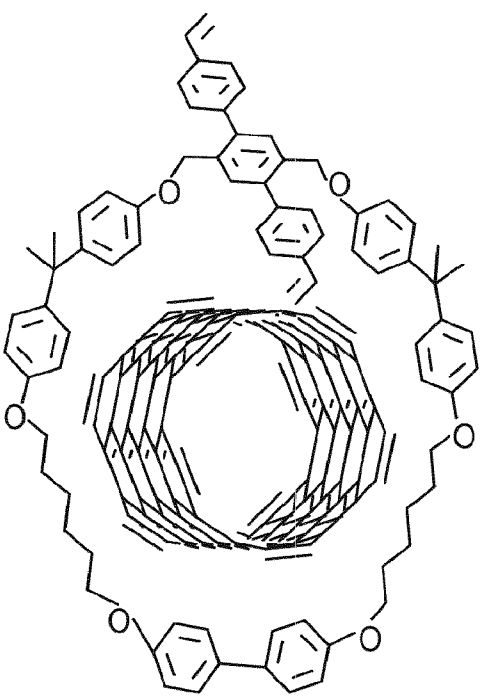


Fig. 162

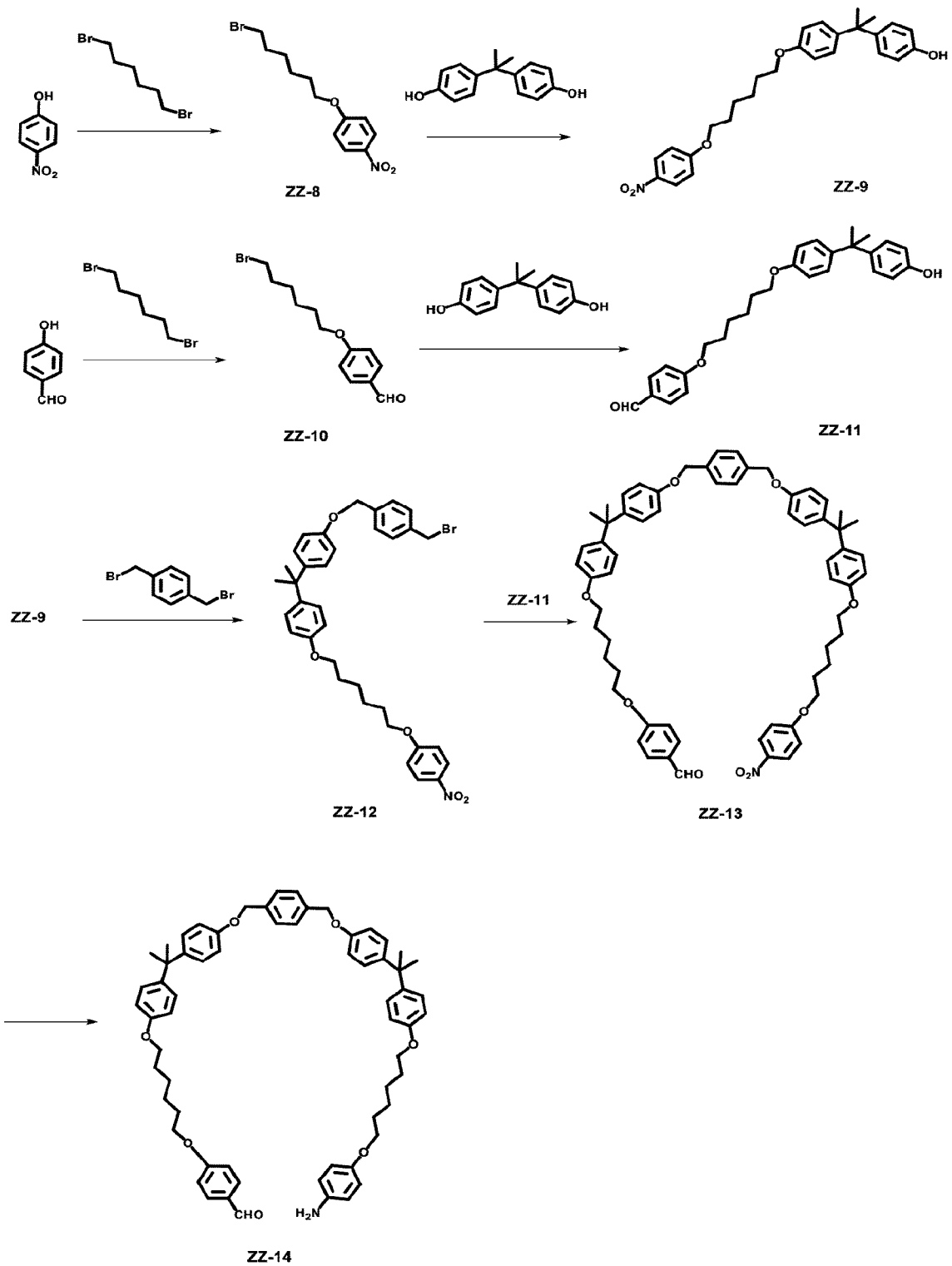
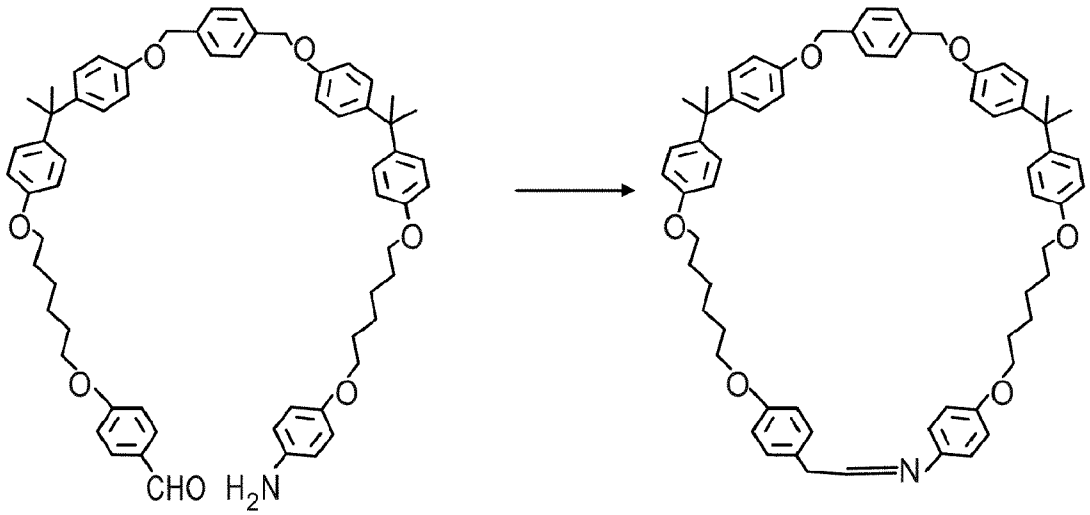


Fig. 163



ZZ-14 ZZ-15

Fig. 164

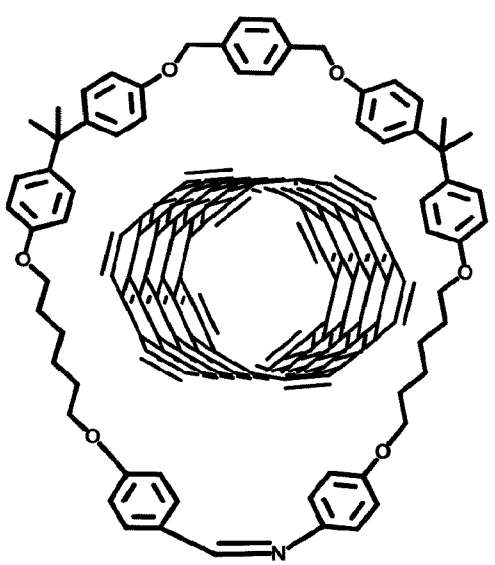


Fig. 165

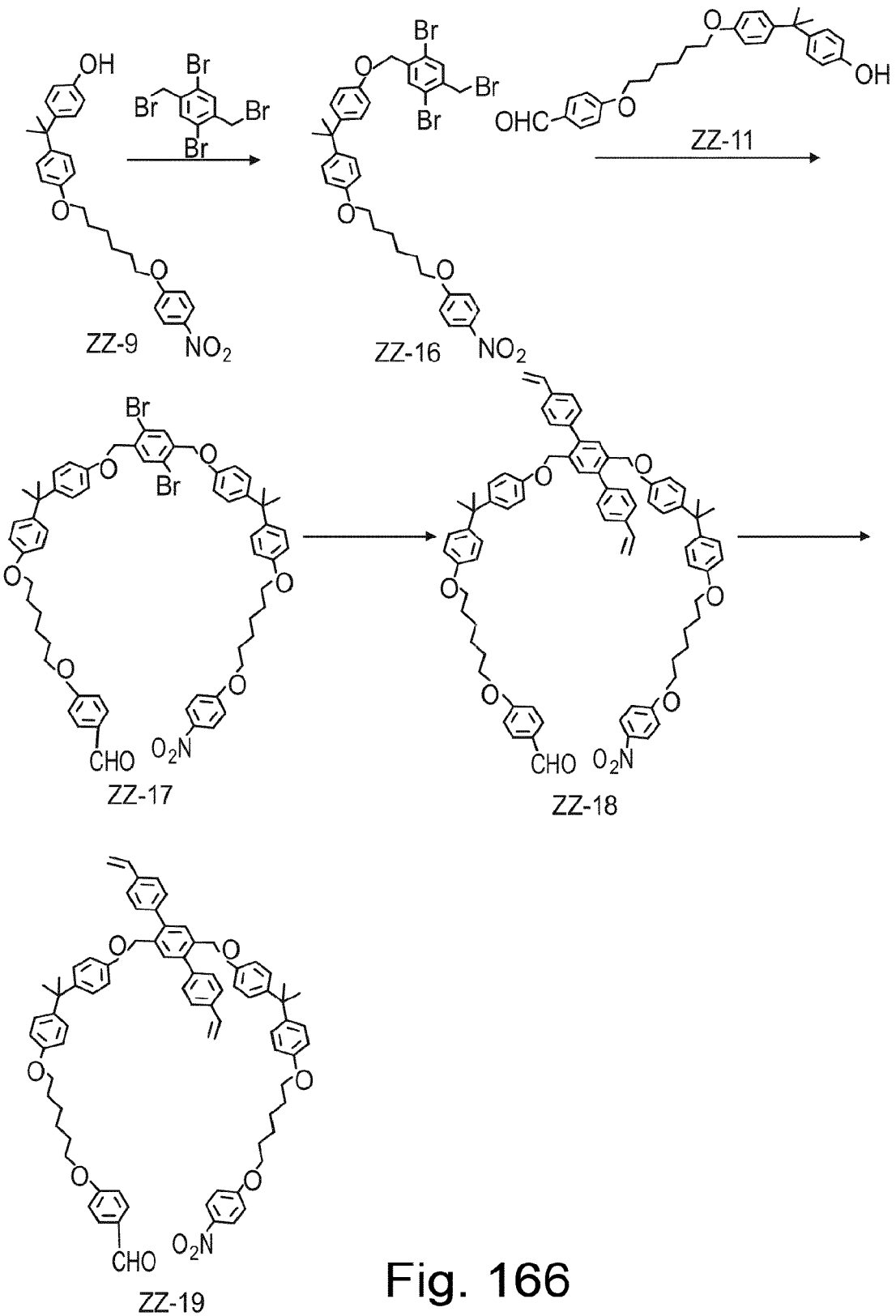
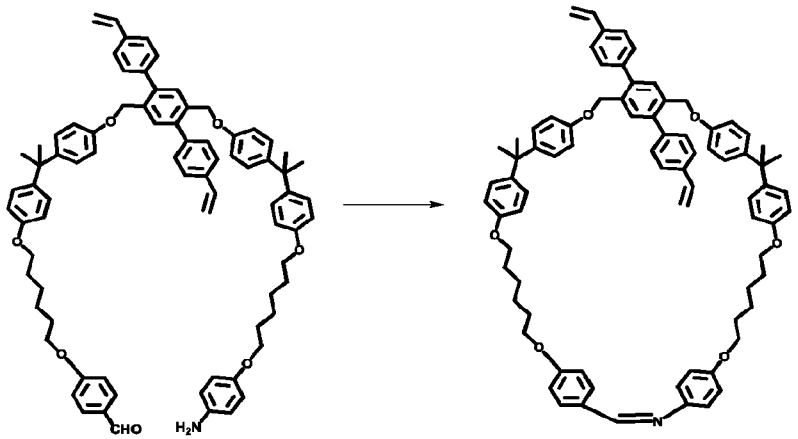

OH
Br
Br
Br
Br
ZZ-9
NO2
Br
Br
Br
OHC
O
OH
ZZ-11
ZZ-16
NO2
Br
Br
CHO
O2N
ZZ-17
CHO
O2N
ZZ-18
CHO
O2N
ZZ-19

Fig. 166



ZZ-19 ZZ-20

Fig. 167

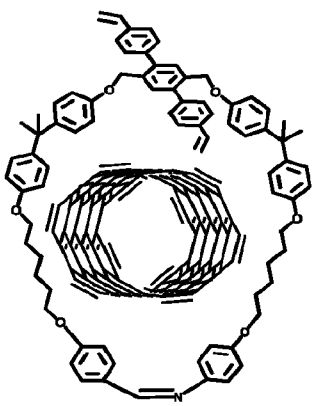


Fig. 168

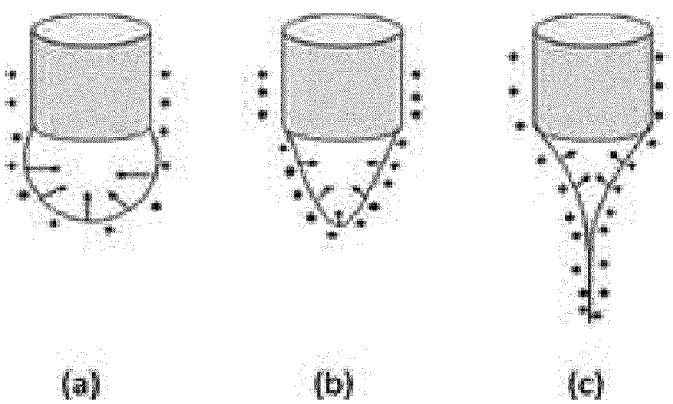
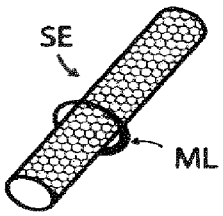


Fig. 169

A.

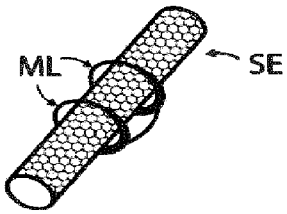


≡



$SE_1 - ML_1$

B.

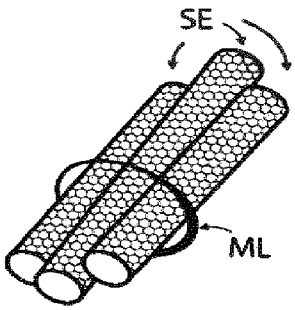


≡



$SE_1 - ML_2$

C.

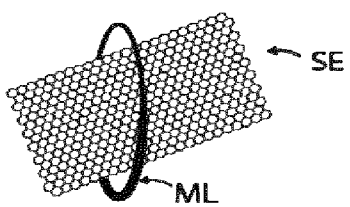


≡



$SE_3 - ML_1$

D.



≡



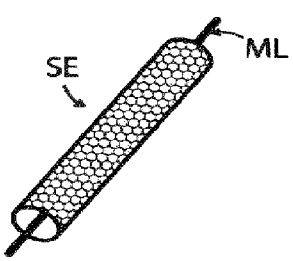
$SE_1 - ML_1$

E.



$SE_1 - ML_1$

F.



≡



$SE_1 - ML_1$

Fig. 1