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(54) **Title:** ENCAPSULATION OF MODIFIERS IN DEPOLYMERIZED PRODUCTS

(57) **Abstract:** A method of encapsulating modifiers in a depolymerized product is disclosed. In some embodiments the material undergoing depolymerization is one of polypropylene, polystyrene, and/or polyethylene. In some embodiments, the material is composed, at least partially, of recycled material. In some embodiments, the encapsulated modifiers are added to a formulation such as an asphalt, plastic lumber, plastic wood composite, a plastic formulation, a rubber formulation, an ink formulation, a coating formulation, and/or an adhesive formulation.

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ENCAPSULATION OF MODIFIERS IN DEPOLYMERIZED PRODUCTS

Cross-Reference to Related Application

[0001] This application claims priority benefits from U.S. provisional patent application Serial No. 62/591,434 filed on November 28, 2017 entitled, "Encapsulation of Modifiers in Depolymerized Products". The '434 application is hereby incorporated by reference herein in its entirety.

Field of the Invention

[0002] The present invention relates to methods of encapsulating modifiers, the resulting encapsulated-modifier granules, methods of utilizing the encapsulated-modifier granules with formulations, and formulations made from utilizing encapsulated-modifier granules. In some embodiments, the formulations are asphalt formulations, and/or the modifiers are asphalt modifiers. In some embodiments, the formulations are wood-plastic composites. In some embodiments, the formulations are polyethylene, polypropylene, and/or polystyrene plastic processing or compounding. In other embodiments, the formulation can be rubber compounding, such as ABS, SBS, or ABS rubber compounding.

[0003] In some embodiments, the formulations are ink and/or coatings. In some embodiments, the inks are energy curable inks. In some embodiments, the inks are UV curable inks. In some embodiments, the inks are water based. In some embodiments, the inks are solvent based.

[0004] In some embodiments, the inks/coatings can be used for inkjet, overprint, lithography, flexography, gravure, screen and/or digital printing.

[0005] In some embodiments, the formulations are adhesives. In some embodiments, the formulations are hot-melt formulations, such as hot-melt adhesives. In some embodiments, the formulations are solvents. In some embodiments, the formulations are emulsions. In some embodiments, the formulations are pressure-sensitive inks and/or coatings. In some embodiments, the formulations are UV cured inks and/or coatings. In some embodiments, the formulations are water-based formulations. In some embodiments, the formulations are epoxies.

[0006] In many instances, formulations, such as asphalt compositions, include multiple components including modifiers such as additives, fillers, rubbers, and plastics. Often, these components have limited solubility/compatibility with each other.

[0007] It can be complex and tedious to mix the components together to achieve uniformity. In many embodiments, uniform distribution can be necessary for maintaining certain desired properties of a given formulation. Encapsulation is one way to improve the distribution of a given component, such as a modifier, in a formulation. Encapsulation of one material (the core) by another material (the shell) can help contain, protect, and distribute the core material during incorporation into a formulation.

[0008] By way of example, encapsulated asphalt-modifiers are used in many industries including, but not limited to, roofing, pavement, sealing, and other industries that utilize asphalt. However, traditional encapsulation methods of encapsulating asphalt-modifiers, such as using asphalt or plastic

as the shell, have many drawbacks, including but not limited to, difficulty blending and forming the material into a product that is solid and stable for bulk storage at various temperatures. When modifiers are added independently (one after the other) into a formulation they can increase both the cost and time required to manufacture the desired formulation. In addition, these modifiers often must be kept at specific concentrations to guarantee their adequate dispersion into a formulation.

[0009] The use of polymer or mineral based modifiers can also require the use of expensive equipment (such as high-shear mixers) and for powders (dust mitigation systems and more robust fire prevention) which not only adds to the manufacturing costs but can also raise safety concerns of producing the desired product. Moreover, modifiers can have negative environmental impacts.

[0010] In addition, modifiers can be incompatible for particular formulations and/or difficult/dangerous to store. For example, in many asphalt formulations various fillers and fire retardants such as, but not limited to, calcium carbonate, anti-oxidant, silica, and graphite are often stored in powder form. Adding the modifiers in a powder form to an asphalt blend can be dangerous as the powder can be flammable and/or cause respiratory issues.

[0011] What is needed is a way of encapsulating modifiers, so the modifiers can be easily stored prior to use. In addition, during use the encapsulated modifiers can be dispersed uniformly, or at least near uniformly, in the formulations. This encapsulation can also protect workers and equipment from unneeded exposure to harmful modifiers or powders.

Summary of the Invention

[0012] In some embodiments, an encapsulated-modifier granule includes a shell made of a depolymerized product; and at least one first-modifier located in the shell. In some embodiments, the encapsulated-modifier granule can further include at least one second-modifier located in the shell wherein the first-modifier and the second-modifier are different types of materials. In some embodiments, the encapsulated-modifier granule is spherical. In other embodiments, the encapsulated-modifier granule is cylindrical, hexagonal, or irregularly shaped.

[0013] In some embodiments, the polymeric material that is depolymerized can be at least one of polyethylene, polypropylene, polyethylene terephthalate, ethylene-vinyl acetate, polyphenylene ether, polyvinyl chloride, polystyrene, lignin, nylon, and/or cellulose. In some embodiments, the depolymerized product is a polymer.

[0014] A method of forming an encapsulated-modifier granule can comprise depolymerizing a feedstock material to create a depolymerized product and mixing at least one modifier in with the depolymerized product to create an encapsulated-modifier granule. In some embodiments, the resulting encapsulated-modifier granule can be added to a formulation. The formulation can be, among other things, an asphalt, wood-plastic composite, ink, coating, adhesive, thermoplastic composite, and/or rubber compound.

[0015] In some embodiments, the depolymerizing process is conducted via a catalytic process. In some embodiments, the depolymerizing process utilizes a [Fe-Cu-Mo-P]/Al_2O_3 catalyst. In some embodiments, the depolymerizing process is conducted via thermal depolymerization. In some

embodiments, the depolymerizing process is conducted via free radical initiators and/or exposure to radiation, such as ionizing radiation. In some embodiments, the radiation is produced via an electron beam. In some embodiments, the initiator is an organic peroxide. In some embodiments, the depolymerization process is conducted, at least in part, via plasma depolymerization.

[0016] In some embodiments, the feedstock is selected from polyethylene, polypropylene and/or polystyrene materials. In at least some embodiments, the feedstock is at least partially comprised of recycled material, scrap material and/or reclaimed material.

[0017] In at least some embodiments, the depolymerized product is a polymer. In some embodiments, the depolymerized product is a wax. In some embodiments, the depolymerized product is a styrenic polymer.

[0018] In some embodiments the modifier is micronized, shredded and powder tire rubber, waxes, expandable carbon nano-tubes, dispersants, secondary acrylamides, tertiary acrylamides, acrylates, ketone resins, monomers, cross-linkable monomers, functional monomers, oligomers, cross-linkable oligomers, functional oligomers, polyacrylate polymers, silicones, surfactants, acrylic monomers, methacrylic monomers, flame-retardant additives, ink additives, flow additives, release additives, sulphur inhibitors, cross-linking agents, extenders, oxidants, antioxidants, hydrocarbons, antistripping agents, defoamers, styrene-butadiene-styrene (SBS), emulsifiers, calcium carbonates, pigments (such as recycled pigments and/or virgin pigments, such as carbon black), slip agents, ethylenically unsaturated monomers, cyclic lactams, photoinitiators, dyes (such as azo,

xanthene and/or azine dyes), shelf-life stabilizers, carbonates, wetting agents, flow agents, de-aerators, and/or asphalt aggregate materials (such as sand, clay, and/or other fillers).

Brief Description of the Drawings

[0019] FIG. 1 is a schematic of a method of encapsulating modifiers and adding the encapsulated-modifier granules into a formulation.

[0020] FIG. 2 is a cutaway perspective view of two types of modifiers encapsulated in a depolymerized product to create an encapsulated-modifier granule.

Detailed Description of Illustrative Embodiment(s)

[0021] Turning to FIG.1, Method 1000 is shown for encapsulating modifiers. In some embodiments the encapsulated modifiers are added to a formulation. In some embodiments, the formulation can be an asphalt. In other embodiments, the formulation can be a wood-plastic composite. In other embodiments, the formulation can be an ink and/or coating. In other embodiments, the formulation can be an adhesive. In other embodiments, the formulation can be a thermoplastic processing. In other embodiments, the formulation can be rubber compounding, such as ABS, SBS, or ABS rubber compounding. In some embodiments, the formulation can be a polypropylene, polyethylene, and/or polystyrene plastic-based processing and/or compounding formulation.

[0022] Section 100 of method 1000 involves the depolymerization of a feedstock to create a depolymerized product. In at least some embodiments, a feedstock is chosen at Material Selection Stage 10 and is depolymerized at Depolymerization Stage 20 to create a depolymerized product at Depolymerized Product Stage 30. In some embodiments, the depolymerized product is a polymer.

[0023] In some embodiments, the feedstock can be a polymeric material. In some embodiments, the polymeric material can include polyethylene, polypropylene, and/or polystyrene material.

[0024] In some embodiments, the polymeric material can be high density polyethylene (HDPE), low density polyethylene (LDPE), linear low-density polyethylene (LLDPE), or other variations and combinations polyethylene including cross-linked polyethylene.

[0025] In some embodiments, lower levels of polystyrene, polyethylene terephthalate (PET), ethylene-vinyl acetate (EVA), (polyvinyl chloride) PVC, (ethylene vinyl alcohol) EVOH, undesirable additives and/or contaminants, such as fillers, dyes, metals, various organic and inorganic additives, moisture, food waste, dirt, or other contaminating particles can be present in the feedstock. In some embodiments, the polymeric material includes combinations of LDPE, LLDPE, HDPE, and PP.

[0026] In some embodiments, the polymeric material can be divided evenly by weight between polyethylene and polypropylene.

[0027] In some embodiments, the polymeric material comprises recycled plastics. In some embodiments, the polymeric material comprises virgin

plastics. In other or the same embodiments, the polymeric material comprises recycled plastics and/or virgin plastics.

[0028] In some embodiments, the polymeric material includes waste polymeric material feed. Suitable waste polymeric material feeds include mixed polyethylene waste, mixed polypropylene waste, and a mixture including mixed polyethylene waste and mixed polypropylene waste. The mixed polyethylene waste can include LDPE, LLDPE, HDPE, PP, or a mixture including combinations of LDPE, LLDPE, HDPE and PP. In some embodiments, the mixed polyethylene waste can include film bags, milk jugs or pouches, totes, pails, caps, agricultural film, and/or packaging material. In some embodiments, the waste polymeric material feed can include up to 10% of material that is other than polymeric material, based on the total weight of the waste polymeric material feed.

[0029] In some embodiments, the polymeric material can be one of, or a combination of, virgin polyethylene (any one of, or combinations of, HDPE, LDPE, LLDPE and medium-density polyethylene (MDPE)), virgin polypropylene, recycled polyethylene terephthalate, or post-consumer, or post-industrial, polyethylene or polypropylene (exemplary sources including bags, jugs, bottles, pails, and/or other items containing PE or PP).

[0030] In certain embodiments, the feedstock material can be a polystyrene. In some embodiments, the polystyrene can be recycled. In some embodiments, the recycled polystyrene can be a pellet made from recycled polystyrene foam and/or rigid polystyrene. Suitable waste polystyrene material includes, but is not limited to, expanded, and/or extruded polystyrene foam, and/or rigid products. Virgin polystyrene can also be used.

In some embodiments, the polystyrene has a low molecular weight. In some embodiments, the polystyrene is expanded polystyrene, general purpose polystyrene, high impact polystyrene and/or polystyrene foam. In some embodiments, the polystyrene is composed of acrylonitrile, butadiene and styrene.

[0031] In some embodiments, the polystyrene material can be dissolved in certain solvents to create products with various properties. In some embodiments, organic solvents, such as toluene, xylenes, cymenes, or terpinenes, are used to dissolve the polystyrene before it undergoes depolymerization within the reactor bed/vessel. In certain embodiments, the desired product can be isolated via separation or extraction and the solvent can be recycled.

[0032] In some embodiments, the polystyrene feed has an average molecular weight between an inclusive range of about 100000 amu to 500000 amu.

[0033] In some embodiments, the polyethylene feed has an average molecular weight between an inclusive range of about 100000 amu to 500000 amu.

[0034] In some embodiments, the polypropylene feed has an average molecular weight between an inclusive range of about 100000 amu to 500000 amu.

[0035] In some embodiments, the depolymerized product can be made by catalytic depolymerization of the polymeric material during Depolymerization Stage 20. In some embodiments, the depolymerized

product can be made by thermally degrading the polymeric material during Depolymerization Stage 20.

[0036] In some embodiments, the depolymerizing process is conducted via free radical initiators and/or exposure to radiation, such as ionizing radiation during Depolymerization Stage 20. In some embodiments, the radiation is produced via an electron beam. In some embodiments, the initiator is an organic peroxide. In some embodiments, the depolymerization process is conducted, at least in part, via plasma depolymerization.

[0037] In some embodiments, the Depolymerization Stage 20 involves thermal, catalytic, radiation and/or initiator depolymerization.

[0038] In some embodiments the depolymerization process utilizes a catalyst such as [Fe-Cu-Mo-P]/Al_2O_3, Zeolite or alumina supported systems, and/or thermal depolymerization. In some embodiments, the catalyst can be contained in a permeable container.

[0039] In some embodiments, the depolymerized product can be a polymer, such as a wax, grease, oligomer, and/or styrenic polymer.

[0040] In at least some embodiments, the depolymerized product can be compatible with asphalt, plastic wood composite, asphalt modifiers, plastic wood composite modifiers, plastic formulations used in plastic compounding/processing, rubber formulations used in rubber compounding/processing, thermoplastic compounding/processing, various inks, various coatings, and/or various adhesives. In some embodiments, use of the depolymerized product as the shell reduces the rotational viscosity of the resulting formulation.

[0041] In some embodiments, the depolymerized product can be compatible with asphalt formulations used in roofing asphalts, paving asphalts, crack fillers, adhesives, and/or other products for waterproofing and joint sealing. In some embodiments, the depolymerized product can be compatible with oxidized asphalt formulations, such as coating-grade asphalt and mopping-grade asphalt, and non-oxidized asphalt, such as saturant-grade asphalt.

[0042] Due to the nature of depolymerization, the depolymerized product(s) can be created with a wide spectrum of hardness and melting points. This allows for the creation of formulation-specific depolymerized products.

[0043] In at least some embodiments, a formulation can require both a modifier and a depolymerized product. In at least some of these embodiments, an encapsulated modifier can be used to remove the need to add both the modifier and the depolymerized product as separate components of the formulation and/or in separate steps.

[0044] In at least some embodiments, the depolymerized products provide hard but not brittle encapsulation media for modifiers for storage or direct blending into formulations. Modifiers encapsulated with depolymerized products can lead to a more uniform dispersion of other modifiers in the formulation. In at least some embodiments, such as embodiments in which the formulation is an asphalt, this greater dispersion creates more stable formulations, with improved physical properties, including, but not limited to, higher softening points, harder formulations, and/or lower viscosities.

[0045] In some embodiments, when modifiers encapsulated with depolymerized product are added to an asphalt formulation, emission of volatile organic compounds can be reduced.

[0046] In some embodiments, when modifiers encapsulated with depolymerized product are added to an asphalt formulation, the performance grade of the asphalt formulation can be increased due to improved (increased) stability at higher temperatures.

[0047] In some embodiments, when modifiers encapsulated with depolymerized product are added to an asphalt formulation, the performance of the asphalt formulation is improved. Specifically, modifiers encapsulated with depolymerized product can increase resistance to flow at high temperatures, increase softening point, and/or decrease penetration of asphalt formulations.

[0048] In some embodiments, when modifiers encapsulated with depolymerized product are added to an asphalt formulation, the time required for asphalt oxidation can be reduced.

[0049] In some embodiments, when modifiers encapsulated with depolymerized product are added to ink and/or coating formulations, the modifier is more evenly dispersed within the formulation matrix.

[0050] In some embodiments, when modifiers encapsulated with depolymerized product are used in ink and/or coating formulations, the modifier is easier and/or safer to handle.

[0051] In some embodiments, when modifiers encapsulated with depolymerized product are used in ink and/or coating formulations, the modifier and/or the formulation is more stable and/or has a longer shelf-life.

[0052] In some embodiments, encapsulating modifiers with a depolymerized product protects the modifier from oxidation and/or degradation often caused by oxygen and/or heat.

[0053] In some embodiments, when modifiers encapsulated with depolymerized product are used in ink and/or coating formulations, the resulting formulation has a lower formulation viscosity which, in turn, can allow for easier processing, blending, and/or the ability to increase the modifier and/or external additive loading.

[0054] At Modifier Selection Stage 40, at least one modifier can be selected. Modifiers can be selected based on their various properties. Modifiers can include, but are not limited to micronized, shredded and powder tire rubber, waxes, expandable carbon nano-tubes, dispersants, secondary acrylamides, tertiary acrylamides, acrylates, ketone resins, monomers, cross-linkable monomers, functional monomers, oligomers, cross-linkable oligomers, functional oligomers, polyacrylate polymers, silicones, surfactants, acrylic monomers, methacrylic monomers, flame-retardant additives, ink additives, flow additives, release additives, sulphur inhibitors, cross-linking agents, extenders, oxidants, antioxidants, hydrocarbons, antistripping agents, defoamers, styrene-butadiene-styrene (SBS), emulsifiers, calcium carbonate, pigments (such as recycled pigments and/or virgin pigments, such as carbon black), slip agents, ethylenically unsaturated monomers, cyclic lactams, photoinitiators, dyes (such as azo,

xanthene and/or azine dyes), shelf-life stabilizers, carbonates, wetting agents, flow agents, de-aerators, and/or asphalt aggregate materials (such as sand, clay, and/or other fillers).

[0055] In some embodiments, the modifier can be an asphalt modifier.

[0056] In some embodiments, the modifier(s), such as the monomer(s) and/or oligomer(s), can have polar and/or polar charged groups.

[0057] In Combination Stage 50 at least one modifier and one depolymerized product are blended together in a mixing vessel. In at least some embodiments the depolymerized product can be in a liquid, semiliquid, or solid form. In at least some embodiments, the modifier(s) is/are added in the inclusive range of 0.001% to 65% wt.% of the total combined product. In some embodiments, the range can be between an inclusive range of about 0.0001% to 99.999% wt.% of the total combined product. In some preferred embodiments, the range can be between an inclusive range of about 60% to 70% wt.% of the total combined product. In some more preferred embodiments the range can be between an inclusive range of about 40% to 50% wt.% of the total combined product.

[0058] In at least some embodiments, modifiers are mixed in-line with the depolymerized product. Some advantages of using depolymerization products in-line is a decrease in cost and reduction in the amount of energy used.

[0059] In at least some embodiments involving asphalt formulations, the depolymerization product can act as a compatibilizer between the modifier, asphalt binder, and/or aggregate by lowering the surface energy in the boundary layer. This prevents, or at least reduces, agglomeration and aids in

distributing the modifier particles uniformly throughout the asphalt formulation. A similar phenomenon can occur when depolymerization products are used in plastic wood composites, plastic formulations used in plastic compounding/processing, or rubber formulations used in rubber compounding/processing.

[0060] In at least some embodiments involving ink/coating formulations, the depolymerized product can be used to incorporate modifiers that can be used to modify flow, surface tension, gloss, pigment wetting and/or abrasion resistance.

[0061] In some embodiments, such as those involving ink and/or coating formulations, the depolymerized product can act as a compatibilizing agent.

[0062] In some embodiments, encapsulating a modifier in a depolymerized product before addition to the formulation can lead to improved performance than if the modifier and depolymerized product are added separately to the formulation.

[0063] In at least some embodiments, in Combination Stage 50 the mixing vessel can be heated to a temperature above the melting point of the depolymerization product(s). In some embodiments, the mixing vessel can be heated by means of electric external heaters, electric jackets, and/or steam jackets. In at least some embodiments, the depolymerization product provides consistent dispersion for the modifiers and encapsulates the modifiers.

[0064] In some embodiments, in Combination Stage 50, the semi-solid and/or solid depolymerized products can be mixed with modifiers. In some embodiments, this can be accomplished by the use of compression.

[0065] In some embodiments, the combination can be transferred into optional pelletizing equipment and/or various dimension slabs that can be grinded to a desired size at Solidification Stage 60. In at least some embodiments, the pellets are between an inclusive range of about 1 mm-30 mm in size. In some preferred embodiments, the pellets are between an inclusive range of about 1 mm to 10 mm in size.

[0066] In some embodiments, the encapsulated modifiers can be stored in Storage Stage 70 or directly mixed into various formulations at Formulation Combination Stage 80. A product can be created at End Product Stage 90. In some embodiments, the product created at End Product Stage 90 can be further modified.

[0067] In some embodiments, such as when the formulation is an asphalt, the percentage of the encapsulation product can be roughly 1% to 50% by weight of the asphalt formulation. In some preferred embodiments, the percentage of the encapsulation product can be roughly 1% to 20% by weight of the asphalt formulation. In other embodiments, where the formulation can be a plastic wood composite the percentage of the encapsulation product can be roughly 1% to 50% by weight of the plastic wood composite formulation. In some preferred embodiments, the percentage of the encapsulation product can be roughly 1% to 20% by weight of the plastic wood composite formulation. In some preferred embodiments, the percentage of the encapsulation product can be roughly 1% to 30% by weight of a plastic formulation used in plastic compounding/processing. In some preferred embodiments, the percentage of the encapsulation product can be roughly 1% to 30% by weight of a rubber formulation used in rubber compounding/processing. In other embodiments, where the formulation can

be an ink formulation the percentage of the encapsulation product can be roughly 1% to 75% by weight of the ink formulation. In some preferred embodiments, the percentage of the encapsulation product can be roughly 10% to 60% by weight of the ink formulation.

[0068] In some embodiments, the encapsulation product can be compatible with asphalt formulations used in roofing asphalts, paving asphalts, crack fillers, adhesives, and/or other products for waterproofing and joint sealing. In some embodiments, the depolymerized product can be compatible with oxidized asphalt formulations, such as coating-grade asphalt and mopping-grade asphalt, and non-oxidized asphalt, such as saturant-grade asphalt.

[0069] Depolymerization products can be chosen to match specific viscosity, hardness, melting temperature, and/or dropping point ranges required for given applications. In at least some embodiments, Method 1000 allows for modifiers to be dispersed uniformly, thus eliminating, or at least reducing, the need for using modifying agents, high-shear mixers, and/or excessive energy consumption.

[0070] The above method can employ a variety of depolymerized products, including those with melt points between an inclusive range of about 90°C to 170°C and viscosities between an inclusive range of about 25cps to 3000cps. In some preferred embodiments, the depolymerized products employed have melting points between an inclusive range of about 110°C to 130°C and 150°C to 170°C.

[0071] Encapsulation can allow for the reduction, if not complete elimination, of the use of powder modifiers. Powder modifiers can be

dangerous, as they are often flammable and can cause respiratory issues. As a result, powder management equipment is often used when powder modifiers are added to formulations. This equipment can be expensive.

[0072] FIG. 2 is a cutaway perspective view of first modifier 210 and second modifier 220 encapsulated in depolymerized product 230 to create encapsulated-modifier granule 200. In some embodiments, first modifier 210 can be the same type as second modifier 220. In some embodiments, first modifier 210 and second modifier 220 are different types. In some embodiments, encapsulated-modifier granule 200 can be spherical. In some embodiments, encapsulated-modifier granule 200 can be cylindrical shaped.

Specific Example 1

[0073] In one embodiment of the above method, 500 g of micronized tire rubber with an average diameter of 30 micron was mixed with 500 g of melted wax by stirring a paddle mixer at 30 rpm at 125 °C for five minutes. The resulting product was then poured into 0.5" (1.27cm) diameter forms and allowed to solidify. The resulting product was able to be placed in a storage container before blending it into an asphalt formulation.

[0074] Remelting experiments demonstrated that the tire rubber integrity was maintained. This demonstrated that the process prevented, or at least reduced, agglomeration of the particles and/or modification of the particles. Remelting experiments also demonstrated that the 30-micron powder could be dispersed upon melting of the depolymerized product.

Specific Example 2

[0075] In one embodiment of the above method, 500 g of carbon graphite powder was mixed with 500 g of melted wax by stirring a paddle mixer at 30 rpm at 125 °C for five minutes. The resulting product was then poured into a 0.5" (1.27cm) diameter form and allowed to solidify. The resulting product was able to be placed in a storage container before blending it into an asphalt formulation.

[0076] Remelting experiments demonstrated that the graphite particle did not agglomerate and its integrity was maintained and that the 30-micron powder could be dispersed upon melting of the depolymerized product.

[0077] Changes in melting point, viscosity, molecular weight, and/or polymer backbone structure of the depolymerized product can change the properties of a formulation. Properties can include, but not limited to, the force ductility, thermal stability, softening point, phase separation, and/or penetration of the formulation.

[0078] Encapsulating modifiers in depolymerized products can provide the following benefits including, but not limited to:

- encapsulating hard to manage powder modifiers, in a preferred easier to handle larger form;
- easing the disbursement of modifiers into formulations such as hot asphalt, reducing mixing or extrusion times;
- improving the dispersion of modifiers;
- allowing a pathway for use of harder to blend/higher viscosity polymer and rubber modifiers;
- improving the performance and/or product quality of certain formulations, such as particular asphalt and plastic wood composite

formulations, plastic formulations used in plastic compounding/processing, rubber formulations used in rubber compounding/processing various ink and coating formulations, and/or various adhesive formulations;

- lowering the viscosity of certain inks and/or coating formulations which in turn can allow for easier processing, blending, and/or the ability to increase the modifier and/or external additive loading;
- reducing emission of volatile organic compounds in some formulations such as asphalt formulations;
- improving stability of some formulations such as asphalt formulations at higher temperatures;
- improving the quality of asphalt formulations by increasing the asphalt resistance to flow at high temperatures and improving the hardness properties of the asphalt such as increasing the softening point and decreasing the penetration of the asphalt formulation;
- reducing the time required for asphalt oxidation; and
- reducing the manufacture cost of certain formulations, such as particular asphalt and plastic wood composite formulations, plastic formulations used in plastic compounding/processing, and/or rubber formulations used in rubber compounding/processing.

[0079] While particular elements, embodiments, and applications of the present invention have been shown and described, it will be understood, that the invention is not limited thereto since modifications can be made without departing from the scope of the present disclosure, particularly in light of the foregoing teachings.

What is claimed is:

1. An encapsulated-modifier granule comprising:
    a) a shell made of a depolymerized product; and
    b) an at least one first-modifier located in said shell.

2. The encapsulated-modifier granule of claim 1 wherein said encapsulated-modifier granule further comprises:
    c) an at least one second-modifier located in said shell.

3. The encapsulated-modifier granule of claim 2 wherein said at least one first-modifier and said at least one second-modifier are different types of modifiers.

4. The encapsulated-modifier granule of claim 1 wherein said encapsulated-modifier granule is spherical.

5. The encapsulated-modifier granule of claim 1 wherein said encapsulated-modifier granule is cylindrical shaped.

6. The encapsulated-modifier granule of claim 1 wherein said depolymerized product is made of depolymerized polystyrene.

7. The encapsulated-modifier granule of claim 1 wherein said depolymerized product is made of depolymerized polyethylene.

8. The encapsulated-modifier granule of claim 1 wherein said depolymerized product is a wax, wherein said wax is made via catalytic or thermal depolymerization.

9. The encapsulated-modifier granule of claim 1 wherein said encapsulated-modifier granule is hexagonal or irregularly shaped.

10. A method of forming an encapsulated-modifier granule comprising:

a) depolymerizing a feedstock material to create a depolymerized product;

b) mixing an at least one modifier with said depolymerized product to create an encapsulated-modifier granule.

11. The method of claim 10 further comprising:

c) adding said encapsulated-modifier granule to a formulation.

12. The method of claim 11 wherein said formulation is an asphalt, a plastic lumber, a plastic wood composite, a plastic formulation, a rubber formulation, an ink formulation, a coating formulation, and/or an adhesive formulation.

13. The method of claim 10 wherein said depolymerizing is done via a catalytic process.

14. The method of claim 13 wherein said catalytic process utilizes a [Fe-Cu-Mo-P]/Al_2O_3 catalyst.

15. The method of claim 10 wherein said depolymerizing is done via a thermal process.

16. The method of claim 10 wherein said feedstock material is at least one of a polyethylene, polypropylene, polyethylene terephthalate, ethylene-vinyl acetate, polyphenylene ether, polyvinyl chloride, polystyrene, lignin, nylon, or cellulose.

17. The method of claim 15 wherein said feedstock material comprises at least partially recycled material.

18. The method of claim 10 wherein said depolymerized product is a wax.

19. The method of claim 10 wherein said depolymerized product is a styrenic polymer.

20. The method of claim 10 wherein at least one modifier is selected from the group consisting of micronized, shredded and powder tire rubber, waxes, expandable carbon nano-tubes, dispersants, secondary acrylamides, tertiary acrylamides, acrylates, ketone resins, monomers, cross-linkable monomers, functional monomers, oligomers, cross-linkable oligomers, functional oligomers, polyacrylate polymers, silicones, surfactants, acrylic monomers, methacrylic monomers, flame-retardant additives, ink additives, flow additives, release additives, sulphur inhibitors, cross-linking agents, extenders, oxidants, antioxidants, hydrocarbons, antistripping agents, defoamers, styrene-butadiene-styrene (SBS), emulsifiers, calcium carbonates,

pigments (such as recycled pigments and/or virgin pigments, such as carbon black), slip agents, ethylenically unsaturated monomers, cyclic lactams, photoinitiators, dyes (such as azo, xanthene and/or azine dyes), shelf-life stabilizers, carbonates, wetting agents, flow agents, de-aerators, and/or asphalt aggregate materials (such as sand, clay, and/or other fillers).

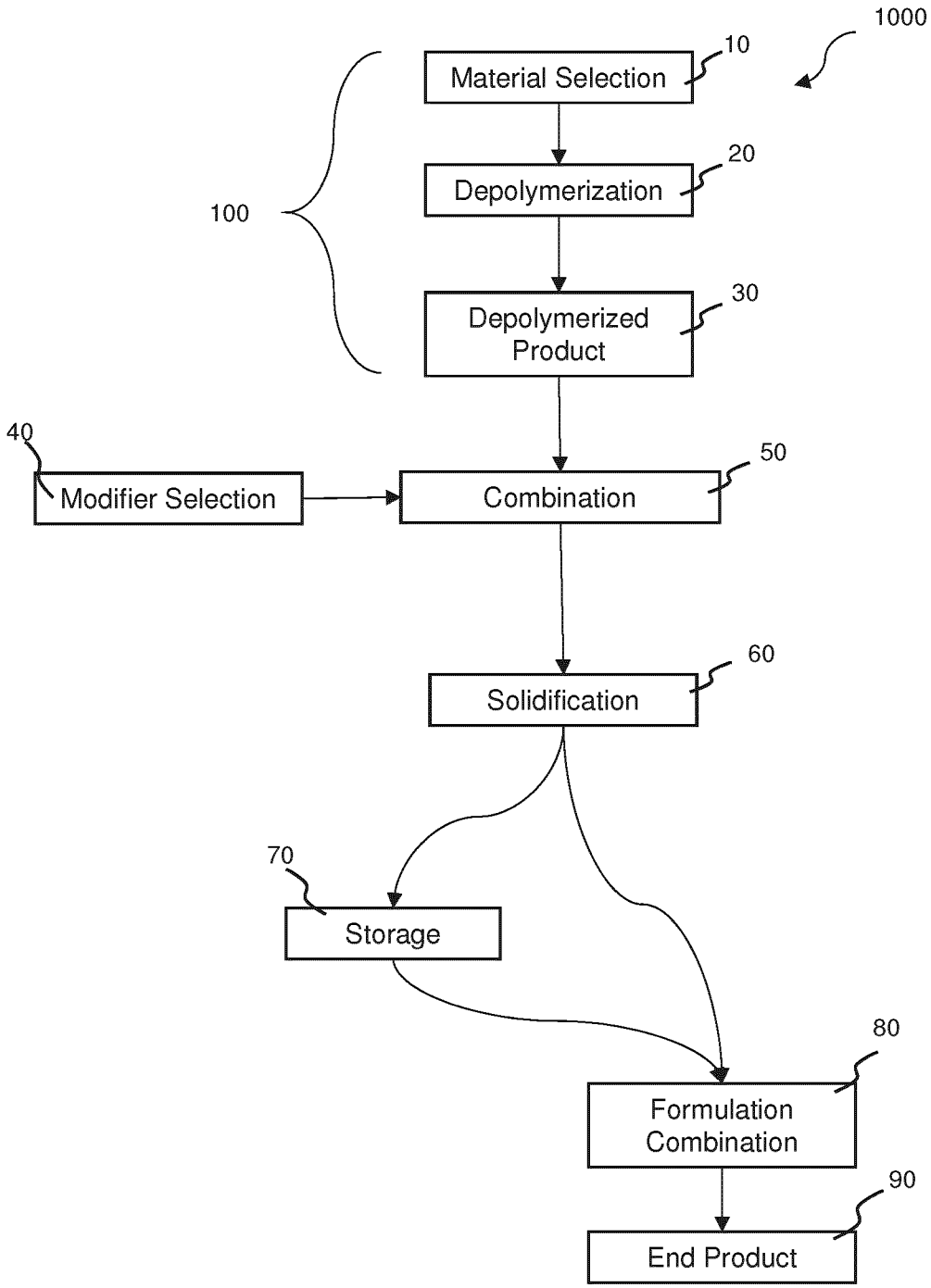
1000
Material Selection
10
Depolymerization
20
100
Depolymerized Product
30
40
Modifier Selection
Combination
50
Solidification
60
70
Storage
80
Formulation Combination
90
End Product

FIG. 1

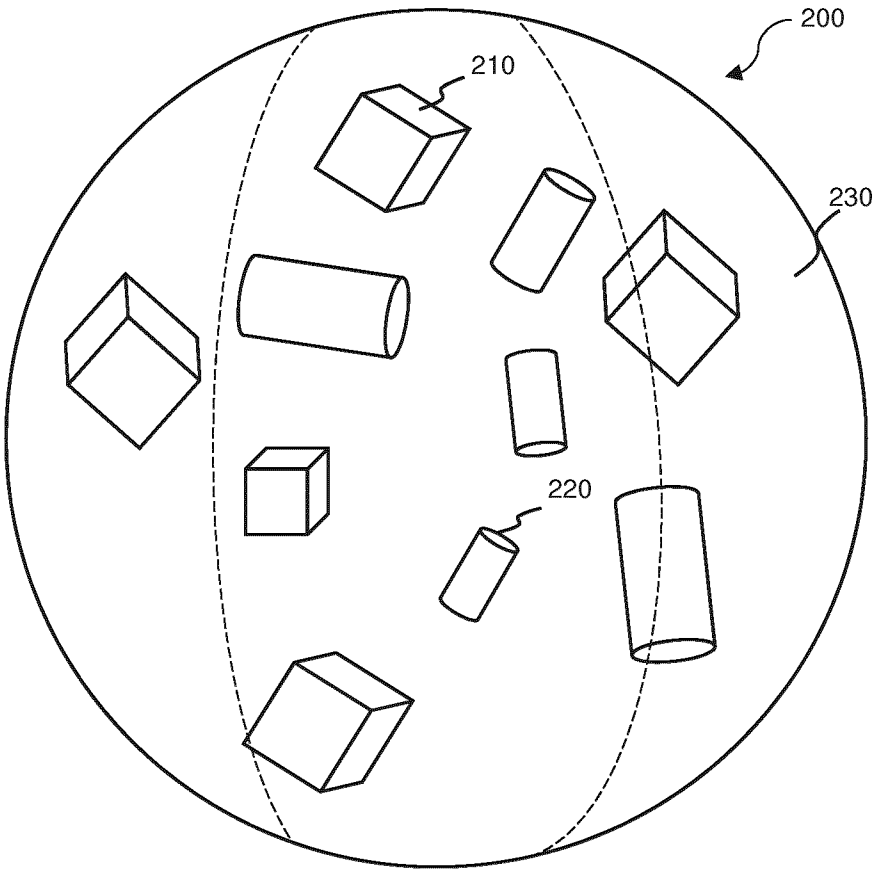

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2018/051517

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***C08K 9/10*** (2006.01) , ***B01J 13/14*** (2006.01) , ***C08J 11/12*** (2006.01) , ***C08J 11/16*** (2006.01) , ***C08J 3/20*** (2006.01) , ***C09D 11/00*** (2014.01) (more IPCs on the last page)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C08K 9/10 , B01J 13/14 , C08J 11/12, C08J 11/16, C08J 3/20, C09D 11/00 , C09D 7/40 (2018.01) , C09J 11/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
n/a

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Databases used: Intellect, Questel-Orbit, Espacenet, Science Direct, American Chemical Society publication search, Scopus, Google scholar and Francis and Taylor online. *Keywords* used: depolymerized polymer and encapsulation, depolymerized polymer as shell to entrap nanoparticles, depolymerized polystyrene as shell, core-shell with depolymerized polymer and modifier, waste polystyrene feedstock depolymerisation, encapsulation shell material and polymer, micronized rubber, depolymerized polyethylene, depollymerized polypropylene, depolymerized rubber and asphalt, depolymerisation and encapsulation, modified polymer in asphalt. Also *inventors* and *applicant* search.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	'*Encapsulation of Leu-Enkephalin in core-shell isobutylcyanoacrylate-thiolated chitosan nanoparticles for oral administration*." Victor H. Campos Requena et al. *Journal of the Chilean Chemical Society* 2008, 53(4), 1677-1681 Whole document	1, 4 and 10
Y	WO 2017136957 A1((DIMONDO, D) 17 August 2017 (17-08-2017) Whole document	1-20
Y	WO 2017161463A1 (DIMONDO, D) 28 September 2017 (28-09-2017) Whole document	1-20
A	CN 104877699A (KUMAR, A et al.) 02 September, 2015 (02-09-2015) Whole document	1-20

☑ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier application or patent but published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 29 January 2019 (29-01-2019)	Date of mailing of the international search report 05 February 2019 (05-02-2019)
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 819-953-2476	Authorized officer Wendy Young (819) 639-9418

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO2017139333 (JUREK, MJ et al.) 17 August 2017 (17 -08-2017) Whole document	1-20
A	"*Depolymerizable polymers: preparation, applications, and future outlook.*" Joshua A. Kaitz et al. MRS Communications 2015, 5, 191-204 Whole document	1-20

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2018/051517

Patent Document Cited in Search Report	Publication Date	Publication Family Member(s)	Publication Date
WO2017161463A1	28 September 2017(28-09-2017)	AU2017239181A1	04 October 2018(04-10-2018)
		CA3015859A1	28 September 2017(28-09-2017)
		CN108884264A	23 November 2018(23-11-2018)
		US2019023867A1	24 January 2019(24-01-2019)
WO2017136957A1	17 August 2017(17-08-2017)	AU2017218908A1	23 August 2018(23-08-2018)
		BR112018016499A2	26 December 2018(26-12-2018)
		CA3013953A1	17 August 2017(17-08-2017)
		CN108779398A	09 November 2018(09-11-2018)
		EP3414302A1	19 December 2018(19-12-2018)
		US2018346683A1	06 December 2018(06-12-2018)
CN104877699A	02 September 2015(02-09-2015)	CN104877699B	26 April 2017(26-04-2017)
		CA2805570A1	19 January 2012(19-01-2012)
		CN103168016A	19 June 2013(19-06-2013)
		CN103168016B	22 April 2015(22-04-2015)
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		JP5964825B2	03 August 2016(03-08-2016)
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		US8664458B2	04 March 2014(04-03-2014)
		WO2012007833A2	19 January 2012(19-01-2012)
		WO2012007833A3	08 March 2012(08-03-2012)
		WO2012007833A4	26 April 2012(26-04-2012)
WO2017139333A1	17 August 2017(17-08-2017)	CN108473808A	31 August 2018(31-08-2018)
		EP3414295A1	19 December 2018(19-12-2018)

C09D 7/40 (2018.01) , ***C09J 11/00*** (2006.01)