



- (51) International Patent Classification:
B29C 70/34 (2006.01)
- (21) International Application Number:
PCT/DK2012/050147
- (22) International Filing Date:
3 May 2012 (03.05.2012)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
PA 2011 70218 4 May 2011 (04.05.2011) DK
61/482,626 5 May 2011 (05.05.2011) US
- (71) Applicant (for all designated States except US): VESTAS
WIND SYSTEMS A/S [DK/DK]; Hedeager 44, DK-8200
Aarhus N (DK).
- (72) Inventor; and
- (75) Inventor/Applicant (for US only): RICHTER, Jed
[GB/GB]; 324 Park Road, Isle of Wight, Cowes Hampshire
PO31 7NN (GB).
- (81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD,
SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR,
TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished
upon receipt of that report (Rule 48.2(g))

- (54) Title: METHOD OF PREPARING A COMPOSITE LAMINATE

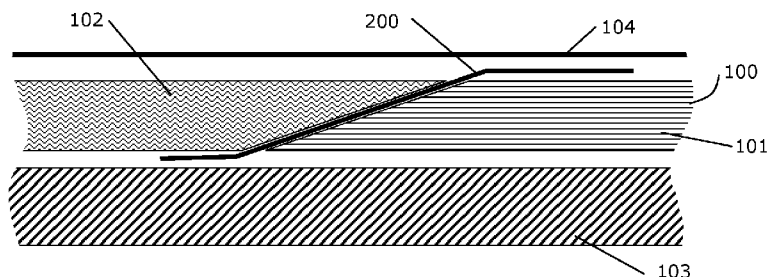


Fig. 2

(57) Abstract: This invention relates to a method of preparing a hybrid composite laminate of layers of fiber reinforced material of different resin viscosities. The method comprises providing in a mould a first layer of a pre-impregnated material and a second layer. An uncured resin film is placed between the first and second layers. A resin of a second viscosity is provided to impregnate the second layer. The viscosity of the resin film is equal to or higher than the lowest viscosity of the first and second resins, whereby the resin migration between the fibrous layers during the resin impregnation may be controlled. The invention further relates to a composite laminate and a wind turbine blade component prepared by a method as mentioned above. The wind turbine blade may comprise a root part, a tip part, and an intermediate part therebetween, the intermediate part comprising a first layer of a pre-impregnated fiber reinforced material, and the root part comprising a second layer of fiber reinforced material.



METHOD OF PREPARING A COMPOSITE LAMINATE

Field of the invention

The present invention relates to a method of preparing a composite laminate composed of different types of fiber reinforced materials. The invention furthermore relates to a composite laminate and more specifically to wind turbine blade prepared according to such method.

Background

Large, integrated composite structures such as e.g. wind turbine blades may contain several different regions with differing functional requirements in terms of both technical and commercial requirements, which are to be fulfilled by the material of the construction. Such requirements may be related to the strength, stiffness, physical thickness, weight etc.

In order to meet such differing requirements different materials are often needed, which then often induce differing process requirements. For example, one region of the composite component may desirably be constructed from pre-impregnated material whereas an adjacent region may desirably be constructed from e.g. biaxial fabrics where significant cost benefits can be derived from liquid infusion processes of dry fabrics.

However, the use of such different materials in the same composite component may impose several difficulties to the finished component such as e.g. potential adhesion problems between the different materials. Also, the use of differing materials may cause manufacturing difficulties due to potentially likewise differing process parameters to be observed. For instance, the resins used for the different material formats may require differing temperatures for processing. In this respect, resins in pre-impregnated materials (such as e.g. epoxies, vinyl-esters or DCPD's) are typically almost solid at room temperature but liquefy at elevated temperatures typically in the range of 60-120°C. Some resins suitable for infusion or injection processes are considered 'liquid' at ambient temperatures, whereas others require a temperature elevation to 60-100°C to reduce their viscosity sufficiently to enable infusion. When infusing at these temperatures, it is therefore desirable or in some cases even necessary to heat the mould and fabrics to be infused to a similar temperature or else the resin will rapidly lose temperature and become too high in viscosity to infuse.

Further, the different resins are prone to result in unpredictable migration of the resins between the different materials during the manufacture, and thereby correspondingly unpredictable distribution and amount of the different resins the finished composite. As a result, the region in which the different types of resins meet and thereby the component as

such may suffer from unpredictable material properties and even from void content due to the potentially incomplete impregnation in places. The consequences hereof may be poor structural performance and premature failure.

5 The problems addressed above are of even more significance when using partially impregnated prepregs (so-called semi-pregs or PIP's, where the reinforcing material comprises the full amount of resin but is not fully impregnated so that dry or partially dry regions are present) such as commonly applied in e.g. vacuum-only processing. In this case, unless the semi-preg has fully wet-out itself by the time a later liquid infusion commences, the reinforcing material may be preferentially wet-out by the infusion resin, leading to the
10 semi-preg resin layer remaining a discrete resin-rich region which is undesirable in structural performance terms.

Description of the invention

It is therefore an object of embodiments of the present invention to overcome or at least reduce some or all of the above described disadvantages of the known composite
15 components by providing a manufacturing method allowing for the use of fiber-reinforced materials of different resin materials.

It is a further object of embodiments of the invention to provide a method of preparing a composite laminate resulting in laminates of improved and more well-defined mechanical properties, and with a minimized risk of voids or resin rich region.

20 A further object of embodiments of the invention is to provide a method of preparing a composite laminate which allows for a wider choice of combinations of applicable resin materials without or with reduced risk of insufficient or uncontrolled resin distribution in the finished composite component caused by the different materials used.

25 It is a yet further object of embodiments of the invention to provide manufacturing methods which are simple and fast to apply and yet effective.

In accordance with the invention this is obtained by a method of preparing a composite laminate comprising

- providing layers of fiber reinforced material;
- said layers comprising a first layer being at least partly pre-impregnated by a resin
30 having a first viscosity and a second layer;

- providing a resin of a second viscosity to at least partly impregnate said second layer; and
- providing an at least partly uncured resin film between said first and second layers, wherein the viscosity of the resin film when providing said resin to said second layer, is substantially equal to or higher than the lowest viscosity of the first and second resins.

Hereby is obtained that the resin flow across the material interface between the first and second layers may be controlled, in that the resin film will act as a barrier reducing or even preventing migration of the structural matrix material (i.e. the resin) between the layers of different material during the preparation of the laminate. This effect may be mainly due to the low-flow properties of the resin film relative to one or both of the resins of the neighboring material layers at the time and temperature of the impregnation of the second layer.

The resin may be provided to the second layer by e.g. injection, or infusion, or a combination hereof, i.e. by resin transfer moulding (RTM). The low-flow properties of the resin film is obtained by choosing the resin film such that its viscosity μ_{film} at the temperature of the resin impregnation is at least comparable to or higher than the most liquid of the two resins of the layers being combined, i.e. $\mu_{film} \geq \min(\mu_1; \mu_2)$.

The first layer of fiber reinforced material may comprise a prepreg and/or semi-preg. Prepreg materials are fiber reinforced materials which are completely impregnated comprising the full and necessary amount of resin. Semi-pregs likewise comprise the full and necessary amount of resin, but is not completely impregnated in the sense that dry areas may exist. In this way the semi-preg may impregnate itself at the appropriate temperature and consolidation pressure. As an example, a semi-preg may comprise the full amount of resin placed in between the layers of the semi-preg leaving the outer surfaces dry to touch, with the advantage that the material becomes easier to handle and store.

In case the second viscosity of the infusion resin is the highest, the resin film may advantageously act to reduce or even prevent the resin from the pre-impregnated layer to migrate into the second layer of dry fibres first, otherwise leading to areas of void in the pre-impregnated layer.

In case the second viscosity of the infusion resin is lower than that of a semi-preg constituting the first layer, the resin film may advantageously act to reduce or even prevent the infusion resin to migrate into the semi-preg causing resin rich areas.

The resin film may be fully or at least partly uncured, i.e. uncured in some parts or comprises uncured resin material or combinations hereof. Further, the resin film may be at an intermediate stage of curing. Hereby may be obtained that the film may stay between the layers and is co-cured with the laminate to become an integral part of the laminate without or with only minimal reduction of the structural properties of the finished laminate.

The fiber reinforced material may comprise fabrics of e.g. woven, non-woven, stitched, knitted, filted or otherwise fibrous materials. Further, the first and second layers may be placed on top of each other, next to each other, in an overlapping fashion, or placed to form a joint such as e.g. a stepped joint or a scarf joint or any combinations hereof. The stacking order of the materials above and below the resin film is of no importance. I.e. the pre-impregnated layers may be placed either above or below the resin film and the dry fibres to be impregnated.

The resin film may be placed across a part of or across the entire the joint surface or interface between the layers of fiber reinforced material. Further, the resin film may be placed to extend a certain distance on one or both sides of the interface between the dry fibres and the pre-impregnated material such as e.g. between 20-50mm to deal with any transverse flow, such as in the range of 30-40 mm.

By the use of a resin film as described above, the resin migration may be controlled during the entire resin impregnation of the dry layers or during a longer period hereof in dependence of the viscosities of the different resins, on their curing temperatures, and on the temperature applied to the mould and to the material during the resin transfer moulding.

This may e.g. be achieved by using an uncured resin film of e.g. an epoxy, a vinyl-ester or a DCPD, which exhibits highly-controlled flow characteristics in the temperature regions at which the resin migration can occur. The resin film may further have curing characteristics that allow the material to cure at a similar temperature to the prepreg or liquid infusion resin (whichever is the higher) – so the resin film then becomes an integral part of the laminate and remains essentially at or close to the interface of the two other structural materials.

The resin film may be chosen such as to have a curing temperature in between or around the curing temperature of either of the surrounding systems, optionally closer to the higher curing temperature, thereby obtaining that a chemical bonds may be formed successfully with both mating materials, which in general may be greatly aided by the resin still being liquid. Hereby may be obtained a high toughness interface with increased resistance to shear and peel forces due to a combination of chemical and mechanical bonding of the resin film to the neighbouring materials.

Good chemical bonding and adhesion may be ensured by choosing a resin film of compatible chemistry with both of the mating resin systems. This may be obtained by using resins of the same chemistry group - i.e. epoxy film for epoxy mating systems, vinyl-ester film for vinyl-ester mating systems, etc.

- 5 In an embodiment of the invention different resin types of each of the different materials to be combined may be mixed and matched. For example, a vinyl-ester film may be used to enable a high performance epoxy prepreg to be mated with a low-cost polyester infusion resin. In this way, the resin film may be used to enable a stronger bond between the mating parts of the laminate of different resin types. Hereby may be obtained a larger number of possible combinations for the resins of the different materials to be combined whereby may be chosen for instance resins of lower cost, of easier handling, of more appropriate curing temperatures etc.

- 15 Further, the use of a resin film in accordance with embodiments of the invention may be advantageous in providing structural enhancement of the interface area between the layers to be combined. This effect may especially be obtained by the use of resin films of high toughness (for example adhesive films with a high content of rubber tougheners) known to act as a barrier to crack propagation in the more brittle structural resins at the interfacial region thereby providing a high performance bond.

- 20 The resin film may optionally in whole or in part be placed on a carrier scrim thereby making it easier to handle prior to and during the preparation of the laminate.

The resin film may be a toughened adhesive film such as e.g. AF163-3 supplied by 3M, Redux 312 supplied by Hexcel, and MTA240 supplied by Advanced Composites Group. These films typically have a relatively high viscosity and limited flow at higher temperatures.

- 25 The thickness of the resin film may depend on its tendency to flow prior to the infusion or injection, and may be of approximately 0.1- 1.0 mm, such as in the range of 0.3-0.6mm.

The resin film may further be perforated or comprise holes in various sizes and patterns. Such perforations may be advantageous in increasing the bond of the resin film to the adjacent materials while the film still acts to reduce the resin migration across the interface.

- 30 As an example a resin film with a resistance to flow at temperatures between 40-80°C may be practical for application in a manufacturing process with curing temperatures of the mating resin systems between 60-120°C such as between 80-100°C.

As an example, when infusing liquid resins into a pre-laminated stack for the mating of dry fibres with Hexcel M9.1/9.6 prepreg laminates at an infusion temperature of around 55°C - the laminate stack having been pre-heated to this temperature, a resin film such as an adhesive film of a viscosity approximately 1 order of magnitude higher than the prepreg resin would be usable. An appropriate resin film could for example be a resin film such as the epoxy adhesive film of MTA240 manufactured by Advanced Composites Group. This will ultimately co-cure with the prepreg at a final cure temperature of around 120°C.

According to an embodiment of the invention, the method described in the preceding further comprises increasing the temperature of the composite laminate to or above the liquefying temperature of the resin film prior to curing the laminate. Hereby the bonding of the resin film to the neighboring materials and thereby into the final laminate may be increased. Further, an increase of the temperature to or above the liquefying temperature of the resin film may be performed without or with only minimal effect on the barrier-acting properties of the resin film, as the viscosity of the resin film is still higher than the most liquid resin at the time when the second layer is impregnated.

In an embodiment of the invention the method further comprises increasing the temperature of the first and second layer prior to providing the resin to the second layer. Hereby the resin transfer into the second layers of material may be enhanced.

In a further embodiment of the invention the viscosity of the resin film, when providing said resin to said second layer, is between the values of the viscosities of the resins of the first and second layers. Hereby the resin film may act as barrier for the resin migration across the film while allowing for a controlled and moderate impregnation of the resin film itself into the surrounding fiber reinforced material. This may further provide a high toughness interface with a combination of chemical and mechanical bonding to resist shear and peel forces.

In yet a further embodiment of the invention the resin impregnating the second layer is provided by resin infusion and/or resin injection.

In an embodiment of the invention the resin film comprises a thermosetting resin which may be advantageous as the resin film thereby is compatible to the resin used for the resin transfer. Hereby the resin film may be integrated fully into the finished laminate and may increase the interfacial properties such as strength and resistance to wear.

Alternatively or additionally the resin film may comprise a thermoplastic resin of a type allowing to bond to the adjacent resins.

A further aspect of the invention relates to a composite laminate prepared by a process according to any of the preceding and comprising providing layers of fiber reinforced material, where the layers comprise a first layer being at least partly pre-impregnated by a resin having a first viscosity, and a second layer. Further, a resin of a second viscosity is provided to at least partly impregnate the second layer, and an at least partly uncured resin film is provided between the first and second layers.

The invention further relates to a wind turbine blade component comprising a composite laminate prepared by a method according to any of the preceding.

The advantages hereof are as described in the foregoing in relation to the method of preparing the laminate.

In an embodiment of the invention the wind turbine blade comprising a root part, a tip part opposite said root part, and an intermediate part between said root part and said tip part, and wherein the intermediate part comprises said first layer of an at least partly pre-impregnated fiber reinforced material and the root part comprises said second layer of fiber reinforced material. In this way the resin film is provided at the interface between the root part of dry fibres to be resin impregnated by resin transfer moulding and the intermediate part comprising pre-impregnated layers such as prepregs or semi-prepregs.

Hereby and by the use of the proposed resin film may be obtained a better processing control in that the resin amounts in the different parts of the component may be more precisely controlled. Further may be obtained a structural enhancement of the interface between the dry fiber lay-up in the root end to be impregnated by resin transfer moulding and the pre-impregnated layers or slabs in the tip end of the blade. The resin film further enables the use of semipreggs which may be advantageous to use in that they generally yield better quality laminates and handling characteristics when compared to fully wet-out prepregs.

Brief description of the drawings

In the following different embodiments of the invention will be described with reference to the drawings, wherein:

Fig. 1 shows a sketch of different materials laid-up on a mould in a cross-sectional view,

Fig. 2 is a sketch of the positioning of a barrier film according to an embodiment of the invention and in a cross-sectional view, and

Fig. 3 is in a cross-sectional view of a part of a component for a wind turbine under manufacture according to an embodiment of the invention.

5 Detailed description of the drawings

Figure 1 illustrates in a cross sectional view the manufacture of a hybrid composite component 100 according to prior art, where the fiber reinforcement 101, 102 is laid up on a mould surface 103 and covered with a vacuum bag or foil 104. The laminate 100 comprises a prepreg material 101 and dry fabrics 102 which are to be impregnated by resin infusion or injection. As the entire system is raised to elevated temperatures such as required for the resin infusion or injection, the resin from the prepreg materials 101 will liquefy prior to the resin infusion process. In this case, the resin will migrate unpredictably into the dry materials 102 from the prepreg material 101 as illustrated by the arrows 105. During the resin infusion phase, the liquid resins may or may not infuse the region from which the prepreg resin has migrated. Further, the region in which the injected resin and prepreg resin meet can suffer from unpredictable void content and fibre volume fractions leading to poor structural performance and premature failure.

Such problem of unintended and uncontrollable resin flow may be even more pronounced in case the prepreg materials are substituted or supplemented by semi-preg materials. Here, unless the semi-preg has completely wet-out itself by the time the resin transfer into the dry fabrics commences, the fibres will most likely be wet-out by the resin transferred into the dry fabrics, thereby leading to the semi-preg resin layer remaining a discrete resin-rich region.

In figure 2 is illustrated the manufacture of a composite component according to an embodiment of the invention. A resin film 200 is here provided between the dry fibrous material 102 and the already to some extent impregnated fiber reinforced material 101. The material of the resin film 200 is chosen such as to have a viscosity μ_{film} higher than the lowest viscosity of either of the resins of the materials which it separates, $(\mu_1; \mu_2)$ i.e. of either the resin injected or infused into the dry fibrous material 102, μ_2 or of the pre-impregnated material 101, μ_1 . Formulated differently, the resin film is chosen such that $\mu_{film} \geq \min(\mu_1; \mu_2)$. In this way the resin film will act as a barrier preventing or reducing the migration of resin between the different types of material 101, 102 of the composite component 100.

Figure 3 illustrates the lay-up of a part of a wind turbine blade as seen in a cross-sectional view A-A along the length of the wind turbine blade 400 as indicated in figure 4. The wind turbine blade comprises a root part 401, a tip part 402 opposite the root part, and an

intermediate part 403 between the root part and the tip part. The root part 401 comprises layers of dry fiber material 102 to be impregnated by resin infusion and optionally a pre-cured 'spear' or core 301 into which the bushings for the blade connection may be inserted or embedded. The intermediate part 403 comprises layers of pre-impregnated material 101
5 such as prepreg slabs 302, semi-preg layers 303 and a spar 304 of carbon material extending along the length of the wind turbine blade. In accordance with an embodiment of the invention the pre-impregnated layers and the dry fibre layers are separated by a resin film 200. The resin film here acts as a low-flow barrier reducing or preventing the resin flow from the pre-impregnated materials 302 into the dry fibres 102 or the other way of infused resin
10 into the semi-preg 303 during the resin transfer.

The use of the resin film 102 in this way provides a better processing control and control of the fiber-to-resin ratio of the different laminate parts of the blade along with a structural enhancement of the interface between the dry fiber lay-up in the root end and the pre-impregnated layers and carbon slabs further out in the blade.

15 Further, the application of the resin film enables the use of more semi-pregs instead of prepregs, thereby reducing the material count and improving the deposition rate. This may further be advantageous as the handling characteristics of semi-pregs are generally higher than of prepregs where the handling in general involves touching the resin and due to the general tackiness of the prepreg surfaces.

20 While preferred embodiments of the invention have been described, it should be understood that the invention is not so limited and modifications may be made without departing from the invention. The scope of the invention is defined by the appended claims, and all devices that come within the meaning of the claims, either literally or by equivalence, are intended to be embraced therein.

25

Claims

1. A method of preparing a composite laminate comprising

- providing layers of fiber reinforced material;
- said layers comprising a first layer being at least partly pre-impregnated by a resin having a first viscosity, and a second layer;
- providing a resin of a second viscosity to at least partly impregnate said second layer; and
- providing an at least partly uncured resin film between said first and second layers, wherein the viscosity of the resin film when providing said resin to said second layer, is substantially equal to or higher than the lowest viscosity of the first and second resins.

2. A method according to claim 1, further comprising increasing the temperature of the composite laminate to or above the liquefying temperature of said resin film prior to curing the laminate.

3. A method according to claim 1-2, further comprising increasing the temperature of the first and second layer prior to providing said resin to said second layer.

4. A method according any of the preceding claims, where the viscosity of the resin film when providing said resin to said second layer is between the values of the viscosities of the resins of the first and second layers.

5. A method according any of the preceding claims, wherein said resin impregnating said second layer is provided by resin infusion and/or resin injection.

6. A method according any of the preceding claims, wherein said first layer of fiber reinforced material comprises a pre-preg.

7. A method according any of the claims 1-5, wherein said first layer of fiber reinforced material comprises a semi-preg.

8. A method according any of the preceding claims, wherein said resin film comprises a thermosetting resin.

9. A method according any of the preceding claims, wherein the first and second layers are placed in an overlapping fashion.

10. A method according any of the preceding claims, wherein the first and second layers are placed to form a scarf joint or a stepped joint.

5 11. A composite laminate prepared by a process according to any of the claims 1-9 comprising

- providing layers of fiber reinforced material;
- said layers comprising a first layer being at least partly pre-impregnated by a resin having a first viscosity, and a second layer;

10 – providing a resin of a second viscosity to at least partly impregnate said second layer; and

- providing an at least partly uncured resin film between said first and second layers.

12. A wind turbine blade component comprising a composite laminate prepared by a method according to any of the claims 1-10.

15 13. A wind turbine blade prepared by a method according to any of the claims 1-9, the wind turbine blade comprising a root part, a tip part opposite said root part, and an intermediate part between said root part and said tip part, and wherein the intermediate part comprises said first layer of an at least partly pre-impregnated fiber reinforced material and the root part comprises said second layer of fiber reinforced material.

1/2

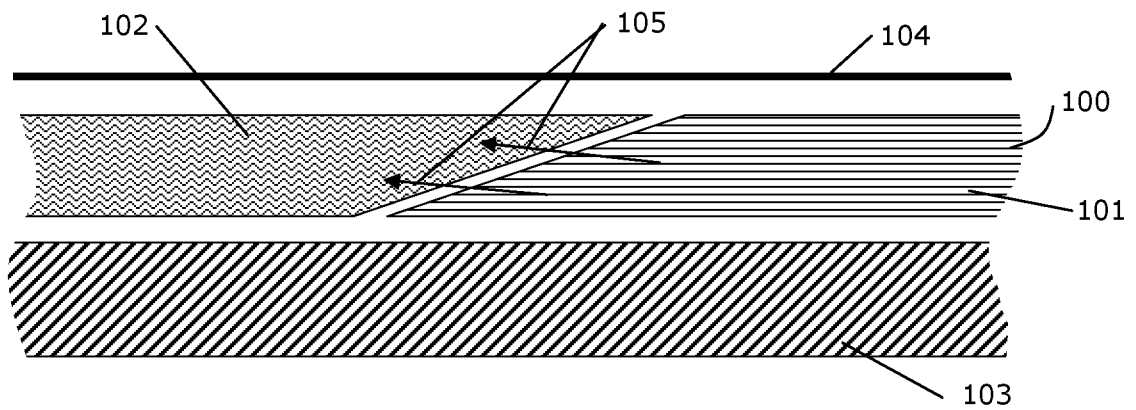


Fig. 1 (prior art)

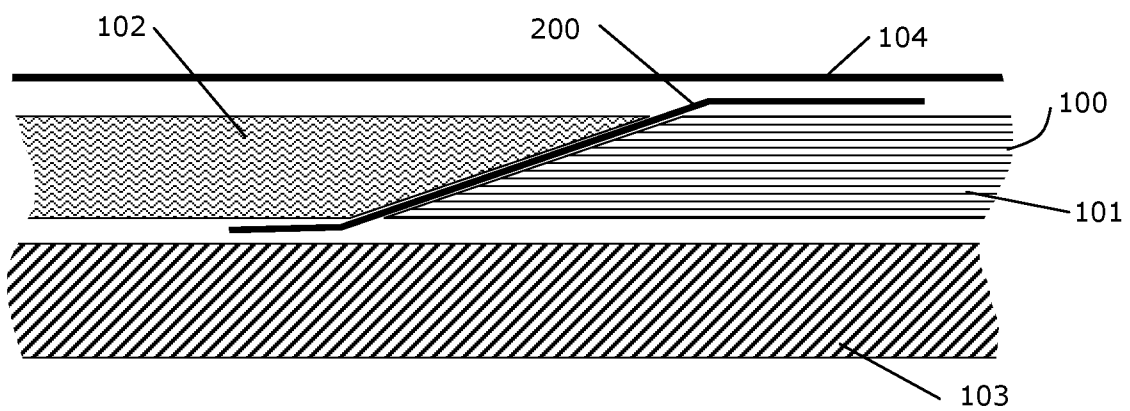


Fig. 2

2/2

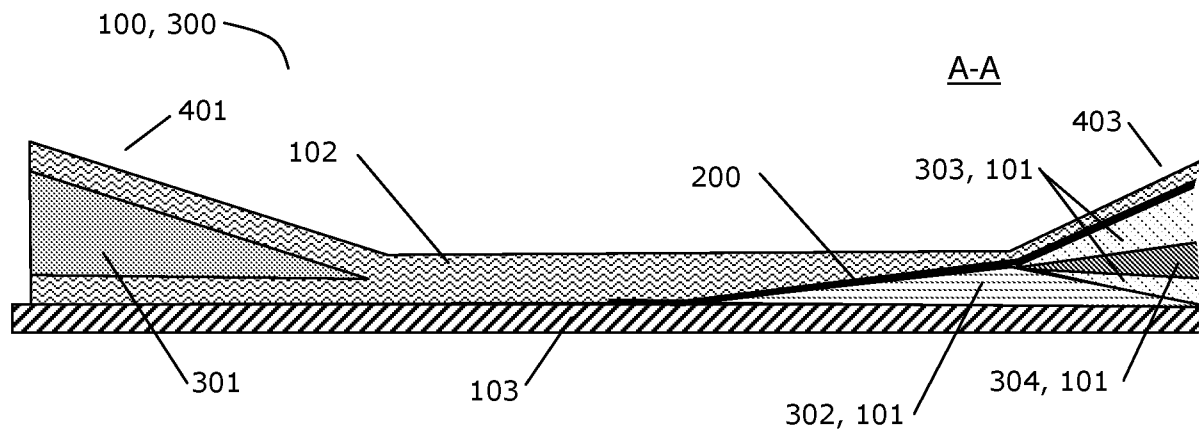


Fig. 3

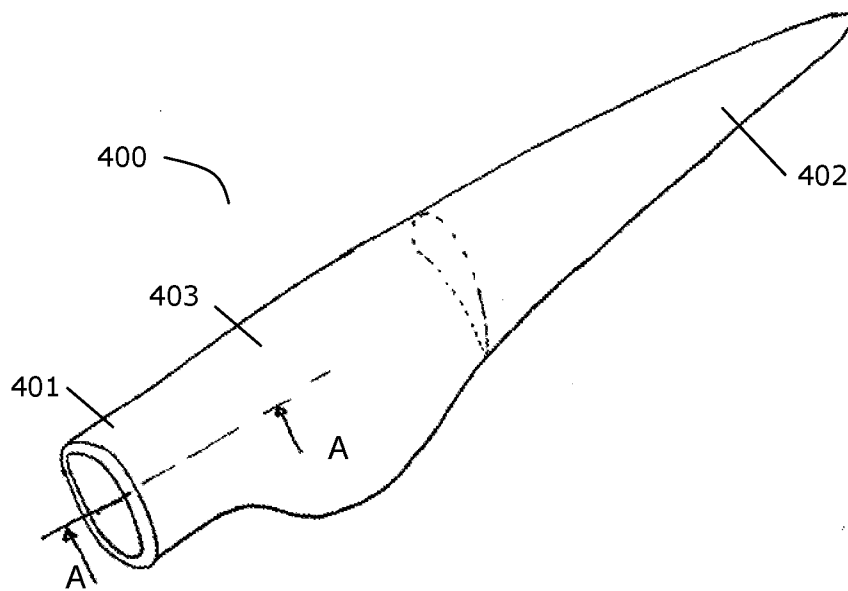


Fig. 4