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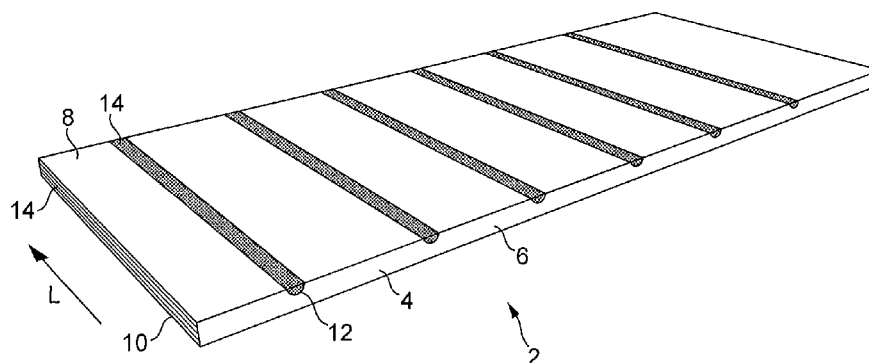


FIG. 1

(57) Abstract: A prepreg for manufacturing a fibre-reinforced composite material, the prepreg comprising a layer of fibrous reinforcement having a plurality of dry fibre channels in a first major surface thereof and a portion of the layer of fibrous reinforcement which is fully impregnated by a matrix resin material, the portion being adjacent to the channels, and a scrim material covering at least one major surface of the layer of fibrous reinforcement and adhered to the matrix resin material, the scrim material being partly embedded in the matrix resin material.

COMPOSITE MATERIALS

The present invention relates to a prepreg for manufacturing a fibre-reinforced composite material and to a method of manufacturing such prepreg. The present invention further relates to the use of such a prepreg for manufacturing a fibre-reinforced composite material.

It has been known for many years in the field of fibre-reinforced composite materials to provide a prepreg which comprises a layer of fibrous reinforcement impregnated with a structural polymer resin. The amount of structural polymer resin is carefully matched with the amount of fibrous reinforcement. Accordingly, the prepreg may be used in a method for forming a fibre-reinforced composite material, in which a multilayer stack of prepregs is provided having a desired shape and configuration, and then is subjected to heating so that the structural polymer resin melts and then solidifies to form a single unified resin matrix in which the fibrous reinforcement is disposed in the desired fibre orientation. The amount of resin in the stack is sufficient to make a fibre-reinforced structural article from the stack of prepregs which has the desired mechanical properties. Typically, the structural polymer resin is a thermosetting resin, most typically an epoxy resin, which is cured to form the solid resin matrix. The fibres may be selected from a variety of materials, most typically comprising glass fibres or carbon fibres.

It is very well known to provide prepregs in which the structural polymer resin is fully impregnated into the layer of fibrous reinforcement. This provides the outer major surfaces of the prepreg with a resin surface, distributes the fibres substantially uniformly throughout the prepreg resin so that the fibres are uniformly embedded within the resin and minimise the presence of inadvertent voids within the initial resin layer. This provides the advantage that the resin surface can be slightly tacky to assist lay up of the prepregs into the mould by supporting the prepreg at a desired position as a result of the adhesion of the prepreg by the tacky resin surface to an adjacent surface. In addition, the full impregnation of the fibrous reinforcement obviates the need for the structural polymer resin to flow significantly the curing phase, and ensures that the fibres wet out uniformly during the curing phase.

However, one particular problem with fully impregnated preregs is that when a stack of such preregs is formed, air can be trapped between the adjacent prepreg plies, with the result that in the final cured resin matrix of the fibre reinforced composite material inter-ply voids can exist. The presence of these voids can significantly reduce the mechanical properties of the composite material. As the layers of fully impregnated preregs are progressively built up to form a multilayer stack thereof during the prepreg lay-up process, air can be trapped between the adjacent prepreg layers. The tackiness of the resin surfaces of the adjacent prepreg layers increases the possibility of air being trapped between the plies at the prepreg interfaces.

EP-A-1595689 discloses a conventional, i.e. fully impregnated, prepreg which is coated with a scrim material on at least one major surface. The fibres of the scrim material are impregnated into the resin surface so that less than 50% of their diameter is resin coated. The exposed portions of the scrim fibres enhance air transport between adjacent prepreg plies. However, the use of such a scrim material requires scrim material on both major surfaces to provide any significant reduction in void content, which increases the manufacturing cost of the prepreg. Furthermore, even with such two scrim plies, one on each major surface, the void content is still unacceptably high for some applications.

In an alternative attempt to overcome this undesirable formation of inter-ply voids, it has also been to provide preregs which are only partially impregnated with the structural polymer resin so that a layer of dry fibre reinforcement is present on one or both of the major surfaces of the prepreg. Such a known partially impregnated prepreg, or semipreg, is manufactured by the applicant and sold under the registered trade mark SPRINT®.

Such partially impregnated preregs provide the advantage that when the preregs are laminated as a stack, the layer of dry fibre reinforcement permits, during an initial vacuum consolidation phase, air to be evacuated through the dry fibre reinforcement progressively as full wet out of the dry fibrous reinforcement occurs on melting of the structural polymer resin. During vacuum consolidation of the preregs, the stack of preregs is subjected to a negative pressure, i.e. a vacuum, to assist air removal from between the adjacent preregs and the regions of dry fibre reinforcement. The regions of

dry fibre reinforcement are progressively wetted out by the multi-structural polymer resin under the applied vacuum prior to subsequent curing. This partially impregnated prepreg structure therefore provides the advantage that inter-ply voids between adjacent plies tend to be reduced or even eliminated.

It is known to use prepregs for manufacturing a wide variety of products, having a wide variety of thicknesses, shapes and volumes, and desired mechanical properties. One particular application for composite materials is the manufacture of structural elements in the form of elongate spars or beams which are required to exhibit a high mechanical stiffness and compressive strength. A "sparcap" is an elongate spar laminate which is incorporated into a particular layup for manufacturing a wind turbine blade, as is known in the art. The sparcap is an outer elongate capping laminate layer on opposite sides of a central structural element to form an elongate beam of enhanced mechanical strength similar to an "I" beam construction. For such spars or beams, in order to maximise the mechanical stiffness and compressive strength, it is desired to provide fibres which primarily are oriented along the direction of the elongate spar or beam, in particular are unidirectional fibres.

In contrast, to provide composite materials having a sheet-like construction, or providing a torsional strength, it would be desirable to provide biaxially oriented fibres.

However, when manufacturing such structural spars or beams which incorporate unidirectional fibres extending along the length of the spar or beam, there is a technical problem when such partially impregnated prepregs are employed having outer layer surfaces of dry fibre reinforcement. The technical problem is that the outer unidirectional dry fibres which are not impregnated with the structural polymer resin tend to be easily distorted in a transverse direction within the plane of the prepreg. When the prepregs are assembled together as a multi-laminar stack, this can cause the unidirectionally oriented fibres to become non-linear, causing some degree of fibre waviness, distortion or curvature in the plane of the resultant composite material. Such non-linearity of the unidirectional fibres can lower the compressive strength of the structural member, such as a spar.

Furthermore, when such partially impregnated prepregs are assembled together in a multi-laminar stack to form a structural member, during vacuum consolidation of the prepregs, the multi-laminar stack of prepregs can shrink in thickness, a phenomenon known in the art as “de-lofting”. This “de-lofting” induces some out-of plane waviness to the uni-directional fibre which lowers the compressive mechanical properties, as the fibres will buckle earlier under compressive loads.

In addition, when manufacturing such structural spars or beams which incorporate unidirectional fibres extending along the length of the spar or beam, there is a further technical problem when dry fibre or partially impregnated unidirectional prepregs are employed. There is a strong tendency for intra ply voids to be formed, as air remains within the prepreg due to the relatively low air permeability of the well nested unidirectional fibres, which can significantly lower the mechanical properties of the structural member.

There is therefore still the need for a prepreg which has particular application for the manufacture of spars which over comes the problems of fully impregnated prepregs, scrim-coated fully impregnated prepregs and partially impregnated prepregs as discussed above.

The present invention at least partially aims to overcome these technical problems of known prepregs for the manufacturing of elongate structural members in the form of spars or beams.

Accordingly, the present invention provides a prepreg for manufacturing a fibre-reinforced composite material, the prepreg comprising a layer of fibrous reinforcement having a plurality of dry fibre channels in a first major surface thereof and a portion of the layer of fibrous reinforcement which is fully impregnated by a matrix resin material, the portion being adjacent to the channels, and a scrim material covering at least one major surface of the layer of fibrous reinforcement and adhered to the matrix resin material, the scrim material being partly embedded in the matrix resin material.

In one embodiment, the scrim material covers a second major surface of the layer of fibrous reinforcement which is opposite to the first major surface. In another embodiment, the scrim material covers the first major surface. In a further embodiment, a first scrim material covers the first major surface and a second scrim material covers a second major surface of the layer of fibrous reinforcement which is opposite to the first major surface. In any embodiment, the covering by the scrim material may be whole or partial covering.

Optionally, the layer of fibrous reinforcement is fully impregnated by the matrix resin material apart from at the plurality of dry fibre channels.

Optionally, the channels are parallel and extend in a longitudinal direction along the length of the prepreg.

Optionally, the layer of fibrous reinforcement is a unidirectional fibrous reinforcement extending in a longitudinal direction along the length of the prepreg.

Optionally, the channels have a width of from 2 to 20 mm, optionally from 3 to 10 mm. Further optionally, the channels have a spacing pitch between adjacent channels of from 20 to 200 mm, optionally from 30 to 160 mm. Optionally, the channels have a depth which is up to 50% of the thickness of the fibrous reinforcement. Typically, the channels have a depth of from 0.1 to 0.75 mm, optionally from 0.1 to 0.4 mm.

Optionally, there is a higher concentration of the matrix resin material at longitudinal boundaries of the plurality of dry fibre channels.

Optionally, the scrim material comprises fibres and greater than 50% of the fibre diameter is exposed above the matrix resin material. Typically, the scrim material comprises a woven or non-woven scrim material, optionally of polyester.

The present invention further provides a method of producing a prepreg for manufacturing a fibre-reinforced composite material, the method comprising the steps of:

- a. providing a layer of fibrous reinforcement;
- b. forming a plurality of substantially resin-free lines in a first film of resin material;
- c. applying the first film of resin material to a first major surface of the layer of fibrous reinforcement;
- d. impregnating the first film of resin material into the layer of fibrous reinforcement to form a plurality of dry fibre channels in the first major surface, the dry fibre channels corresponding to the substantially resin-free lines, the dry fibre channels having a portion of the layer of fibrous reinforcement adjacent thereto which is fully impregnated by the resin; and
- e. applying a scrim material to at least one major surface of the layer of fibrous reinforcement, the scrim being adhered to and partly embedded in the resin material.

In one embodiment, the scrim material is applied to cover a second major surface of the layer of fibrous reinforcement which is opposite to the first major surface. In another embodiment, the scrim material is applied to cover the first major surface. In a further embodiment, a first material is applied to cover the first major surface and a second material is applied to cover a second major surface of the layer of fibrous reinforcement which is opposite to the first major surface. Again, the covering may be whole or partial covering.

Optionally, in forming step (b) a plurality of scraper elements are pushed through the resin film to form the substantially resin-free lines on the first major surface. Optionally, in forming step (b) the pushing action of the plurality of scraper elements forms elongate longitudinal borders of additional resin at the elongate boundaries of the substantially resin-free lines.

Optionally, the impregnating step (d) forms a higher concentration of the resin material at longitudinal boundaries of the plurality of dry fibre channels.

Optionally, the impregnating step (d) causes full impregnation of the layer of fibrous reinforcement by the resin material apart from at the plurality of dry fibre channels.

Optionally, the method further comprises, before impregnating step (d), applying a second film of resin material to the second major surface of the layer of fibrous reinforcement, so that in the impregnating step (d) the first and second films of resin material fully impregnate the layer of fibrous reinforcement sandwiched therebetween.

Optionally, the scrim material comprises fibres and in step (e) the scrim material is partly embedded in the resin material so that greater than 50% of the fibre diameter is exposed above the resin material.

The present invention further provides a method of manufacturing an elongate structural member of fibre-reinforced composite material, the method comprising the steps of:

- i. providing a plurality of prepregs according to the present invention or produced according to the method of the present invention;
- ii. assembling the plurality of prepregs as an elongate stack thereof;
- iii. subjecting the stack to a vacuum to consolidate the stack and remove air from between the adjacent prepregs of the stack; and
- iv. curing the matrix resin material to form the elongate structural member.

The present invention further provides the use of a prepreg according to the present invention or produced according to the method of the present invention for manufacturing an elongate structural member of fibre-reinforced composite material, in particular a spar or beam.

The present invention is predicated on the finding by the present inventors that a prepreg for the manufacture of an elongate structural member, such as a spar or beam, can be provided with a combination of surface properties which can provide enhanced air removal from a stack of prepregs yet the prepreg has gross material properties which are similar to those of a fully impregnated prepreg. The result is a prepreg which can

provide even lower void content in the resulting cured fibre reinforced resin matrix composite materials, such as sparcaps.

Each fully impregnated prepreg ply has a low initial air content within the prepreg, lower than for a partially impregnated prepreg, and this in turn reduces the presence of voids within the cured composite material.

The fully impregnated prepreg structure retains the unidirectional fibres in the correct longitudinal alignment, and there is little or no distortion of the fibres in a transverse or through thickness direction. The dry fibre lines do not materially affect longitudinal fibre alignment. This not only increases the mechanical properties of the structural member, in particular as compared to the use of semi-pregs in which misalignment is problematic, but also decreases the lay-up times compared to semi-pregs, because semi-pregs require careful positioning when forming the prepreg stack in order to minimise inadvertent distortion of the exposed outer dry fibres. The fully impregnated prepreg structure also avoids the de-lofting and in-plane waviness problems associated with the use of semi-pregs.

Embodiments of the present invention will now be described by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic perspective drawing from one side of a prepreg to form a fibre-reinforced composite material in accordance with a first embodiment of the present invention;

Figure 2 is a schematic perspective drawing from the other side of the prepreg of Figure 1;

Figure 3 is a schematic perspective drawing showing one embodiment of a method for the manufacture of the prepreg of Figure 1; and

Figure 4 is a schematic section of the resin film showing the resin-free lines produced by the method of Figure 3.

Referring to Figures 1 and 2, there is shown a prepreg 2 in accordance with a first embodiment of the present invention. For clarity of illustration, some dimensions in the drawings are exaggerated and only some of the fibres are shown.

The prepreg 2 comprises a layer of fibrous reinforcement 4 that is substantially fully impregnated by a matrix resin 6, except for plural parallel elongate dry fibre channels 12 of dry fibre 14 extending in the length direction of the prepreg 2. The full impregnation provides that the opposed major surfaces 8, 10 of the fibrous reinforcement 4 comprise resin surfaces except for the dry fibre channels 12. The resin 6 is typically an epoxy-functional resin including a latent curing agent, as is known in the art. Other resins, particularly thermosetting resins, may be employed. The fibrous reinforcement 4 comprises fibres 14 made of glass, carbon, aramid or similar materials. The fibres 14 are unidirectional (UD), being oriented in a common longitudinal direction L. Most typically, for manufacture of a carbon sparcap, the fibrous reinforcement 4 comprises 300-900 g/m², and more preferably 600g/m² unidirectional carbon fibre in an epoxy or vinyl ester resin matrix.

Most typically, for manufacture of a glass fibre sparcap, the fibrous reinforcement 4 comprises 900-1800 g/m², and more preferably 1200-1600g/m² unidirectional glass fibre in an epoxy or vinyl ester resin matrix.

The dry fibre channels 12 typically have a width of from 2 to 20 mm, more typically from 3 to 10 mm, most typically from 4 to 6 mm. The centre-to-centre spacing pitch between the dry fibre channels 12 may typically range from 20 to 200 mm, more typically from 30 to 160 mm, most typically about 40 mm. The dry fibre channels 12 typically have a depth which is up to 50% of the thickness of the fibrous reinforcement 4, for example from 0.1 to 0.75 mm, optionally from 0.1 to 0.4 mm. The prepreg thickness may typically range from 0.4 to 1.5 mm.

The pitch distance is chosen to ensure that the frequency of dry fibre tows in the channels to provide an air transport path is sufficient for the structure area and configuration of the product to be manufactured, in turn so that the overall air transport pathway for any given area of the product is sufficient. It has been found that a dry channel width of 4 mm combined with a spacing pitch of 40 mm reliably provides effective air removal for a variety of different layup configurations without providing excess dry fibres which in turn could result in void problems.

On the other side of the prepreg 2, namely on the opposite major surface from that which has the dry fibre channels 12, a scrim material 16 is impressed into the resin surface. The scrim typically comprises a polyester woven or non-woven material, such as that disclosed in EP-A-1595689. The scrim 16 is impressed into the resin surface after impregnation of the resin into the fibres. The impressing is controlled so that greater than 50% of the fibre diameter is exposed. The wetout of the scrim by the prepreg resin is therefore less than 50%.

In the illustrated embodiment, the scrim material covers a second major surface of the layer of fibrous reinforcement which is opposite to the first major surface. In another embodiment, the scrim material covers the first major surface. In a further embodiment, a first scrim material covers the first major surface and a second scrim material covers a second major surface of the layer of fibrous reinforcement which is opposite to the first major surface. In any embodiment, the covering by the scrim material may be whole or partial covering.

Referring to Figure 3, there is shown a schematic perspective drawing showing one embodiment of a method for the manufacture of the prepreg of Figure 1. In the illustrated embodiment, the prepreg 2 is manufactured by impregnating the fibrous reinforcement 4 from opposed sides, by using two resin films 20a, 20b and with the fibrous reinforcement 4 sandwiched therebetween. During the impregnation step, each resin film 20a, 20b is impregnated towards the centre of the layer of fibrous reinforcement 4, and the two resins join at the centre to form a fully impregnated prepreg with resin extending through the entire thickness of the fibrous reinforcement 4 apart from at the dry fibre channels 12.

Each resin film 20a, 20b has a thickness selected to achieve the desired degree of impregnation of the fibrous reinforcement 4. When two resin films impregnate the fibrous reinforcement 4, one from each side, each resin film 20a, 20b typically has a thickness just less than one half of the thickness of the fibrous reinforcement 4; for example each resin film typically has a thickness of from 0.125 mm to 0.5 mm. A typical prepreg thickness for glass fibre, in particular unidirectional glass fibre, is about 1.2 mm, with the two resin films each having a thickness of about 0.3 mm, whereas a typical prepreg thickness for carbon fibre, in particular unidirectional carbon fibre, is about 0.6 mm, and with the two resin films each having a thickness of about 0.15 mm.

In an alternative embodiment which is not illustrated, the prepreg is manufactured by impregnating the fibrous reinforcement from one side, by using a single resin film on the side of the fibrous reinforcement which has the dry fibre channels; for example the single resin film typically has a thickness of from 0.25 mm to 1.0 mm. During the impregnation step, the resin is impregnated through the entire thickness of the fibrous reinforcement.

Referring again to Figure 3, and Figure 4 which shows exaggerated dimensions for clarity of illustration, one of the resin films 20a is supported on an elongate backing web 21a of release material, such as silicon-coated paper or plastic material, e.g. polyethylene or polypropylene. The resin film 20a on the backing web 21a is unwound from a reel and passes continuously under a comb-like scraper mechanism 26 which extends transversely across the resin film 20a. The scraper mechanism 26 comprises a longitudinal array of a plurality of transversely spaced scraper elements 28 which are drawn through the resin film 20a. Each scraper element 28 pushes away an elongate line 30 of the resin film 20 in the manner of a plough, leaving a plurality of resin-free lines 32 in the resin film 20a. Each line 32 has a width corresponding to the width of the scraper element 28. The line 32 comprises a gap 33 between spaced segments 35 of the resin film 20. The resin-free lines 32 in the resin film 20a are formed using a scraping and pushing mechanism.

Each resin-free line 32 is substantially resin-free since the scraper elements 28 are spaced a very small distance from the backing web 21a of release material and so leave a very small thickness, for example 10 to 50 microns, of residual resin 36 at the bottom of the gap 33. Such a substantially negligible thickness of residual resin 36 in the resin-free lines 32 provides no technical effect in the resultant prepreg.

Due to the ploughing action, elongate longitudinal borders 34 edges of additional resin are formed at the elongate boundary 38 of the resin-free line 32 as a result of the resin 6 being pushed to opposite longitudinal sides by the plough-like action of the scraper elements 28. This provides a thicker border of resin 6 at edges of the segments 35.

These resin-free lines 32 in the resin film 20a subsequently form the dry fibre channels 12 after impregnation of the resin 6 into the fibrous reinforcement 4. Since the resin-free lines 32 are present in only one of the two opposed resin films 20a, the dry fibre channels 12 can penetrate through a maximum of 50% of the thickness of the fibrous reinforcement 4.

Thereafter, the fibrous reinforcement 4 is brought into contact with the resin film 20a, for example by pressing using a roller 25. In the illustrated embodiment, a lower surface 22 of the fibrous reinforcement 4 is pushed downwardly onto the upper surface of the combed resin film 20a. Subsequently, the second of the resin films 20b, as for the resin film 20a supported on an elongate backing web 21b of release material, is pushed downwardly onto the upper surface 24 of the fibrous reinforcement 4, for example by a pair of nip rollers 27. In this way, each of the two resin films 20a, 20b of the resin 6 is applied to a respective surface 22, 24 of the fibrous reinforcement 4. In an alternative embodiment, the two resin films 20a, 20b of the resin 6 may simultaneously be applied to a respective surface 22, 24 of the fibrous reinforcement 4, for example by a single pair of nip rollers. The resultant assembly comprised a three layer sandwich of combed resin film 20/fibre reinforcement layer 4/continuous resin layer 20b temporarily located between backing layers 21a, 21b.

Subsequently, the resin 6 is fully impregnated into the fibrous reinforcement 4 using a conventional impregnation step. The dry fibre channels 12 in the resultant impregnated prepreg are formed at locations substantially corresponding to the resin-free lines 32 in the resin film 20a prior to impregnation, subject to some minor transverse movement of the resin during the impregnation step. When the resin 6 is impregnated into the fibrous reinforcement 4, this causes the regions 38 of the prepreg 2 adjacent to the boundary 40 of the dry fibre channels 12 to have a higher resin content than the bulk resin content of the remainder of the impregnated prepreg.

During subsequent curing when manufacturing the article of fibre reinforced resin matrix composite material, the resin fully wets out the dry fibres to provide a uniform resin concentration throughout the entire cured fibre reinforced composite material.

The scrim 16 is applied to the other surface 24 of the fibrous reinforcement 4 in a conventional manner after resin impregnation, and after removal of the backing layer 21b.

Typically, the prepreg 2 has an indeterminate or unspecified length in the longitudinal direction L of orientation of the fibres 14, and is supplied on a reel. The prepreg 2, when used to manufacture an elongate structural member such as a sparcap as described hereinbelow, has a relatively narrow width W, so that an elongate spar or beam can be manufactured. However, the prepreg may be manufactured by the formation of an initial wider sheet of unspecified length, with the sheet subsequently being slit longitudinally into a plurality of narrower strips, each defining a respective prepreg 2.

The prepreg is laminated as a stack and then subject to vacuum consolidation and curing. During layup of the prepregs, typically the dry fibre channel side of one prepreg is laid adjacent to the scrim side of an adjacent prepreg. The resultant layup, particularly to form a spar, may comprise a single planar body, although other shapes and configurations may be employed. In order to modify the flexural modulus of the spar along its length, it is known to change the section width. In this case trapezium or

triangular shaped sections, as well as parallel strips, may be also cut from the wider sheet to avoid wasting any of the prepreg material.

The resin of the prepreg is provided with particular properties so that when a multi-laminar stack of the prepregs is formed, and the multi-laminar stack is subjected to a vacuum in a consolidation step, air can readily be evacuated that is present near the surfaces of the prepregs and between the prepreg plies at the interfaces therebetween. In particular, the resin is typically selected so as to have a relatively high viscosity and a relatively low tack. The combination of the resin and unidirectional fibres is typically selected so as to provide a relatively high stiffness, in both (a) the longitudinal length direction, which is the direction of orientation of the unidirectional fibres, and (b) the transverse direction orthogonal thereto.

The scrim provides a surface roughness to the prepreg which enhances the creation and maintenance of separation between the surfaces of adjacent prepreg plies in the layup stack. The longitudinal dry fibre channels 12 act to provide air passages along the layup length which greatly increase air removal during vacuum consolidation. This in turn provides a reduced void content. The scrim is adhered to the outer resin surface by the inherent tack of the resin 6.

The scrim fibres may be patterned to enhance air removal. For example, the fibres may comprise two mutually inclined sets of parallel fibres defining diamond-shaped air paths which typically extend in directions that are inclined to the longitudinal direction of the prepreg, and inclined to the longitudinal direction of any unidirectional fibres in the prepreg. For example, the scrim fibres may be oriented at +45/-45 degrees or +60/-60 degrees to the longitudinal direction of the prepreg and/or of any such unidirectional fibres in the prepreg.

The prepregs of the present invention have particular application in the manufacture of carbon fibre or glass fibre spar caps as part of a male moulded spar, comprising a spar and a shear web assembly, for wind turbine blades manufactured using prepregs in typical known blade manufacturing techniques. Alternatively, carbon fibre or glass fibre

sparcaps may be formed as a discreet item, for example to be employed in combination with wind turbine blades manufactured using typical resin infusion. The prepregs of the present invention may also be used in other applications for the manufacture of thick section unidirectional fibre reinforced composite material laminates.

The prepreg of the present invention allows the production of low void content carbon fibre laminates in male moulded sparcaps. When using fully resin impregnated conventional prepreg with 100% fibre wetout by the resin in accordance with the prior art as discussed above, the use of a scrim on both major surfaces of the prepreg can provide an air path to reduce inter-ply voiding. It has been found by the present inventors that with elongate channels of dry fibre on one surface of the prepreg it is only necessary to use such a scrim on one surface of the prepreg, i.e. on the other side from the dry fibre channels, thus saving the cost of the additional scrim layer and reducing the manufacturing cost of the prepreg product.

Accordingly, by providing a controlled amount of dry fibre, in the form of elongate channels, on one surface of the prepreg it has been found that one scrim can be removed from the prepreg as compared to the double-scrim product and still achieve low void content laminates. In fact, even lower void contents can be achieved. The dry fibre channels provide additional breathing between plies, thus allowing the removal of one of the two scrims, and further enhanced air removal and consequently lower void contents. .

The prepreg structure can accommodate the fact that the vacuum consolidation of the multilayer stack of prepregs to form the elongate structural member can be carried out so as to require only a relatively short air path length, typically up to about 500 mm. This is because the elongate structural member typically has a maximum width of 1 metre, and air can be evacuated in a transverse direction in opposite directions extending from the longitudinal center of the elongate member.

When manufacturing a product in which the elongate structural member is integrally formed within other composite laminate sections of the product, such as a wind turbine blade where each unidirectional spar is surrounded by biaxial composite material, the evacuation of air is assisted by the stack of prepregs to form the elongate structural

member being surrounded, during the vacuum consolidation phase, by dry fibrous reinforcement. These dry fibres have high permeability and permit the transport of trapped gasses back to the vacuum source in a large composite moulding. Such dry fibrous reinforcement may be present in a semipreg, or in a product such as the applicant's SPRINT® material, which comprises as a discrete central resin layer with dry fibre outer surfaces.

When the prepregs are formed into a multi-laminar stack for forming a structural elongate member such as a spar, typically from 2 to 30 unidirectional prepreg layers are stacked to provide a thickness of uni-directional material. Depending on the spar design, multi-axial material is then added followed by repeat layers of the unidirectional prepreg, again another typically from 2 to 30 unidirectional prepreg layers are stacked to provide a further thickness of uni-directional material in the spar cap. This process can be repeated to give a final thickness in the ultimate spar cap from about 25 to 75 mm.

The aim is to maximise the amount of uni-directional material in the spar cap but to add the multi-axial fibres at strategic points to prevent the spar cap suffering a low transverse buckling resistance, provide sufficient shear transfer to the webs, and torsional rigidity, and to limit the thickness of uni-directional material to prevent shear cracking in the uni-directional (UD) stack. In general if glass fibre uni-directional pre-preg is used the thickness of the uni-directional elements is larger than if carbon uni-directional pre-preg is used.

In a particularly preferred embodiment in which a spar within a wind turbine blade is manufactured, containing glass uni-directional sections formed from typically about 10-25 prepreg layers stacked together to provide a uni-directional thickness of from 10 to 25 mm and a final spar cap thickness of 20 to 70mm. In another preferred embodiment in which a spar within a wind turbine blade is manufactured, the spar contains carbon uni-directional sections formed from typically about 6 to 30 prepreg layers stacked together to provide a uni-directional thickness of from 3 to 16mm and a final thickness of 20 to 60mm.

The present invention is further illustrated by the following non-limiting examples.

The prepreg of the following examples were all manufactured from 600gsm carbon fibre impregnated with the same di-functional diglycidyl ether bisphenol A (DEGBA) epoxy resin and dicy urea catalyst to give a resin content of 35wt% and a final cured thickness of 37-38mm. No de-bulking vacuum operations were carried out prior to starting the cure. The laminates were all cured with vacuum bag processing and the same two-stage cure cycle.

The first stage of the cure consisted of an 80 minute ramp to a temperature of 85-90°C followed by a dwell at this temperature for 130 minutes. The second stage of the cure consisted of a 60 minute second ramp to 115-120°C and hold for 2 hours to ensure the full cure of the prepreg material. The 5°C temperature difference corresponded to the natural temperature variation at points measured along the component due to the size of the component and the oven used.

Example 1

In this Example, a format of a single sided prepreg was manufactured, in which 100% of the resin was fully impregnated into the prepreg from one side to provide a fully impregnated prepreg with dry fibre longitudinally-extending channels in one surface of the prepreg as discussed above. A scrim was impressed onto the other side of the fully impregnated prepreg. A 6m long spar cap, 38mm thick and tapering from 700 to 500mm wide, was manufactured with this prepreg.

The spar cap was tested for voiding using ultrasound using a typical test protocol used by wind blade manufacturers. The surface of the spar was inspected using an ultrasound testing technique every 50mm and the degree of voiding at each point was quantified by a ranking from A-E, with ranking A representing large delaminations and ranking E representing low voiding. The general quality of the spar can then be described by the percentage mix of the different ultrasound rankings with the most desirable result to have the greatest percentage of D or E ranking relating to the lowest void content and no A or

B ratings which represent areas with high void levels which would have a high risk of early laminate failure.

The ultrasonic test method applies ultrasound to a plurality of points on a front surface of the resultant cured fibre reinforced resin composite material laminate, the points being identified by a grid extending over the surface area of the laminate. The echo of the ultrasound signal is measured, and the attenuation is correlated to the presence of voids, comprised of intra-laminar voids, or delamination, and inter-laminar voids, or porosity, according to a ranking as set out below in Table A. The ultrasound rankings in Table A were previously statistically related to the typical void content by destructive testing spar caps and measuring the void levels using an optical microscope technique. This permits direct comparison of void content of different laminate panels. The ranking uses a scale from A to E where A represents the highest void content level and E the lowest level of detectable voids. Level E in the ultrasound ranking represents very high quality laminates.

Table A

Ultrasound ranking	Backwall echo	Void content
A	0%	>4.5%
B	0-50%	2.5-4.5%
C	50-80%	1.5-2.5%
D	80-90%	<1.5%
E	90-100%	<1%

The results are summarised in Table 1.

Table 1

	Material	Scrim	Ultrasound ranking
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Example 1	Single side filmed – channels of dry fibres on one surface	1 scrim	1% C 99% D
Comparative Example 1	Double sided filmed – no dry fibres	2 scrims	2% C 98% D
Comparative Example 2	Double sided filmed– no dry fibres	1 scrim	2% B 39% C 59% D
Comparative Example 3	Single side filmed – dry fibres on one surface	0 scrim	20% A 33% B 42% C 5% D

It may be seen that the use of the dry fibre channels provided a 98% or 99% D void content rating.

Comparative Examples 1 and 2

In these Comparative Examples, the same fully impregnated prepreg was manufactured but using resin impregnation from both sides and no dry fibre longitudinally-extending channels were present. A scrim was impressed onto both prepreg sides, for Comparative Example 1, or onto one prepreg side, for Comparative Example 2, of the fully impregnated prepreg. Spars were manufactured with these prepreps, and the void content tested as for Examples 1 and 2.

It may be seen that the use of the two scrim layers but no dry fibre channels for Comparative Example 1 provided a 2% C and 98% D void content rating, worse than for Example 1. The provision of the combination of a single-surface scrim and dry fibre channels on the opposite surface of the prepreg in accordance with the present invention gave a better result than the use of two scrims on opposite sides of the prepreg, as disclosed in EP-A-1595689.

It may be seen that the use of only one scrim layers but no dry fibre channels for Comparative Example 2 provided a significantly worse 2%B/39%C/59%D void content rating than for Example 1.

Comparative Example 3

In Comparative Example 3, the same fully impregnated prepreg was manufactured but using resin impregnation from a single side and with dry fibre longitudinally-extending channels on one side. No scrim was present. A spar was manufactured with this preregs, and the void content tested as for Example 1.

It may be seen in Table 2 that without the scrim layer the dry fibre channels alone were insufficient to remove the air, resulting in large void areas.

Comparison of these results shows that the combination of a single-surface scrim and dry fibre channels of the prepreg in accordance with the present invention gave a synergistically better result than could be expected for the use of one or two scrim alone, or dry fibre channels alone.

Example 2 and Comparative Examples 4 and 5

In this Example and these Comparative Examples, a small scale panel 20 ply thick of the 600gsm 35wt% resin content prepreg, 600mm wide and 1 metre in length, was manufactured. Three of the four of the edges of the laminate were sealed to reduce the available air escape path to simulate the full scale manufacturing process of a spar. Each panel was made with a different prepreg format. The prepreg formats are defined in Table 2

Table 2

	Material	Scrim	Ultrasound ranking
Example 2	Double sided filmed – Single scrim on one side, dry fibre channels with 180mm pitch on other side	1 scrim	84% D 16% C

Comparative Example 4	Double sided filmed – No scrim, no dry fibre channels (Conventional prepreg)	No scrim	33% C 54% B 13% A
Comparative Example 5	Double sided filmed – Single scrim on one side, no dry fibre channels	1 scrim	48% D 52% C

It can be seen that the introduction of a scrim improves the ultrasound ranking from predominantly Bs and Cs with some As to all Cs and Ds. This improvement relates to a significant reduction in voiding quantity and size. The panel of Example 2 which exhibited the best ultrasound results had a single scrim and dry fibre channels at a 180mm pitch. This panel demonstrated 84% D ranking.

Examples 3 and 4

In these Examples, 6 metre long spar caps, 38mm thick and tapering from 700 to 500mm wide, were made with the 600g/m² unidirectional carbon fibre prepregs, all using the same epoxy resin matrix and 35wt% resin content, with a scrim on one side and dry fibre channels on the other side, the channels having a 4mm width. In Example 3 the spacing pitch was 40mm and in Example 4 the spacing pitch was 80mm.

Each spar was ultrasonically tested as before and the results are shown in Table 3.

Table 3

	Material	Scrim	Ultrasound ranking
Example 3	Double sided filmed – Scrim on one side, dry fibre channels on other side at 40 mm pitch	1 scrim	90% E 10% D
Example 4	Double sided filmed – Scrim on one side, dry fibre channels on other side at 80 mm pitch	1 scrim	100% E

The dry fibre channels result in a lower void content than achieved by a single side filmed prepreg without such channels. It also importantly demonstrated a significant

improvement over previously manufactured spars employing equivalent prepregs before the introduction of the dry fibre channels.

Claims

1. A prepreg for manufacturing a fibre-reinforced composite material, the prepreg comprising a layer of fibrous reinforcement having a plurality of dry fibre channels in a first major surface thereof and a portion of the layer of fibrous reinforcement which is fully impregnated by a matrix resin material, the portion being adjacent to the channels, and a scrim material covering at least one major surface of the layer of fibrous reinforcement and adhered to the matrix resin material, the scrim material being partly embedded in the matrix resin material.
2. A prepreg according to claim 1 wherein the scrim material covers a second major surface of the layer of fibrous reinforcement which is opposite to the first major surface.
3. A prepreg according to claim 1 wherein the scrim material covers the first major surface.
4. A prepreg according to claim 1 wherein a first scrim material covers the first major surface and a second scrim material covers a second major surface of the layer of fibrous reinforcement which is opposite to the first major surface.
5. A prepreg according to any foregoing claim wherein the layer of fibrous reinforcement is fully impregnated by the matrix resin material apart from at the plurality of dry fibre channels.
6. A prepreg according to any foregoing claim wherein the channels are parallel and extend in a longitudinal direction along the length of the prepreg.
7. A prepreg according to any foregoing claim wherein the layer of fibrous reinforcement is a unidirectional fibrous reinforcement extending in a longitudinal direction along the length of the prepreg.
8. A prepreg according to any foregoing claim wherein the channels have a width of from 2 to 20 mm.
9. A prepreg according to claim 8 wherein the channels have a width of from 3 to 10 mm.
10. A prepreg according to claim 8 or claim 9 wherein the channels have a spacing pitch between adjacent channels of from 20 to 200 mm.
11. A prepreg according to claim 10 wherein the channels have a spacing pitch between adjacent channels of from 30 to 160 mm.

12. A prepreg according to any foregoing claim wherein the channels have a depth which is up to 50% of the thickness of the fibrous reinforcement.
13. A prepreg according to claim 12 wherein the channels have a depth of from 0.1 to 0.75 mm.
14. A prepreg according to claim 13 wherein the channels have a depth of from 0.1 to 0.4 mm.
15. A prepreg according to any foregoing claim wherein there is a higher concentration of the matrix resin material at longitudinal boundaries of the plurality of dry fibre channels.
16. A prepreg according to any foregoing claim wherein the scrim material comprises fibres and greater than 50% of the fibre diameter is exposed above the matrix resin material.
17. A prepreg according to claim 16 wherein the scrim material comprises a woven or non-woven scrim material.
18. A prepreg according to claim 17 wherein the scrim material is of polyester.
19. A method of producing a prepreg for manufacturing a fibre-reinforced composite material, the method comprising the steps of:
 - (a) providing a layer of fibrous reinforcement;
 - (b) forming a plurality of substantially resin-free lines in a first film of resin material;
 - (c) applying the first film of resin material to a first major surface of the layer of fibrous reinforcement;
 - (d) impregnating the first film of resin material into the layer of fibrous reinforcement to form a plurality of dry fibre channels in the first major surface, the dry fibre channels corresponding to the substantially resin-free lines, the dry fibre channels having a portion of the layer of fibrous reinforcement adjacent thereto which is fully impregnated by the resin; and
 - (e) applying a scrim material to at least one major surface of the layer of fibrous reinforcement, the scrim being adhered to and partly embedded in the resin material.

20. A method according to claim 19 wherein the scrim material is applied to cover a second major surface of the layer of fibrous reinforcement which is opposite to the first major surface.
21. A method according to claim 19 wherein the scrim material is applied to cover the first major surface.
22. A method according to claim 19 wherein a first scrim material is applied to cover the first major surface and a second scrim material is applied to cover a second major surface of the layer of fibrous reinforcement which is opposite to the first major surface.
23. A method according to any one of claims 19 to 22 wherein in forming step (b) a plurality of scraper elements are pushed through the resin film to form the substantially resin-free lines on the first major surface.
24. A method according to claim 23 wherein in forming step (b) the pushing action of the plurality of scraper elements forms elongate longitudinal borders of additional resin at the elongate boundaries of the resin-free lines.
25. A method according to claim 24 wherein the impregnating step (d) forms a higher concentration of the resin material at longitudinal boundaries of the plurality of dry fibre channels.
26. A method according to any one of claims 19 to 25 wherein the impregnating step (d) causes full impregnation of the layer of fibrous reinforcement by the resin material apart from at the plurality of dry fibre channels.
27. A method according to claim 26 further comprising, before impregnating step (d), applying a second film of resin material to the second major surface of the layer of fibrous reinforcement, so that in the impregnating step (d) the first and second films of resin material fully impregnate the layer of fibrous reinforcement sandwiched therebetween.
28. A method according to any one of claims 19 to 27 wherein the channels are parallel and extend in a longitudinal direction along the length of the prepreg.
29. A method according to any one of claims 19 to 28 wherein the layer of fibrous reinforcement is a unidirectional fibrous reinforcement extending in a longitudinal direction along the length of the prepreg.

30. A method according to any one of claims 19 to 29 wherein the channels have a width of from 2 to 20 mm.
31. A method according to claim 30 wherein the channels have a width of from 3 to 10 mm.
32. A method according to claim 30 or claim 31 wherein the channels have a spacing pitch between adjacent channels of from 20 to 200 mm.
33. A method according to claim 32 wherein the channels have a spacing pitch between adjacent channels of from 30 to 160 mm.
34. A method according to any one of claims 19 to 33 wherein the channels have a depth which is up to 50% of the thickness of the fibrous reinforcement.
35. A method according to claim 34 wherein the channels have a depth of from 0.1 to 0.75 mm.
36. A method according to claim 35 wherein the channels have a depth of from 0.1 to 0.4 mm.
37. A method according to any one of claims 19 to 36 wherein the scrim material comprises fibres and in step (e) the scrim material is partly embedded in the resin material so that greater than 50% of the fibre diameter is exposed above the resin material.
38. A method of manufacturing an elongate structural member of fibre-reinforced composite material, the method comprising the steps of:
 - (a) providing a plurality of prepregs according to any one of claims 1 to 18 or produced according to the method of any one of claims 19 to 37;
 - (b) assembling the plurality of prepregs as an elongate stack thereof;
 - (c) subjecting the stack to a vacuum to consolidate the stack and remove air from between the adjacent prepregs of the stack; and
 - (d) curing the matrix resin material to form the elongate structural member.
39. Use of a prepreg according to any one of claims 1 to 18 or produced according to the method of any one of claims 19 to 37 for manufacturing an elongate structural member of fibre-reinforced composite material.
40. Use according to claim 39 wherein the elongate structural member of fibre-reinforced composite material is a spar or beam.

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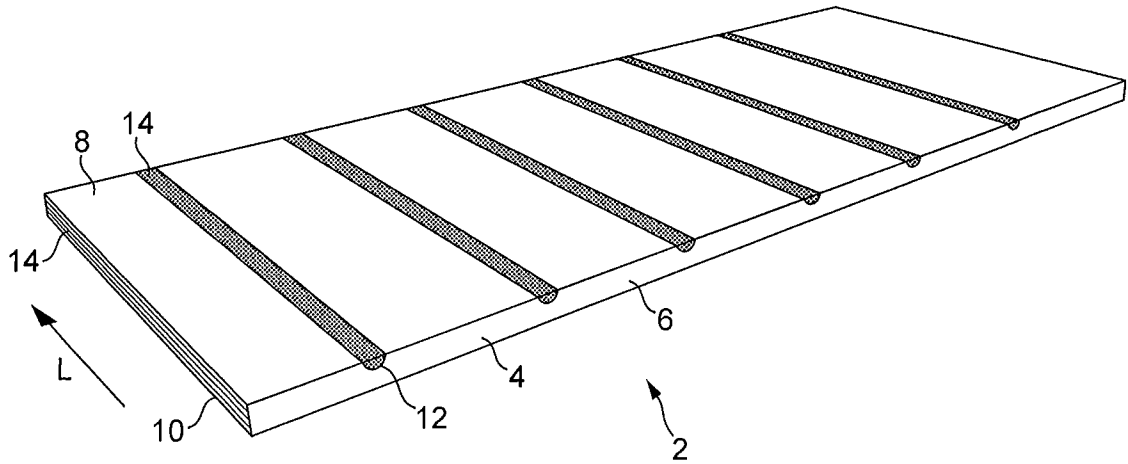


FIG. 1

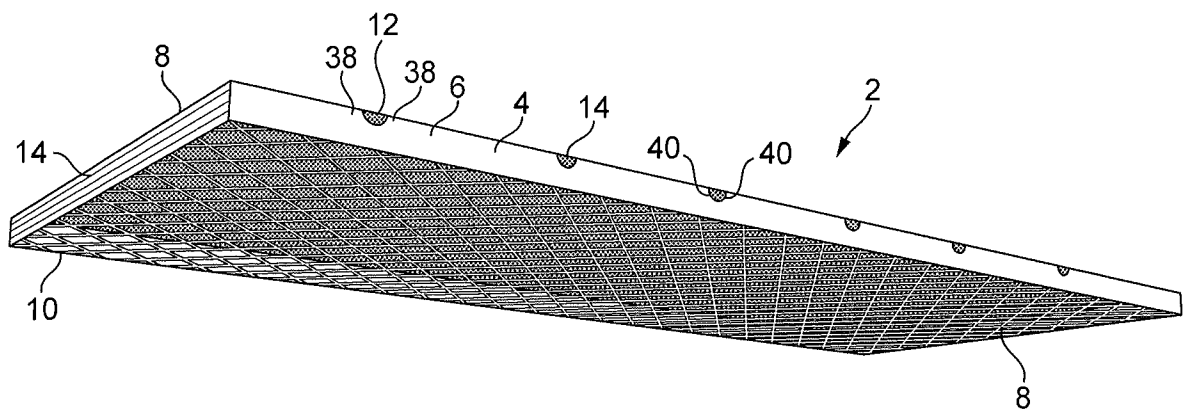
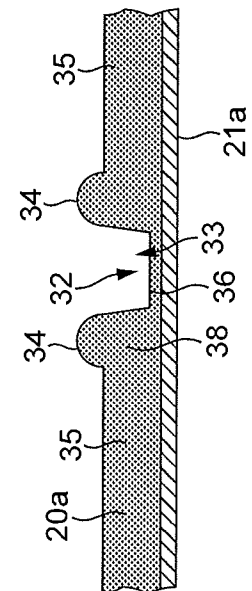
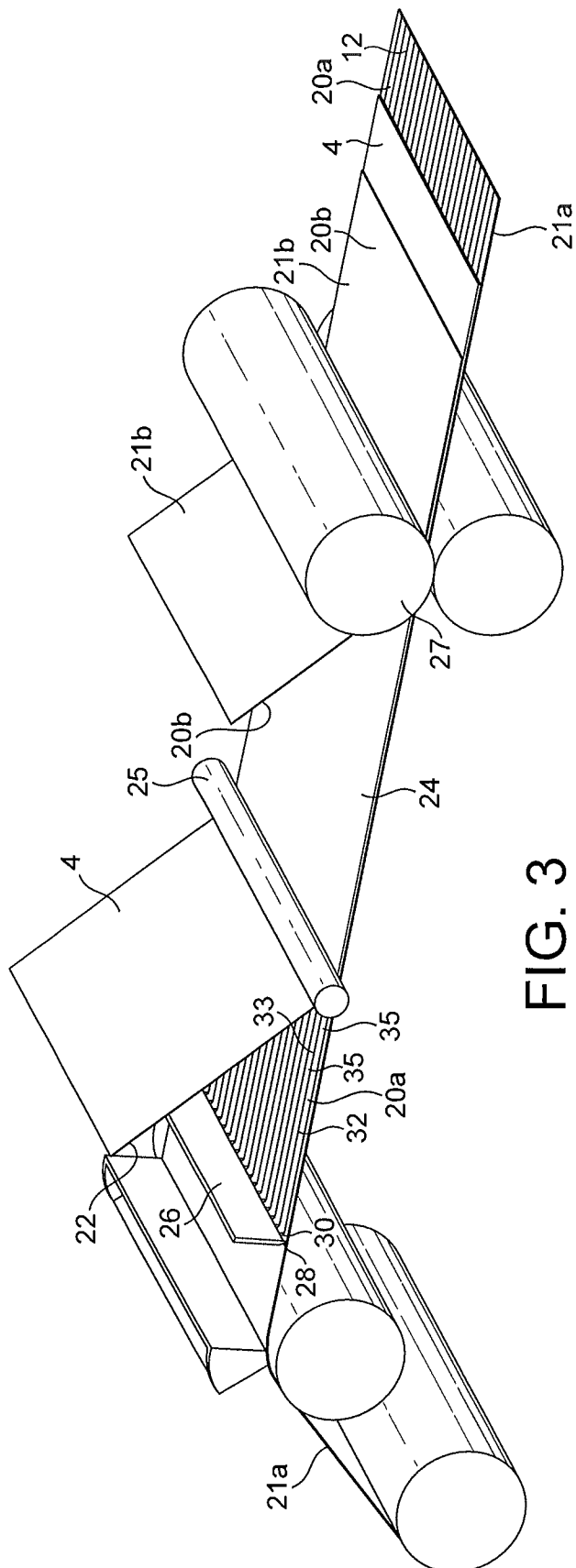


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/066936

A. CLASSIFICATION OF SUBJECT MATTER
INV. C08J5/24
ADD.

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)
C08J

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, CHEM ABS Data, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 02/090089 A1 (STRUCTURAL POLYMER SYSTEMS LTD [GB]; JONES DANIEL THOMAS [GB]) 14 November 2002 (2002-11-14) abstract page 10, line 17 - line 28	1-40
A	----- AU 2005 232 257 A1 (STRUCTURAL POLYMER SYSTEMS LTD GURIT UK LTD) 8 December 2005 (2005-12-08) claims	1-40
A	----- US 5 104 718 A (ASADA SHIRO [JP] ET AL) 14 April 1992 (1992-04-14) abstract -----	1-40



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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