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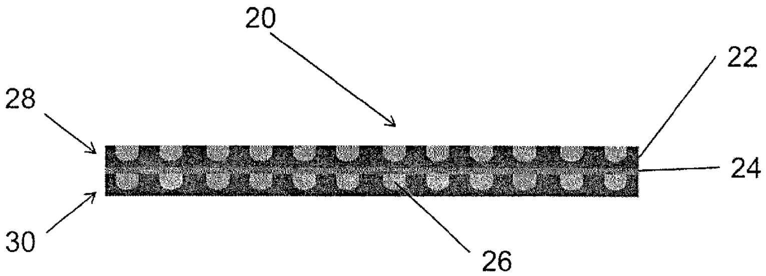

Figure 10

(57) Abstract: A laminated structure comprising a plurality of layers of fibre reinforced thermoset resin in which the layers are selected from two or more of the following i) a first moulding material comprising a layer of curable resin and a fibrous material on at least one side of the curable resin matrix, said moulding material further comprising a further fibrous layer adhered to the fibrous reinforcement material; ii) a second moulding material comprising a fibrous material comprising two cross bonded fibrous plies, each ply comprising fibre tows oriented at differing angles, the fibrous material further comprising a curable resin matrix; iii) a third moulding material comprising at least two reinforcement layers having unidirectional fibre tows and a curable resin matrix bonding the layers together; iv) a fourth moulding material comprising a layer of fibrous reinforcement and a curable liquid resin wherein the fibrous reinforcement comprises a plurality of tows each tow comprising a plurality of filaments wherein resin is provided at least partially between interstices between tows of the fibrous reinforcement to provide an air venting path in at least the interior of the tows; and v) a resin impregnated fibrous layer.

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IMPROVEMENTS IN OR RELATING TO FIBRE REINFORCED COMPOSITES

The present invention relates to fibre reinforced composite materials comprising fibrous reinforcement material and resin material, particularly but not exclusively to resin impregnated or preimpregnated composite materials or prepregs. The invention is concerned with such materials which can be used in the manufacture of wind turbine blades and the components from which the blades are manufactured as well as the wind turbine blades themselves.

Conventionally, composite parts are manufactured by stacking layers of a fibrous reinforcement material which is preimpregnated with a curable resin material (known as a prepreg). Subsequently, the resin material is cured by heating the stack whilst it is being compressed. This causes the resin to flow to consolidate the fibrous stack, and then to subsequently cure. This results in an integral laminar composite structure. Composite laminar structures are strong and light-weight; their use is well known and they are frequently used in industrial applications such as automotive, aerospace and marine applications. These structures are widely used in wind energy applications such as wind turbine blades, and in particular the outer shells of the blades, the internal spars, the root ends of the spars and the hub of the turbine to which the blades are attached.

According to the invention, there is provided a structure, a blade, a part, and a moulding material as defined in any one of the accompanying claims.

In particular the present invention relates to materials useful in making components and to the use of such materials for the manufacture of wind turbine parts particularly the spar and shell of a wind turbine blade.

Wind turbine blades may be constructed in two principle pieces, a load bearing spar which extends along the interior of the blade which has a root that is attached to the hub of the wind turbine and extends, usually in a tapered fashion to a tip close to or at the end of the blade. The spar can be of any convenient shape, an I beam being particularly useful. The spar is typically of rectangular cross section and can comprise 2 halves firmly attached to each other. A shell is mounted around the spar to provide the surfaces that are exposed to the wind and the shell is aerodynamically shaped appropriately to gain maximum interaction with the wind. The shell is usually bonded to the spar and may also be in two halves that are joined together to provide the finished blade. The vertical pillar upon which the blades are mounted is provided with a hub to which each of the blades is attached by the root of the spar.

The blades, both the shell and the spar may be manufactured in sections for assembly on site. The sections may be made so that they force fit together. This enables manufacture and transport of smaller sections for assembly of the large blades on site.

Wind turbine blades are increasing in size particularly in length, the lengths of some blades now exceeds 50 metres and in some instance exceeds 70 metres. This increase in length requires greater strength which requires thicker blades made from larger stacks of multiple layers of composite fibre and resin reinforcement, it is preferred that the thickness be accomplished by increasing the number of layers rather than increasing the thickness of the individual layers. However as the number of layers increases it is increasingly difficult to get the desired surface finish and homogeneity throughout the thickness and along the length of the blade. Conventionally, resin preimpregnated fibrous reinforcement (prepreg) is laid up in a mould to form these stacks. Alternatively, dry fibre layers are laid up in a mould and these are subsequently infused with a curable resin matrix using a vacuum assisted resin transfer moulding process (VARTM).

It is known in the art that bent fibres, linear distortion, wrinkles or humps of fibres in a fibre-reinforced composite material greatly degrade the mechanical properties particularly the strength and E-modulus, of the ultimate composite structure. Manufacturing of composites with highly aligned fibres is therefore very desirable. Particularly in VARTM lay-ups containing dry fibre layers, maintaining fibre alignment during both lay-up and processing is a problem.

Various methods have been proposed for the provision of prepreg moulding materials that may be used in the manufacture of wind turbine blades. One process is the infusion process previously described in which the prepreg is prepared by dry lay-up of reinforcing fibres such as glass fibre, or carbon fibre. This is not however a satisfactory technique for use across the entire width of the shell or spar of a wind turbine blade of extended length. Alternatively it has been suggested that cured laminates may be interleafed with prepregs which may be wet or dry and the stack cured to produce the final blade. Another technique that has been proposed is to lay-up a permeable non woven fabric in conjunction with prepregs to enable air to be removed from the system during lay-up and prior to curing. The non woven fabric may be in the form of a fleece. Preferably the fleece has a weight in the range of from 20 to 100 gsm, preferably from 40 to 60 gsm. Here again this use of a single material across the width of the shell or spar has not been satisfactory. As the length of wind turbine blades increases we have found that no one material and no one material manufacturing process is optimum for the production of the whole blade.

We have now found that shells having an improved surface aerodynamic finish and components with improved homogeneity and reduced void formation may be achieved by use of different prepreg materials across the width of wind turbine components such as the shell, spar and hub.

This invention is therefore concerned with various materials that may be used in various parts of the blade including the spar, the shell and the hub. Additionally it is concerned with spars, shells and hubs made from two or more of such materials. Additionally the invention provides a collection of components produced from those materials that may be assembled to produce a blade comprising the shell, perhaps in two parts, the spar perhaps in two parts and optionally the hub.

The invention therefore provides the following materials suitable for use in the manufacture of wind turbine blades particularly the spar and shell of wind turbine blades.

First moulding material

In a first embodiment the invention provides a first moulding material comprising a layer of curable resin and a fibrous material on at least one side of the curable resin matrix, said moulding material further comprising a further fibrous layer adhered to the fibrous reinforcement material.

In a preferred embodiment the fibrous reinforcement is impregnated from one side of the material and the further fibrous layer is adhered to the opposite side of the fibrous reinforcement material. The use of a further fibrous layer comprising a non-woven fibrous material having an area weight ranging from 5 to 50 g/m^2, preferably from 5 to 20 g/m^2 (gsm) is particularly suitable.

The non-woven material may be in the form of a scrim or web which is preferably wide-meshed and which may be made of any suitable material, but thermoplastic yarns are preferred. The key requirement of the yarn material is that it has a melting point similar to or higher than the prepreg gelling temperature so that the scrim yarns do not melt during the curing process. Preferably, the difference between yarn melt point and the matrix gelling point should be at least 10 ^{0}C. Suitable materials for the scrim include polyester (76 – 1100 dtex) such as polyethylene terephthalate and polybutylene terephthalate and copolymers thereof, polyamide (110-700 dtex) such as nylon 6, nylon 66, nylon 11, and nylon 12, polyethersulphone, polypropylene, viscose staple yarn (143 – 1000 dtex), meta and para-amid (Kevlar 29 220-1100 dtex) and Nomex T-430 220-1300 dtex, glass 220-1360 dtex), jute (2000 dtex), flax (250-500 dtex), cotton (200-500 dtex) and combinations of one or more of these. Such material is available under the Bafatex tradename from Bellingroth GmbH.

Additionally it is preferred that the fibrous reinforcement material comprises fibre tows comprising filaments having an average diameter in the range of from 1 to 20 μm, preferably from 10 to 15 μm and has a fibre volume fraction (FVF) in the range of from 15 to 70% by volume of the tows, from 18 to 68% by volume of the tows, from 20 to 65 % by volume of the tows, from 25 to 60% by volume of the tows, from 25 to 55% by volume of the tows, from 25 to 50% by volume of the tows, from 25 to 45% by volume of the tows, from 25 to 40% by volume of the tows, from 25 to 35% by volume of the tows, from 25 to 30% by volume of the tows, from 30 to 55% by volume of the tows, from 35 to 50% by volume of the tows and/or combinations of the aforesaid ranges.

Second moulding material

In a second embodiment the invention provides a second moulding material comprising a fibrous material comprising two cross bonded fibrous plies, each ply comprising fibre tows oriented at differing angles, the fibrous material further comprising a curable resin matrix. An example of such a suitable material is the product available from Hexcel HexPly® M 9.6 GF/38%/BB 600 which is a biaxial woven glass fibre BB600 impregnated with 38 wt % of the epoxy resin M 9.6 GF.

In a preferred embodiment the plies are electrically conductive typically by the inclusion within the plies of carbon fibre such plies being sacrificial upon being struck by lightning.

Third moulding material

A third embodiment of this invention comprises a third moulding material comprising at least two reinforcement layers having unidirectional fibre tows and a curable resin matrix bonding the layers together. An example of such a suitable material is the product available from Hexcel as Hexfit. The material contains 34 wt % epoxy resin.

Fourth moulding material

In a fourth embodiment, there is provided a fourth moulding material or structure comprising a layer of fibrous reinforcement and a curable liquid resin wherein the fibrous reinforcement comprises a plurality of tows each tow comprising a plurality of filaments wherein resin is provided at least partially between interstices between tows of the fibrous reinforcement to provide an air venting path in at least the interior of the tows. The interior of the tows is at least partially resin free to provide an air venting path to allow air to be removed during processing of the material or structure.

Fifth moulding material

In a fifth embodiment there is provided a fifth moulding material comprising a unidirectional press cured laminate such as the product available from Hexcel named PolySpeed®. A preferred cured laminate may be Polyspeed® GR 120 which is a press cured laminate containing unidirectional fibre particularly 2400 tex glass fibre of average weight about 1200 grams per square metre and containing from 25 to 30 wt % epoxy resin.

The cured laminate may comprise one or more chamfered end portions.

In another embodiment, there is provided a fifth moulding material in the form of a unidirectional laminate wherein the laminate comprises unidirectional fibres in a cured resin matrix and dry fibre areas, preferably in a longitudinal or warp direction. The laminate may comprise partially impregnated areas in a warp direction. We have discovered that these dry or impregnated areas improve the drapability of the laminate in moulds of a complex shape. Also they improve the venting of any entrapped gases during processing and curing and they improve the bond between the laminate and materials surrounding it in the lay-up. The laminate may be a press cured or pultruded laminate.

In a further embodiment, there is provided a fifth moulding material in the form of a unidirectional laminate wherein the laminate comprises unidirectional fibres in a cured resin matrix and longitudinal gaps extending in the longitudinal or warp direction. We have discovered that these gaps improve the drapability of the laminate in moulds of a complex shape. The laminate may be a press cured or pultruded laminate.

In another embodiment, there is provided a fifth moulding material in the form of multiple cured laminate layers co-bonded by dry reinforcement and/or stitching and/or prepreg material. The cured laminate layers may be in the form of a laminate comprising unidirectional fibres in a cured resin matrix and dry fibre areas, preferably in a longitudinal or warp direction. The laminate may comprise partially impregnated areas in a warp direction.

The laminate comprises unidirectional fibres in a cured resin matrix and dry fibre areas, preferably in a longitudinal or warp direction. The laminate may comprise partially impregnated areas in a warp direction. The laminate may also comprise unidirectional fibres in a cured resin matrix and longitudinal gaps extending in the longitudinal or warp direction. The laminate may be a press cured or pultruded laminate.

In yet another embodiment, there is provided a fifth moulding material in the form of a unidirectional laminate wherein the laminate comprises fibrous reinforcement in the form of unidirectional carbon fibres and a fabric on one or both sides of the carbon fibres, the fabric being stitched thereto, said fibrous reinforcement being impregnated with resin and cured. The fabric may comprise fibres in the warp direction and fibres in a weft direction, said weft direction being at 90° or at an angle between 30° to 85°, preferably between 60° to 80°. The fabric may be non-woven. The fabric may comprise a glassfiber.

In a further embodiment, there is provided a fifth moulding material comprising a cured resin impregnated fibrous reinforcement layer having bonded thereto a further reinforcement layer, said further reinforcement layer comprising a dry (unimpregnated) fibrous reinforcement material and/or an uncured resin impregnated reinforcement layer. The further reinforcement layer may extend beyond the cured resin impregnated fibrous reinforcement layer.
With respect to the aforesaid embodiments of the fifth moulding material, we have discovered that these dry or impregnated areas improve the drapability of the laminate in moulds of a complex shape. Also they improve the venting of any entrapped gases during processing and curing and they improve the bond between the laminate and materials surrounding it in the lay-up.

We have found that an additional benefit of this invention is that the surface defects may be reduced or eliminated by the inclusion of one or more layers of the fifth moulding material. This also has the advantage of reducing the release of exotherm heat during curing of the layup thereby reducing the overall cure time, as this enables the layup to be cured at a higher temperature in comparison to a layup in which the cured layers are substituted by equivalent uncured layers.

In a sixth embodiment the material is a conventional fibre reinforced prepreg such as carbon or glass fibres enclosed in a matrix of thermohardenable material particularly an epoxy resin.

The invention is therefore also concerned with the use of combinations of two or more of these materials in the manufacture of components used in wind turbine blades such as the shell, spar and hub of the blade. The materials may further be combined or integrated in a lay-up of dry reinforcement which is subsequently infused with an infusion resin, such as Prime 20 as supplied by Gurit.

The selection of the combination of materials to be used in the production of the components of wind turbine blades is determined by the properties required and also the economics with glass fibre reinforcement generally being cheaper than carbon fibre reinforcement. Carbon fibre on the other hand provides increased strength at reduced weight. We have however found that the inclusion of one or more layers of a product according to the first embodiment in a stack comprising a plurality of layers of carbon fibre based prepregs such as a product according to the third embodiment results in a more uniform surface finish and also a more uniform and less porous structure upon curing which contains fewer voids and has increased strength. Additionally we have found that inclusion of one or more layers of a product of the fifth embodiment such as PolySpeed® GR 120 to a stack consisting of a plurality of layers of the product UD 600 optionally including one or more layers of a product of the third embodiment such as HexFIT® 2000 also improves surface finish, reduces porosity and voids and enhances the strength of the wind turbine blade component.

In a preferred embodiment the layers of products such as HextFit® 2000 and PolySpeed® GR 120 are provided at substantially regular intervals throughout the stack of prepregs. Intermediary layers making up from 10% to 30% preferably 15% to 25% of the total number of layers is particularly suitable.

In some instances it may be necessary to include additional materials in the components of the invention. For example transverse wires or carbon tows for increasing electrical conductivity may be required.

In another aspect of the invention, the moulding material or structure also contains tows of fibrous reinforcement material which provide air venting paths. The tows are structural or reinforcement fibres so in effect, as they serve multiple purposes: on the one hand they provide air venting paths, and on the other hand, they provide structural reinforcement. In this material the intersticial resin ensures that the material has adequate structure at room temperature to allow handling of the material. This is achieved because at room temperature (23°C), the resin has a relatively high viscosity, typically in the range of from 1000 to 100,000 Pa.s, more typically in the range of from 5000 Pa.s to 500,000 Pa.s.

Also, the resin may be tacky. Tack is a measure of the adhesion of a prepreg to a tool surface or to other prepreg plies in an assembly. Tack may be measured in relation to the resin itself or in relation to the prepreg in accordance with the method as disclosed in “Experimental analysis of prepreg tack”, Dubois et al, (LaMI)UBP/IFMA, 5 March 2009. This publication discloses that tack can be measured objectively and repeatably by using the equipment as described therein and by measuring the maximum debonding force for a probe which is brought in contact with the resin or prepreg at an initial pressure of 30N at a constant temperature of 30°C and which is subsequently displaced at a rate of 5 mm/min. For these probe contact parameters, the tack F/F_{ref} for the resin is in the range of from 0.1 to 0.6 where F_{ref} = 28.19N and F is the maximum debonding force. For a prepreg, the tack F/F_{ref} is in the range of from 0.1 to 0.45 for F/F_{ref} where F_{ref} = 28.19N and F is the maximum debonding force. However, a fibrous support web, grid or scrim may also be located on at least one exterior surface of the fibrous reinforcement to further enhance the integrity of the material or structure during storage and processing.

In a further embodiment, the material or structure may also comprise unimpregnated tows and/or at least partially impregnated tows. Preferably the reinforcement comprises unimpregnated tows (“dry tows”) and completely impregnated tows. The layer of fibrous reinforcement comprises air venting tows at least partially embedded in at least partially impregnated fibrous reinforcement. The partially impregnated fibrous reinforcement may be a unidirectional reinforcement or a woven fibrous reinforcement or a non woven fibrous reinforcement.

One or more of the two or more separate layers of fibrous reinforcement may be impregnated with resin and other layers may be unimpregnated or substantially unimpregnated, the layers being conjoined so that resin is present between the interstices of the tows. Preferably the layers are conjoined so that the unimpregnated or substantially unimpregnated tows are at least partially embedded among impregnated tows. The layers may comprise unidirectional tows, the tows of each layer being substantially parallel. The two layers may be conjoined by compression so that the unidirectional tows are all in the same plane or substantially in the same plane. One or more additional fibrous layers may also be combined with the conjoined layers.

A non-woven material may be present on a surface of the resin impregnated fibrous reinforcement. The non-woven material may be held in place by the tack of the resin. The non-woven material is thus lar

In a further aspect impregnated and unimpregnated tows may be co-located to form a single plane of fibrous reinforcement. The longitudinal axes of the impregnated and unimpregnated tows in a layer or sheet of the fibrous reinforcement may be parallel to one another and their axes may all be located in a single plane.

In a further embodiment, the material or structure may comprise conjoined layers of impregnated and unimpregnated tows, the longitudinal axes of the impregnated and impregnated tows being located in the same plane.

We have found that if two or more of the various materials of this invention are used together optionally with other materials described herein to form various parts of the wind turbine blade, blades of improved surface finish, strength and homogeneity can be obtained. Accordingly the invention also provides sections of wind turbine blades or parts thereof manufactured from two or more materials of the invention. Accordingly in a further embodiment the invention provides a wind turbine blade or part thereof comprising a first section and a section section across the width of the component wherein the sections comprise different moulding materials of the invention.

It is preferred that the second section of the blade comprises a moulding material which may comprise a material comprising a reinforcement layer having unidirectional fibre tows and a curable resin matrix impregnating said reinforcement layer from one side. The reinforcement layer may comprise a permeable thermoplastic layer on the opposite side from which the layer is impregnated, in this way air can be removed during lay-up and curing so reducing void formation in the component.

In yet a further embodiment the wind turbine blade or part, comprising first and second sections may contain additional sections which can comprise further moulding materials of the invention.

The invention further provides a kit of parts for manufacturing a wind turbine blade or part thereof comprising any of the moulding materials of this invention. The kit may comprise various shorter sections that can be assembled on site into the finished blade.

The resin material used in all the materials of the present invention is a thermosetting resin such as an epoxy resin or a polyurethane resin, epoxy resins being preferred. The selection of the resin material depends on the application and use of the laminate. It is preferred that the resin in all materials is an epoxy resin and the resins in each material used to produce a single component should cure under the same curing conditions. Also, the reinforcement material present in the materials can be selected from a range of suitable fibres, commonly these comprise carbon, aramid, basalt or glass fibres. The fibrous material may be provided in woven or non-woven form. In preferred systems of the invention the different sections across the thickness of the component may contain different fibre reinforcement and the differences may be the nature of the fibre, the orientation of the fibre, whether the fibrous layer is woven or unwoven.

Woven fabrics may be used in this invention and they generally contain both warp tows in the lengthwise direction of the fabric and weft fibre tows in the transverse direction of the fabric. The tows consist of multiple fibre elements called filaments which together form the tow. The warp tows and weft tows may contain the same material and be of the same weight, or they may contain different materials and/or weights. The warp and weft tows may be arranged at an angle relative to one another which may range from +/-10° to +/- 90°. Some woven fabrics contain a relatively low number of warp tows. This provides the fabric with sufficient stability to allow the weft tows to be skewed in relation to the lengthwise direction. This is achieved by applying tension to one side of the fabric whilst retaining the fabric at the opposite side. This is, for example, disclosed in EP 1880819. Typically fabrics of this nature possess 70-90% weft fibres and 30-10% stabilising warp fibres. Skewed fabrics have the disadvantage that the presence of the weft fibre tows introduces crimps into the warp fibre tows. In turn, this affects the mechanical performance of composite parts which are produced from these materials. Furthermore, the woven fibres cause small deviations on the otherwise flat surface of the fabric, these deviations act as sites for trapping air when resin is applied to form a prepreg, the trapped air then become voids in the final laminate further reducing mechanical properties.

Non-woven fabrics range from fabrics which contain fibre elements in random directions such as chopped strand fabrics, to fabrics which contain tows in a regular, substantially parallel direction. Within this application we shall refer to the latter fabrics as “oriented reinforcement fabrics” which are preferred in the materials of the present invention.

An important advantage of oriented reinforcement fabrics as opposed to the aforesaid woven fabrics is that the fibre tows are not affected by crimp and the resulting composite structure therefore has improved mechanical performance.

In some aspects of the invention the material used can be partially or fully cured fibre-reinforced sheet material such as PolySpeed® GR 120 previously described which allows for very high fibre content and highly aligned fibres in the sheets. Furthermore, the fact that the sheet is cured facilitates transportation of the sheets, as no special conditions, such as temperature range or humidity range, are required. In addition, the combination of the sheet shape with the cured state facilitates adjustment of the sheets to the shape of the mould without compromising the alignment, or in other words the straightness, of the fibres in the lay-up forming the composite member or part. This is particularly important to complex shapes such as the airfoil (shell) of a wind turbine blade, where the desired fibre distribution is a complicated three-dimensional shape.

Elements of a desired shape may be cut from the sheet material to facilitate a particular lay-up to form a composite member or part.

In the manufacture of the components of the wind turbine blade at least some of the elements of cured fibre-reinforced sheet material may be positioned as partially overlapping plies so that a number of substantially parallel element edges are provided. This allows for positioning of the elements very close to the surface of the mould, and by adjusting the overlapping area between elements, almost any desired overall distribution of reinforcing fibres may be realised. Particularly, the elements may be positioned in a cross section of the shell of a wind turbine blade so that the fibres substantially resemble the distribution of water in a lake having a depth profile corresponding to the distance from the centreline of the blade to the surface of the cross section. In a particularly preferred embodiment, the substantially parallel element edges are edges, which are substantially parallel to the length of the elements of cured fibre-reinforced sheet material. This leads to a relatively short resin introduction distance and hence easier manufacturing and greater reproducibility. The cured fibre-reinforced sheet material may be positioned near the outer surface of the blade as partially overlapping tiles. The cured fibre-reinforced sheet material is pultruded or band pressed cured fibre- reinforced sheet material and has been divided into elements of cured fibre-reinforced sheet material.

The cured element may comprise one or more chamfered end portions to facilitate the joining of the elements.

In another embodiment, a wind turbine blade according to the invention has a length of at least 40 m. The ratio of thickness, t, to chord, C, (t / C) is generally substantially constant for airfoil sections in the range between $75\% < r / R < 95\%$, where r is the distance from the blade root and R is the total length of the blade. Preferably the constant thickness to chord is realised in the range of $70\% < r / R < 95\%$, and more preferably for the range of $66\% < r / R < 95\%$. This may be realised for a wind turbine blade according to the invention due to the very dense packing of the fibres in areas of the cross section of the blade, which areas provide a high moment of inertia. Therefore, it is possible according to the invention to achieve the same moment of inertia with less reinforcement material and/or to achieve the same moment of inertia with a more slim profile. This is desirable to save material and to allow for an airfoil design according to aerodynamic requirements rather than according to structural requirements.

The cured moulding material that constitutes the turbine blade or component thereof may comprise structural fibres at a level of from 45% to 75% by volume (fibre volume fraction), preferably from 55% to 70% by volume, more preferably from 58% to 65% by volume (DIN EN 2564 A). The moulding material may comprise 10% - 60% of resin by weight of the moulding material, preferably from 20% to 50% by weight, more preferably 30% to 40% by weight, and most preferably 35% by weight.

A moulding material may be formed with the fibrous reinforcement material having an overall areal weight of substantially 600 gsm. The fibrous reinforcement may comprise two fabric layers with tows arranged at substantially +30° or -30° or +45° or -45° in each layer. The individual fabric layers may each have an areal weight of substantially 300 gsm. The individual fabric layers may include a support layer of 10 gsm areal weight. This fabric may be combined with a resin, an example of which may be M9.6 resin as supplied by Hexcel. The resin may be combined with the fibrous reinforcement to comprise 35% by weight of the moulding material, for example.

The elements of cured fibre-reinforced sheet material may be provided along a shorter or a longer fraction of the length of the shell of the blade. However, it is typically preferred that the elements are positioned along at least 75% of the length of the wind turbine blade shell member, and in many cases it is more preferred that the cured fibre-reinforced sheet material is positioned along at least 90% of the length of the shell of the blade.

The materials of this invention are relatively flat usually having a length, which is at least ten times the width, and a width, which is at least 5 times the thickness of the sheet material. Typically, the length is 20 - 50 times the width or more and the width is 20 to 100 times the thickness or more. In a preferred embodiment, the shape of the sheet material is band-like.

It is preferred that the fibre-reinforced sheet materials are dimensioned such that they are coilable. By coilable is meant that the sheet material may be coiled onto a roll having a diameter that allows for transportation in standard size containers. This greatly reduces the manufacturing cost of the composite member, as endless coils of the cured fibre-reinforced sheet material may be manufactured at a centralised facility and shipped to the blade manufacturing site, where it may be divided into elements of suitable size. To further enhance shipping, it is preferred that the thickness of the fibre-reinforced sheet material is chosen so that the cured fibre-reinforced sheet material may be coiled onto a roll with a diameter of less than 2 m based on the flexibility, stiffness, fibre type and fibre content utilised. Typically, this corresponds to a thickness up to 3.0 mm, however, for high fibre contents and stiffness, a thickness below 2.5 mm is usually more suitable On the other hand, the thick sheet materials provide for rather large steps at the outer surface, which favours the thinner sheet materials. However, the sheet materials should typically not be thinner than 0.5 mm as a large number of sheets then would be needed leading to increased manufacturing time. In a preferred embodiment, the thickness of the cured fibre-reinforced sheet material is about 1.5 to 2 mm.

The cured fibre-reinforced sheet material that may be used as a layer of the composite may have the following properties (refers to measurement standard):

Fibre volume fraction (%)	57 to 60;
Tensile strength(ISO527-5) (MPa)	1600 to 2000;
Tensile modulus (ISO527-5) (GPa)	120 to 150;
Tensile elongation (ISO527-5) (%)	1.20 to 1.33
Flexural strength (ISO527-5) (MPa)	2100 to 2200;
Flexural modulus (EN2562) (GPa)	120 to 150;
Interlaminar shear strength (EN2563) (MPa)	90 to 100;
Compression strength (ASTM D6641) (MPa)	1200 to 1300;
Compression modulus (ASTM D6641) (GPa)	120 to 130;
Elongation (ASTM D6641)(%)	0.99

The fibre volume fraction is the volume of the sheet material that is occupied by the fibres. The sheet may have an area weight in the range of from 2000 to 4000 g/m^2, preferably from 2200 to 2800 g/m^2, more preferably 1500 g/m^2. The Tg of the resin matrix may be 100 to 150°C, preferably 110 to 140°C, more preferably 110 to 130°C

Where a cured fibre reinforced layer is employed the surface of the layer may be modified by sandblasting and the like, the surface texture may in addition to this or as an alternative comprise recesses, such as channels into the main surface of the cured fibre-reinforced sheet material, preferably the recesses are in the order of 0.1 mm to 0.5 mm below the main surface, but in some cases larger recesses may be suitable. Typically, the protrusions and/or recesses are separated by 1 cm to 2 cm and/or by 0.5 to 4 cm, but the spacing may be wider or smaller dependent on the actual size of the corresponding protrusions and/or recesses.

Surface texture of the types described above may be provided after the manufacturing of the cured fibre-reinforced sheet material, e.g. by sand blasting, grinding or dripping of semi-solid resin onto the surface, but it is preferred that the surface texture to facilitate introduction of resin between adjacent elements of cured fibre-reinforced sheet material at least partially is provided during manufacturing of the cured fibre-reinforced sheet material. This is particularly easily made when the cured fibre-reinforced sheet material is manufactured by belt pressing, as the surface texture may be derived via a negative template on or surface texture of the belt of the belt press. In another embodiment, a foil is provided between the belt and the fibre-reinforced sheet material is formed in the belt press. Such a foil may also act as a liner and should be removed prior to introduction of the cured fibre-reinforced sheet material in the mould.

It may be necessary to introduce resin into the stacks of layers of materials of this invention prior to curing. The introduction of resin may advantageously be vacuum assisted. This comprises the steps of forming a vacuum enclosure around the composite structure. The vacuum enclosure may preferably be formed by providing a flexible second mould part in vacuum tight communication with the mould. Thereafter a vacuum may be provided in the vacuum enclosure by a vacuum means, such as a pump in communication with the vacuum enclosure so that the resin may be introduced by a vacuum assisted process, such as vacuum assisted resin transfer moulding, VARTM. A vacuum assisted process is particularly suitable for large structures, such as the wind turbine blade shell and spar members, as long resin transportation distances could otherwise lead to premature curing of the resin, which could prevent further infusion of resin. Furthermore, a vacuum assisted process will reduce the amount of air in the wind turbine blade shell member and hence reduce the presence of air in the infused composite, which increases the homogeneity and the strength as well as the reproducibility.

The infusion resin may be curable by the external application of temperatures of from 60 to 100°C, preferably from 60 to 90°C, more preferably from 80 to 100°C. The temperature during curing will be higher due to the exotherm of the curing reaction. The resin may have a viscosity during the infusion phase of from 50 to 200 mPas, preferably from 100 to 160 mPas and more preferably of from 120 to 150 mPas. The neat infusion resin may have a density ranging of from 1.1 to 1.20 g/cm^3; a flexural strength of from 60 to 150 N/mm^{2,} preferably from 90 to 140 N/mm^2; an elasticity modulus of from 2.5 to 3.3 kN/mm^2, preferably from 2.8 to 3.2 kN/mm^2; a tensile strength of from 60 to 80 N/mm^2, preferably from 70 to 80 N/mm^2; a compressive strength of from 50 to 100 N/mm^2; elongation at break of from 4 to 20%, preferably from 8 to 16% and/or combinations of the aforesaid properties.

A suitable infusion resin may be Epikote MGS RIM 135 as supplied by Hexion or Prime 20 as supplied by Gurit.

As discussed, the infusion lay-up may be combined with any one of the moulding materials as described herein, either alone or in combination.

An optional inner surface layer material may be provided over the elements of cured fibre-reinforced sheet material. The optional inner surface layer material may also be provided after introduction of resin between the elements, but the presence of an inner surface layer material is not essential for the wind turbine blade shell member. An inner surface layer material as well as an outer surface layer material may comprise fibres, which are oriented differently from the fibres of the elements of cured fibre-reinforced sheet material and hence e.g. increase the transverse strength of the wind turbine blade shell member.

One of the major advantages of the use of elements comprising layers of cured fibre-reinforced sheet material is that the reinforcement material may be positioned with very high freedom of design. In general, it is preferred that the reinforcement material is positioned as far away from the centreline of the structure as possible to realise a high momentum of the reinforcement. By using overlapping layers or elements, this may substantially be achieved by a plurality of elements having the same shape or - in situations where a complex geometrical overall reinforcement structure is desired - by a plurality of elements having only a few different shapes. This is possible by varying the degree of overlapping and the angles between the outer surface of the composite surface and the elements of cured fibre-reinforced sheet material.

The exact positioning of the elements of fibre-reinforced sheet material in the mould may be facilitated by the use of a template means showing the desired positions. This is particularly the case when more complex systems of elements are desired or if manual lay-up is utilised. A template means may indicate the relative position of elements of cured fibre-reinforced sheet material towards an end corresponding to the end of the wind turbine blade shell member and/or indicate the relative position of at least one element relative to the mould, such as a mould edge or a feature of the mould, e.g a hole or a tap. The indication of the correct position may involve the longitudinal position, the width-wise position and/or the height-wise position relative to the mould and/or relative to further elements of cured fibre-reinforced sheet material or other elements to be included in the composite structure.

The template means may be integrated in the wind turbine blade shell member so that it is a single use template. In a preferred embodiment, the template means is integrated with a core element of the composite structure.

For large elements, such as for a wind turbine blade, where the length of the elements of cured fibre-reinforced sheet material typically may be in the order of the total length of the wind turbine blade, it may be advantageous to apply several template means, e.g. one at each end and 1, 2, 3 or more on selected positions along the length of the blade

The elements of fibre-reinforced sheet material are bonded together by resin as discussed previously, but during the lay-up, it is highly advantageous to at least temporarily fix the elements of fibre-reinforced sheet material to the mould and/or to another element in the mould, such as one or more other material of this invention. The temporary fixing should be formed so that the fixing does not lead to unacceptable defects during subsequent introduction of resin or during use of the final product. The fixing may for example involve one or more adhesive, such as a curable or non-curable hot-melt resin or a double-coated tape; or mechanical fastening means, such as a clamp, wires, wires with loops or an elastic member. In a particularly preferred embodiment, the means for temporary fixing are not removed prior to introduction of resin and hence included in the completed composite structure. In this case, it is particularly important that the means for temporary fixing is compatible with the elements of the final structure in both chemical terms (e.g. in relation to the resin) and mechanical terms (e.g. no formation of mechanically weak spots).

In a preferred embodiment, the plurality of elements of cured fibre-reinforced sheet material comprises at least two types and/or size of fibres. The fibres are preferably selected from the group consisting of carbon fibres, glass fibres, aramid fibres and natural fibres, such as cellulose-based fibres, preferably wood fibres.

The fibres may be arranged so that one or more of the elements comprises two or more types of fibres, such as e.g. a combination of carbon fibres with wood fibres or carbon fibres with glass fibres. In a particularly preferred embodiment, the plurality of elements comprises a first group of elements, which has a first fibre composition, and a second group of elements, which has a second composition. Preferably, the first fibre composition consists substantially of carbon fibres so that the first group of elements is particularly stiff relative to the weight and volume of the cured fibre- reinforced sheet material. The second fibre composition may comprise other carbon fibres or another fibre such as glass fibres.

A support structure that supports the arrangement of the unidirectional tows in the materials of the invention so that their orientation is maintained may be provided. The support structure may be provided in different forms: as additional fabric layers, as a binder, as a yarn in the form of stitching, or as loops of fibres or lashings to bind the tows, as the resin matrix in cured, partially cured or uncured form and/or a combination of the aforesaid forms. The support structure is applied so that it does not significantly disrupt the arrangement of the fibre tows, and does not comprise any fibres which are woven in the fabric and so does not introduce any crimps into the fabric. This enables the surface of the fabric to be formed with a smoother surface profile, reducing air trapped against or inside the fabric (intra laminar air) when resin is applied.

In an embodiment the support structure may comprise support structure fibres which are applied in the form of loops that are passed around the tows. The loops may be arranged such that the support structure fibres extend from one surface of the layer of fibrous reinforcement through to the opposing surface, thereby encircling tows to bind the tows together. The support structure fibres may pass between adjacent tows, in doing so they can also introduce spacing between tows. This arrangement provides air venting pathways in the inter and intra laminar directions as well as providing support for the fabric. The spacing also facilitates complete wetting out during the curing phase, which is especially important for applications requiring the use of heavy fabrics or a high fibre density.

The support structure fibres preferably comprise continuous fibres applied to the fabric in a repeating stitch pattern, but may also comprise discontinuous fibres. The support structure fibres preferably bind the tows of the fabric with repeating loops applied in a linear pattern, which can be applied in any direction but preferably in the 0° direction. Additional support structure fibres may be applied to an opposing surface of the fabric such that they pass through loops made by fibres originating from the first surface of the fabric.

The unidirectional alignment of fibrous reinforcement is aligned at an angle substantially greater than 0° to the lengthwise direction. Typically the support structure is applied to the fibrous reinforcement parallel to the lengthwise direction, it can however be applied at any angle relative to the lengthwise direction. A non-parallel arrangement of support structure and fibre direction offers greater stability to the fibrous reinforcement. However, it must be noted that the fibre direction can be parallel to the lengthwise direction and the support structure applied non-parallel to this. Alternatively the support structure can be applied parallel to the fibre direction, but this may reduce support for the fibrous reinforcement.

The support structure may comprise a resin, wherein a resin provides support for the fibrous reinforcement. The use of resin as a support structure may eliminate or reduce the quantity of support structure fibres required for stability of the fabric.

A resinous support structure may be applied to a fabric in a resin layer that may be continuous. The resin support structure may be applied to one or both surfaces of a layer of fibrous reinforcement.

The support structure may comprise resin applied in discrete elements, preferably comprising cured or partly cured resin. The discrete elements of resin may be applied in patterns in the form of strips, globules or random line patterns for example. Such elements can be applied on one or both surfaces of a layer of fibrous reinforcement. Both uncured and cured resins can be used to provide sufficient stability to a layer of fibrous reinforcement for handling. Spaces between the resin elements can act as channels providing venting pathways for the removal of air during lay-up. The resin support structure also provides spacing between adjacent fibrous layers for improved venting. The resin support structure may comprise a curable resin, a resinous support layer of this nature can be applied to a layer of fibrous reinforcement and immediately cured or it can be left uncured until it is cured as part of a lay-up. The resin support structure may comprise a thermoplastic that is melted, applied to the layer of fibrous reinforcement and frozen.

The support structure may also comprise a scrim, arranged on either or both surfaces of the layer of fibrous reinforcement. The scrim may enter the interstices between tows in the fibrous reinforcement. As well as supporting the layer of fibrous reinforcement, the scrim may improve venting by providing pathways for gases to be removed during cure. The scrim may comprise a veil. The veil may comprise a light weight fabric having a weight in the range of from 3 to 30 gsm (g/m^2), preferably from 5 to 15 gsm.

The veil may be attached to the fibrous reinforcement. The veil may comprise a thermoplastic material and impart toughness on the laminate as well as providing support for the layer of fibrous reinforcement. The support structure may be bonded to the layer of fibrous reinforcement, by melt bonding, stitching, adhesives, or the tack from cured or uncured resin.

The support structure may comprise a fibrous support layer. The fibrous support layer may be a layer onto which the layer of fibrous reinforcement is attached. The support layer may be melt bonded, stitched, adhered with an adhesive or attached with any bonding method known to the art including utilising resinous tack. The support layer confers stability to the fibrous reinforcement and improves handling characteristics. The support layer may also enhance venting of the moulding material. The fibrous support layer may be attached to the fabric by support fibres that may pass through the entire thickness of the support layer. The support layer may comprise a fibrous mat, a woven fabric or unidirectional fibres. In an embodiment where the support layer comprises a fibrous mat, preferably it comprises fibres with a weight range of from 3 to 30 gsm, preferably from 5 to 15 gsm, more preferably from 2-13 gsm. Preferably the fibres are formed from glass or carbon or a polymer but can be formed from jute, flax, basalt or any other fibres known to the art.

One of the moulding materials of the invention comprises a non-woven fibrous reinforcement layer having fibrous tows in a single layer oriented at a selected angle (typically 30^{o} or 45^{o} in relation to the warp). The non-woven fibrous reinforcement has no crimp, as it is non-woven. This improves the mechanical performance of a laminate which may be formed from this material. The fibrous tows of the non-woven fibrous reinforcement layer are preferably held in place by a support structure in the form of cross-stitching. The cross-stitching promotes the release of entrapped gases during processing and curing of the moulding material. This is particularly advantageous in out of autoclave, vacuum assisted moulding processes.

In certain materials, the fibrous material is impregnated with a resin material. The viscosity of the resin and the method employed for impregnation are selected to achieve the desired degree of impregnation. The degree of impregnation can be assessed using the water pickup test. In order to increase the rate of impregnation, the process may be carried out at an elevated temperature so that the viscosity of the resin is reduced. However it must not be so hot for a sufficient length of time that curing of the resin is to far accelerated. The relative amount of resin to reinforcement material, the impregnation line speed the viscosity of the resin and the density of the multifilament tows should be correlated to achieve the desired degree of impregnation between the tows and to leave spaces between the individual filaments within the tows which are unoccupied by the resin to provide air venting paths. Thus, the impregnation process is preferably carried out at temperatures in the range of from 40°C to 110°C more preferably 60°C to 80°C. It is preferred that the resin content of the prepregs is such that after curing the cured moulding material contains from 30 to 40 wt %, preferably 31 to 37 wt % more preferably 32 to 35 wt % of the resin.

The resin may be spread onto the external surface of a roller and coated onto a paper or other backing material to produce a layer of curable resin. The resin composition can then be brought into contact with the multifilament tows for impregnation perhaps by the passage through rollers. The resin may be present on one or two sheets of backing material, which are brought into contact with one or both sides of the tows and consolidated such as by passing them through heated consolidation rollers to cause the desired degree of impregnation. Alternatively, the resin may be applied via a resin bath by conducting the tows through the resin (direct fibre impregnation). The resin may also comprise a solvent which is evaporated following impregnation of the fibre tows.

In a further embodiment, during impregnation the resin may be maintained in liquid form in a resin bath either being a resin that is liquid at ambient temperature or being molten if it is a resin that is solid or semi-solid at ambient temperature. The liquid resin can then be applied to a backing employing a doctor blade to produce a resin film on a release layer such as paper or polyethylene film. The fibre tows may then be placed into the resin and optionally a second resin layer may be provided on top of the fibre tows and then consolidated or the backing sheet may be removed and a second fibrous layer applied to the to the other surface of the resin layer.

A backing sheet may be applied either before or after impregnation of the resin. However, it is typically applied before or during impregnation as it can provide a non-stick surface upon which to apply the pressure required for causing the resin to impregnate the fibrous layer. It can be removed prior to the addition of further layers of fibrous reinforcement or resin material.

The moulding material may comprise reinforcing fibers in the form of tows. The tows may be unidirectional or woven.

The tows employed in the present invention are made up of a plurality of individual filaments. There may be many thousands of individual filaments in a single tow. The tow and the filaments within the tow are generally unidirectional with the individual filaments aligned substantially parallel. Typically the number of filaments in a tow can range from 2,500 to 10,000 to 50,000 or greater. Tows of about 25,000 carbon filaments are available from Toray and tows of about 50,000 carbon filaments are available from Zoltek.

The reinforcing fibres may comprise synthetic or natural fibres or any other form of material or combination of materials that may be combined with the resin composition of the invention. Exemplary fibres include glass, carbon, basalt, natural or organic fibers, graphite, boron, ceramic and aramid and/or combinations of the aforesaid fibres. Preferred fibres are carbon and glass fibres. Hybrid or mixed fibre systems may also be envisaged. The weight of fibres within the fibrous reinforcement is generally 20-10000 g/m^2, preferably 50 to 800-2500 g/m^2, even more preferably from 1200 to 2400 g/m^2 and especially preferably from 150 to 600 g/m^2 and/or combinations of the aforesaid ranges The number of carbon filaments per tow can vary from 3000 to 100,000, again preferably from 6,000 to 80,000 and most preferably from 12,000 to 40,000 and/or combinations of the aforesaid ranges. For fiberglass reinforcements, fibres of 600-2400 tex are particularly adapted.

The multifilament tows used in this invention may comprise cracked (i.e. stretch-broken), selectively discontinuous or continuous filaments. The filaments may be made from a wide variety of materials, such as carbon, basalt fibre, graphite, glass, metalized polymers, aramid and mixtures thereof. Glass and carbon fibres tows are preferred; carbon fibre tows, being preferred for wind turbine shells of length above 40 metres such as from 50 to 60 metres. The structural fibres are individual tows made up of a multiplicity of unidirectional individual fibres. Typically the fibres will have a circular or almost circular cross-section with a diameter for carbon in the range of from 3 to 20 µm, preferably from 5 to 12 µm. For other fibres, including glass, the diameter may be in the range of from 3 to 600 µm, preferably from 10 to 100 µm.

Exemplary fabrics include B315-E05 manufactured by Devold. In an embodiment, this fabric is produced by aligning fibre tows at 30° to the lengthwise direction, cutting the tows and applying a support structure such as stitching in the 0° direction. Another exemplary fabric is B310NW/G as supplied by Saertex. The fabric may comprise multiple unidirectional tow layers bonded to form a multidirectional fabric. The fabric may be provided with a support fibre having an areal weight of between 2 and 200 gsm (g/m^2), or preferably 4 to 100 gsm, or more preferably 5 to 50 gsm, more preferably still, 6 to 15 gsm. The yarn may be applied with a stitch length between 0.5 to 15 mm, preferably 1 to 10 mm or more preferably 2 to 5 mm, or more preferably still, 2.5 - 3.8 mm. The fabric may be supplied with a width of 10 mm to 4000 mm, from 200 to 4000 mm or more preferably 1200 to 3600 mm, from 100 to 400 mm, from 120 to 240, at 120 mm or 240 mm and/or combinations of the aforesaid widths.

An example of a fabric which may be suitable for use in the invention may have substantially the following properties either alone, but preferably in combination with one or more of the following properties: an areal weight of 310 gsm (g/m^2); comprising unidirectional tows of 300 gsm arranged at 30°; a stitched with a fibre of 10 gsm; with stitching applied in the lengthwise direction; the tows of the fabric may have a linear mass density of 1200 tex and the support fibre may have a linear mass density of 34 tex. Another fabric suitable for use in the invention may have an areal weight of 310 gsm with the tows substantially arranged at 30° or 45° to the lengthwise direction, the fabric may include a support structure comprising fibres of 10 gsm or 13 gsm, for example. A further example of a suitable fabrics may be one with an areal weight of substantially 600 gsm with the tows substantially arranged at either 30° or 45° to the lengthwise direction, and a support layer of substantially 10 gsm or 13 gsm. An example of a fabric which may be suitable for use in the invention may have substantially the following properties: an areal weight of 1181 gsm, comprising a layer of unidirectional tows of 301 gsm arranged at + 45 or 30°, a layer of unidirectional tows of 301 gsm arranged at -45 or 30° and a layer of unidirection tows of 567 gsm, which are bonded with a support structure in the form of a fibre of 12 gsm. The stitching fibre may comprise polyethersulphone and be applied in a tricot stitch

The moulding materials of this invention may be produced from conventionally available epoxy resins which may contain a hardener and optionally an accelerator. In an embodiment the epoxy resin may contain a hardener such as a dicyandiamide or a urea based or urea derived curing agent. The relative amount of the curing agent and the epoxy resin that should be used will depend upon the reactivity of the resin and the nature and quantity of the fibrous reinforcement in the moulding material.

When the epoxy resin composition comprises one or more urea based curing agents and it is preferred to use from 0.5 to 10 wt % based on the weight of the epoxy resin of a curing agent, more preferably from 1 to 8 wt %, and even more preferably from 2 to 8 wt %. Preferred urea based materials are the range of materials available under the commercial name Urone® as supplied by Alzchem, such as UR500 and/or UR505. In addition to a curing agent, a suitable accelerator such as a latent amine-based curing agent, such as dicyanopolyamide (DICY) or dicyandiamide.

The epoxy resin used in the materials of this invention preferably has an Epoxy Equivalent Weight (EEW) in the range from 150 to 1500 preferably a high reactivity such as an EEW in the range of from 200 to 500 and the resin composition comprises the resin and an accelerator or curing agent. Suitable epoxy resins may comprise blends of two or more epoxy resins selected from monofunctional, difunctional, trifunctional and/or tetrafunctional epoxy resins.

Suitable difunctional epoxy resins, by way of example, include those based on: diglycidyl ether of bisphenol F, diglycidyl ether of bisphenol A (optionally brominated), phenol and cresol epoxy novolacs, glycidyl ethers of phenol-aldelyde adducts, glycidyl ethers of aliphatic diols, diglycidyl ether, diethylene glycol diglycidyl ether, aromatic epoxy resins, aliphatic polyglycidyl ethers, epoxidised olefins, brominated resins, aromatic glycidyl amines, heterocyclic glycidyl imidines and amides, glycidyl ethers, fluorinated epoxy resins, glycidyl esters or any combination thereof.

Difunctional epoxy resins may be selected from diglycidyl ether of bisphenol F, diglycidyl ether of bisphenol A, diglycidyl dihydroxy naphthalene, or any combination thereof.

Suitable trifunctional epoxy resins, by way of example, may include those based upon phenol and cresol epoxy novolacs, glycidyl ethers of phenol-aldehyde adducts, aromatic epoxy resins, aliphatic triglycidyl ethers, dialiphatic triglycidyl ethers, aliphatic polyglycidyl amines, heterocyclic glycidyl imidines and amides, glycidyl ethers, fluorinated epoxy resins, or any combination thereof. Suitable trifunctional epoxy resins are available from Huntsman Advanced Materials (Monthey, Switzerland) under the tradenames MY0500 and MY0510 (triglycidyl para-aminophenol) and MY0600 and MY0610 (triglycidyl meta-aminophenol). Triglycidyl meta-aminophenol is also available from Sumitomo Chemical Co. (Osaka, Japan) under the tradename ELM-120.

Suitable tetrafunctional epoxy resins include N,N, N',N'-tetraglycidyl-m-xylenediamine (available commercially from Mitsubishi Gas Chemical Company under the name Tetrad-X, and as Erisys GA-240 from CVC Chemicals), and N,N,N',N'-tetraglycidylmethylenedianiline (e.g. MY0720 and MY0721 from Huntsman Advanced Materials). Other suitable multifunctional epoxy resins include DEN438 (from Dow Chemicals, Midland, MI) DEN439 (from Dow Chemicals), Araldite ECN 1273 (from Huntsman Advanced Materials), and Araldite ECN 1299 (from Huntsman Advanced Materials).

In a further embodiment the resin may comprise an epoxy resin containing from 20% to 85% by weight of an epoxy resin of EEW (epoxy equivalent weight) from 150 to 1500, said resin being curable by an externally applied temperature in the range of 70°C to 110°C. The epoxy resin may contain from 0.5 to 10 wt % of a curing agent. The epoxy resin may be cured in the absence of a traditional hardener such as dicyandiamide.

The epoxy equivalent weight can be calculated as follows: (Molecular weight epoxy resin)/ (Number of epoxy groups per molecule). Another way is to calculate with epoxy number that can be defined as follows: Epoxy number = 100 / epoxy eq. weight. To calculate epoxy groups per molecule : (Epoxy number x mol. weight) / 100. To calculate mol. weight : (100 x epoxy groups per molecule) / epoxy number. To calculate mol. weight: epoxy eq. weight x epoxy groups per molecule. The present invention is particularly concerned with providing a prepreg that can be based on a reactive epoxy resin that can be cured at a lower temperature with an acceptable moulding cycle time.

In a further embodiment, the resin can be cured in less than ten hours particularly less than eight hours. The curing agent may be urea based. In a further embodiment, the moulding material may comprise from 20 to 85 wt % of epoxy resin and from 80 to 15 wt % of fibres.

Toughening materials may be included with the resin to impart durability to the matrix. Toughening materials may be applied as a separate layer in the form of a veil, or as particles, or mixed into the resin material. If the additional toughening material is a polymer it should be insoluble in the matrix epoxy resin at room temperature and at the elevated temperatures at which the resin is cured. Depending upon the melting point of the thermoplastic polymer, it may melt or soften to varying degrees during curing of the resin at elevated temperatures and re-solidify as the cured laminate is cooled. Suitable thermoplastics should not dissolve in the resin, and include thermoplastics, such as polyamides (PAS), polyethersulfone (PES) and polyetherimide (PEI). Polyamides such as nylon 6 (PA6) and nylon 12 (PA12) and mixtures thereof are preferred.

A stack of two or more materials of this invention containing prepregs for preparing cured laminates may contain more than 40 prepreg layers, typically more than 60 layers and at times more than 80 layers, some or all of which are at least two materials of the present invention. One or more of the prepreg layers in the stack may be cured or precured to part process the resin in the prepreg layer. It is however preferred that all the prepregs are materials according to the invention. Typically the stack will have a thickness of from 1 cm to 10 cm, preferably from 2 cm to 8 cm, more preferably from 3 to 6 cm.

Once prepared, the prepreg or prepreg stack is cured by exposure to an elevated temperature, and optionally elevated pressure, to produce a cured laminate.

The curing process may be carried out at a pressure of less than 2.0 bar absolute, preferably less than 1 bar absolute. In a particularly preferred embodiment the pressure is less than atmospheric pressure. The curing process may be carried out at one or more temperatures in the range of from 80 to 200°C, for a time sufficient to cure the thermosetting resin composition to the desired degree.

Curing at a pressure close to atmospheric pressure can be achieved by the so-called vacuum bag technique. This involves placing the prepreg or prepreg stack in an air-tight bag and creating a vacuum on the inside of the bag. This has the effect that the prepreg stack experiences a consolidation pressure of up to atmospheric pressure, depending on the degree of vacuum applied.

Once cured, the prepreg or prepreg stack becomes a composite laminate, suitable for use in a structural application, for example the shell, spar or hub of a wind turbine blade.

Composite parts or members according to the invention may either form a wind turbine blade shell or spar individually or form a wind turbine blade shell or spar when connected to one or more further such composite members, e.g. by mechanical fastening means and/or be adhesive. From such wind turbine blade shells and spars, a wind turbine blade may advantageously be manufactured by connecting two such wind turbine blade shells together by adhesive and/or mechanical means, such as by fasteners and by assembly together with the spar. Both the wind turbine blade shell and the combined wind turbine blade spar may optionally comprise further elements, such as controlling elements, lightning conductors, etc. In a particularly preferred embodiment, each blade shell consists of a composite member manufacturable from materials of the invention. In another preferred embodiment, the wind turbine blade shell member manufactured by the method according to the invention forms substantially the complete outer shell of a wind turbine blade, i.e. a pressure side and a suction side which are formed integrally during manufacturing of the wind turbine blade shell member. The blade may be formed in sections for assembly on site, the sections may be complete shell and spar, half shell, half spar or any combination thereof or two or more lengths that may be assembled to form the entire blade.

The length and shape of the shells vary but the trend is to use longer blades (requiring longer shells) which in turn can require thicker shells and a special sequence of prepregs within the stack to be cured. This imposes special requirements on the materials from which they are prepared. Prepregs based on unidirectional multifilament carbon fibre tows are preferred for blades of length 30 metres or more particularly those of length 40 metres or more such as 45 to 65 metres. The length and shape of the shells and spars may also lead to the use of different prepregs along the length of the shell. In view of their size and complexity the preferred process for the manufacture of wind energy components such as shells and spars is to provide the appropriate curable material within a vacuum bag, which is placed in a mould and heated to the curing temperature. The bag may be evacuated before or after it is placed within the mould.

The reduction in the number of voids and improved fibre alignment in the laminates obtained by the present invention is particularly useful in providing shells and/or spars and/or spar caps for wind turbine blades having uniform mechanical properties. Particularly spars and parts thereof are subjected to high loads. Any reduction in void content or increase of fibre alignment greatly improves the mechanical performance of these parts. This in turn allows the parts to be built at a reduced weight (for example by reducing the number of prepreg layers) in comparison to a similar part which would have a higher void content. Furthermore, in order to withstand the conditions to which wind turbine structures are subjected during use it is desirable that the cured prepregs from which the shells and spars are made have a high Tg and preferably a Tg greater than 90°C.

The laminates produced from two or more of the materials of this invention can contain less than 3% by volume of voids, or less than 1% by volume of voids, typically less than 0.5% by volume and particularly less than 0.1% by volume based on the total volume of the laminate as measured by microscopic analysis of 20 spaced cross sections measuring 30 x 40 mm in cross section (spacing 5 cm) of a cured sample of the laminate. The cross section is polished and analysed under a microscope over a viewing angle of 4.5 to 3.5 mm to determine the surface area of the voids in relation to the total surface area of each cross section of the sample and these measurements are averaged for the number of cross sections. This method for determining the void fraction is used within the context of this application, although alternative, standardized methods are available such as DIN EN 2564. These methods are however expected to provide comparative results in relation to the microscopic analysis as outlined here. Also, the maximum size of the voids is assessed in each viewing angle section and this number is averaged over the 20 samples. The average surface area of the voids is taken as the value of the void content by volume. We have found that void fractions or levels as low as no more than 0.01% by volume have been achieved.

The moulding materials of this invention contain a low level of voids between the tows. It is therefore preferred that each moulding material and the moulding material stack has a water pick-up value of less than 15% or less than 9%, more preferably less than 6%, most preferably less than 3%.

The water pick-up test determines the degree of waterproofing or impregnation between the unidirectional tows of the layers of reinforcement in the moulding material of this invention. In this test, a specimen of moulding material is initially weighed and clamped between two plates in such a way that a strip 5 mm wide protrudes. This arrangement is suspended in the direction of the fibres in a water bath at room temperature (21°C) for 5 minutes. The specimen is then removed from the plates and weighed again and the difference in weight provides a value for the degree of impregnation within the specimen. The smaller the amount of water picked up, the higher the degree of waterproofing or impregnation.

Fibre alignment can be quantified using the protocol described in Creighton et al. A Multiple Field Image Analysis Procedure for Characterisation of Fibre Alignment in Composites; Composites: Part A 32 (2001) 221-229. Firstly specimens are sectioned and ground with 1200 grit SiC paper. The ground surface is then flooded with acetone and lightly abraded with wire wool. Micrographs are then taken of the prepared surface and then analysed with an automated image analysis algorithm. The algorithm automatically detects structural features such as fibres and matrix. The algorithm creates an array of pixels which represent a fibre, inclination angle is then calculated along the array between neighbouring pixels and used to deduce extent of fibre misalignment.

The present invention will now be illustrated by way of example only and with reference to the accompanying drawings in which

Figure 1 presents three different lay-ups of moulding materials in accordance with embodiments of the invention;
Figure 2 presents a cross section of lay-up 1 of Figure 1;
Figure 3 presents a cross section of lay-up 2 of Figure 1;
Figure 4 presents a cross section of lay-up 3 of Figure 1;
Figure 5 presents a microscopy cross section of lay-up 1 of Figure 1;
Figure 6 presents a microscopy cross section of lay-up 2 of Figure 1;
Figure 7 presents a microscopy cross section of lay-up 3 of Figure 1;
Figure 8 presents a cross section of a lay-up of prepreg layers in which a wire is present;
Figure 9 presents a cross section of a lay-up of prepreg layers and a laminate layer in which the same wire is present; and
Figure 10 presents a laminate structure according to another embodiment of the invention.

Figure 11 presents a laminate structure according to a further embodiment of the invention The present invention is illustrated by reference to the following examples in which the following materials of the invention were used.

Prepreg 1) An all unidirectional carbon fibre epoxy resin based prepreg comprising 66% Panex, 35 carbon fibre and 34 wt % epoxy resin available from Hexcel as HexPly® M 9.6 GF/34%/UD 600.

Prepreg 2) A film of epoxy resin combined with dry unidirectional glass fibre reinforcements on either side of the film of epoxy resin available from Hexcel as HexFit® 2000. The resin content is 35 wt % and the exterior surfaces of the material are dry to the touch.

Prepreg 3) A press cured unidirectional glass fibre epoxy laminate available from Hexcel as PolySpeed® GR 120 containing 2400 tex glass fibre having of weight 1200± 60 grams per square metre and containing 27 wt % cured epoxy resin.

Prepreg 4) An all unidirectional glass fibre epoxy resin based prepreg comprising 68% glass fibre and 32% epoxy resin available from Hexcel as HexPly® M 9.6 GF/32%/UD 800. A nonwoven fleece of glass fibre of a weigh of 50 gsm is tacked to the surface of the prepreg.

The prepregs were laid-up in the following stacks.

Lay-Up	Prepreg 1 Plies	Prepreg 2 Plies	Prepreg 3 Plies
1	62		
2	64	12	
3	60	11	3

The distribution of the layers within the stack is shown in Figure 1. The stacks were cured in a vacuum bag at 80°C. The cured stacks were evaluated for porosity and uniformity.

The porosity, appearance and uniformity of the cured materials of lay-ups 1,2 and 3 of Figure 1 is shown in respective Figures 2, 3 and 4. Respective figures 5, 6 and 7 present microscopy cross sectional views for each of these cured lay-ups. In the Figures numeral

(1) denotes prepreg (1), numeral (2) denotes prepreg (2) and numeral (3) denotes prepreg (3).

Figures 8 and 9 show that the use of a cured laminate in combination with prepreg layers 3 in the stack produces a more regular and uniform surface even if a disturbance (wire (4)) is present in the lay-up structure.

Figure 10 presents a moulding material 20 in the form of multiple cured laminate layers 28,30 co-bonded by a prepreg material layer 24. The cured laminate layers 28, 30 comprise unidirectional carbon fibres in a cured resin matrix 22 and dry fibre areas 26 in longitudinal or warp direction. Instead of dry fibre areas 26, these areas may also be in the form of longitudinal gaps or open areas. The laminates 28,30 may be press cured or pultruded.

In use, the material 20 is laid up in combination with other moulding materials as hereinbefore described to thereby form a composite laminate structure which is subsequently processed and cured to form a composite part.

We have discovered that these dry or impregnated areas improve the drapability of the laminate in moulds of a complex shape. Also they improve the venting of any entrapped gases during processing and curing and they improve the bond between the laminate and materials surrounding it in the lay-up.

Figure 11 presents a moulding material 30 in the form of a cured laminate layer 36 in the form of cured resin impregnated fibrous reinforcement, having a reinforcement layer 32 co-bonded thereto. The layer 32 is preferably a dry fibrous reinforcement layer or it may be a prepreg material layer.

In use, the material 30 is laid up in combination with other moulding materials as hereinbefore described to thereby form a composite laminate structure which is subsequently processed and cured to form a composite part. The layer 32 improves the integration and bonding with the other moulding materials.

CLAIMS

1. A laminated structure comprising a plurality of layers of fibre reinforced thermoset resin in which the layers are selected from two or more of the following

i) a first moulding material comprising a layer of curable resin and a fibrous material on at least one side of the curable resin matrix, said moulding material further comprising a further fibrous layer adhered to the fibrous reinforcement material

ii) a second moulding material comprising a fibrous material comprising two cross bonded fibrous plies, each ply comprising fibre tows oriented at differing angles, the fibrous material further comprising a curable resin matrix

iii) a third moulding material comprising at least two reinforcement layers having unidirectional fibre tows and a curable resin matrix bonding the layers together

iv) a fourth moulding material comprising a layer of fibrous reinforcement and a curable liquid resin wherein the fibrous reinforcement comprises a plurality of tows each tow comprising a plurality of filaments wherein resin is provided at least partially between interstices between tows of the fibrous reinforcement to provide an air venting path in at least the interior of the tows

v) a resin impregnated fibrous layer.

2. A laminated structure according to Claim 1 comprising at least layers (i) and (iv).

3. A laminated structure according to Claim 1 or Claim 2 comprising layer (iii).

4. A laminated structure according to any of the preceding claims comprising conjoined layers of impregnated and unimpregnated tows, the longitudinal axes of the impregnated and unimpregnated tows being located in the same plane.

5. A laminated structure according to any of the preceding claims comprising layer (i), wherein the fibrous reinforcement is impregnated from one side of the material and the further fibrous layer is adhered to the opposite side of the fibrous reinforcement material.

6. A laminated structure according to any of the preceding claims comprising layer (i) wherein the further fibrous layer comprises a non-woven fibrous material having an areal weight ranging from 200 to 2400 gsm, preferably from 400 to 1600 gsm, and more preferably from 600 to 1200 gsm and/or combinations of the aforesaid ranges.

7. A laminated structure according to any of the preceding claims comprising layer (i), wherein the fibrous reinforcement material comprises fibre tows comprising filaments having an average diameter in the range of from 1 to 20 μm, preferably from 10 to 15 μm.

8. A laminated structure according to any of the preceding claims comprising layer (ii) wherein the plies comprise carbon fibre.

9. A laminated structure according to any of the preceding claims comprising layer (ii) wherein the plies are sacrificial upon being struck by lightning.

10. The use of a laminated structure according to any of the preceding claims for the production of components of wind turbine blades.

11. The use according to Claim 10 in which the component is part or all of the shell.

12. The use according to Claim 10 in which the component is part or all of the spar.

13. A wind turbine blade or part thereof comprising a first section and a second section, wherein the first section comprises the first moulding material according to any of Claims 1 to 8.

14. The blade or part of Claim 13 wherein the first section comprises a third moulding material comprising at least two reinforcement layers having unidirectional fibre tows and a curable resin matrix bonding layers together.

15. The blade or part of Claim 13 or Claim 14 wherein in each of the unidirectional fibrous reinforcement layers the orientations of the fibre tows differ from the adjacent layer or layers.

16. The wind turbine blade or part according to any of Claims 13 to 15 wherein the second section comprises a fourth moulding material comprising a reinforcement layer having unidirectional fibre tows and a curable resin matrix impregnating said reinforcement layer from one side.

17. The wind turbine blade or part of Claim 16 wherein the reinforcement layer comprises a permeable thermoplastic layer on the opposite side from which the layer is impregnated.

18. The wind turbine blade or part according to any of Claims 13 to 17 wherein the first section and/or second section comprises a fifth moulding material, the fifth moulding material comprising a cured fibrous reinforced laminate structure.

19. A first moulding material comprising a fibrous reinforcement material impregnated from at least one side with a curable resin matrix, said moulding material further comprising a further fibrous layer adhered to the fibrous reinforcement material.

20. The first moulding material according to Claim 19 wherein the fibrous reinforcement is impregnated from one side of the material and the further fibrous layer is adhered to the opposite side of the fibrous reinforcement material.

21. The first moulding material according to Claim 19 or Claim 20 wherein the further fibrous layer comprises a non-woven fibrous material having an areal weight ranging from 0.5 to 10 gsm, preferably from 1 to 4 gsm.

22. The first moulding material according to any of Claims 19 to 21 wherein the fibrous reinforcement material comprises fibre tows comprising filament having an average diameter in the range of from 1 to 20 μm, preferably from 10 to 15 μm.

23. The first moulding material according to any of Claims 19 to 22 wherein the first moulding material is adapted for use in a resin infusion lay up.

24. A second moulding material comprising a fibrous material comprising two cross bonded fibrous plies, each ply comprising fibre tows oriented at different angles, the fibrous material further comprising a curable resin matrix.

25. The second moulding material according to Claim 24 wherein the plies comprise carbon fibre.

26. The second moulding material according to any of Claim 24 or Claim 25 wherein the plies are sacrificial upon being struck by lightning.

Layup 1	Layup 2	Layup 3
62 layers of prepreg 1	65 layers of prepreg 1	11 layers of prepreg 2
	12 layers of prepreg 2	3 layers of prepreg 3
thickness 34 mm	*thickness 41 mm*	*thickness 39.5 mm*
62 thermo	77	74
61	76	73
60	75	72
59	74	71
58	73	70
57	72	69
56	71	68
55	70	67
54	69	66
53	68	65
52	67	64
51	66	63
50	65	62
49	64	61
48	63	60
47 thermo	62	59
46	61	58
45	60	57
44	59	56
43	58	55
42	57	54
41	56	53
40	55	52
39	54	51
38	53	50
37	52	49
36	51	48
35	50	47
34	49	46
33	48	45
32	47	44
31 thermo	46	43
30	45	42
29	44	41
28	43	40
27	42	39
26	41	38
25	40	37
24	39	36
23	38	35

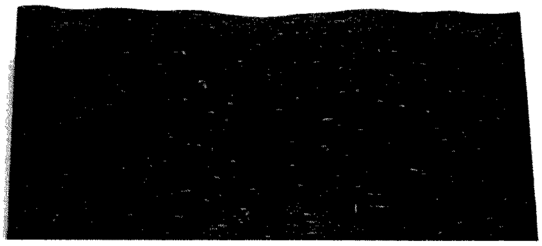
Figure 1

Layup 1 Continued
22
21
20
19
18
17
16
15 thermo
14
13
12
11
10
9
8
7
6
5
4
3
2
1 thermo

Layup 2 Continued
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

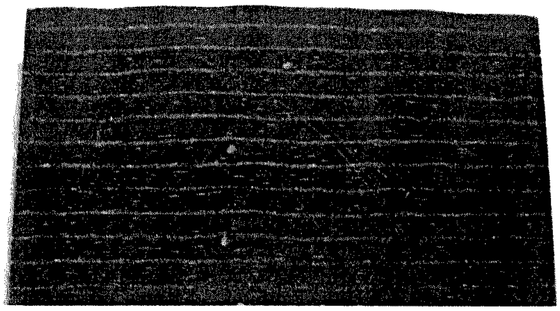
Layup 3 Continued
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

Figure 1 Continued



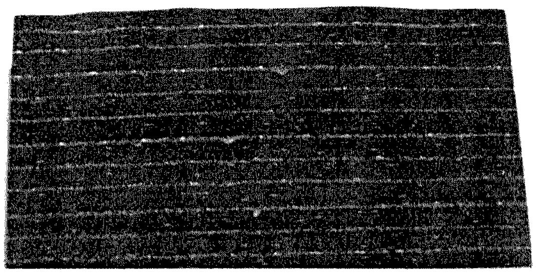
Lay-up 1

Figure 2



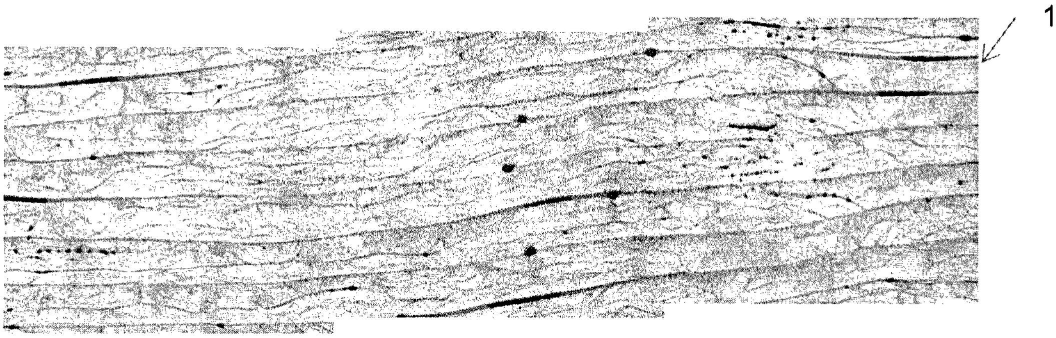
Lay-up 2

Figure 3



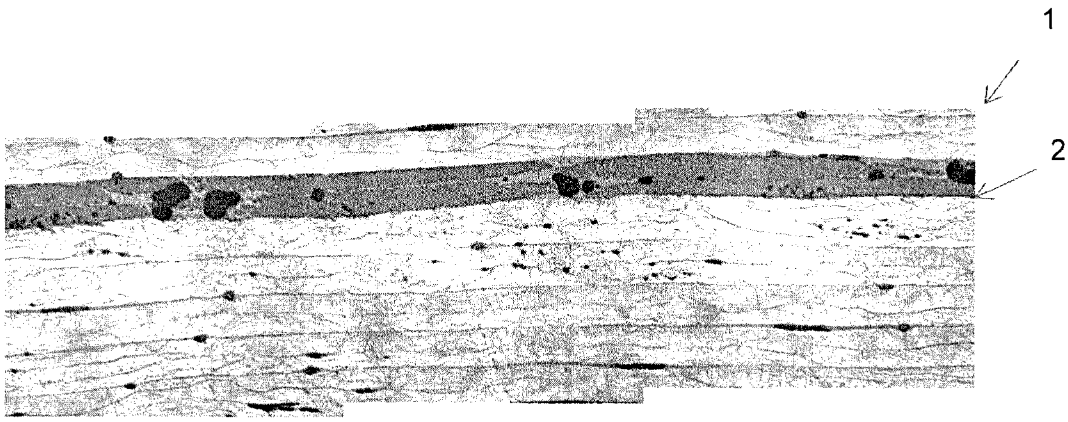
Lay-up 3

Figure 4



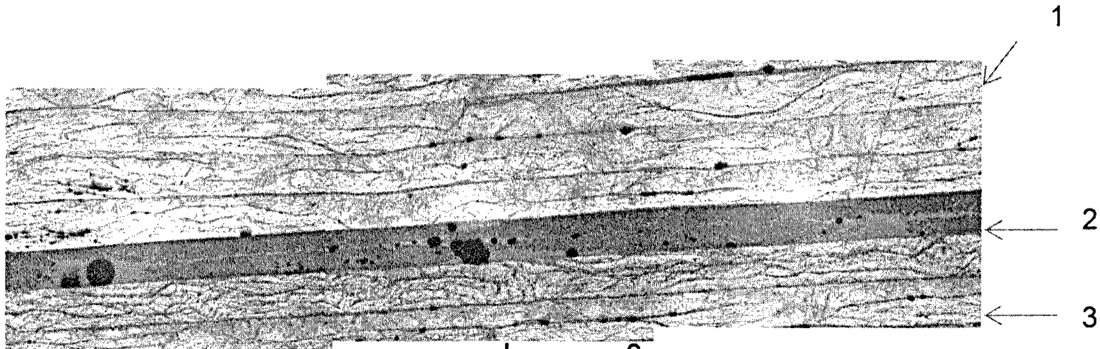
Lay up 1

Figure 5



Lay up 2

Figure 6



Lay up 3

Figure 7

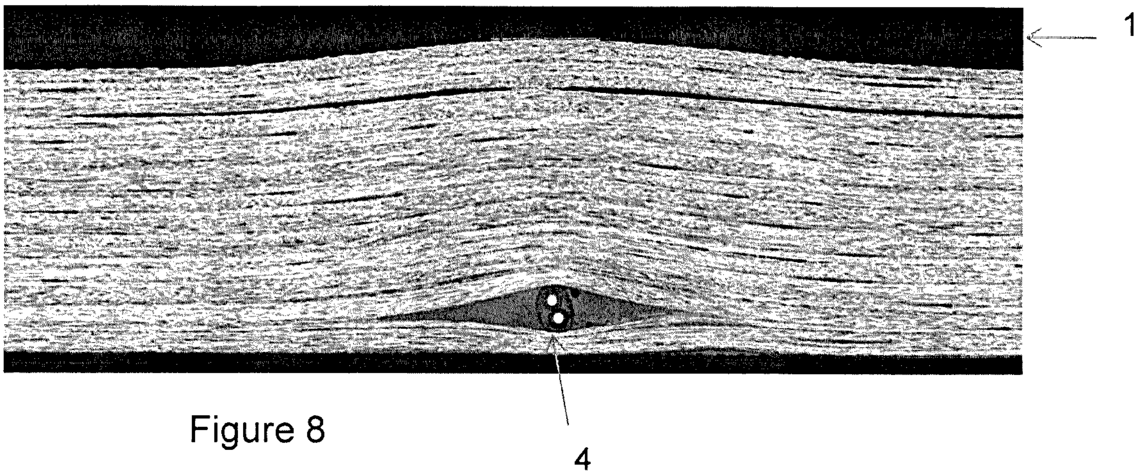


Figure 8

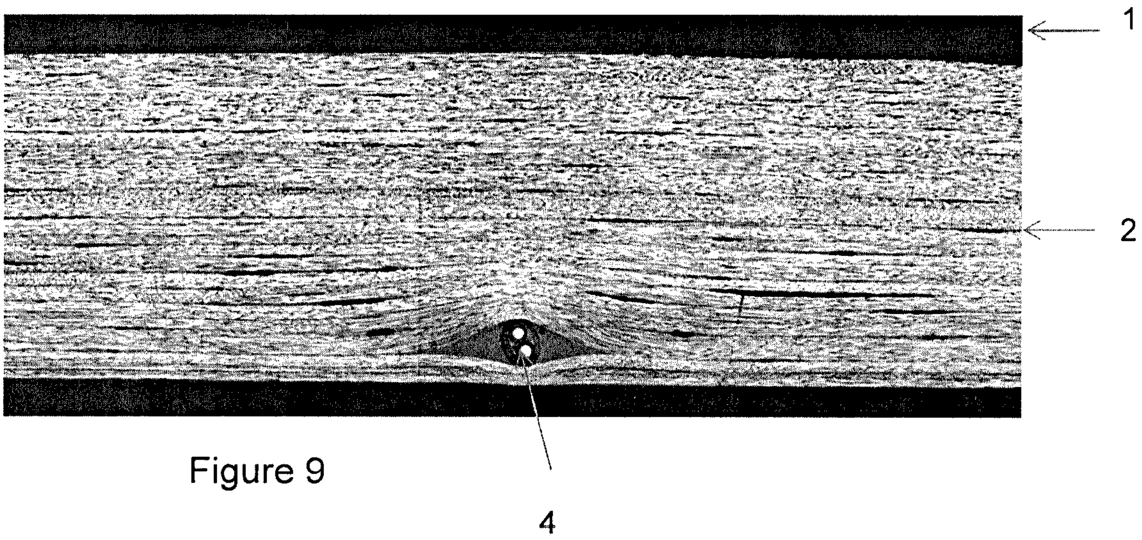


Figure 9

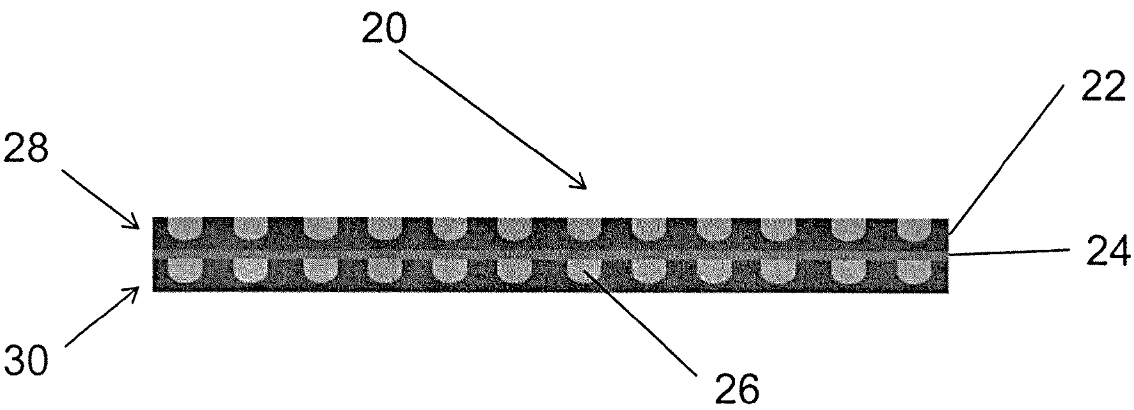


Figure 10

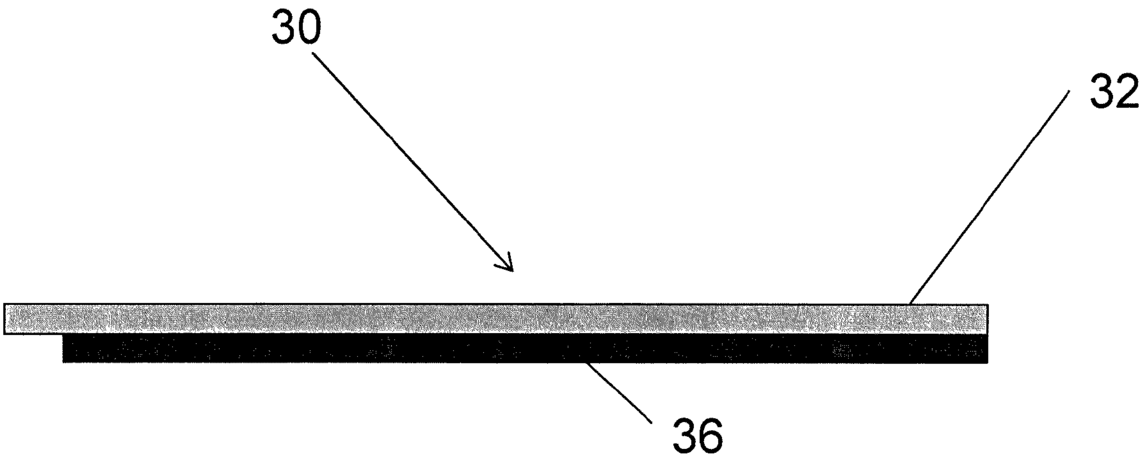


Figure 11