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(54) Title: WIND TURBINE BLADE, SPAR FOR WIND TURBINE BLADE AND METHOD OF PREPARING THESE

(57) Abstract: A wind turbine blade comprising a spar and a method of preparing these are provided. The spar comprises a laminated member having a surface to be connected to the surface shells of the blade reinforced by oriented first type fibres and the first type fibres are supported by second type fibres. Aspects concerning buckling, cross-sectional shape, twisting of fibres, straightness of fibres and electrical potential equalising are also considered. A band comprising fibres for electrical potential equalising is also provided. The wind turbine blade and elements of it will be appreciated for being relatively light, stiff and easy to manufacture, for example by automated processes.

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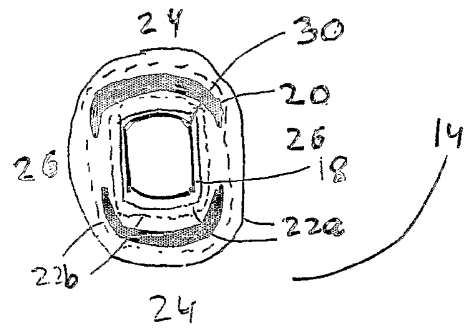

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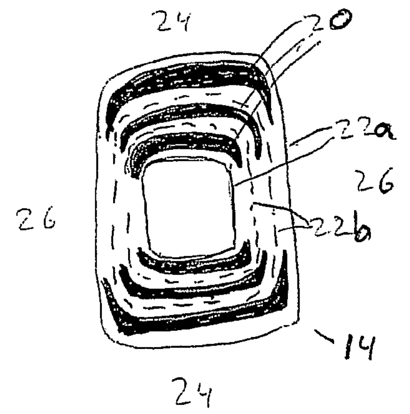

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WIND TURBINE BLADE, SPAR FOR WIND TURBINE BLADE AND METHOD OF PREPARING THESE.

TECHNICAL FIELD OF THE INVENTION

The invention relates to wind turbine blades. In particular, the invention relates to blades having a spar, which comprises a laminated member with different types of reinforcement fibres and/or pre-forms.

BACKGROUND OF THE INVENTION

The size of wind turbine blades tends to increase with the development of still larger wind turbines. Traditionally, wind turbine blades are produced from glass fibre reinforced plastics. However, as the size of wind turbine blades increases, the stiffness of the blades should also be increased to prevent the tip of the blade to hit the wind turbine tower in strong winds. Furthermore, the strength of the blade should be increased to carry the increasing weight of the blade. Hence, the weight of the blades increases dramatically and reduces the advantage of the larger blades. It is therefore necessary to introduce new structural designs and/or lighter, stiffer and stronger materials and elements to realise a better performance.

A wind turbine blade having two sections - one being reinforced by carbon fibre and one being reinforced by glass fibres - are disclosed in DE 202 06 942 U1. DE 202 06 942 U1 does not provide any specific details on how the sections are connected and does not indicate or foresee any effect of combining different fibre types other than what is related to reduction of the weight. Therefore, the two types of reinforcement fibres do not collaborate in a synergetic fashion but merely provide two sections having different properties.

In US 6,457,943, lightning protection for a wind turbine blade is disclosed. The lightning protection comprises strips of carbon fibre-reinforced plastic in the blade. The strips contribute to the stiffness of the wing. Conductors are provided between the strips and an inner lightning conductor to reduce the risk of flashovers by potential equalising. The connectors are provided on the inside of the blade shell only and it is not indicated how potential equalising may be realised if more than one layer of conducting flange material is present. US 6,457,943 does not indicate synergetic collaboration between different types of reinforcement fibres.

OBJECTS OF THE INVENTION

It is the object of the invention to provide a wind turbine blade wherein reinforcement fibres having different properties are combined to realise a strong, affordable and/or relatively light structure.

It is another object of the invention to provide a laminated member for a spar for a wind turbine blade.

A further object of the invention is to provide a band comprising fibres particularly suitable for potential equilibration of materials separated by the band comprising fibres.

It is yet another object of the invention to provide a method for preparing of a laminated member and a spar for a wind turbine blade.

DISCLOSURE OF THE INVENTION

The above and more objects are realised by the invention as described and explained in the figures, preferred embodiments and claims.

A wind turbine blade according to the invention comprises at least two surface shells and a spar. The surface shells are preferably prepared from fibre reinforced plastic like for example epoxy reinforced with any type or combination of types of the fibres mentioned herein. For example the surface shells may be made from glass fibres and epoxy. The shape and surface of the shells are highly important to the aerodynamic properties of the blade. Furthermore, the shells may or may not contribute to the strength and/or the stiffness of the blade; however, it is preferred that the shells do not contribute significantly to the strength and/or stiffness of the blade.

A spar is the load-carrying element of a wind turbine blade. Typically, a spar is a hollow, fibre reinforced plastic, which is connected to the wind turbine near one end and connected to the surface shells either directly or indirectly along a substantial part of the length. This invention is particularly suitable for spars with an adjusted quadrangle cross-section having two sides connected directly to the surface shells, but several aspects of the invention may be adapted to a spar having another cross-section geometry by a person skilled in the art. These aspects are not limited to spars having an adjusted quadrangle cross-section. Such cross-section geometry may for example by a circular cross-section or an I-shaped cross-section with one or more web sides.

In a preferred embodiment, the spar comprises a laminated member having an adjusted quadrangle cross-section. A side to be connected to a surface shell is mainly reinforced by substantially unidirectionally oriented first type fibres. The first type fibres are supported by second type fibres and the second type fibres are mainly oriented off the direction of the first type fibres.

The quadrangle cross-section of the spar is adjusted to provide a better contact to the surface shells. For example the cross-section of the spar may be adjusted to increase the contact area between the spar and the surface shells of the blade.

By the term substantially unidirectionally oriented is meant that at least about 75 % of the fibres are oriented in this direction or within about ±10° of this direction.

During use, the force on a spar in a wind turbine blade is rather complex. When a gust of wind meets the blade, the side of the spar connected to the pressure side surface shell of the blade will mainly be loaded in tension, whereas the side of the spar connected to the suction side surface shell will mainly be loaded in compression. When the gust of wind has passed the wind turbine, the opposite loading will take place (i.e. front (pressure side) in compression and rear (suction side) in tension). As a consequence of the load pattern of the pressure and suction side of the spar, the web sides of the spar, i.e. the sides which are not connected to the surface shells, will mainly experience shear loading.

To provide a high tension strength the first type fibres, which are the main tension strength provider in the sides connected to the surface shells, is preferably oriented unidirectionally in the direction of the expected tension, i.e. in the longitudinal direction of the spar. Materials reinforced with unidirectional fibres (i.e. first type fibres) are usually stronger in tension (fibre stretching) than in compression, since compression may lead to fibre bending or - on macro scale - buckling of the spar suction side. It is therefore crucial to the overall strength of the spar that the sides reinforced by unidirectional first type fibres are prevented from buckling.

In a preferred embodiment, the laminated member is symmetrical in the sense that the pressure side and the suction side comprise the same type and number of layers. However, asymmetrically laminated members and methods of the preparing of such are within the scope of the present invention. In case of asymmetrical laminated members, it is preferred that the pressure side of the laminated member is reinforced more heavily than the suction side of the laminated member.

According to the present invention this may be realised by supporting the layers comprising first type fibres with layers comprising second type fibres. The highest support strength is in theory realised when the second type fibres are oriented orthogonally to the first type fibres (i.e. with second type fibres orthogonal to the longitudinal direction of the spar), however, this orientation provides substantially no shear strength from the second type fibres. Preferably, the orientation should rather be chosen as a compromise between shearing strength and supporting strength of the second type fibres. In a preferred embodiment, aspects of behaviour of thermal properties and strength ratio of the fibre types are furthermore considered (see below). In absolute terms, at least some of the second type fibres in a preferred embodiment are organised in layers, which prevent buckling of the laminated member. These layers comprise second type fibres, wherein at least some of the second type fibres are oriented at biaxial angles of about ±50° to ±85° relative to the orientation of the first type fibres, preferably about ± 55° to ±70° like for example ±60°. In a particularly preferred embodiment with first type fibres being carbon fibres and the second type fibres being glass fibres, the second type fibres are organised with a biaxial angle of about ±60° relative to the orientation of the first type fibre.

Biaxial angles between for example ±50° to ±85° relative to the orientation of the first type fibres should be interpreted as fibres oriented in one or more of the directions in the two ranges of -85° to -50° and +50° to +85°. If the fibres are organised in a band comprising fibres like for example a prepreg and/or a semi-preg and/or woven or non-woven fabric, which is rolled onto the structure in a direction substantially orthogonal to the length of the spar, then the actual orientations of the fibres within the band-like structure are mirrored 45°. For example second type fibres oriented at biaxial angles of between ±50° to ±85° relative to the orientation of the first type fibres correspond to rolling of a band comprising fibres having biaxial angles of between ±40° to ±5° relative to longitudinal direction of the band comprising fibres.

Whereas the task of second type fibres on a side, which is connected to a surface shell, is mainly to support the first type fibres and - as discussed above - to prevent buckling of the layers comprising first type fibres, a further task of the second type fibres in a preferred embodiment is to reinforce and prevent shearing of one or more web sides of the spar. It is well-known that the greatest resistance towards shearing is realised with biaxially oriented fibres at biaxial angles of about ±45° relative to the shear direction, which in this case is parallel to the orientation of the first type fibres. However, due to a preferred method of fabrication involving winding of bands comprising fibres - see below - the range of preferred angles is widened to biaxial angles of about ±35° to ±55° relative to the orientation of the first type fibres.

In a preferred embodiment of the present invention, the laminated member comprises a large number of layers. The layers preventing buckling of the laminated member (i.e. layers comprising second type fibres) are positioned to provide a sandwich-like structure, i.e. at least two of these layers are separated by a distance realised by other types of layers. Sandwich-like structures are known to provide very high efficiency relative to the weight. This may for example be realised by having layers, which prevent buckling of said laminated member, comprising second type fibres, mainly positioned near the innermost layer and/or near the outermost layer of the laminated member. In a particularly preferred embodiment, the layers, which prevent buckling of said laminated member, comprising second type fibres, are the innermost layer(s) and/or the outermost layer(s) of the laminated member.

In a preferred embodiment, the laminated member has a quadrangle cross-section, and a side to be connected to a surface shell is reinforced by first type fibres that are provided in a flange, which is secured to the spar. The laminated member may have one or more layers of flanges like for example 1, 2, 3, 4, 5, 8, 10, 20 or more layers of flanges.

By flange is herein meant a member comprising a collection of oriented first type fibres. Examples of flanges are pre-forms, pre-consolidated pre-forms or other members comprising layers of oriented first type fibres. A flange may comprise other fibres than first type fibres and these fibres may be oriented with another orientation than the first type fibres. However, it is preferred to use flanges with only one type of fibres, i.e. first type fibres, having a unidirectional orientation.

By pre-form is for example meant a composite material comprising fibres and cured or uncured resin. The fibres are preferably provided in layers of oriented fibres like for example individual fibres, fibre tows, fibre tow-pregs, prepregs or semi-pregs. Here, individual fibres, fibre tows and fibre tow-pregs are in some cases advantageous over prepregs, since the individual fibres are less bounded and hence may rearrange easier during subsequent processing. Furthermore, individual fibres, fibre tows and tow-pregs are advantageous over prepregs in that they may be provided in the pre-form with a greater freedom, the price is lower as well as the amount of waste may be lower. The advantage of using a pre-form will increase as the number of layers of oriented fibre tows is increased. Hence, even if the concept of pre-forms includes pre-forms with two layers of fibres, the pre-form preferably comprises at least three layers of oriented fibre tows. A higher number of layers, like e.g. 4, 5, 8, 10, 15, 20, 50,100 or more layers may be used within an individual pre-form. Examples of pre-forms and methods of preparing pre-forms are disclosed in PCT/EP03/02293.

By pre-consolidated pre-form is for example meant a process, whereby gas inside a pre-form is removed and a low porosity pre-form is produced. Pre-consolidation involves redistribution of a resin and optionally a redistribution of fibres. Furthermore, pre-consolidation may involve a limited curing of the resin. Pre-consolidation is particularly useful as it produces a dense, partially cured or uncured pre-form (hereinafter named a pre-consolidated pre-form). Use of pre-consolidated pre-forms for preparation of laminated members and spars provides for good reproducibility, low porosity, high homogeneity, high strength, ability to plastically shaping the pre-consolidated pre-form, ability to be connected to other pre-forms and/or other structures, suitability for automation and long shelf life without premature curing. Examples of pre-consolidated pre-forms and methods of preparing pre-consolidated pre-forms are disclosed in PCT/EP03/02292.

In a preferred embodiment of the present invention, the securing of the flange to the laminated member is preferably realised at least partially by second type fibres being applied off the axis of the first type fibres in the flange. The second type fibres are preferably applied by winding of a band comprising fibres, a fibre tow or a fibre tow-preg around the laminated member. The band comprising fibres is preferably a prepreg, semi-preg, woven or non-woven fabric or equivalent. A fibre tow is a bundle of a number of individual, dry fibres, e.g. 10's, 100's, 1,000's, 10,000's or 100,000's of fibres. Tow-pregs are at least partially impregnated fibre tows.

By semi-preg is meant a partially impregnated collection of fibres or fibre tows. The partial impregnation provides for enhanced removal of gas through or along the dry fibres during consolidation and/or curing. An examples of a semi-preg is a layer of fibres (e.g. glass fibres or any other type of fibres mentioned herein) partially impregnated in the upper part and/or in the lower part.

By gas is herein meant entrapped atmospheric air as well as gaseous products, by-products and starting materials related to the elements involved in the process of preparing the laminated member and the spar.

In a preferred embodiment of the present invention, an edge of the laminated member is reinforced. This may for example be realised if a flange is either wider than the width of a side of the laminated member to be connected to the surface shells, or the flange is placed off axis on the laminated member. The part of the flange extending over an edge of the laminated member may hence be bent around the edge of the laminated member. The flange will then reinforce the edge of the laminated member. A web side of the laminated member may be partially of completely reinforced in the same manner if the part of the flange that extends over an edge of the laminated member is large enough.

In a preferred embodiment, the part of the flange being shaped or bend towards a web side of the laminated member is formed three-dimensionally to enhance the bending. This form may for example comprise a taper section. The taper section may for example starts where the flange is bend and finishes where the flange reaches the substantially flat part of the web side but other embodiments are feasible. A taper section is for example advantageous in allowing for each of the layers in the flange comprising first type fibres to be connected to the layers comprising second type fibres. Hence it provide for a direct connection between most or all of the layers comprising first type fibres and a layer comprising second type fibres. This is particularly advantageous when the first type fibres are relatively stiff like e.g. carbon fibres. Furthermore, a taper section provides for a stepwise change in the stiffness of the laminated member and hence prevents or reduces the formation of stress build-up between the pressure/suction sides and the web sides.

The first type fibres and the second type fibres may be any type of fibres; however, it is preferred that the fibres are selected from the group consisting of carbon fibres, glass fibres, aramid fibres, synthetic fibres (e.g. acrylic, polyester, PAN, PET, PE, PP or PBO-fibres, etc.), bio fibres (e.g. hemp, jute, cellulose fibres, etc.), mineral fibres (e.g. Rockwool™, etc.), metal fibres (e.g. steel, aluminium, brass, copper, etc.), boron fibres and combinations of these. It is preferred but not required that the first type fibres and the second type fibres are selected with respect to each other to realise compatible properties, for example with respect to coefficient of thermal expansion (hereinafter CTE) as discussed below. In a preferred embodiment, the first type fibres are carbon fibres and the second type fibres are glass fibres.

By fibres are herein meant particles having an aspect ratio (length/equivalent diameter) of more than 10. By equivalent diameter is meant the diameter of a circle having the same area as the cross-sectional area of the particle. However, in a preferred embodiment, the fibres are continuous fibres, i.e. fibres that substantially run from one edge of an element to another. It is particularly preferred that the first type fibres are continuous fibres.

By carbon fibres is herein meant fibres where the main component is carbon. Hence, by this definition carbon fibres comprise fibres with graphite, amorphous carbon or carbon nano-tubes. Thus, carbon fibres produced via for example a polyacrylonitril-route and a pitch-based route are comprised by this definition.

The resin in the laminated member may be a thermoplastic or a thermosetting resin, however, it is preferred to use a thermosetting resin for reasons of chemical and thermal stability as well as ease of processing. It is further preferred that the resin is based on unsaturated polyester, polyurethane, polyvinyl ester, epoxy, similar chemical compounds or combinations of these, preferably an epoxy-based resin. The resin may comprise more than one resin system. It may be advantageous to use more than one resin system to be able to optimise the properties of the resin during processing, for example with respect to viscosity and timing/controlling of the curing process. These systems may or may not be based on the same type of resin(s), however, it is preferred that such systems are based on the same type of resin like for example two or more epoxy-based systems. In another preferred embodiment, the resin types differ but the resins are compatible.

The thermal expansion of fibre reinforced plastic depends to a large extent on the thermal properties of the fibres, at least in the longitudinal direction of the fibres. Hence, the thermal expansion behaviour is usually highly anisotropic. When fibres or layers comprising fibres are connected at an angle, e.g. unidirectional first type fibres and biaxial second type fibres, building up of stress is therefore likely to take place when the temperature is changed or residual stress may be present, e.g. from the preparation. Wind turbine blades and spars within wind turbine blades are subjected to great variations in temperature during preparation and use. The temperature may for example vary between up to about +120°C during curing down to about -40°C during extreme weather.

Experimental results have shown that the thermal stress reduces the strength of composite members considerably. It may be theorised that this is due to twisting of fibres on a local scale. Modelling has indicated that the support strength of ±45° biaxially oriented glass fibres (second type fibres) with unidirectional glass fibres (first type fibres) may be reduced as much as up to about 50% due to thermal stress. Large cost reductions and increased design freedom may therefore be realised if this is taken into account in the selection of fibres. The second type fibres should be selected to reduce twisting of the fibres due to thermal expansion. Furthermore, the biaxial angle of the second type fibres in the layers, which support the first type fibres, is of importance. It was found that the best result is obtained when the first type fibres have a coefficient of thermal expansion of about or below zero in the longitudinal direction and the second type fibres have a coefficient of thermal expansion above zero. Hence, examples of highly desirable first type fibres are carbon fibres and aramid fibres. Modelling has indicated that with a relative angle of about 60° between the first type fibres and the second type fibres very desirable second type fibres for these first type fibres are glass fibres and hemp fibres, respectively. As carbon fibres are stronger than aramid fibres, the fibre pair of carbon fibres together with glass fibres are the preferred choice of these.

If first type fibres with CTE considerably above zero, like most of the other types of fibres mentioned herein, are selected then the importance of the biaxial angle of the second type fibres in the layers, which support the first type fibres, increases, and modelling or experimental tests should be employed to optimise the biaxial angle.

The strength and stiffness of a fibre and a layer comprising fibres depend highly on how straight the fibre or fibres are. If there is a hump - even a small one - the strength is decreased, as this spot will lead to a stress concentration. The strength of a laminated member may hence be increased by either reducing the number and size of humps or by ensuring that the fibres are straight, irrespective of presence of humps or other types of uneven substructure. Modelling has shown that humps in the magnitude of millimetres may reduce the strength of a laminated member considerably. In a preferred embodiment of the invention, the first type fibres are therefore provided mainly in straight lines irrespective of uneven substructure. It is preferred that the fibres are provided in straight lines with a tolerance of less than 2 mm over a distance of 20 mm, more preferably with a tolerance of less than 1 mm over a distance of 20 mm and/or with a tolerance of less than 3 mm over a distance of 100 mm, more preferably with a tolerance of less than 2 mm over a distance of 100 mm. Humps in this order of magnitude are about the size of the thickness of a band comprising fibres and care should therefore be taken during preparation of a laminated member according to the invention if second type fibres are provided in bands comprising fibres. If care is not taken during preparation, a band comprising fibres may by accident create wrinkles for example when a roll of band comprising fibres is changed. Such wrinkles are typically greater than the required tolerance.

It is therefore important that the first type fibres are provided in a way ensuring that it is the second type fibres, which adjust to the first type fibres, and not vice versa. This may for example be ensured by providing the first type fibres in pre-forms or pre-consolidated pre-forms, however, experimental results have shown that pre-consolidated pre-forms are the more efficient of these and pre-consolidated pre-forms are therefore preferred.

Another way to ensure that the first type fibres are straight in the laminated member is to subject at least some of the fibres to tension during fibre laying and/or during fixation of the first type fibres and/or during curing of the spar. This may for example be realised by temporary fixing ends of the fibres in an elastic member and pull during one or more of the above mentioned processes.

Wind turbine blades are at risk of being hit by lightning and even if the blade or the spar is equipped with a lightening conducting cable, the laminated member may be damaged by lightning if flashover to a conducting material like for example conducting fibres appears. An example of a conducting material is layers comprising carbon fibre, which may be the first type fibres or the second type fibres. However, if the second type fibres are carbon fibres, then the required potential equalising, which is needed to prevent flashover, may for example occur on the web sides, which are not connected to the surface shells, and further potential equalising may not be required. On the other hand, if the first type fibres are carbon fibres and the second type fibres are not conducting, then the potential between the individual flanges has to be equalised. At least three types of equalising has to be accounted for:

i) between flanges incorporated into the pressure side of the laminated member and flanges incorporated into the suction side of the laminated member;

ii) between flanges incorporated into the same side of the laminated member and being electrically isolated, e.g. by layers comprising second type fibres;

iii) between flanges connected end to end if this is required, e.g. if the flange length is shorter than the full length of the laminated member.

In a preferred embodiment of a laminated member according to the invention, at least two electrically conducting flanges in separated layers are connected electrically to ensure potential equalising between the electronically connected flanges. The electrically conducting connection may for example be realised by a string, band, tow, tow-preg or equivalent comprising electrically conducting material. More specifically, by a metal string or band or by a band, tow or tow-preg comprising electrically conducting fibres like for example carbon fibres. This type of connection is particularly suitable for type i) and ii) connections as described above.

When it comes to connection type iii), i.e. an extension of a flange comprising first type fibres, which are electrically conducting, it is preferred that the adjacent flanges are connected via an electrically conducting interface. I.e. a connection ensuring a good mechanical connection is electrically conducting through the interface between the flanges. This may for example be realised with a connection member comprising a sandwich comprising two layers of carbon veil or equivalent, preferably unimpregnated, and a non-continuous layer of resin incorporated in-between, like for example dots or lines of resin. By carbon veil is for example meant a non-woven, open, gas permeable web of randomly distributed carbon fibres held together by an organic binder. Such sandwich should also enhance removal of gas during consolidation and/or curing. Knowing this type of interface, a person skilled in the art will be able to deduce a number of ways to realise an electrically conducting interface, without departing from the inventive idea of the present invention. It should be noted that if connection type iii) is realised through the interface between adjacent flanges having fibres oriented end to end, then the connection should - in excess of being electrically conducting - typically possess a significant mechanical strength. The mechanical strength is particularly important, if the fibres are used to increase e.g. the tensile strength of the flanges to be connected.

Other types of potential equalising connections are feasible. Such connections may for example comprise conducting or partially conducting material in woven or non-woven fabric, prepreg, semi-preg, etc., or direct connecting the members to be equalised by a conducting member.

In a preferred embodiment, the connection is obtained via layers comprising second type fibres. This is very advantageous as it facilitates a simple design with high flexibility with regard to the number and order of the layers of the laminated member. An example of a way whereby this may be realised is to use a special type of at least partially conducting band comprising fibres.

Such a band comprising fibres should comprise second type fibres and have an electrical connection between a first and a second side. These sides may for example be the main surfaces of the band comprising fibres, but the connection may also be between an edge of the band comprising fibres and a main surface or between two edges. The band comprising fibres may for example be prepreg, semi-preg, woven or non-woven fabric, etc.

The electrical connection may for example comprise a band, string, tow, tow-preg or equivalent, which either go through the band-comprising fibres or around an edge of the band comprising fibres. In another embodiment, two or more conducting bands, strings, tows, tow-pregs or equivalent collaborate to form the electrical connection by one being connected to a first side of the band comprising fibres and another being connected to a second side of the band comprising fibres and the conducting bands etc. being connected electrically. In a third embodiment, dots of electrically conducting material going through the band comprising fibres are used to form the electrical connection. This may for example be formed by a drop of metal. For example, the conducting band, string, tow or tow-preg is wound around the band comprising fibres in rings orthogonal to the edges of the band comprising fibres or – preferably – the band, string, tow or tow-preg is wound around the band comprising fibres in an advancing fashion like for example a helix. More than one band, string, tow or tow-preg may be provided on a band comprising fibres.

The electrically conducting material may for example comprise a metal, like e.g. copper, iron, nickel, chromium, steel, aluminium or alloys comprising any of these metals, and/or the electrically conducting material may comprise conducting fibres like e.g. carbon fibres. Carbon fibre tows or carbon fibre tow-pregs are the preferred fibre type, as carbon fibres are in many cases already present in the laminated member. If a resin is applied with the conducting material, e.g. integrated with carbon fibres in a tow-preg, the resin should be compatible to the resin in the laminated member. In a preferred embodiment, carbon fibres are provided in tow-pregs as this may reduce the formation of electrically conducting dust. Such dust may be detrimental to electronics and should be avoided.

In a preferred embodiment, with reference to the aim of realising very straight first type fibres, it may be advantageous if the electrically conducting connection is realised without changing the thickness of the band comprising fibres non-uniformly, for example by having points or lines with greater thickness as the bulk of the band comprising fibres. However, a minor variation is acceptable as discussed in the section regarding tolerance of the flatness. The limited size of carbon fibres in the form of for example a small, optionally flat tow or tow-preg comprising dry, impregnated or partly impregnated carbon fibres means that these are advantageous for this purpose. In a preferred embodiment, the electrical conductor is incorporated into the band comprising fibres like for example in a band comprising glass fibres, where some of the glass fibres have been replaced with conducting material like carbon fibres or a metal strip. This provides for a band comprising fibres having an equally uniform thickness as a band comprising fibres without an incorporated conductor.

When designing a band comprising fibres according to the invention, it should be emphasised, that the goal of the electrical conduction connection is not to conduct the current of a lightning (in a preferred embodiment this is realised by a dedicated lightning conductor) but only to equalise the potential, which may in theory be realised by conducting an infinitesimal current. The conductivity of the electrical connection and the electrical conducting members of the laminated member need therefore not be particularly high. For example, the conductivity of a small tow of carbon fibres should usually provide sufficient conductivity.

The spar may have an integrated base member, which is preferably prepared separately. This may be advantageous since the requirement for the base part of the spar may be different to the requirement of the main part of the spar. Typically, the base part also requires relatively large dimensions to realise a stable connection to the wind turbine, and it is hence advantageous, if the base member may be prepared by more affordable materials and/or production methods. The base member is for example a fibre reinforced material and comprises first type fibres, second type fibres, another type of fibres or a mixture of fibres. However, it is preferred that the base member is prepared from glass fibres as this is an affordable material. In another preferred approach, carbon fibres or a combination of carbon fibres and glass fibres are used for reinforcement. This is particularly useful when the first type fibres and the second type fibres are carbon fibres and glass fibres, respectively, since this provides for highly compatible properties.

The spar may have an integrated tip member, which is preferably prepared separately. It is advantageous to prepare a tip member separately, as very long structures may be difficult to prepare in one go. Furthermore, the load on the tip may be considerably different from the load on the rest of the spar and other types of material and/or production methods may be advantageous from an economical or mechanical point of view. In a preferred embodiment according to the present invention, the tip member is a fibre reinforced material and comprises first type fibres, second type fibres, another type of fibres or a mixture of fibres. However, it is preferred that the tip member is prepared from glass fibres as this is an affordable material. In another preferred approach, carbon fibres or a combination of carbon fibres and glass fibres are used for reinforcement. This is particularly useful when the first type fibres and the second type fibres are carbon fibres and glass fibres, respectively, since this provides for highly compatible properties.

Tip members and base members may comprise one or more parts or sections, but it is preferred that they are prepared for and provided to the integration with the laminated member in one piece (i.e. one tip member and/or one base member per spar). The members may be uncured (e.g. to be cured separately after connecting to the spar or together with at least a part of the rest of the spar), partially cured (e.g. pre-consolidated) or cured prior the connecting to the laminated member.

In a preferred embodiment of the invention, the tip member and/or the base member is/are connected to a laminated member via a connection, which comprises a transition zone with a layered structure. The number of layers may vary considerably dependent on the design of the connection and the size and type of composite members. In some cases only a few layers like for example 2, 3, 4, 6 or 10 layers are needed, whereas in other cases, a higher number like for example 20, 30, 50, 100 or more layers are needed to obtain the desired quality of the connection. The structure of the transition zone is layered to enhance controlled orientation of the fibres, to facilitate optimisation of the reduction of stress between the composites as well as to facilitate ease of production like for example enhance suitability for automation of the production. Each of the layers of the layered structure comprises first type fibres, second type fibres, a combination of these, the fibre type(s) of the tip or base member or other fibre types having substantially the same properties as these fibre types or a combination of these. In a more preferred embodiment of the connection, the fibres of each layer consist of first type fibres, second type fibres or the fibre type of the tip or base member.

A transition zone of this type may comprise two or more types of layers comprising fibres; one type comprising fibres having substantially the same fibre composition as the laminated member and one type comprising fibres having substantially the same fibre composition as the tip or base member. The two types of layers are partially interlaced in the sense that in a part of the transition zone, at least one of the types of layers extend beyond the other type(s) of layers. At least some of this part of the transition zone is used for the connection with the laminated member or tip/base member having substantially the same fibre composition. Due to the interlaced layers, the contact surface is very high and the connection is hence under the right conditions very strong. In a preferred embodiment, both types of layers extend beyond the other in a part of the contact zone. In a preferred embodiment, the transition zone is integrated at least partially with the tip or base member and/or with the laminated member.

A laminated member as described herein may for example be prepared according to a method comprising the following steps:

- providing a mould core,
- providing a layer comprising mainly unidirectionally oriented first type fibres,
- providing a layer comprising mainly biaxially oriented second type fibres,
- optionally curing the laminated member.

The mould core may or may not be removed from the prepared laminated member, however, it is preferred to remove the mould core as it may be reused and the integration of a mould in the final spar will lead to an increase of the weight of the spar. It is preferred that the thermal expansion of the mould core is greater than the thermal expansion of the laminated member as this will facilitate the release of the mould core during cooling after the curing reaction.

The laminated member comprises one or more layers comprising first type fibres. A laminated member may for example have 1, 2, 3, 4, 5, 8, 10, 20 or more layers comprising mainly unidirectionally oriented first type fibres. The layers comprising second type fibres, which are mainly biaxially oriented, may be positioned above, below or in-between the layers comprising first type fibres. In a preferred embodiment, at least one layer comprising second type fibres is provided in-between all of the layers comprising first type fibres. In another preferred embodiment, two or more layers of second type fibres are provided between at least two of the layers comprising first type fibres. In a further preferred embodiment according to the invention, the innermost and the outermost layer of the laminated member are layers comprising second type fibres.

The laminated member may optionally be cured if it is desired to use cured laminated members for the preparation of the spar. This may for example be relevant if the thermal expansion of the members to be integrated into the spar exhibits considerable differences in thermal expansion and too great residual thermal stress may arise from a combined cure of all members to be incorporated in the spar.

In a highly preferred embodiment of the present invention, the layers comprising first type fibres are provided in pre-forms, pre-consolidated pre-forms or flanges. It may be advantageous to provide the first type fibres in pre-consolidated pre-forms, as this facilitates the first type fibres being straight, as discussed elsewhere.

The second type fibres are in a preferred embodiment provided in bands comprising fibres, preferably biaxially oriented second type fibres. Examples of bands are prepregs, semi-pregs, woven or non-woven fabrics or equivalent relatively flat collection of fibres, which may comprise other material like for example a resin. Such bands are readily available and the band shape facilitates the distribution of the fibres. In a preferred embodiment, the band comprising fibres is having an electrical connection between a first and a second side and hence contributes to potential equalising between layers comprising first type fibres. The layers comprising second type fibres may for example be distributed by winding of the band comprising fibres around the laminated member and if the winding is performed with a slight bias, a very even layer of second type fibres may easily be distributed over a substantial part of the laminated member. If, for example, the slight bias is between 1/4 to 1x the width of the band comprising fibres per rotation, then between 1 to 4 layers of band comprising fibres may be distributed on the laminated member. More specifically, it is preferred that the slight bias is 1/4, 1/3, 1/2 or 1x the width of the band comprising fibres as this corresponds to 4, 3, 2 or 1 layer(s) of band comprising fibres, respectively, with a uniform number of layers throughout all of the laminated member.

In a preferred embodiment, the layers comprising second type fibres are provided by winding a band comprising biaxially oriented second type fibres onto the laminated member. The biaxial angles of the outermost and/or the innermost layer(s) are about ±50° to ±85° relative to the orientation of the first type fibres, preferably about ±55° to ±70° like for example about ±60°. If further layers comprising second type fibres are provided, these layers may have the same orientation, but it is preferred that at least some of these further layers - particularly the layers placed away from the inner or the outer surface of the laminated member - comprise oriented second type fibres with biaxial angles of about ±35° to ±55° relative to the orientation of the first type fibres and more preferably about ±45°. The layers comprising second type fibres and having the first of the above orientations may involve one or more layers (e.g. 1, 2, 3, 4, 5, 10 or more layers) near the innermost or constitute the innermost and/or the outermost layers of the laminated member. The layers comprising second type fibres and having the latter of the above orientations typically involve layers, which are placed away from the surfaces of the laminated member.

Even if this is not a requirement for either, the laminated members or the methods of preparing laminated members according to the invention, the laminated members are typically prepared with substantially the same layers on each of the sides to be connected to the surface shells of the blade. Hence, flanges are typically provided on two sides at a time, and temporary fixation of the first pre-form, pre-consolidated pre-form or flange is therefore required while the second pre-form, pre-consolidated pre-form or flange is placed on the laminated member. Furthermore, the layers comprising second type fibres may be placed by winding of a band comprising second type fibres. This may for example be realised by rotating the roll with a band comprising fibres around the laminated member or by rotating the laminated member while slowly biasing the roll with the band comprising fibres sidewards along the laminated spar. If the laminated spar is rotated, then both flanges must be temporarily fixed prior to rotating. In a preferred embodiment, a pre-form, a pre-consolidated pre-form or a flange comprising first type fibres are therefore temporarily fixed (until it is fixed by the layers comprising second type fibres) to the laminated member by a string, band, tow or tow-preg comprising fibres. The string, band, tow or tow-preg may beside fibres for example also comprise a resin and/or additives. The fibres are preferably either first type fibres or second type fibres, but any type of fibres mentioned in herein is usable. If potential equalising is required, it is preferred that the string, band, tow or tow-preg is conducting, as this may enhance potential equalising between the pre-forms, pre-consolidated pre-forms or flange on the pressure side and the suction side of the laminated member.

In a preferred embodiment of a method for preparing a laminated member, which comprises electrically conducting material like for example carbon fibres, according to the invention, the method further comprises the step of providing a means for potential equalising between elements of said laminated member. These means may for example comprise a string, band, tow or tow-preg comprising fibres and/or metal. The string, band, tow or tow-preg may beside fibres for example also comprise a resin and/or additives, however, for example a tow of dry fibres may also be feasible. In a preferred embodiment, the means for potential equalising is a tow-preg comprising carbon fibres. Examples of suitable metals are copper, iron, nickel, chromium, steel, aluminium or alloys comprising any of these metals. The fibres are preferably carbon fibres. In a particularly preferred embodiment, a string, band, tow or tow-preg, which is used for potential equalising between elements of the laminated member, is made sufficiently strong that at the same time it may be used for temporary fixing of a pre-form, a pre-consolidated pre-form or a flange comprising first type fibres on preceding layers of the spar.

When the second type fibres are provided in a band comprising fibres like for example a prepreg, semi-preg, woven or non-woven fabric or equivalent, it is preferred that the means for potential equalising between elements of the laminated member comprise a band comprising fibres, which has an electrical connection between a first and a second side of the band comprising fibres. Particularly, it is preferred that the band comprising fibres has an incorporated helix of conducting material.

A spar according to the invention may be prepared by a method comprising the steps of:

- providing a laminated member as described herein,
- connecting the laminated members if more than one laminated member is present,
- optionally providing a vacuum enclosure around said members,
- providing a pressure on said members, preferably via a vacuum within said vacuum enclosure,
- initiating the curing reaction, preferably by heating and
- curing the member(s).

The spar may comprise one or more laminated members as described herein. If more than one laminated member is present, then the laminated members may be connected by any suitable type of connection known by a person skilled in the art or connections, which may be derived by a person skilled in the art on the basis of the co-pending PCT-application on April 22, 2003 by the same inventors. The laminated members may be uncured, cured or pre-consolidated prior to integration in a spar, however, it is preferred that the laminated member is either uncured or pre-consolidated prior to the integration. The pressure to be provided on the connected members to be integrated in the spar may for example be provided by a press or via a vacuum within a vacuum enclosure around the members. It is preferred to use a vacuum as this facilitates the removal of gas from within the laminated member and hence provide for a stronger spar. If the pressure is applied via a vacuum, then a vacuum enclosure has to be provided prior to the applying of the pressure. In a particular embodiment, where one or more members to be integrated into the spar is cured prior to the connection, the vacuum enclosure need not cover the formerly cured part of the spar. Likewise, this part of the spar need not have the curing reaction initiated for example by heating unless the heating will lead to a reduction of residual thermal stress. The curing reaction may as discussed for example (and preferably) be initiated by heating, but other types of initiation may be applied like for example radiation by UV-light or more energetic light or by pressure. The curing reaction should be controlled carefully to prevent curing failures. For example, the temperature during curing should be controlled, as curing reactions overall are exothermic reactions and too high temperature may lead to degradation of the resin as well as excessive residual thermal stress, which may lead to fibre-twisting and reduction of strength, as discussed elsewhere. For the same reason, the cooling after curing should also be controlled.

If a tip member or a base member, which for example may be prepared separately from the laminated member, is to be integrated with the spar, the method according to the invention of preparing the spar should further comprise the steps of providing a base member and/or a tip member and connecting the base member and/or tip member to a laminated member, which is incorporated in the spar. The connecting is preferably performed according to the method and connection described herein, but any type of connection, which provides for a stable mechanical and optionally electrical connection, may be utilised. In a preferred embodiment, the connection is realised prior to or during the curing of the laminated member.

As it will be appreciated by a person skilled in the art, the laminated member as revealed in present invention is particularly useful for production of a spar for a wind turbine blade. This is mainly due to the nature of the sides of the laminated member being prepared for collaboration with the blade surface shells and that the laminated member is particularly designed to withstanding the loads, which are expected in a wind turbine blade.

The band comprising fibres having an electrical connection between two sides are particularly useful for providing an electrical connection between electrically conducting members. Particularly, the band comprising fibres is advantageous for use in relation to a wind turbine like in a wind turbine blade or a spar or laminated member in a wind turbine blade.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a schematic overview of a wind turbine,

Fig. 2 shows schematic examples of laminated spars in cross-sectional view,

Fig. 3 shows the principle of a method of applying second type fibres, which are incorporated in a band comprising fibres,

Fig. 4 shows preferred embodiments of a band comprising fibres for potential equalising, and

Fig. 5 shows conditions regarding layering of bands comprising fibres.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

An important application of the product and the method according to the present invention is the technical field of wind turbines and particularly wind turbine blades.

A wind turbine 2 is shown in Fig. 1A. The turbine 4 is placed on a tower 5 and wind turbine blades 6 are connected symmetrically to the turbine. Typically, a wind turbine has three blades, however, two, three, four or more blades are feasible. An exploded view of a wind turbine blade is shown in Fig. 1B, where the spar 8 is seen inside the surface shells 16. In a preferred embodiment, the wind blade surface shells 16 comprise two parts, a pressure side surface shell 16a and a suction side surface shell 16b. The spar comprises at least one laminated member 14 and may further comprise a base member 10 and/or a tip member 2 as the spar shown in Fig. 1C. However, the spar need not have a tip member or a base member, as the functions of these members may be integrated into one or more laminated members. The spar may comprise more than one laminated member like for example two, three, four or more laminated members. This is a particularly interesting option when very long blades are produced. Typically, the wind turbine blade is also equipped with at least one lightning conductor cable or equivalent. The lightning conductor may for example be connected to the inner or the outer side of a surface shell, placed inside the laminated member or in another place inside the blade.

Examples of cross-sections of laminated members according to the invention are sketched in Fig. 2. The cross-sections are sketched with a distance between the layers to provide a better overview. In a real laminated member, substantially all air between the layers are removed and the layers are connected and fixed to each other to form a solid, dense laminated composite.

In Fig. 2A, a laminated member 14 has only one layer of flanges 20 on the sides 24 to be connected to the surface shells 16. The flange is bent around the edges of the laminated member 30 to provide extra strength to the edges and the web sides 26 not to be connected to the surface shells 16. In the centre of the laminated member, a mould core is found. The mould core 18 may or may not be removed after the preparation of the laminated member or the spar. It is preferred to remove the mould core 18 to reduce cost of preparing new mould cores and to reduce weight of the spar. A layer 22 comprising second type fibres is placed on the mould core. More than one layer like e.g. two, three, four or more layers may be provided if this is needed to realise the required strength (supporting strength and/or shear strength) of the layer(s). It is preferred that the layer(s) 22a is(are) oriented to provide supporting strength to support the flanges comprising first type fibres. The second type fibres in the layers 22a may for example be oriented biaxially at about ±60° relative to the fibre orientation of the first type fibres, however, the exact orientation or the second type fibres should be decided based on experimental tests or modelling on the chosen fibre types, etc., of the system. Further layer(s) 22b comprising second type fibres may next be provided and this/these layers are preferably oriented to provide shear strength of the web sides 26 not to be connected to the surface shells 16. The second type fibres in the layers 22b are preferably oriented biaxially at about ±45° relative to the fibre orientation of the first type fibres.

Then a first flange is placed on the laminated member and temporarily fixed to the laminated member by a fixing member like for example by tying with a string, a band or a tow for example comprising fibres, or by adhesive. It is preferred to use conducting fibres, as these will provide a means for potential equalising between the flanges on the pressure side and on the suction side of the laminated member. Then the laminated member is turned half a rotation and a second flange is temporarily fixed to the laminated member in the same manner as the first flange.

Layer(s) comprising second type fibres 22a and optionally 22b are provided on the laminated member to further fix the flanges, support the flanges and optionally further strengthen the shear strength of the laminated member web sides 26.

In Fig. 2B, a sketch of a laminated member having several flanges comprising first type fibres on each of the sides 24 to be connected to the surface shells is shown. Each of the lines indicating a layer 22 comprising second type fibres should be understood as one or more layers comprising second type fibres. It should be noted that the layers 22a comprising second type fibres mainly supporting the layers 20 comprising first type fibres are positioned near or on the innermost and outermost layers of the laminated member. This is due to these positionings providing for the highest yield of these layers, whereas the layers 22b are not as sensitive to the positioning relative to the innermost and/or outermost layers.

In a preferred embodiment, the fibre composition and/or the types of fibres of the layers 22a and 22b are not the same. Particularly, it is preferred that the fibre composition of the layers 22a are optimised to support the first type fibres and the fibre composition of the layers 22b are optimised to obtain a high shear strength in the web sides 26. In other words, this preferred embodiment of the invention may comprise three different types of fibres.

It should be understood that the shown examples of cross-sections are merely examples of how a laminated member according to the invention may be prepared and large variations in the number of layers and positioning of the layers are feasible within the scope of the invention.

In a preferred embodiment of the invention, where an element of the laminated member is electrically conducting, the layers comprising second type fibres are provided with an electrical connection between the two main sides. This may for example be realised by utilising a band comprising fibres as shown in Fig. 4 for providing the layers comprising second type fibres.

A preferred method of providing layers comprising second type fibres involves rolling layers of band comprising fibres comprising second type fibres onto the laminated member. The band comprising fibres is typically provided on a roll and is distributed by rotating the laminated member and slowly moving the roll with band comprising fibres sidewards along the laminated member. Alternatively, the roll with band comprising fibres is rotated about the laminated member while slowly moving the roll sidewards. The rate of the sidewards movement is adjusted to the rotation of or about the laminated member and depends on the desired number of layers. In Fig. 3A, a laminated member 14 is rotated about an axis 36. A layer 20 comprising first type fibres are temporarily fixed to the laminated member 14 by fixing members 28 to prevent the layer comprising first type fibres to move or fall off during rotation of the laminated member 14. A layer 22 comprising second type fibres are distributed on the laminated member during the rotation while the roll is moved sidewards in the direction of the arrow 29. It is observed that the layer is positioned to cover half of the preceding layer and hence provide two layers of second type fibres.

The slow movement of the roll sidewards will bias the orientation of the fibres relative to the length of the laminated member. However, the sidewards movement is typically only a fraction of the width of the band comprising fibres on a full rotation and will hence only shift the orientation slightly relative to the orientation of the first type fibres.

It is preferred that the sidewards movement is adjusted to provide a constant number of layers on the laminated member. Examples of preferred embodiments of this is shown in Fig. 3B, C, D and E, where the constant number of applied layers are 1, 2, 3 and 4, respectively, by having an overlay of 0, 1/2, 2/3 and ¾, respectively. Higher number of layers may be provided in this manner, however, if larger number of layers are needed, it is preferred to provide the layers in two or more goes (e.g. 8 layers in 4 + 4 layers). If this approach is taken when electrically conducting material is present in the laminated member (i.e. potential equalising is needed), then special care should be taken to ensure sufficient electrical contact between the electrically conducting materials.

As described previously, a particularly preferred embodiment comprises a band 40 comprising fibres with an electrical connection between two sides of the band comprising fibres. In Fig. 4, some preferred embodiments of such a band comprising fibres are shown. These embodiments are in no sense limiting to the scope of such a band and should be considered as examples only. For example, the band comprising fibres may alternatively comprise drops of conducting material, which is connected to two sides of the band. In Fig. 4, the lighter lines indicate that the conducting material is below the band comprising fibres and a black line indicates that the conducting material is above or in the top of the band conducting fibres.

The band comprising fibres shown in Fig. 4A is an example of an electrically conducting connection around an edge of the band comprising fibres. This provides for a very good electrical connection between the sides as well as a large contact area on the main sides. The band comprising fibres shown in Fig. 4A has a helix of a conducting material 42 either incorporated or wound around it. The main fibres incorporated into the band comprising fibres may or may not be oriented in the same manner as the conducting material. For example, the main fibre of the band comprising fibres may be unidirectional fibres, biaxial fibres or randomly distributed fibres, however, it is preferred that the main fibres are distributed unidirectionally or biaxially. In a preferred embodiment, the helix is oriented to reduce the twisting of fibres as described elsewhere in the present invention. When the conducting material is wound around the band comprising fibres, the conducting material may be unfixed, partially fixed or completely fixed to the band comprising fibres. For example, the nature of the winding around the band comprising fibres may sufficiently hold the conducting material. When the conducting material is at least partially fixed relative to the band comprising fibres, this may for example be by the resin of the band comprising fibres, by an external adhesive or by mechanical means like e.g. stitching. Examples of external adhesives are the adhesive in a tow-preg, directly applied adhesive, etc. In a preferred embodiment, a fibre tow or tow-preg comprising carbon fibres are integrated into the band comprising fibres to form a flat surface. The conducting material need not be applied in a helix-like pattern. Rings, straight lines of conducting material, etc. may be provided within the scope of the present invention to realise the same type of conducting band-comprising fibres.

In Fig. 4B, a number of strings, pins, fibre tow, fibre tow-pregs or equivalent of conducting material are provided with random distribution through the band comprising fibres. In Fig. 4E, the relative positioning of the elements are indicated in a cross-sectional view. The lighter straight line indicates the band comprising fibres and the black full line indicates the positioning of the conducting member. This provides for a good electrical contact between the two main sides of the band comprising fibres. The contact area is also very good. However, if the band comprising fibres is applied in more than one layer, the contact area will decrease dramatically, as the contact will hence depend on the connection between the conducting members in covering parts of the band comprising fibres. This is an equivalent to that described below in relation to Fig. 4C.

In Fig. 4C, an embodiment of a band comprising fibres with individual strips, strings, bands or tows of conducting material is used. The conducting material may for example be incorporated into the band comprising fibres to form a hybrid band comprising fibres. If the band comprises only one layer comprising fibres, the conducting material will have a rather large contact area to both sides of the band comprising fibres and in this case a good electrical connection may be realised but only if the band is applied in one layer only. If more layers are provided, the connection relies on point contact (see section on winding of band comprising fibres). However, if the band comprising fibres has more than one layer comprising fibres (as the example shown in Fig. 4C), it is important that a good electrical connection is realised between the strips of the two sides, however, it is adequate if this connection is realised during the consolidation or curing of the structure. The point contacts 43, where electrical connection is obtained, are indicated on Fig. 4C. These points may form hot spots that heat up during conducting and may lead to considerable damage if the conductivity is not sufficiently high.

Fig. 4D shows a preferred embodiment of the band comprising fibres, shown in Fig. 4B. In Fig. 4D, the conducting members are oriented orthogonally to the length of the band comprising fibres. This provides for a band with decreased sensitivity of conductivity towards being provided in more than one layer when the layers are formed as indicated in Fig. 3C to E.

The bands comprising fibres shown in Fig. 4A and D as well as equivalent embodiments, which a person skilled in the art may derive, are highly preferred embodiments. The band comprising fibres shown in Fig. 4D may under some conditions provide a better conductivity than the band comprising fibres shown in Fig. 4A due to a shorter conduction path. However, the band shown in Fig. 4A may be easier to manufacture.

In Fig. 5 the conditions regarding layering of bands comprising fibres are illustrated. In Fig. 5A two layers of a band comprising fibres having a conducting helix is shown in an overview. The areas having dark hatching indicate areas in contact with an upper and a lower flange, respectively. This is also illustrated in Fig. 5B where a cross-section of the band shown in Fig. 5A is sketched. The band comprising fibres is placed to provide two layers of band comprising fibres over the lower flange 44, for example as described in Fig. 3. Layers comprising second type fibres 50 are observed having a helix of conducting material 42 surrounding them. It is observed that an area 52 of the band comprising fibres is in electrical connection to the lower flange and another area 54 of the same band comprising fibres is in electrical connection to the upper flange. As the two areas are connected via the electrically conducting material 42, a potential equalising connection is formed between the lower flange 44 and the upper flange 46.

In Fig. 5C, the overview equivalent to Fig. 5A is shown for the band comprising fibres shown in Fig. 4D. It is observed that large contact areas and direct connection between the two sides are present.

In Fig. 5D, a hybrid band comprising fibres, i.e. a band having some conducting fibres incorporated together with the second type fibres. The fibres indicated by the substantially horizontal lines are positioned in the top part of the band comprising fibres, whereas the substantially vertical lines indicate conducting material in the lower part of the band comprising fibres. It is observed that even though a large contact area is provided on both sides, the current must pass through the points 43. It is obvious that - if two such layers are positioned to form two layers - more points like 43 are formed leading to an increased risk of a weak electrical connection.

When preparing a band comprising fibres, which is to be used for potential equalising, it is highly important to consider the quality of the electrical connection between the sides of the band. By quality is here meant the overall resistance of the connection and the lower the resistance, the better the quality. The main contribution to the overall resistance is i) the contact resistance between the conducting material and the flanges and ii) the resistance between the conducting material on either side.

When considering conducting material like carbon fibres, the resistance of the fibres (e.g. fibre tows, tow-pregs or equivalent) is typically negligible in the longitudinal direction of the fibres compared to the contact resistance. However, if the electrical current is forced to jump from one conductor to another, for example as in the points 43 in Fig. 4B, where the electrical conduction relies on point contact, the resistance is likely to be considerably larger. The contact resistance depends highly on the contact area, i.e. the greater the contact area, the lower the resistance.

TABLE OF IDENTIFICATION

2	Wind turbine
4	Turbine
5	Tower
6	Wind turbine blade
8	Spar
10	Base member
12	Tip member
14	Laminated member
16	Wind blade surface shell
16a	Pressure side surface shell
16b	Suction side surface shell
18	Mould core
20	Layer or flange comprising first type fibres
22	Layer comprising second type fibres
22a	Layer mainly supporting the layers comprising first type fibres
22b	Layer mainly reinforcing the web sides
24	Side to be connected to a surface shell
26	Web side
28	Fixing members
29	Arrow indicating the movement of the roll with layers comprising second type fibres
30	Edge of laminated member
32	Means for temporarily fixing of flange comprising first type fibres
34	Roll with layers comprising second type fibres
36	Axis of rotation of laminated member
40	Band comprising fibres
42	Electrically conducting material
43	Point where good electrical connection is required
44	Upper flange
46	Lower flange
50	Second type fibres
52	Area with electrical contact upwards
54	Area with electrical contact downwards

CLAIMS

1. A wind turbine blade comprising at least two surface shells and a spar, said spar comprises a laminated member having an adjusted quadrangle cross-section, where a side to be connected to a surface shell is mainly reinforced by substantially unidirectionally oriented first type fibres, said first type fibres being supported by second type fibres and said second type fibres are mainly oriented off the direction of said first type fibres.

2. A laminated member according to claim 1, c h a r a c t e r i s e d in that a web side is mainly reinforced by second type fibres, preferably said second type fibres are oriented to prevent shearing of said web side, more preferably at least some of said second type fibres are organised in layers comprising second type fibres oriented at biaxial angles of about ±35° to ±55° relative to the orientation of the first type fibres and more preferably about ±45°.

3. A laminated member according to any of the claims 1 to 2, c h a r a c t e r i s e d in that at least some of said second type fibres are organised in layers, which prevent buckling of said laminated member, comprising second type fibres, preferably said layers, which prevent buckling of said laminated member, comprise second type fibres oriented at biaxial angles of about ±50° to ±85° relative to the orientation of the first type fibres, preferably about ± 55° to ±70° and most preferably about ±60°.

4. A laminated member according to claim 3, c h a r a c t e r i s e d in that said layers, which prevent buckling of said laminated member, comprising second type fibres, are mainly positioned near the innermost layer and/or near the outermost layer of said laminated member, more preferably the layers, which prevent buckling of said laminated member, comprising second type fibres, are the innermost layer(s) and/or the outermost layer(s) of said laminated member.

5. A laminated member according to any of the claims 1 to 4, having an adjusted quadrangle cross-section, where a side to be connected to a surface shell is reinforced by first type fibres, c h a r a c t e r i s e d in that first type fibres are provided in a flange, which is secured to the spar.

6. A laminated member according to claim 5, characterised in that said flange is secured to the laminated member at least partially by second type fibres being applied off the axis of the first type fibres, preferably by winding of a band comprising fibres and/or a fibre tow and/or a fibre tow-preg around said laminated member.

7. A laminated member according to claim 5, characterised in that an edge of said laminated member is reinforced, preferably by bending a side of a flange around said edge of said laminated member.

8. A laminated member according to claim 5, characterised in that a web side is reinforced at least partially by first type fibres, preferably by bending a side of a flange around an edge of said laminated member.

9. A laminated member according to any of the claims 1 to 8, characterised in that the first type fibres and the second type fibres are selected to prevent or reduce the twisting of the fibres due to thermal expansion, preferably this is realised by the first type fibres having a coefficient of thermal expansion about or below zero in the longitudinal direction and the second type fibres having a coefficient of thermal expansion above zero.

10. A laminated member according to claim 9, characterised in that the pair of first type fibres and second type fibres are carbon fibres together with glass fibres or aramid fibres together with hemp fibres, preferably carbon fibres together with glass fibres.

11. A laminated member according to any of the claims 1 to 10, characterised in that the strength and/or the stiffness of the spar are increased by providing the first type fibres mainly in straight lines irrespective of uneven substructure, preferably with a tolerance of less than about 2 mm over a distance of 20 mm and more preferably with a tolerance of less than 1 mm over a distance of 20 mm and/or with a tolerance of less than 3 mm over a distance of 100 mm, more preferably with a tolerance of less than 2 mm over a distance of 100 mm.

12. A laminated member according to claim 11, c h a r a c t e r i s e d in that the first type fibres are provided in pre-forms or pre-consolidated pre-forms, preferably in pre-consolidated pre-forms.

13. A laminated member according to claim 11, c h a r a c t e r i s e d in that the first type fibres are subjected to tension during fibre laying and/or fixation and/or curing of the spar.

14. A laminated member according to any of the claims 1 to 13, comprising pre-forms comprising first type fibres and said first type fibres are electrically conducting, wherein at least two flanges in separated layers are connected electrically to ensure potential equalising between said electronically connected flanges, preferably by a string, band, tow, tow-preg or equivalent comprising electrically conducting material and more preferably by a metal string or band or by a string or band comprising electrically conducting fibres like for example carbon fibres.

15. A laminated member according to any of the claims 1 to 14, comprising flanges comprising first type fibres and said first type fibres are electrically conducting, wherein at least a pair of adjacent flanges is connected electrically via an electrically conducting interface.

16. A laminated member according to any of the claims 14 to 15, c h a r a c t e r i s e d in that an electrical connection between at least two pre-forms is obtained via layers comprising second type fibres.

17. A laminated member according to any of the claims 1 to 16, wherein the first type fibres are selected from the group consisting of carbon fibres, glass fibres, aramid fibres, synthetic fibres (e.g. acrylic, polyester, PAN, PET, PE, PP or PBO-fibres, etc.), bio fibres (e.g. hemp, jute, cellulose fibres, etc.), mineral fibres (e.g. Rockwool™, etc.), metal fibres (e.g. steel, aluminium, brass, copper, etc.), boron fibres and combinations of these, preferably carbon fibres.

18. A laminated member according to any of the claims 1 to 17, wherein the second type fibres are selected from the group consisting of carbon fibres, glass fibres, aramid fibres, synthetic fibres (e.g. acrylic, polyester, PAN, PET, PE, PP or PBO-fibres, etc.), bio fibres (e.g. hemp, jute, cellulose fibres, etc.), mineral fibres (e.g.

Rockwool™, etc.), metal fibres (e.g. steel, aluminium, brass, copper, etc.), boron fibres and combinations of these, preferably glass fibres.

19. A laminated member according to any of the claims 1 to 18, further comprising a resin, said resin being based on unsaturated polyester, polyurethane, polyvinyl ester, epoxy, thermoplastics, similar chemical compounds or combinations of these, preferably said resin is based on epoxy.

20. A spar according to claim 1, further comprising a base member for connecting said blade to a wind turbine, said base member comprises reinforcement fibres, preferably said base member being reinforced mainly by glass fibres and/or carbon fibres and more preferably mainly by glass fibres.

21. A spar according to claim 1 and/or 20, further comprising a tip member for supporting the outer part of the wind turbine blade, preferably said tip member being reinforced mainly by glass fibres and/or carbon fibres, more preferably by glass fibres.

22. A spar according to any of the claims 20 to 21, wherein said tip member and/or said base member is connected to a laminated member according to any of the claims 2 to 19 via a connection and said connection comprises a transition zone having a layered structure, preferably said transition zone comprises layers comprising fibres, each of said layers comprising first type fibres and/or second type fibres and/or the fibre type(s) of the tip or base member, more preferably the fibres of each layer consist of either first type fibres, second type fibres or the fibre type(s) of the tip or base member.

23. A band comprising second type fibres, c h a r a c t e r i s e d in having an electrical connection between a first and a second side, said band comprising fibres is a prepreg, semi-preg, woven or non-woven fabric or equivalent.

24. A band comprising fibres according to claim 23, c h a r a c t e r i s e d in that said electrical connection comprises a band, string, tow, tow-preg or a through-going point of electrically conducting material, which is at least partially integrated with said band comprising fibres, preferably a band, string, tow or tow-preg is wound

around the band comprising fibres, more preferably said band, string, tow or tow-preg forms a helix around said band comprising fibres.

25. A band comprising fibres according to any of the claims 23 to 24, c h a r a c t e r i s e d in that said electrically conducting material comprises a metal, like e.g. copper, iron, nickel, chromium, steel, aluminium or alloys comprising any of these metals, or conducting fibres, like e.g. carbon fibres, preferably said electrically conducting material is carbon fibre tows or carbon fibre tow-pregs.

26. A method of preparing a laminated member for a spar comprising the steps of:
- providing a mould core,
- providing a layer comprising mainly unidirectionally oriented first type fibres,
- providing a layer comprising mainly biaxially oriented second type fibres,
- optionally curing said laminated member.

27. A method according to claim 26, c h a r a c t e r i s e d in that the layers comprising mainly unidirectionally oriented first type fibres are provided in pre-forms, pre-consolidated pre-forms or flanges, preferably in pre-consolidated pre-forms.

28. A method according to any of the claims 26 to 27, c h a r a c t e r i s e d in that said layers comprising mainly biaxially oriented second type fibres are provided in bands comprising fibres, said band comprising fibres is a prepreg, semi-preg, woven or non-woven fabric or equivalent.

29. A method according to claim 28, c h a r a c t e r i s e d in that said layers comprising mainly biaxially oriented second type fibres comprise a band comprising fibres according to any of the claims 23 to 25.

30. A method according to any of the claims 28 to 29, c h a r a c t e r i s e d in that said layers comprising second type fibres are provided by winding a band comprising fibres around said laminated member, preferably with a slight bias during winding to produce an even layer of second type fibres over a substantial part of said laminated member, more preferably said slight bias is between about 1/4 of the width to 1x the width of said band comprising fibres per rotation and most preferably said slight bias is 1/4, 1/3, 1/2 or 1x the width of said band

comprising fibres corresponding to 4, 3, 2 or 1 layer(s) of band comprising fibres, respectively.

31. A method according to any of the claims 28 to 30, wherein said layers comprising second type fibres are provided by winding a band comprising biaxially oriented second type fibres around said laminated member, preferably the biaxial angles of the outermost and/or the innermost layer(s), which comprise second type fibres, are between about ±50° to ±85° relative to the orientation of the first type fibres, more preferably about ±55° to ±70° and most preferably about ±60°, optionally a further layer is provided by winding a band comprising biaxially oriented second type fibres around said laminated member with biaxial angles of about ±35° to ±55° relative to the orientation of the first type fibres and more preferably about ±45°.

32. A method according to any of the claims 26 to 28, further comprising the step of temporarily fixing a pre-form, pre-consolidated pre-form or flange comprising mainly unidirectionally oriented first type fibres on the preceding layers of said laminated member by a string, a band, a tow or a tow-preg comprising fibres, preferably said string or band consists of fibres and more preferably first type fibres or second type fibres.

33. A method according to any of the claims 26 to 28, further comprising the step of shaping the pre-form, pre-consolidated pre-form or flange comprising mainly unidirectionally oriented first type fibres, before or as a part of the temporarily fixing on the preceding layers of said laminated member, preferably said pre-form, pre-consolidated pre-form or flange is bend parallel to the main fibre direction towards the web sides, more preferably said pre-form, pre-consolidated pre-form or flange is formed to enhance the shaping and most preferably said pre-form, pre-consolidated pre-form or flange has at least one tapered part.

34. A method according to any of the claims 26 to 28, further comprising the step of providing a means for potential equalising between elements of said laminated member.

35. A method according to claim 34, characterised in that said means for potential equalising comprises a string, band, tow or tow-preg comprising fibres and/or metal, preferably said means is a tow-preg comprising carbon fibre.

36. A method according to claims 32 and 34, c h a r a c t e r i s e d in that a string, band, tow or tow-preg provides a means for potential equalising between elements of said laminated member and temporarily fixes a pre-form, a pre-consolidated pre-form or a flange comprising mainly unidirectionally oriented first type fibres on the preceding layers of said laminated member.

37. A method according to claim 34, c h a r a c t e r i s e d in that said means for potential equalising between elements of said laminated member comprises a band comprising fibres according to any of the claims 23 to 25.

38. A method for preparing a spar comprising the steps of:
- providing a laminated member according to any of the claims 1 to 16 and/or 17 to 19,
- if more than one laminated member is present connecting the laminated members,
- optionally providing a vacuum enclosure around said members,
- providing a pressure on said members, preferably via a vacuum within said vacuum enclosure,
- initiating the curing reaction, preferably by heating, and
- curing the members.

39. A method according to claim 38, further comprising the steps of:
- providing a base member, and
- connecting said base member to said laminated member.

40. A method according to any of the claims 38 to 39, further comprising the steps of:
- providing a tip member, and
- connecting said tip member to said laminated member.

41. Use of a laminated member according to any of the claims 1 to 16 and/or any of the claims 17 to 19 for a spar for a wind turbine blade.

42. Use of a band comprising fibres according to any of the claims 23 to 25 for providing of an electrical connection between members, preferably between electrically conducting members, more preferably for use in relation to a wind

turbine, even more preferably for a wind turbine blade and most preferably for use in a spar for a wind turbine blade.

Fig. 1

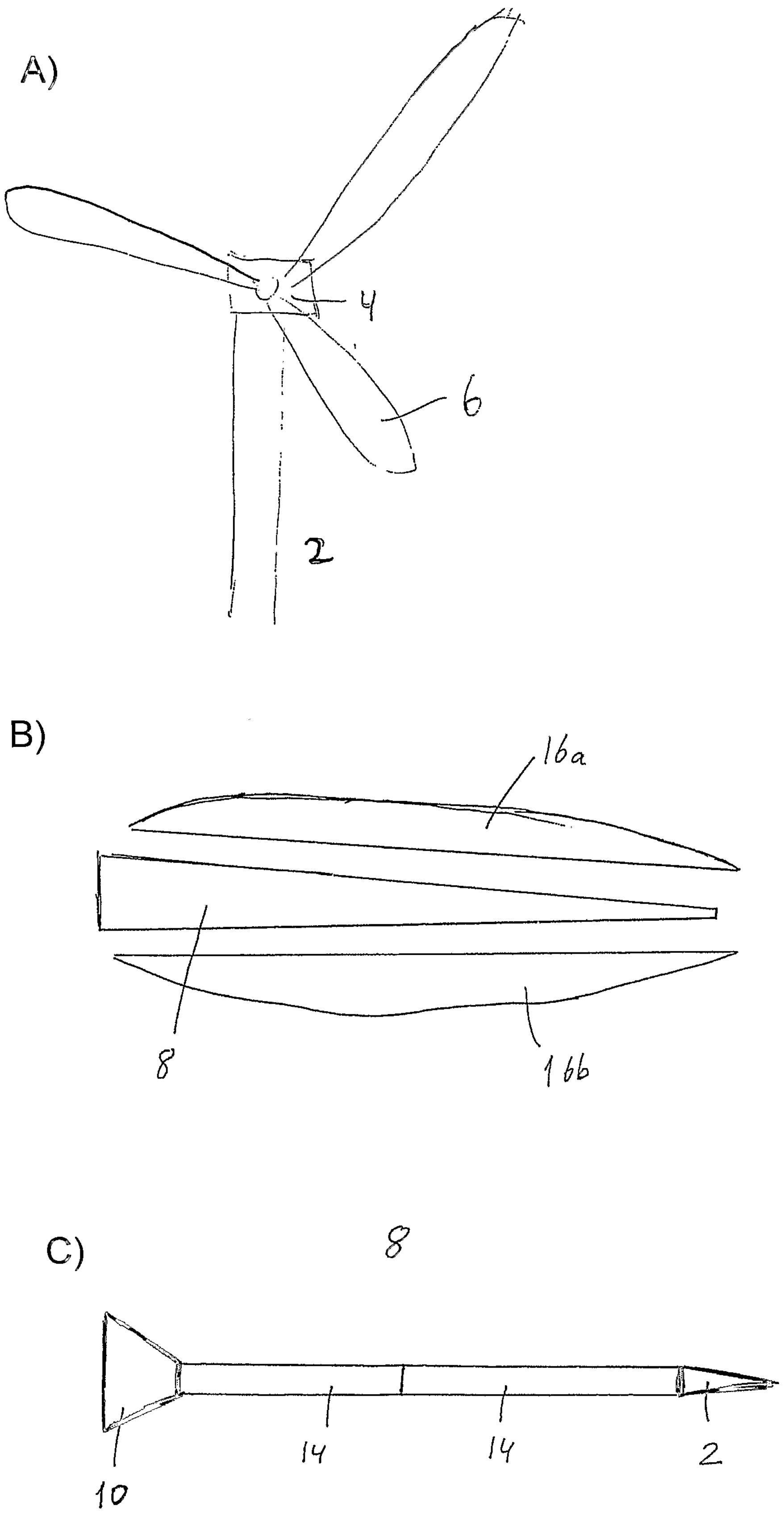
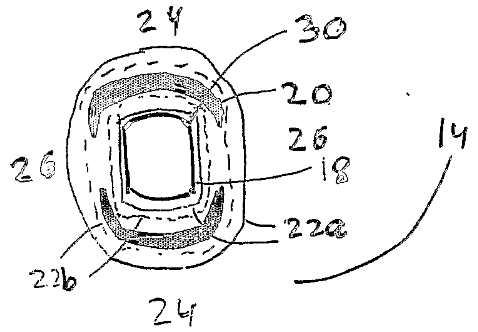


Fig. 2

A/



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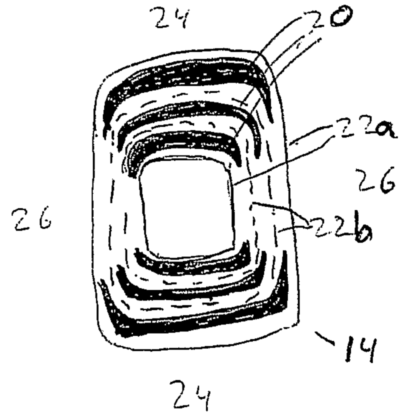
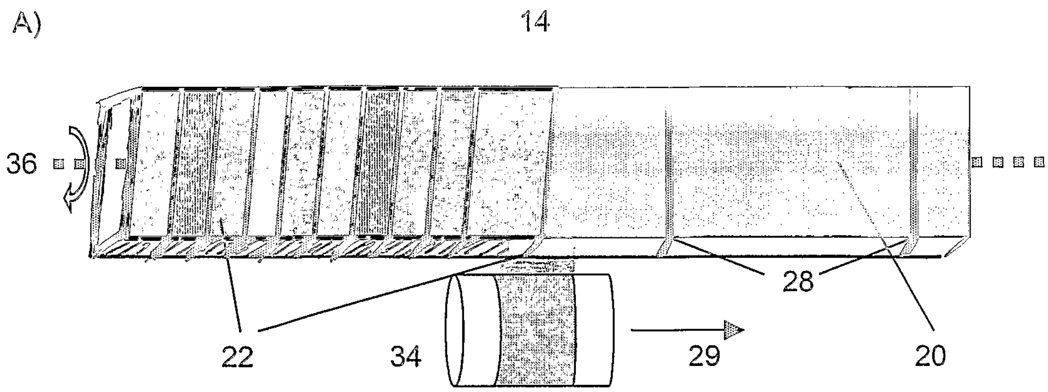


Fig. 3

A)



B)

C)

D)

E)

Fig. 4

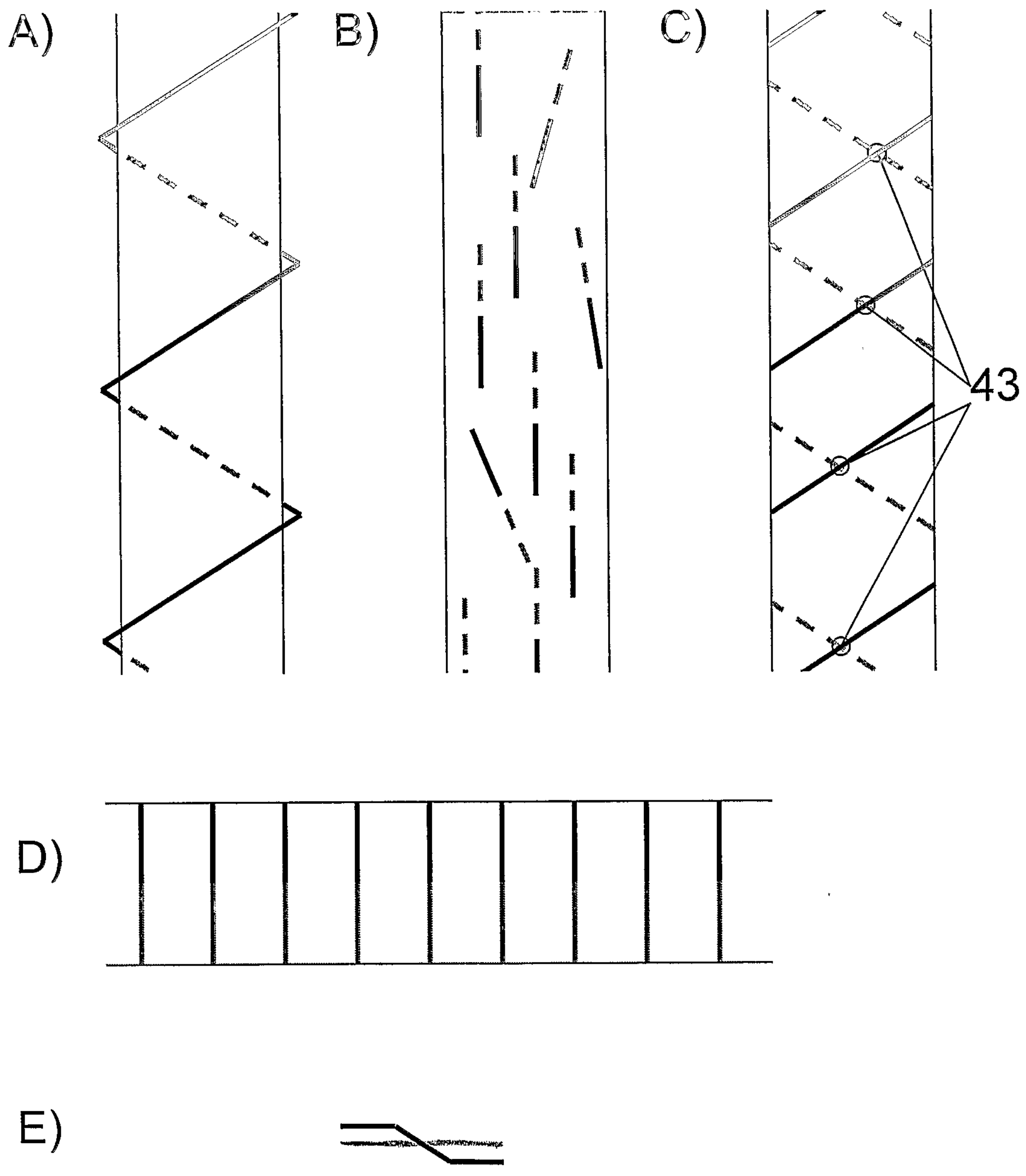
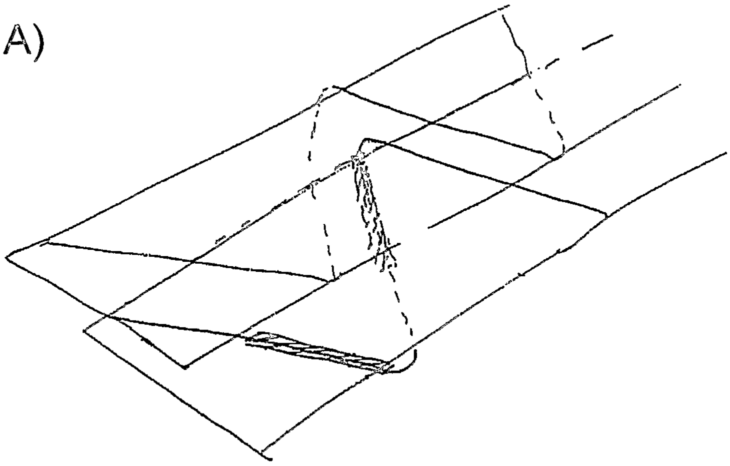


Fig. 5

A)



B)

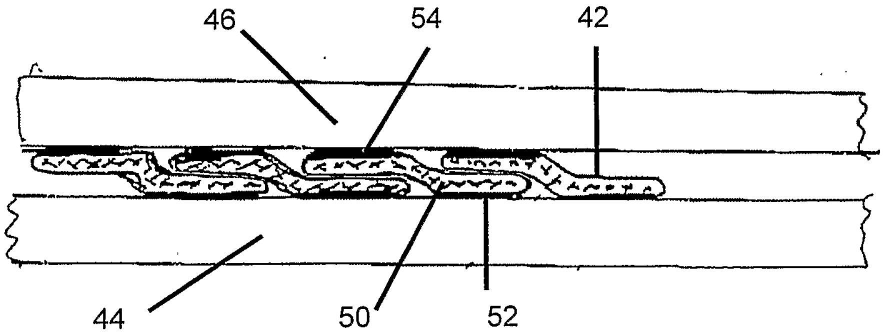
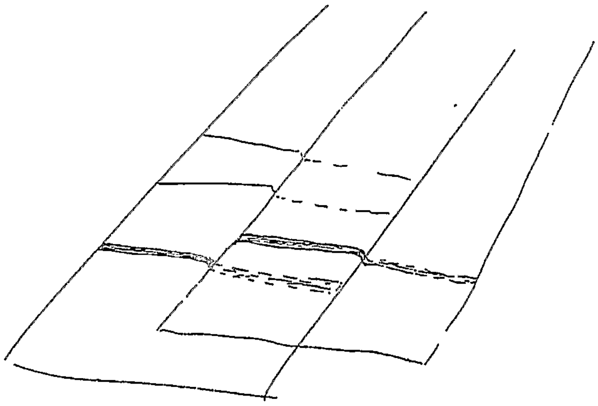


Fig. 5

C)



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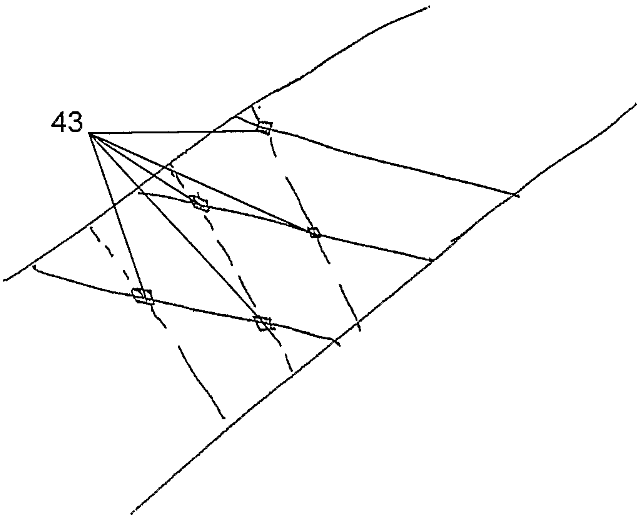

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 03/04167

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B29D31/00 B29C70/32 B29C70/08 B64C11/24

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)
IPC 7 B29D B29C B64C

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, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 976 587 A (JOHNSTON J FORD ET AL) 11 December 1990 (1990-12-11) column 9, line 38 -column 10, line 55	1,11,12, 17-22, 26-31, 38,41
X	US 4 339 230 A (HILL PAUL W) 13 July 1982 (1982-07-13) column 7, line 56 -column 8, line 17	1,2,5-7, 11,13, 17-21,41
X	US 4 273 601 A (WEINGART OSCAR) 16 June 1981 (1981-06-16) column 1, line 58 -column 2, line 23	26-31
A	US 4 728 263 A (BASSO ROBERT J) 1 March 1988 (1988-03-01) column 2, line 8 - line 21	1-42

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
30 October 2003	06/11/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Van Wallene, A

INTERNATIONAL SEARCH REPORT
Information on patent family members

International Application No
PCT/EP 03/04167

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4976587 A	11-12-1990	NONE	
US 4339230 A	13-07-1982	NONE	
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