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(71) Applicant: **LM WP PATENT HOLDING A/S** [DK/DK]; Jupitervej 6, 6000 Kolding (DK).

(72) Inventor: **LEHMANN MADSEN, Kristian**; Lodsvej 8, Skærbæk, 7000 Fredericia (DK).

(74) Agent: **HEINRICH, Bernd**; LM Wind Power A/S, Jupitervej 6, 6000 Kolding (DK).

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(54) Title: METHOD OF MOLDING A SHELL PART OF A WIND TURBINE BLADE

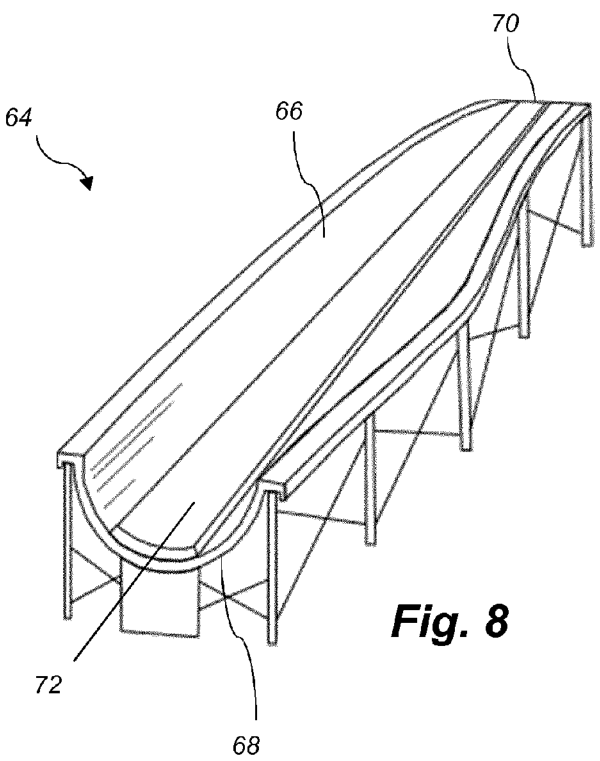

Fig. 8

(57) Abstract: The present invention relates to a method of molding a shell part of a wind turbine blade comprising the steps of providing a mold (64) comprising a mold cavity (66) with a root end (68) and an opposing tip end (70), arranging one or more preformed sheets (72a, 72b, 72c) in the mold cavity (66), wherein each preformed sheet comprises a mixture of fibre rovings (82) and a binding agent, wherein the fibre rovings are at least partially joined together by means of the binding agent, and injecting the one or more preformed sheets (72a, 72b, 72c) with a resin to mold the shell part. The present invention also relates to a shell part of a wind turbine blade obtainable by said method, to a preformed sheet for use in said method and to a method of manufacturing said preformed sheet.

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Title: Method of molding a shell part of a wind turbine blade

Field of the Invention

The present invention relates to a method of molding a shell part of a wind turbine blade. In other aspects, the present invention relates to a shell part of a wind turbine blade obtainable by said method, to a preformed sheet for use in said method and to a method of manufacturing said preformed sheet.

Background of the Invention

Wind power is becoming increasingly popular due to its clean and environmentally friendly production of energy. The rotor blades of modern wind turbines capture kinetic wind energy by using sophisticated blade design created to maximize efficiency. Turbine blades may today exceed 80 metres in length and 4 metres in width. The blades are typically made from a fibre-reinforced polymer material and comprise a pressure side shell half and a suction side shell half. The cross-sectional profile of a typical blade includes an airfoil for creating an air flow leading to a pressure difference between both sides. The resulting lift force generates torque for producing electricity.

The shell halves of wind turbine blades are usually manufactured using molds. First, a blade gel coat or primer is typically applied to the mold. Subsequently, fibre reinforcement and/or fabrics are placed into the mold followed by resin infusion. A vacuum is typically used to draw epoxy resin material into a mold. Alternatively, prepreg technology can be used, in which a fibre or fabric pre-impregnated with resin forms a homogenous material which can be introduced into the mold. Several other molding techniques are known for manufacturing wind turbine blades, including compression molding and resin transfer molding. The shell halves are assembled by being glued or bolted together substantially along a chord plane of the blade. The root region of each shell half typically has a circular cross section.

In vacuum assisted resin transfer molding (VARTM), glass fibre plies are placed in a mold with the correct orientation and subsequently resin is forced to flow through the fibres using a vacuum pump. This is usually followed by a curing cycle at atmospheric pressure.

A typical molding process includes bagging, resin infusion and subsequent curing. Bagging involves placing a vacuum foil on the fibre plies that have been laid up on the tool. The vacuum foil is used to press this part to the tool and to allow a vacuum to be drawn into the void formed by the bag and the tool such that the fibres of the part are infused with resin. Typical vacuum foils may be formed by one or more plastic sheets which are placed to cover the blade. Infusion comprises feeding resin under a vacuum to wet the laid out fibres to form a solid shell part. In subsequent curing, heating and subsequently cooling may be applied to harden the resin.

In particular when manufacturing large blades, the glass fibre layup at the root end becomes critical. Glass fibre material may slide down the almost vertical shell mold walls. The sliding of fibre material during manufacturing may lead to the formation of undesired wrinkles in the shell structure, which may present zones of structural weakness within the blade.

European Patent EP 2617555 B1 discloses a method for manufacturing a wind turbine rotor blade comprising a trailing edge comprising fibre rovings. The method comprises the steps of laying up a number of layers comprising fibre material onto the inner surface of a first mold part, laying up a plurality of fibre rovings onto the number of layers at a position which forms the trailing edge of the blade, and casting the blade using Vacuum Assisted Resin Transfer Molding.

Similarly, US 2012/0261864 A1 discloses a method involving layering of fibre material on a mold surface, includes laying rovings of said fibre material on the mold surface, or on a fibre material already laid on the mold surface, and applying vacuum to a space between the rovings and the mold surface. The rovings are rolled off a reel or laid out of a cassette.

US 2015/0285083 A1 relates to a curved fibre mat including rovings being arranged side by side and being connected to one another in at least two connection areas by stitching. At least one of the rovings is continuous between the at least two connection areas and at least one of the rovings is discontinuous between the at least two connection areas.

Some of the afore-mentioned prior art approaches present challenges in handling the components such as fibre rovings, in particular in the root lay-up, as the slope of the mold for forming the wind turbine shell part can be quite steep. Thus, although fibre rovings may present an economical alternative to woven fibre mats or similar materials, their used is limited by these problems in layup and handling.

It is therefore an object of the present invention to overcome one or more of the above-discussed drawbacks of the known methods.

It is another object of the present invention to provide a method for molding a shell part of a wind turbine blade that is simple and cost-effective.

In particular, it is an object of the present invention to provide a method for molding a shell part of a wind turbine blade that is associated with improved stability and easier handling of the components used in said method.

Summary of the Invention

In a first aspect, the present invention relates to a method of molding a shell part of a wind turbine blade, the blade having a profiled contour including a pressure side and a suction side, and a leading edge and a trailing edge with a chord having a chord length extending therebetween, the wind turbine blade extending in a spanwise direction between a root end and a tip end, said method comprising:

- providing a mold comprising a mold cavity with a root end and an opposing tip end,
- arranging one or more preformed sheets, such as two or more preformed sheets, in the mold cavity, wherein each preformed sheet comprises a mixture of fibre rovings and a binding agent, wherein the fibre rovings are at least partially joined together by means of the binding agent, and
- injecting the one or more preformed sheets, such as two or more preformed sheets, with a resin to mold the shell part.

By mixing and joining together the fibre rovings with a binding agent, the resulting preformed sheet is both cost-effective and easy to handle in the subsequent shell part molding step. The method of the present invention was found to result in material cost savings of up to 30-45 % owing to the simple and efficient use of fibre rovings instead of more costly materials, such as woven fibre mats. It has also been found by the present inventors, that the inventive method results in a reduced tendency of the fibre rovings to produce irregularities in the shell part laminate, since the individual roving will not be able to “stand up” or fold in a vertical direction. The latter is a problem of prior art fibre mats.

Without being bound by theory, it is believed that the binding agent is also beneficial in creating channels for the subsequent resin infusion by providing spacings between the rovings. This facilitates resin infusion of the preformed sheets after the sheets have been arranged in the blade mold.

The preformed sheet of the present invention was found to be sufficiently flexible and able to follow the necessary movements and form adaptions during manufacturing of the blade. In particular, such preformed sheet can be advantageously used for lay-up in parts of the blade molds, which are too steep for some of the afore-mentioned prior art approaches using fibre rovings. Since the fibre rovings are mixed and joined together by the binding agent, the risk of slipping, displacement or other unwanted movement is greatly diminished.

Typically, the shell part molded by the method of the present invention will be a shell half. Usually, the tip end of the mold cavity will correspond to the tip end of the blade to be manufactured. Likewise, the root end of the mold cavity will usually correspond to the root end of the blade.

Preferably, at least two or more preformed sheets are arranged in the mold cavity. In other embodiments, at least three, such as at least four, or at least five preformed sheets are arranged in the mold cavity. The preformed sheets may be arranged side-by-side in the mold cavity. Typically, each preformed sheet has a length, a width and a thickness, as well as two longitudinally extending lateral edges in between a top surface and an opposing bottom surface. Also, each preformed sheet will usually have a front edge and an opposing back edge. The top surface and bottom surface of the sheet may be constituted by a top fibre mat and a bottom fibre mat, respectively.

In a preferred embodiment, the rovings comprise glass fibres or consist of glass fibres. In other embodiments, the rovings may comprise, or consists of, glass fibres, carbon fibres, aramid fibres, basalt fibres, natural fibres or mixtures thereof.

In one embodiment, the rovings are arranged side-by-side within the preformed sheets. In other embodiments, the rovings are arranged unidirectionally within the preformed sheets. Usually, the mixture between fibre rovings and binding agent is such that at least 75%, more preferably at least 90%, most preferably at least 95% of the surface of the fibre rovings is contacted with the binding agent.

The resin for injecting the one or more preformed sheets may be an epoxy, a polyester, a vinyl ester or another suitable thermoplastic or duroplastic material.

In a preferred embodiment, each preformed sheet further comprises at least one fabric, such as a top fibre mat and/or a bottom fibre mat. The fibre rovings may be arranged on top and/or below such fabric.

In a preferred embodiment, the binding agent is present in an amount of 0.1-15 wt% relative to the weight of the fibre rovings. Preferably, the binding agent is present in an amount of 0.5-10 wt%, preferably 0.5-5 wt%, more preferably 0.5-3.5 wt%, relative to the weight of the fibre rovings. The binding agent may also comprise two or more different substances, as long as the total binding agent is present in an amount of 0.1-15 wt% relative to the weight of the fibre rovings.

It was found that the comparatively low amount of binding agent of 0.1-15 wt% relative to the weight of the fibre rovings provides improved flexibility as contrasted to known fibre preforms for manufacturing wind turbine blades. It was also found that this amount of binding agent results in sufficient stability for handling during the blade molding process.

In a preferred embodiment, the binding agent is a thermoplastic binding agent. Typically, the fibre rovings are at least partially joined together by means of the binding agent by thermal bonding. In a preferred embodiment, the binding agent is a binding powder, such as a thermoplastic binding powder.

According to another embodiment, the melting point of the binding agent is between 40° and 220 °C, preferably between 40 and 180 °C, such as between 40 and 170 °C, or between 40 and 160 °C.

According to another embodiment, the preformed sheets have an elastic modulus (Young's modulus) of between 0.01 and 250 GPa, preferably 0.01-100 GPa, such as between 0.01-45 GPa or between 0.01-10 GPa. Preformed sheets with such elasticity were found to be particularly well suited for a blade manufacturing process according to the present invention.

According to one embodiment, the binding agent is a thermoplastic binding agent. According to another embodiment, the binding agent comprises a polyester, preferably a bisphenolic polyester. An example of such binding agent is a polyester marketed under the name NEOXIL 940. Examples include NEOXIL 940 PMX, NEOXIL 940 KS 1 and NEOXIL 940 HF 2B, all manufactured by DSM Composite Resins AG. Preferably, the binding agent is a polyester, preferably a bisphenolic polyester. In other embodiments, the binding agent is a hotmelt adhesive or based on a prepreg resin.

In one embodiment, the preformed sheets are arranged in the mold cavity such that the longitudinal axes of the preformed sheets are aligned substantially parallel to each other.

According to another embodiment, the preformed sheets are arranged in the mold cavity such that a longitudinally extending lateral edge of at least one preformed sheet abuts a longitudinally extending lateral edge of an adjacent preformed sheet. The indivdual sheets will then usually be connected to the adjacent sheets by the resin infusion step. If more than two preformed sheets are arranged in this embodiment, for some sheets, both lateral edges will abut respective lateral edges of adjacent sheets on either side.

Alternatively, the preformed sheets may be arranged in the mold cavity such that a longitudinally extending lateral edge of at least one preformed sheet overlaps with an adjacent preformed sheet. Again, the indivdual sheets will then usually be connected to the adjacent overlapping sheets by the resin infusion step.

According to another embodiment, each preformed sheet has a length, width and thickness, wherein its length-width ratio is at least 5:1. In some embodiments, the length-width ratio is at least 8:1, such as at least 10:1 or at least 15:1, such as at least 100:1 or at least 200:1.

According to another embodiment, each of the preformed sheets further comprises a top fibre mat and a bottom fibre mat in between which the fibre rovings are arranged. For the fibre mats, a woven mat of fibre material may be used.

In one embodiment, the one or more preformed sheets are placed onto a fibre material, a blade gel coat and/or a primer, already laid on the surface of the mold cavity.

According to another embodiment, the method further comprises a step of laying up a vacuum foil onto the preformed sheets as the topmost layer prior to resin injection. Preferably, the blade part is molded using Vacuum Assisted Resin Transfer Molding.

Typically, the mold cavity comprises a substantially semi-circular cross section at its root end. The preformed sheets will usually be arranged such in the mold cavity that they extend from the root end towards the tip end of the mold cavity.

According to another embodiment, the length of each preformed sheet is at least 15 m, preferably at least 20 m, such as at least 25 m, or at least 35 m. In another embodiment, the length of a preformed sheet extends along the full length of the blade part.

In a preferred embodiment, the thickness of at least one preformed sheet decreases from its front edge to its back edge as seen in its longitudinal direction. Such a tapered shape is advantageous in that it provides a gradual transition between a relatively high wall thickness in the root region and a usually lower wall thickness in the transition region and the airfoil region of the blade.

According to another embodiment, the preformed sheets are arranged in the mold cavity such that the angle between the horizontal plane and a line that is tangential to the vertex of a curved bottom surface of a preformed sheet is different for each preformed sheet.

According to another embodiment, at least one preformed sheet is arranged in the mold cavity such that the angle between the horizontal plane and a line that is tangential to the vertex of a curved bottom surface of said preformed sheet is more than 45°, preferably more than 60°, such as more than 75°. Thus, the preformed sheet of the present invention is advantageous in that it can be laid along a curved path or a steep mold cavity surface without producing wrinkles or creases, and without any significant sliding of the fibre rovings in the mold.

According to another embodiment, the preformed sheets are arranged in the mold cavity in a region between the root end of the mold cavity and the position of maximum chord length, as seen in the longitudinal direction of the mold cavity.

In another aspect, the present invention relates to a shell part of a wind turbine blade obtainable by the method of the present invention.

In yet another aspect, the present invention relates to a preformed sheet for use in a method according to the present invention, the preformed sheet comprising a mixture of fibre rovings and a binding agent, wherein the fibre rovings are at least partially joined together by means of the binding agent, and wherein the binding agent is present in an amount of 0.1-15 wt% relative to the weight of the fibre rovings.

The different embodiments and features of the preformed sheet, as described above in the context of the method of molding a shell part, equally apply to the preformed sheet as such and may be combined accordingly. In particular, the thickness of the preformed sheet of the present invention may decrease from a front edge to a back edge as seen in its longitudinal direction.

Typically, the preformed sheets have an at least partly curved top surface and/or an at least partly curved bottom surface. When laying the preformed sheet into a curved mold cavity, the bottom surface of the preformed sheet may advantageously adapt the form of the curved mold cavity surface. In other embodiments, the preformed sheets have a planar top surface and/or a planar bottom surface.

In another aspect, the present invention relates to a method of manufacturing a preformed sheet according to any of the preceding claims comprising the steps of contacting fibre rovings with a binding agent, and subsequently heating the fibre rovings and the binding agent for forming the preformed sheet.

The step of contacting the fibre rovings with a binding agent may be accomplished by using a bath containing the binding agent and pulling the fibre rovings through the bath. Subsequently the fibre rovings and binding agent can be laid up in the preform mold, for example after having been pulled through a nozzle or the like, for ensuring unidirectional orientation of the fibre rovings. Alternatively, the step of contacting the fibre rovings with a binding agent may be accomplished during the roving manufacturing process, such as during sizing.

In one embodiment, the mixture of the fibre rovings and the binding agent is laid in a preform mold, followed by heating the laid up fibre rovings and binding agent for forming the preformed sheet. Advantageously, the preform molds do not need to be vacuum tight, which is beneficial in terms of cost reduction. Also, typically no extreme precision is required for manufacturing the preformed sheets (cm range rather than mm range). In some embodiments, the fibre rovings are laid on a bottom fibre mat and subsequently covered by a top fibre mat. Thus, the fibre rovings are sandwiched between two fibre mats. For the fibre mats, a woven mat of fibre material may be used.

The fibre rovings can advantageously be laid back and forth around a pin or similar device. In one embodiment, the rovings are arranged side by side in the preform mold.

Preferably, the mold cavity of the preform mold is substantially horizontal, i.e. only minimally curved. In one embodiment, the preform mold has a curved mold cavity, wherein the ratio of the width (Wm) and the maximum height (H) of the curved mold cavity is 10:1 or more, such as 15:1 or more, or 20:1 or more. Such a mold of minimal curvature may advantageously allow for the lay-up of fibre rovings, which would be more challenging in a more curved, steeper mold cavity. Thus, the resulting shell part may include a higher amount of fibre rovings, replacing some of the previously needed fibre mats. The same approach would not be feasible directly in the blade mold because of the steep slopes of its mold cavity, in particular at the circular root end thereof.

As used herein, the term “sheet” denotes a laminar element having a width and length substantially greater than the thickness thereof.

As used herein, the term "horizontal" refers to an orientation parallel to the ground upon which the mold that used in the method of the present invention is placed.

The term “substantially parallel”, as used herein, refers to the respective longitudinal axes of two adjacent preformed sheets not intersecting at an angle greater than 20°, preferably not greater than 10°, most preferred not greater than 5°.

As used herein, the term “wt%” means weight percent. The term “relative to the weight of the fibre rovings” means a percentage that is calculated by dividing the weight of an agent, such as a binding agent, by the weight of the fibre rovings. As an example, a value of 1 wt% relative to the weight of the fibre rovings corresponds to 10 g of binding agent per kilogram of fibre rovings.

The skilled reader will understand that the elastic modulus, also known as Young's modulus, defines the relationship between stress (force per unit area) and strain (proportional deformation) in a material. Thus, the elastic modulus is a measure of the stiffness of a material. The elastic modulus can be determined by the cantilever beam test, as is well known in the art.

<u>Detailed description of the Invention</u>

The invention is explained in detail below with reference to embodiments shown in the drawings, in which

Fig. 1 shows a wind turbine,

Fig. 2 shows a schematic view of a wind turbine blade,

Fig. 3 shows a schematic view of an airfoil profile through section I-I of Fig. 4,

Fig. 4 shows a schematic view of the wind turbine blade, seen from above and from the side,

Fig. 5 is a perspective drawing of a mold for manufacturing a shell part of a wind turbine blade using the method of the present invention,

Figure 6 is a front view of a mold for manufacturing a shell part of a wind turbine blade using one embodiment of the present invention,

Figure 7 is a front view of a mold for manufacturing a shell part of a wind turbine blade using another embodiment of the present invention,

Fig. 8 is a perspective drawing of a mold for manufacturing a shell part of a wind turbine blade using another embodiment of the method of the present invention,

Fig. 9 is a schematic drawing of a method for manufacturing the preformed sheet of the present invention,

Figure 10 is a perspective drawing of a mold for manufacturing the preformed sheet of the present invention,

Figure 11 is a cross-sectional view of the mold of Figure 8, and

Figure 12 is a perspective view of one embodiment of a preformed sheet according to the present invention.

Detailed Description

Fig. 1 illustrates a conventional modern upwind wind turbine according to the so-called "Danish concept" with a tower 4, a nacelle 6 and a rotor with a substantially horizontal rotor shaft. The rotor includes a hub 8 and three blades 10 extending radially from the hub 8, each having a blade root 16 nearest the hub and a blade tip 14 furthest from the hub 8. The rotor has a radius denoted R.

Fig. 2 shows a schematic view of a first embodiment of a wind turbine blade 10 according to the invention. The wind turbine blade 10 has the shape of a conventional wind turbine blade and comprises a root region 30 closest to the hub, a profiled or an airfoil region 34 furthest away from the hub and a transition region 32 between the root region 30 and the airfoil region 34. The blade 10 comprises a leading edge 18 facing the direction of rotation of the blade 10, when the blade is mounted on the hub, and a trailing edge 20 facing the opposite direction of the leading edge 18.

The airfoil region 34 (also called the profiled region) has an ideal or almost ideal blade shape with respect to generating lift, whereas the root region 30 due to structural considerations has a substantially circular or elliptical cross-section, which for instance makes it easier and safer to mount the blade 10 to the hub. The diameter (or the chord) of the root region 30 may be constant along the entire root area 30. The transition region 32 has a transitional profile gradually changing from the circular or elliptical shape of the root region 30 to the airfoil profile of the airfoil region 34. The chord length of the transition region 32 typically increases with increasing distance *r* from the hub. The airfoil region 34 has an airfoil profile with a chord extending between the leading edge 18 and the trailing edge 20 of the blade 10. The width of the chord decreases with increasing distance *r* from the hub.

A shoulder 40 of the blade 10 is defined as the position, where the blade 10 has its largest chord length. The shoulder 40 is typically provided at the boundary between the transition region 32 and the airfoil region 34.

It should be noted that the chords of different sections of the blade normally do not lie in a common plane, since the blade may be twisted and/or curved (i.e. pre-bent), thus providing the chord plane with a correspondingly twisted and/or curved course, this being most often the case in order to compensate for the local velocity of the blade being dependent on the radius from the hub.

Figs. 3 and 4 depict parameters which are used to explain the geometry of the wind turbine blade according to the invention.

Fig. 3 shows a schematic view of an airfoil profile 50 of a typical blade of a wind turbine depicted with the various parameters, which are typically used to define the geometrical shape of an airfoil. The airfoil profile 50 has a pressure side 52 and a suction side 54, which during use – i.e. during rotation of the rotor – normally face towards the windward (or upwind) side and the leeward (or downwind) side, respectively. The airfoil 50 has a chord 60 with a chord length *c* extending between a leading edge 56 and a trailing edge 58 of the blade. The airfoil 50 has a thickness *t*, which is defined as the distance between the pressure side 52 and the suction side 54. The thickness *t* of the airfoil varies along the chord 60. The deviation from a symmetrical profile is given by a camber line 62, which is a median line through the airfoil profile 50. The median line can be found by drawing inscribed circles from the leading edge 56 to the trailing edge 58. The median line follows the centres of these inscribed circles and the deviation or distance from the chord 60 is called the camber *f*.

The asymmetry can also be defined by use of parameters called the upper camber (or suction side camber) and lower camber (or pressure side camber), which are defined as the distances from the chord 60 and the suction side 54 and pressure side 52, respectively.

Airfoil profiles are often characterised by the following parameters: the chord length *c*, the maximum camber *f*, the position d_f of the maximum camber *f*, the maximum airfoil thickness *t*, which is the largest diameter of the inscribed circles along the median camber line 62, the position d_t of the maximum thickness *t*, and a nose radius (not shown). These parameters are typically defined as ratios to the chord length *c*. Thus, a local relative blade thickness *t/c* is given as the ratio between the local maximum thickness *t* and the local chord length *c*. Further, the position d_p of the maximum pressure side camber may be used as a design parameter, and of course also the position of the maximum suction side camber.

Fig. 4 shows other geometric parameters of the blade. The blade has a total blade length *L*. As shown in Fig. 3, the root end is located at position $r = 0$, and the tip end located at $r = L$. The shoulder 40 of the blade is located at a position $r = L_w$, and has a shoulder width *W*, which equals the chord length at the shoulder 40. The diameter of the root is defined as *D*. The curvature of the trailing edge of the blade in the transition region may be defined by two parameters, viz. a minimum outer curvature radius r_o and a minimum inner curvature radius r_i, which are defined as the minimum curvature radius of the trailing edge, seen from the outside (or behind the trailing edge), and the minimum curvature radius, seen from the inside (or in front of the trailing edge), respectively. Further, the blade is provided with a prebend, which is defined as Δy, which corresponds to the out of plane deflection from a pitch axis 22 of the blade.

Fig. 5 illustrates a mold 64 comprising a mold cavity 66 for molding a shell part of a wind turbine blade. The mold cavity has a root end 68 and an opposing tip end 70 corresponding to the respective root and tip ends of the blade to be manufactured. In the embodiment shown in Fig. 5, three preformed sheets 72a, 72b, 72c are arranged in the mold cavity 66 for subsequent infusion with a resin to mold the shell part, e.g. by Vacuum Assisted Resin Transfer Molding. The respective longitudinal axes 74a, 74b, 74c of the preformed sheets 72a, 72b, 72c are arranged such that they are aligned substantially parallel to each other. A different embodiment of the method is illustrated in Fig. 8. Here, only one preformed sheet 72 is arranged in the mold cavity 66, acting as a main laminate extending along substantially the entire blade length.

As best seen in the root end front view of Fig. 6, the preformed sheets 72a, 72b, 72c are arranged such that a longitudinally extending lateral edge 76a of each preformed sheet abuts a longitudinally extending lateral edge 76b of an adjacent preformed sheet (as exemplified for sheets 72a and 72b). The sheets 72a, 72b, 72c are then joined together in the subsequent resin infusion step, optionally after laying a vacuum foil 78 as the topmost layer.

In an alternative embodiment shown in the root end front view of Fig. 7, the preformed sheets 72a, 72b, 72c are arranged such in the mold 64 that a longitudinally extending lateral edge 76a, 76b of each preformed sheet 72a, 72b, 72c overlaps with an adjacent preformed sheet. Again, the sheets 72a, 72b, 72c are subsequently joined together in by resin infusion and curing (vacuum foil not shown). Fig. 7 also shows that at least the preformed sheet 74c is arranged in the mold cavity such that the angle α between the horizontal plane 83 and a line 79 that is tangential to the vertex of a curved surface of the sheet exceeds 45°.

Fig. 9 illustrates a possible manufacturing method for a preformed sheet 72 of the present invention, in particular one that can be used as main laminate. Herein, the fibre rovings 82 and binding agent are sandwiched between a number of fabrics, or top and bottom mats 84, 86, heated in a heating station 92, and subsequently laminated in a lamination station 94 to produce the preformed sheet 72.

Fig. 10 shows a schematic drawing of another embodiment of a preformed sheet 72 as molded in a substantially horizontally oriented preform mold 80. The sheet 72 has a length Ls, a thickness Ts, and a width Ws. It is formed by sandwiching a plurality of fibre rovings 82 in between a bottom fibre mat 84 and a top fibre mat 86. This could be done by laying a mixture of fibre rovings 82 and a thermoplastic binding agent on top of the bottom fibre mat 84, covering the rovings 82 with the top fibre mat 86, followed by heating to form the preformed sheet. As best seen in Figs. 8 and 10, the preformed sheet 72 has a longitudinally extending lateral edge 76 extending in between a top surface 71 and a bottom surface 73 of the sheet 72.

The cross-sectional view of Fig. 11 shows some dimensions of the preform mold 80. It has a curved mold cavity 80 with a width Wm and a maximum height H, wherein the width Wm and maximum height H have a ratio of 10:1 or more.

Fig. 12 shows another embodiment of a preformed sheet 72 according to the present invention. Here, the thickness of the preformed sheet 72 decreases from its front edge 88 to its back edge 90 as seen in its longitudinal direction. Typically, the front edge 88 with the higher thickness will be located at the root end of the blade mold cavity when laying the preformed sheets, while the back edge 90 with the lower thickness will be closer to the tip end of the mold cavity.

The invention is not limited to the embodiments described herein, and may be modified or adapted without departing from the scope of the present invention.

<u>List of reference numerals</u>

2	wind turbine
4	tower
6	nacelle
8	hub
10	blade
14	blade tip
16	blade root
18	leading edge
20	trailing edge
22	pitch axis
30	root region
32	transition region
34	airfoil region
40	shoulder / position of maximum chord
50	airfoil profile
52	pressure side
54	suction side
56	leading edge
58	trailing edge
60	chord

62	camber line / median line
64	mold
66	mold cavity
68	root end of mold cavity
70	tip end of mold cavity
71	top surface of preformed sheet
72	preformed sheet
73	bottom surface of preformed sheet
74	longitudinal axis of sheet
76	lateral edge of sheet
78	vacuum foil
79	tangent to vertex
80	preform mold
81	mold cavity of preform mold
82	fibre rovings
83	horizontal plane
84	bottom fibre mat
86	top fibre mat
88	front edge of sheet
90	back edge of sheet
92	heating station
94	lamination station
c	chord length
d_t	position of maximum thickness
d_f	position of maximum camber
d_p	position of maximum pressure side camber
f	camber
L	blade length
r	local radius, radial distance from blade root
t	thickness
Δy	prebend
Ls	length of sheet
Ws	width of sheet
Ts	thickness of sheet
H	height of preform mold cavity
Wm	width of preform mold cavity

Claims

1. A method of molding a shell part of a wind turbine blade, the blade (10) having a profiled contour including a pressure side and a suction side, and a leading edge (18) and a trailing edge (20) with a chord having a chord length extending therebetween, the wind turbine blade (10) extending in a spanwise direction between a root end (16) and a tip end (14), said method comprising:

- providing a mold (64) comprising a mold cavity (66) with a root end (68) and an opposing tip end (70),
- arranging one or more preformed sheets (72a, 72b, 72c) in the mold cavity (66), wherein each preformed sheet comprises a mixture of fibre rovings (82) and a binding agent, wherein the fibre rovings are at least partially joined together by means of the binding agent, and
- injecting the one or more preformed sheets (72a, 72b, 72c) with a resin to mold the shell part.

2. A method according to claim 1, wherein at least two or more preformed sheets (72a, 72b, 72c) are arranged in the mold cavity (66).

3. A method according to claims 1 or 2, wherein each preformed sheet further comprises at least one fabric.

4. A method according to any of the preceding claims, wherein the binding agent is present in an amount of 0.1-15 wt%, preferably 0.5-5 wt%, relative to the weight of the fibre rovings.

5. A method according to any of the preceding claims, wherein the melting point of the binding agent is between 40° and 220 °C, preferably between 40 and 160 °C.

6. A method according to any of the preceding claims, wherein the preformed sheets have an elastic modulus (Young's modulus) of between 0.01 and 100 GPa, preferably between 0.01 and 45 GPa.

7. A method according to any of the preceding claims, wherein the binding agent comprises a polyester, preferably a bisphenolic polyester.

8. A method according to any of the preceding claims, wherein the preformed sheets (72a, 72b, 72c) are arranged in the mold cavity (66) such that a longitudinally extending lateral edge (76a) of at least one preformed sheet abuts a longitudinally extending lateral edge of an adjacent preformed sheet (76b).

9. A method according to any of the preceding claims, wherein the preformed sheets are arranged in the mold cavity (66) such that a longitudinally extending lateral edge (76a) of at least one preformed sheet (72a) overlaps with an adjacent preformed sheet (72b).

10. A method according to any of the preceding claims, wherein each preformed sheet has a length (Ls), width (Ws) and thickness (Ts), wherein its length-width ratio is at least 5:1.

11. A method according to any of the preceding claims, wherein each of the preformed sheets further comprises a top fibre mat (86) and a bottom fibre mat (84) in between which the fibre rovings are arranged.

12. A method according to any of the preceding claims, wherein the length (Ls) of each preformed sheet is at least 15 m, preferably at least 20 m.

13. A method according to any of the preceding claims, wherein the thickness (Ts) of at least one preformed sheet (72) decreases from its front edge (88) to its back edge (90) of said sheet as seen in its longitudinal direction (74a).

14. A method according to any of the preceding claims, wherein the preformed sheets (72a, 72b, 72c) are arranged in the mold cavity such that the angle (α) between the horizontal plane and a line that is tangential to the vertex of a curved bottom surface (73) of a preformed sheet (72) is different for each preformed sheet.

15. A method according to any of the preceding claims, wherein at least one preformed sheet (72) is arranged in the mold cavity such that the angle (α) between the horizontal plane and a line (79) that is tangential to the vertex of a curved bottom surface (73) of said preformed sheet (72) is more than 45°, preferably more than 60°.

16. A shell part of a wind turbine blade obtainable by the method of any of the preceding claims.

17. A preformed sheet (72) for use in a method according to any claims 1-15, the preformed sheet comprising fibre rovings (82) and a binding agent, wherein the fibre rovings (82) are at least partially joined together by means of the binding agent, and wherein the binding agent is present in an amount of 0.1-15 wt% relative to the weight of the fibre rovings.

18. A method of manufacturing a preformed sheet (72) according to claim 17 comprising the steps of contacting fibre rovings with a binding agent, and subsequently heating the fibre rovings and the binding agent for forming the preformed sheet.

19. A method according to claim 18, wherein the mixture of the fibre rovings and the binding agent is laid in preform mold (80), followed by heating the laid up fibre rovings (82) and binding agent for forming the preformed sheet (72).

20. A method according to claims 18 or 19, wherein the preform mold (80) has a curved mold cavity (81), wherein the ratio of the width (Wm) and the maximum height (H) of the curved mold cavity is 10:1 or more.

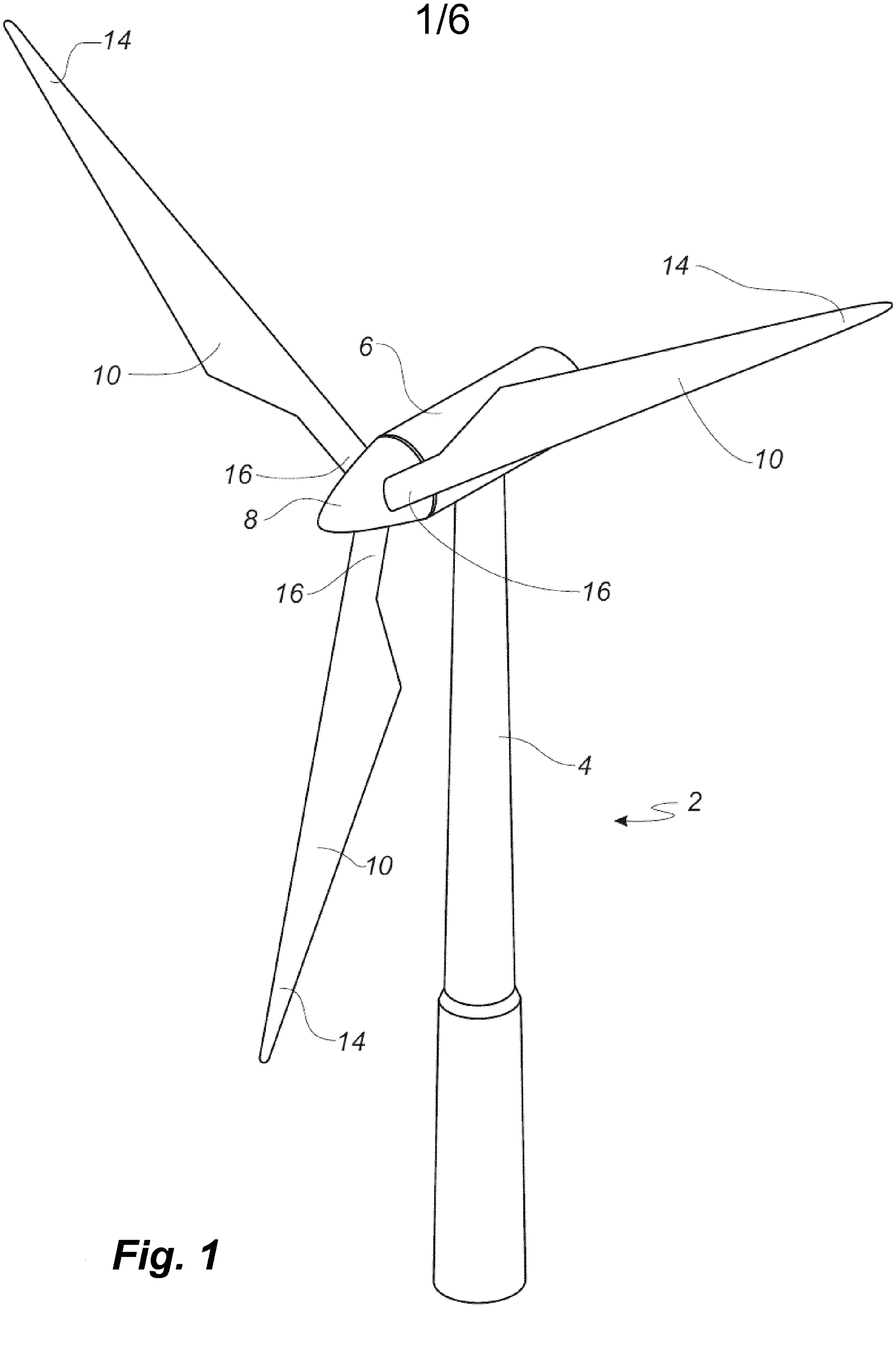
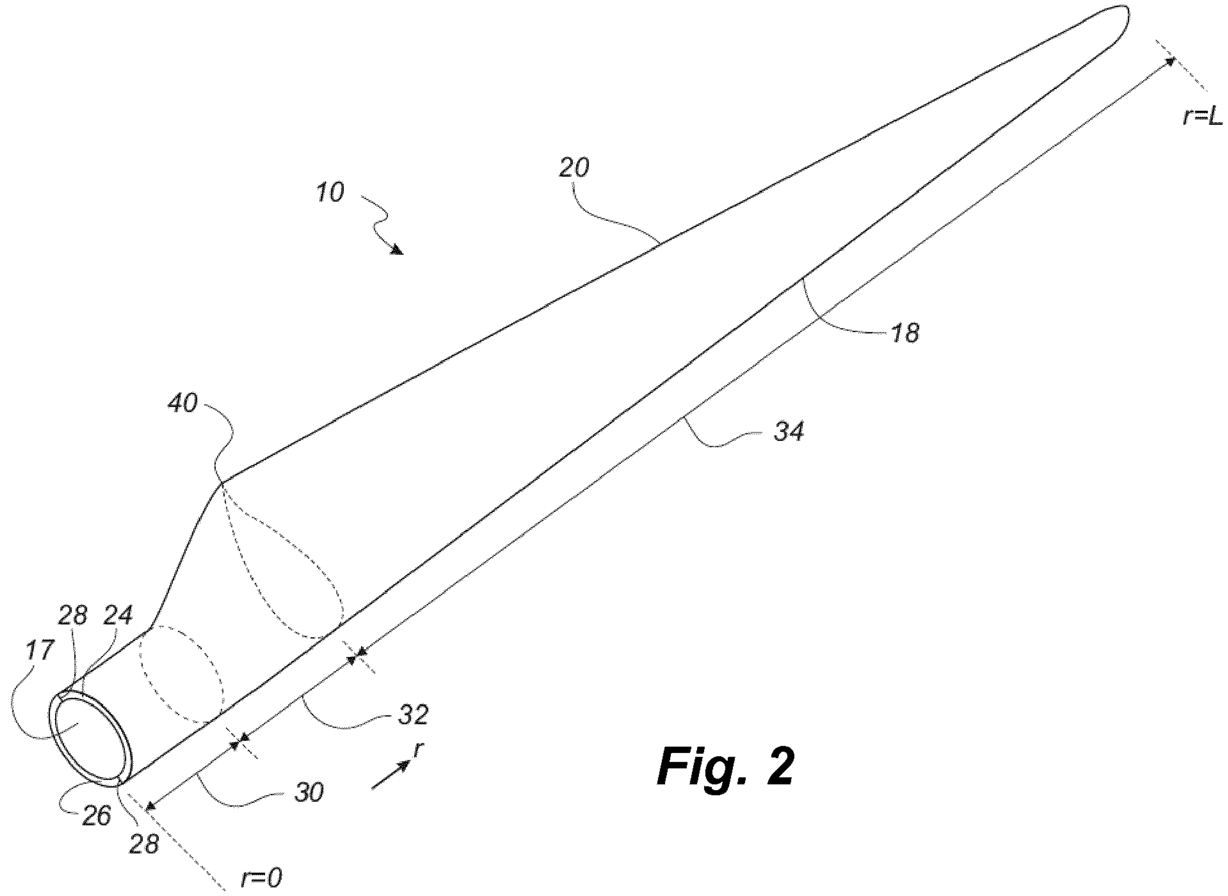


Fig. 1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20
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17
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r
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26
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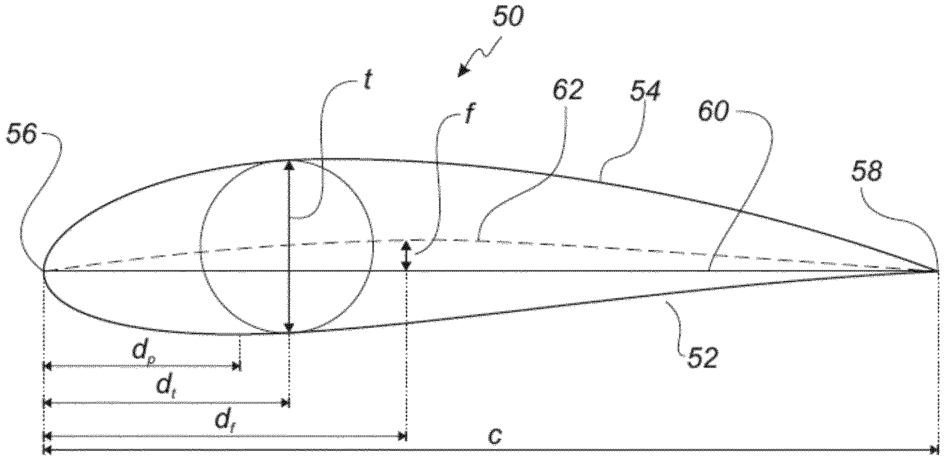
r=0
r=L

Fig. 2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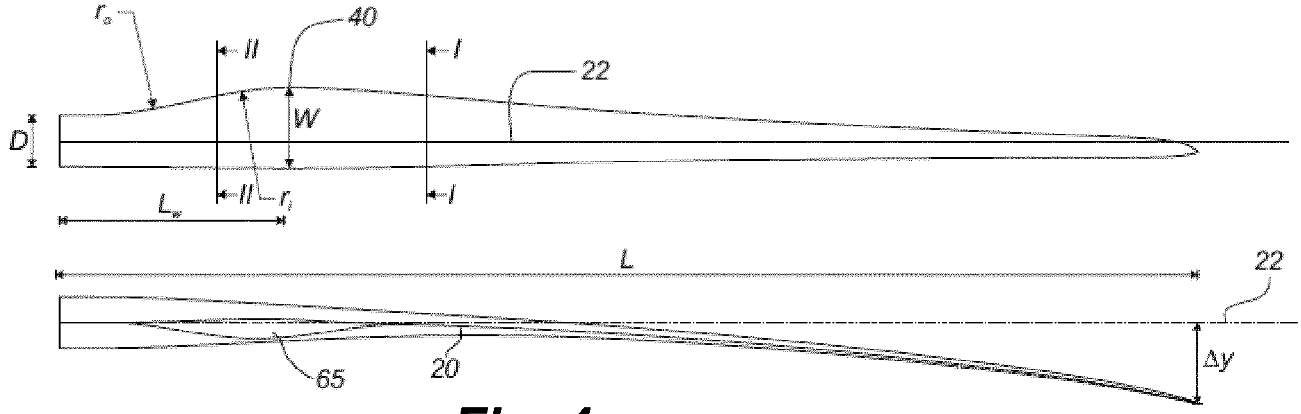
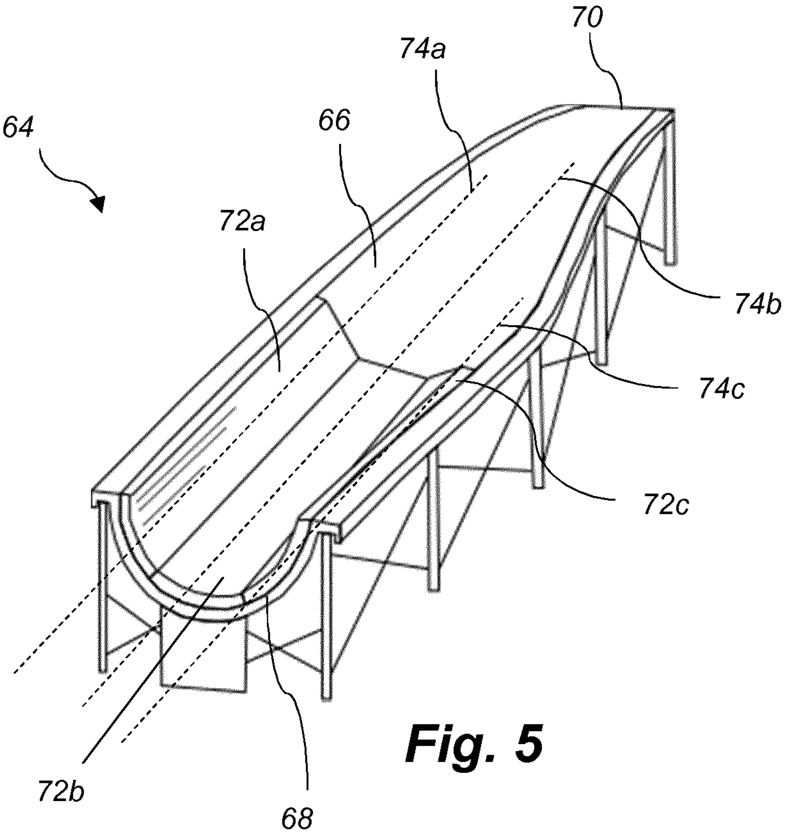
t
f
62
54
60
56
58
52
d_p
d_t
d_f
c

Fig. 3



r_o
40
II
I
22
D
W
II
r_i
I
L_w
L
22
Δy
65
20

Fig. 4



70
74a
64
66
72a
74b
74c
72c
72b
68

Fig. 5

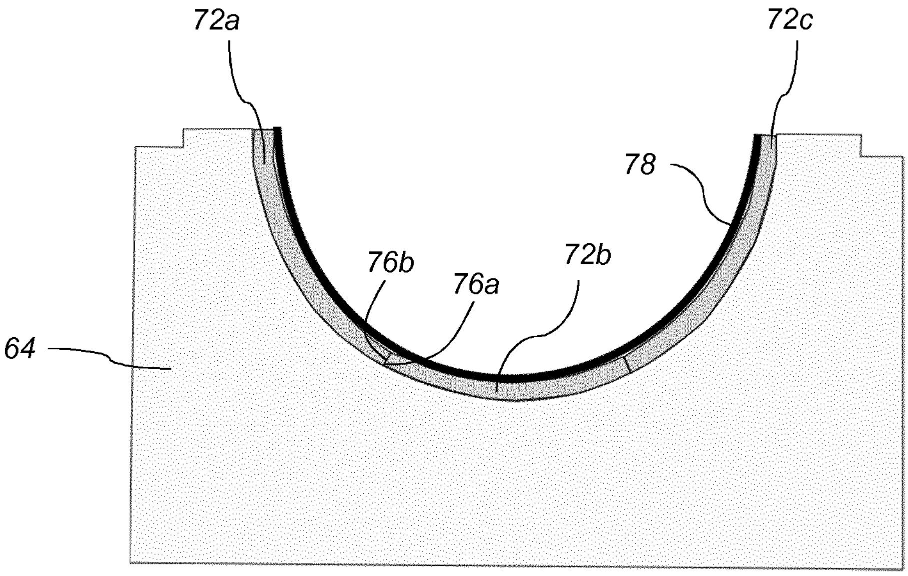


Fig. 6

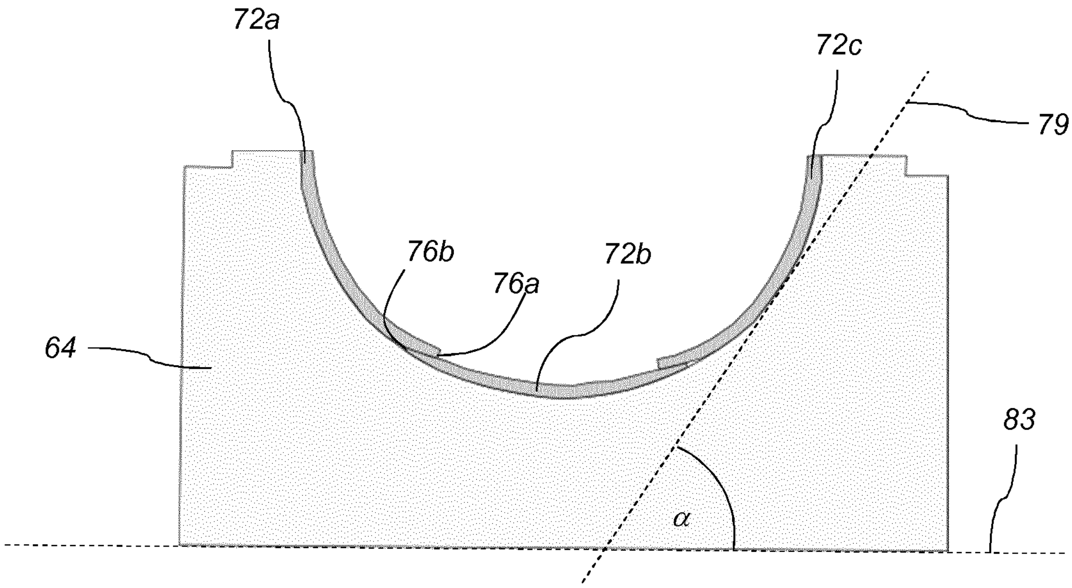


Fig. 7

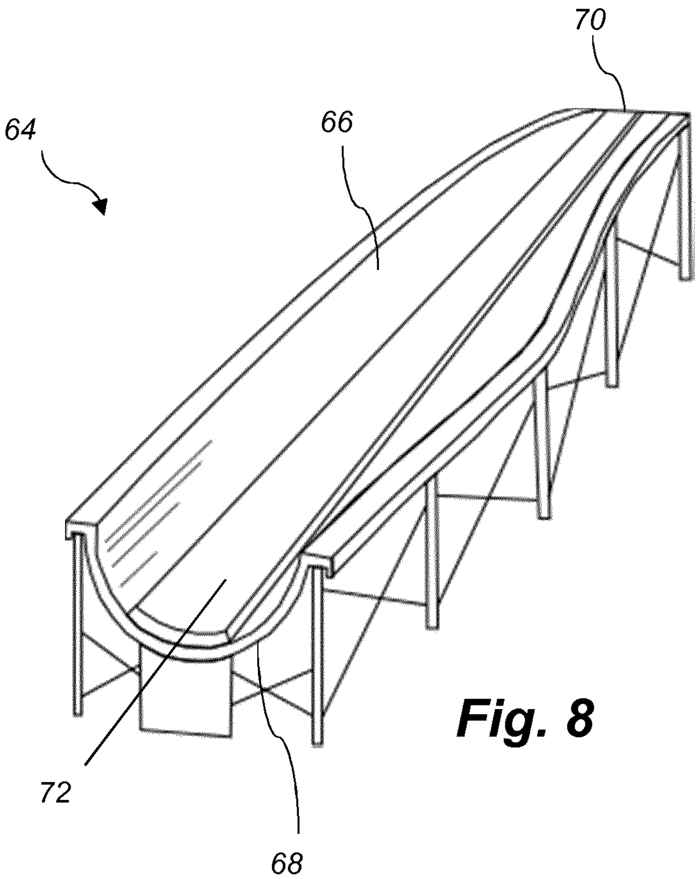


Fig. 8

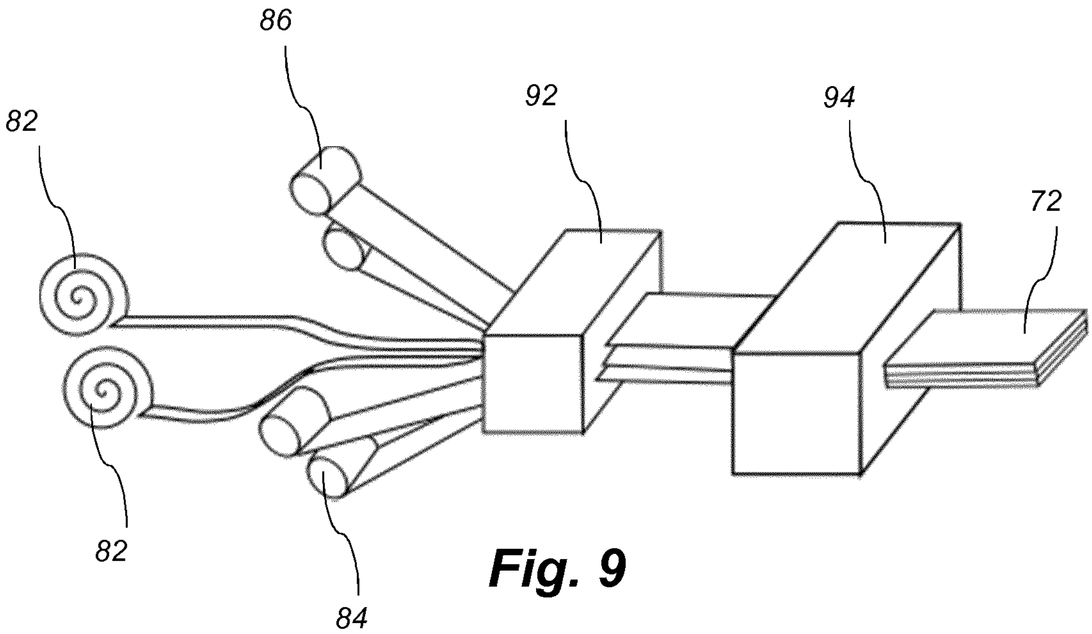


Fig. 9

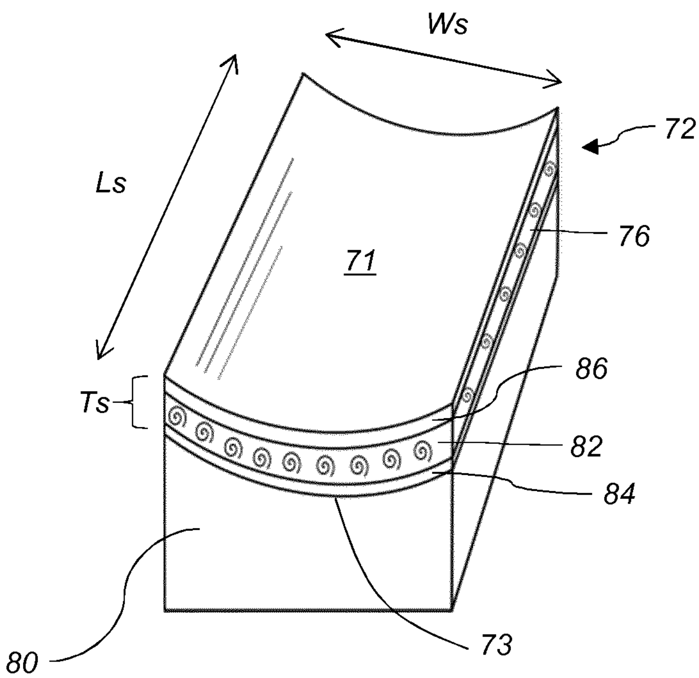


Fig. 10

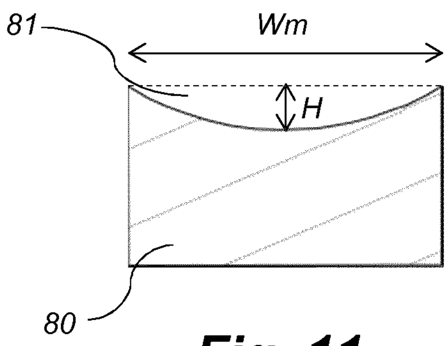


Fig. 11

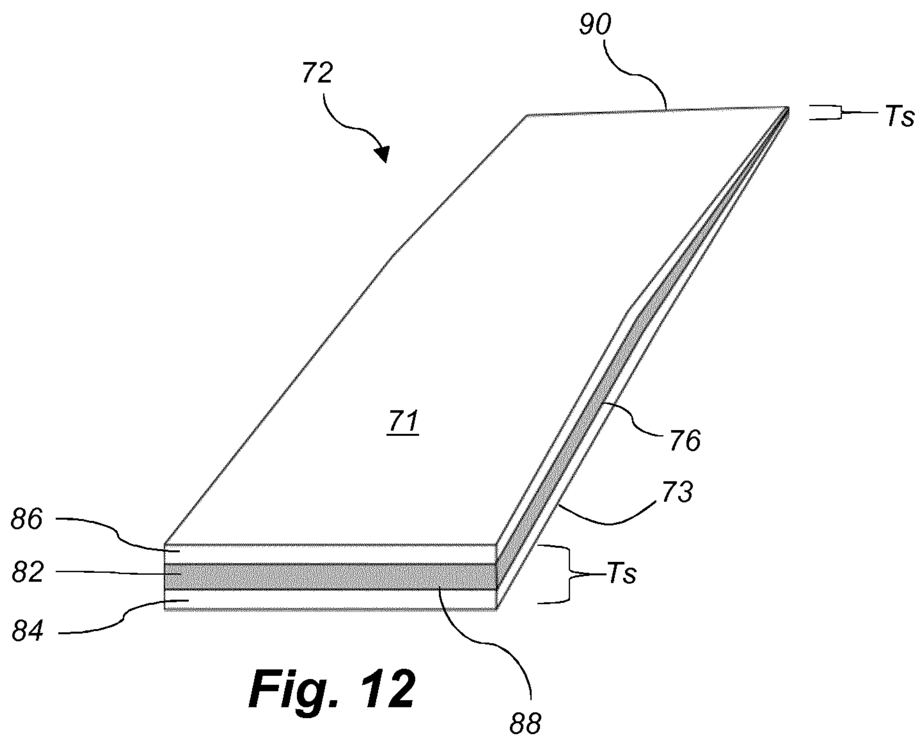


Fig. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/054426

A. CLASSIFICATION OF SUBJECT MATTER
INV. B29D99/00 B29C70/08 B29C70/44 B29B11/16
ADD. B29L31/08

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)
B29L B29D B29C B29B

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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 338 668 A1 (LM GLASFIBER AS [DK]) 29 June 2011 (2011-06-29)	1,3,16
Y	paragraphs [0008], [0009], [0034], [0039], [0044], [0051], [0054], [0063]; claims 1,15; figures -----	2
Y	US 2015/314536 A1 (SMITH JONATHAN [GB] ET AL) 5 November 2015 (2015-11-05) paragraphs [0012], [0013]; figures -----	2

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

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 October 2016	11/01/2017

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, Fax: (+31-70) 340-3016	Bibollet-Ruche, D

2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2016/054426

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-3, 16

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-3, 16

   To reduce the time of application of the preform on the mold

   ---

2. claims: 1, 4, 17

   To increase the stiffness of the preform

   ---

3. claims: 1, 5, 7, 18-20

   To provide a method of joining the rovings of the preform

   ---

4. claims: 1, 6, 8-10

   To facilitate the laying of the preforms sheets

   ---

5. claims: 1, 11

   To provide a more resistant wind turbine blade

   ---

6. claims: 1, 12

   To reduce the number of manipulations for laying the preform on the mold

   ---

7. claims: 1, 13

   To provide a lighter wind turbine blade

   ---

8. claims: 1, 14, 15

   To provide a blade with a specific shape

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/054426

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2338668 A1	29-06-2011	CN 102834247 A	19-12-2012
		EP 2338668 A1	29-06-2011
		EP 2516140 A1	31-10-2012
		US 2012257984 A1	11-10-2012
		WO 2011076857 A1	30-06-2011
US 2015314536 A1	05-11-2015	CN 105073400 A	18-11-2015
		EP 2934873 A1	28-10-2015
		US 2015314536 A1	05-11-2015
		WO 2014094787 A1	26-06-2014