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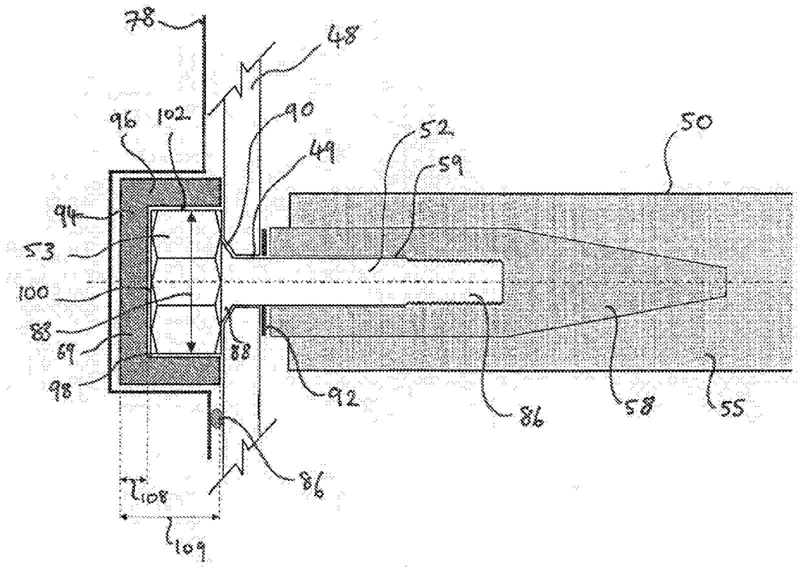

Figure 7

(57) Abstract: A method of making at least a portion of a wind turbine blade is described. The method comprises providing a tool shaped to form at least a portion of a wind turbine blade; providing fibrous reinforcing material on the tool; providing a blade component on the tool or on the fibrous reinforcing material; securing the blade component in a predetermined position relative to the tool using a fastener having a head and a shank; providing a cap shaped to fit snugly over the head of the fastener, and arranging the cap on the head of the fastener; covering the fibrous reinforcing material, the blade component, the fastener and the cap with a vacuum bag and sealing the vacuum bag to form a sealed region encapsulating the fibrous reinforcing material, the blade component, the fastener and the cap; optionally evacuating the sealed region; providing resin to the sealed region; curing the resin to integrate the fibrous reinforcing material and the blade component; removing the vacuum bag; removing the cap from the head of the fastener; and optionally

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removing the fastener from the blade component. The cap prevents the head of the fastener from being contaminated by resin during the manufacturing process.

Wind Turbine Blade Manufacture

Technical Field

The present invention relates generally to the manufacture of wind turbine blades.

Background

The blades of modern utility-scale wind turbines generally comprise a hollow blade shell formed of composite materials, such as glass-fibre reinforced plastic.

The blades are often manufactured in two halves, by forming windward and leeward half shells in respective female blade moulds. The process involves forming a blade shell layup in the mould by arranging fibrous reinforcing material in the mould together with other blade materials and components, such as spar caps. The moulds are then covered with a vacuum bag, which may be sealed against a flange of the mould to form a sealed region encapsulating the blade shell layup. Air is evacuated from the sealed region and resin is admitted into the sealed region.

The resin infuses the fibrous reinforcing material and infiltrates between the various blade components. The resin is then cured such that it hardens and integrates the fibrous reinforcing material and other blade materials and components into a single structure, i.e. a half shell. The two half shells formed in this way are then bonded together along their leading and trailing edges. Shear webs may be bonded inside the blade between the two half shells.

Instead of forming the blade from two half shells, it is also known to form wind turbine blades in a single piece, using a so-called ‘one-shot’ method, which avoids adhesive bonds in the blade shell.

The root end of a blade shell is typically circular and is significantly thicker than the remainder of the shell in order to support the static and dynamic loads of the blade in use. It can be difficult and time consuming to make the root end. One of the challenges is supporting many layers of fibrous reinforcing material on the steeply inclined surfaces of the female blade moulds during the fabrication process. One solution to this problem involves forming the root end of the blade shell separately using a male mould. The prefabricated root end may then be arranged together with the remainder of the blade shell in a female mould and integrated therewith during an infusion process, or bonded or otherwise connected to the remainder of the blade. Alternatively, the root end may be formed by winding fibrous reinforcing material onto a mandrel.

The root end of the blade is connected to a wind turbine hub component such as a flange or pitch bearing when the wind turbine is installed. The root end of the blade shell may be formed to include a hub connection, which may comprise a circular array of threaded bores. These bores are designed to align with bolt holes in the hub flange or pitch bearing and are configured to receive connecting bolts to secure the blade to the hub flange or pitch bearing.

When forming the root end of a blade shell by any of the above methods, it is known to incorporate hub connection components in the root portion of the shell. These components define the threaded bores of the hub connection. These components, which are referred to herein as ‘root inserts’ may comprise cylindrical metal bushings encased in cured composite material.

The root inserts may be assembled into a semi-circular or circular arrangement by temporarily securing them to a root plate. The root plate includes a plurality of holes having the same arrangement as the holes in the hub flange or pitch bearing to which the blade will be connected. Bolts or equivalent fasteners are used to secure the root inserts to the root plates during the shell manufacturing process. The bolts extend through the holes in the root plate and into the metal bushings of the root inserts. The root plate may be a separate plate that is secured to a blade shell mould or tool, or it may be an integral part of the mould or tool. The root plate supports the root inserts in the correct positions during the manufacture of the blade shell or during manufacture of a separate root portion of the blade shell.

Once the blade shell or separate root portion has been formed, it must be released from the root plate by removing the bolts. However, the heads of the bolts become contaminated with resin during the resin infusion process because the vacuum bag is arranged over the root plate and the bolt heads are therefore inside the vacuum bag and are infiltrated with resin.

In order to remove the bolts, the cured resin encasing the bolt heads must be removed. This process is a manual process and involves using a chisel. As there may be ninety or more bolts securing the blade to the root plate, this process takes a considerable amount of time, typically several hours, and is therefore also expensive. Furthermore, the use of chisels introduces health and safety risks to personnel and risks damage to the blade tooling or to the bolts, which are themselves expensive custom components intended to be reused in hundreds of production runs. Even after the bolts are removed, they may require further cleaning before they can be reused.

Prior (non-public) attempts by the present applicant to address the problem of bolt head contamination have involved arranging a secondary vacuum bag over the bolt heads. The secondary vacuum bag may be sealed against the root plate to form a sealed region enclosing the bolt heads. However, this method is not ideal because it introduces considerable extra cost and complexity to the manufacturing process. The secondary vacuum bag and the sealing tape used to seal it are consumable and not inexpensive materials that must be disposed of after each production run. It is time consuming to arrange the secondary vacuum bag correctly. Furthermore, both the main vacuum bag and the secondary vacuum bag have a tendency to tear against the bolt heads when the main vacuum bag is evacuated. The seal of the secondary vacuum bag may also not be perfect and is vulnerable to becoming dislodged during the process. Consequently it is still often the case that resin contaminates the bolt heads and must be removed even when using a secondary vacuum bag. Tearing of the main vacuum bag is a serious problem as it may require the entire manufacturing process to be halted until the main vacuum bag is repaired.

The contamination of bolt heads with resin during blade manufacturing may also affect other components that need to be secured with a bolt or other fastener during the manufacturing process. For example, it may be required to secure the spar caps in position using bolts during the blade manufacturing process. Any such bolts that are within the vacuum bag will become contaminated with resin and will therefore also be difficult to remove after the infusion process is complete.

Against this background it is an objective of the present invention to address the problem of resin contamination of the bolts or other fasteners that are used to secure blade components in their intended positions during blade manufacture. Accordingly it is an objective to provide improved methods of making wind turbine blades that avoid the problem of bolt contamination.

Summary of the invention

According to a first aspect of the present invention there is provided a method of making at least a portion of a wind turbine blade, the method comprising:

a. providing a tool shaped to form at least a portion of a wind turbine blade;
b. providing fibrous reinforcing material on the tool;
c. providing a blade component on the tool or on the fibrous reinforcing material;
d. securing the blade component in a predetermined position relative to the tool using a fastener having a head and a shank;
e. providing a cap shaped to fit snugly over the head of the fastener, and arranging the cap on the head of the fastener;
f. covering the fibrous reinforcing material, the blade component, the fastener and the cap with a vacuum bag and sealing the vacuum bag to form a sealed region encapsulating the fibrous reinforcing material, the blade component, the fastener and the cap;
g. optionally evacuating the sealed region;
h. providing resin to the sealed region;
i. curing the resin to integrate the fibrous reinforcing material and the blade component;
j. removing the vacuum bag;
k. removing the cap from the head of the fastener; and
l. optionally removing the fastener from the blade component.

The mould tool may be a male mould tool, a female mould tool or a mandrel. The mould tool may be shaped to form part of a wind turbine blade or an entire wind turbine blade. The mould tool may be shaped to form a half shell of a wind turbine blade or part of a half shell. For example, the mould tool may be shaped to form a root portion of the blade. In a particular example, the mould tool is a male mould tool and the method comprises making a root portion of the blade using the male mould tool. The root portion, prefabricated in this way, may later be integrated with the remainder of the blade shell in a subsequent moulding or bonding process.

The fasteners are preferably bolts, but other fasteners such as screws may be used.

The fibrous material may be provided in the form of dry plies or plies that are pre-impregnated with resin, i.e. so-called ‘prepreg’. Alternatively the fibrous material may be provided by winding the material onto a mandrel.

The blade component may comprise a blade root insert having a threaded bore for use in attaching the blade to a wind turbine hub. The shank of the fastener may be received within the threaded bore. Alternatively the blade component could be a spar cap or another blade component that must be fixed in a predetermined position during the manufacturing process.

The method may further comprise attaching the blade root insert to a root plate using the fastener. The root plate may be fixed to the tool or integral with the tool and is configured to secure the root insert in the predetermined position. The root plate may have a plurality of holes having the same arrangement as holes in a hub component, such as a hub flange or a pitch bearing, to which the blade is mounted in use. The shank of the fastener may extend through a hole in the root plate and engage with the threaded bore of the root insert. Preferably a plurality of root inserts are secured to the root plate using a plurality of fasteners that extend through the respective holes in the root plate. The head of each fastener is preferably covered by a respective cap. The method may comprise providing a gasket between the root plate and the blade root insert.

The cap prevents resin from contaminating the head of the fastener during the manufacturing process. The cap is preferably made from an elastomeric material. An elastomeric material is any material exhibiting elastic or rubber-like properties. The cap is preferably made from at least one of silicone rubber, nitrile butadiene rubber (NBR) and styrene-butadiene rubber (SBR). The cap may be made from a combination of elastomeric materials. For example, the cap may be made from a combination of nitrile butadiene rubber (NBR) and styrene-butadiene rubber (SBR). In a preferred embodiment the cap is made from nitrile butadiene rubber. These materials have non-stick properties that prevent resin from bonding strongly to the caps. They are also advantageously flexible and durable.

The cap preferably has a hardness on the Shore A scale of between 40 to 80, and preferably between 65 to 75. In a preferred embodiment the cap has a Shore A hardness of 70 +/-5. The Shore hardness scale is an internationally accepted standard that quantifies the hardness of a material. Shore hardness measures the hardness of a material by determining its resistance to indentation. These resistance values can be found using a durometer.

The cap preferably defines a recess for receiving the head of the fastener. The recess preferably has substantially the same shape as the head of the fastener. The recess is preferably designed to form a close fit over the head of the fastener. Preferably the recess has a diameter that is equal to or less than a corresponding diameter of the head of the fastener. Advantageously, the recess may have a diameter that is approximately 0.1 mm less than the corresponding diameter of the head of the fastener.

The cap may comprise a side wall and an end wall together defining a recess for receiving the head of the fastener. The side wall may be a perimeter wall that extends from the perimeter of the cap. The side wall and/or the end wall may have a thickness of between 3 mm to 10 mm, preferably approximately 5 mm.

The invention also provides a kit of parts for use in the manufacture of a wind turbine blade, the kit comprising a plurality of fasteners each having a head and a threaded shank, and a plurality of caps configured to fit snugly over the heads of the fasteners, the fasteners being suitable for connecting a plurality of blade root inserts to a root plate used to support the root inserts in a predetermined position relative to a tool, the threaded shanks of the fasteners being suitable for mating with threaded bores of the root inserts, wherein each cap is made of an elastomeric material and comprises a side wall and an end wall together defining a recess for receiving the head of a respective fastener, the recess having substantially the same shape as the head of the fastener to be covered and the recess having a diameter that is equal to or less than a corresponding diameter of the head of the fastener.

The recess of the cap(s) preferably has a diameter that is approximately 0.1 mm less than the corresponding diameter of the head of a fastener. The caps are preferably made from at least one of silicone rubber, nitrile butadiene rubber (NBR) and styrene-butadiene rubber (SBR). The caps preferably have a hardness on the Shore A scale of between 40 to 80, and preferably between 65 to 75. The side walls and/or the end walls of the caps preferably have a thickness of between 3 mm to 10 mm, preferably approximately 5 mm. Other features of the caps described above in relation to the method also apply to the invention when expressed in terms of a kit of parts. Repetition of such features is avoided purely for reasons of conciseness.

Brief description of the drawings

The present invention will now be described in further detail, by way of non-limiting example only, with reference to the following figures, in which:

Figure 1 is a schematic perspective view of a wind turbine blade incorporating a prefabricated root section;

Figure 2 is a schematic perspective view of a male mould for manufacturing a prefabricated root section, and shows inner fibrous layers being arranged on the mould;

Figure 3 is a schematic perspective view of a root plate and root inserts being arranged on the male mould;

Figure 4 is a schematic perspective view of a root insert;

Figure 5 is a schematic perspective view showing outer fibrous layers being arranged on the male mould;

Figure 6 is a schematic perspective view of a resin infusion process;

Figure 7 is a schematic cross-sectional view of a root insert attached to the root plate by a bolt, and shows a cap covering the bolt head; and

Figure 8 is a front view of the cap shown in Figure 7.

Detailed description

Figure 1 is a schematic perspective view of a wind turbine blade 10. The blade 10 extends in a spanwise direction (S) between a root end 12 and a tip end 14, and in a chordwise direction (C) between a leading edge 16 and a trailing edge 18. The blade 10 comprises an outer shell 20 formed as a composite laminate, for example from glass-fibre reinforced plastic (GFRP). The outer shell 20 comprises first and second half shells e.g. a leeward (suction) half shell 22 and a windward (pressure) half shell 24. The half shells 22, 24 are bonded together by adhesive along their respective leading and trailing edges 16, 18. The root end 12 of each half shell 22, 24 comprises a prefabricated root section 26.

Figure 2 is a schematic perspective view of a male mould 28 shaped to form the prefabricated root section 26 of the wind turbine blade 10. The male mould 28 extends longitudinally in a spanwise direction (S) between an inboard end 30 and an outboard end 32, and transversely in a chordwise direction (C) between a leading edge 34 and a trailing edge 36. The male mould 28 defines a male mould surface 38 of convex curvature in the chordwise direction (C).

In order to produce the root section 26, one or more inner fibrous layers 40 (also known as ‘plies’) are initially arranged on the male mould surface 38. These layers 40 will form the innermost structural layers of the root laminate. In this example, the fibrous layers 40 are glass-fibre fabric layers. A plurality of inner layers 40 are preferably arranged on the mould 28. The layers 40 may be arranged successively until a required thickness has been built up. Alternatively, the layers 40 may be pre-assembled as a preform and draped over the male mould surface 38 in a single step. One or more other layers such as coating layers or release layers may be applied to or arranged on the mould surface 38 prior to arranging the inner layers 40.

Use of a male mould 28 to form a root section 26 is advantageous because the fabric layers 40 do not tend to form wrinkles or creases when arranged on the male mould 28. The convex curvature of the mould 28 means that any creases or wrinkles in the layers 40 are naturally removed under the influence of gravity. The difficulties and problems associated with arranging plies against the steep sides at the root end of a female blade mould are therefore avoided.

Figure 3 illustrates the next stage of the fabrication process, which involves arranging a root plate 48 at the inboard end 30 of the male mould 28. The root plate 48 in this example is a metal plate having a semi-circular profile. The root plate 48 includes a plurality of holes 49 (one of which is shown in Figure 7) that have the same configuration and spacing as the holes on a hub component, such as a hub flange or pitch bearing, to which the blade 10 will eventually be mounted to. A plurality of root inserts 50 project from the root plate 48 along an arcuate path (in this case along a semi-circular path). Each root insert 50 is bolted to the root plate 48 by a respective bolt 52 extending through a respective hole 49 in the root plate 48. The root inserts 50 project from a first side of the root plate 48, whilst heads of the bolts 52 are exposed on a second side of the root plate 48.

Figure 4 shows a root insert 50 by way of example. The root insert 50 comprises an elongate body 55 formed from pre-cured composite material as GFRP or CFRP (carbon-fibre reinforced plastic), which is preferably formed in a pultrusion process. A bushing 58, preferably made of metal, is embedded within the composite body 55. The bushing 58 comprises a threaded bore 59 defining an aperture 60 at the proximal end 54 of the root insert 50. The bolts 52 (shown in Figure 3) are received in the threaded bores 59 of the bushings 58 in order to connect the root inserts 50 to the root plate 48 during the manufacturing process. When the blade 10 is installed in a wind turbine, the bushings 58 receive longer bolts that connect the blade 10 to a hub component such as a hub flange or pitch bearing.

The root insert 50 shown in Figure 4 is merely one example of a root insert and root inserts having different shapes, sizes and configurations may also be used in the present method. In other embodiments, a root insert may be provided that includes a plurality of apertures for receiving a respective plurality of bolts 52. For example, a root insert having a profile corresponding to the combined profile of two or more of the plurality of root inserts shown in Figure 3 may be used.

Referring again to Figure 3, the root plate 48 is arranged at the inboard end 30 of the male mould 28 such that the root inserts 50 overlay the inner fibrous layers 40 at the inboard end 30. It will be appreciated that the inner fibrous layers 40 could be arranged on the mould 28 before or after the root plate 48 is arranged. For example, the inner fibrous layers 40 could be inserted beneath root inserts 50 that have been previously arranged on the mould 28.

The root plate 48 in this example comprises datum features 62 for aligning with corresponding datum features 64 of the male mould 28. The datum features 62 in this example are bolt holes in the root plate 48, which precisely align with bolt holes 64 at the inboard end 30 of the male mould 28. The root plate 48 is bolted to the male mould 28 with a series of bolts 66 (shown in Figure 5) that extend through these bolt holes 62, 64. The datum features 62, 64 ensure precise alignment of the root plate 48 and root inserts 50 with the male mould 28. Accordingly, the root inserts 50 and their bushings 50 are precisely positioned in predetermined positions relative to the male mould 28.

Figure 5 is a schematic perspective view of a further stage in the manufacture of the root section 26 in which one or more outer fibrous layers 68 (e.g. ‘plies’) are arranged on top of the inner fibrous layers 40 (shown in Figure 2) and on top of the root inserts 50 (shown in Figure 3). These outer fibrous layers 68 will form the outermost structural layers of the root laminate. The root inserts 50 thereby become sandwiched between the inner and outer fibrous layers 40, 68 at the inboard end 30 of the male mould 28. The outer fibrous layers 68 are preferably glass-fibre fabric layers.

As shown in Figure 5, a plurality of caps 69 are fitted over the bolt heads 53 (shown in Figure 3). The caps 69 prevent resin from contaminating the bolt heads 53 during the resin infusion process. The caps 69 and their function will be described in further detail later with reference to Figures 7 and 8.

Referring to Figure 6, after the various components have been arranged on the male mould 28, resin 76 may be supplied to the components in a vacuum assisted resin infusion process. Specifically, the mould 28 is covered with a vacuum bag or film 78, which is sealed against surfaces of the mould 28, in this case against a flange 80 and end surfaces 81 of the mould 28 to define a sealed region encapsulating the components. In addition to encapsulating the fibrous layers and the root inserts 50 of the blade shell assembly, the vacuum film 78 also encapsulates the root plate 48 and the bolt heads 53 (shown in Figure 3, which are now covered by the caps 69 shown in Figure 6).

A vacuum pump 82 is employed to remove air from the sealed region. Concurrently, resin 76 is admitted into the sealed region. The resin 76 infuses throughout the fibrous layers 40, 68 and between the root inserts 50 and the fibrous layers 40, 68, aided in part by the vacuum pressure within the sealed region.

It will be appreciated that a vacuum-assisted resin infusion process is only one of a number of applicable methods for providing resin 76 to the fibrous layers 40, 68 and to the root inserts 50, and the invention is by no means limited to the use of this process. In other examples resin 76 may already be contained in the fibrous layers 40, 68 in the case of prepreg or semipreg materials, or wet hand lay-up may be used, whereby the resin 76 is applied to the various components using tools such as a brush or roller.

Once the resin infusion process is complete, the next stage in the process involves curing the resin 76 in the root section 26. This may be achieved by any suitable method, for example by arranging the male mould 28 in an oven. Once the resin 76 has cured, the prefabricated root section 26 is removed from the male mould 28. The root inserts 50 described previously are embedded between the inner and outer laminate layers 40, 68 at the thick inboard end of the shell laminate. The prefabricated root section 26 is subsequently integrated with the remainder of a blade half shell. This may be achieved in a number of ways, for example by arranging the prefabricated root section 26 in or adjacent to a female blade mould used to form the remainder of the half shell. An example of this process is described in WO2020127926A2.

Referring to Figure 7, this shows a schematic cross-sectional view of part of the assembly shown in Figure 6. In particular, Figure 7 shows a root insert 50 connected to the root plate 48 by a bolt 52. The bolt head 53 is covered by a cap 69. The vacuum film 78 extends over the cap 69 and is sealed against the root plate 48 using sealant tape 86.

The root insert 50 comprises a metal bushing 58 encased in a GFRP body 55. The bushing 58 defines a threaded bore 59, which is aligned with a hole 49 in the root plate 48. The bolt 52 comprises a threaded shank 86 extending from the head 53. The shank 86 extends through the hole 49 in the root plate 48 and into the threaded bore 59 of the bushing 58. The screw thread of the bolt 52 mates with the screw thread of the bushing 58. As shown, the root insert 50 projects from a first side of the root plate 48, whilst the bolt head 53 is on a second side of the root plate 48.

The bolt 52 in this example is an M36 threaded bolt, which has a thread diameter of 36 mm. The bolt head 53 is hexagonal and has a diameter 83 of 55 mm. The bolt head diameter 83 is measured as the distance between opposing flat sides of the head 53. Bolts or similar fasteners having different dimensions may be used in other examples. The bolt 52 is tightened to a predetermined torque value using a torque wrench with a socket sized to fit over the bolt head 53.

The shank 86 of the bolt 52 includes a conical portion 88 adjacent to the head 53. The root plate 48 includes a conical portion 90 of similar shape surrounding the hole 49 on the second side of the root plate 48. This conical portion 90 may be machined into the root plate 48 or may be provided as a separate insert. The conical portion 88 of the bolt 52 forms a seal against the conical portion 90 surrounding the hole 49 when the bolt 52 is tightened.

A gasket 92 is provided between the root insert 50 and the first side of the root plate 48. In this example, the bushing 58 protrudes slightly from the end of the root insert 50. The gasket 92 is a rubber ring that covers the end face of the bushing 58 and surrounds the shank 86 of the bolt 52. The gasket 92 is compressed between the bushing 58 and the root plate 48 when the bolt 52 is tightened and forms a tight seal.

The cap 69 is provided on the bolt head 53 to prevent the bolt head 53 from being contaminated by resin during the infusion process. The cap 69 comprises an end wall 94 and a side wall 96 that projects from the end wall 94, perpendicular thereto. The side wall 96 in this example is a perimeter wall as it extends from a perimeter of the cap 69. The cap 69 is open on one side and includes a recess 98 for receiving the bolt head 53. The recess 98 is defined in part by the end wall 94 and in part by the side wall 96. When the cap 69 is fitted to the bolt head 53, the end wall 94 is parallel to and covers an end surface 100 of the bolt head 53 and the side wall 96 is parallel to and covers the side surfaces 102 of the bolt head 53.

The cap 69 is formed of elastomeric material. In this example, the cap 69 is made from nitrile butadiene rubber (NBR) having a hardness of 70 +/- 5 measured on the Shore A scale. The cap 69 is a moulded component and has a monolithic structure.

The cap 69 is designed to form a snug fit on the bolt head 53. Accordingly, the recess 98 of the cap 69 has substantially the same shape and similar dimensions to the bolt head 53. In this example, the recess 98 is hexagonal, as seen in the front view of the cap 69 in Figure 8. The recess 98 has a diameter 99 of 54.9 mm in this example. The diameter 99 is measured between opposite flat internal surfaces 104 of the recess 98, as indicated in Figure 8. The diameter 99 of the recess 98 is therefore slightly less than the diameter 83 of the bolt head 53, which in this example has a diameter of 55 mm.

As the cap 69 is made from an elastomeric material, it is able to stretch slightly when it is pushed onto the bolt head 53. Consequently, the cap 69 forms a tight, i.e. snug, fit on the bolt head 53, such that the internal surfaces 104 of the cap 69 fit closely against the outer surfaces 100, 102 of the bolt head 53.

In this example, and as shown in Figure 8, the outer profile of the cap 69 is also hexagonal. However, in other examples the outer profile could have a different shape, for example it could be circular or any other shape. It is the shape and dimensions of the recess 98 that are more important, and these ideally correspond substantially to the shape and dimensions of the bolt head 53 to ensure a snug fit. The cap 69 advantageously has rounded edges 106. This advantageously avoids any sharp edges that could tear the vacuum film 78.

The side wall 96 of the cap 69 in this example has a thickness 107 of approximately 5 mm, as indicated in Figure 8. The end wall 94 also has a thickness 108 of approximately 5 mm, as shown in Figure 7. The side wall 96 has a height 109 of approximately 26 mm, as also indicated in Figure 7. Accordingly, the cap 69 is only slightly larger than the bolt head 53, which minimises the amount of material needed to form the cap 69, and therefore minimises costs.

During the infusion process, the caps 69 are inside the vacuum film 78 and are exposed to resin. The caps 69 substantially prevent the resin from contacting the bolt heads 53. If any resin should infiltrate the caps 69, the close fit of the caps 69 means that the bolt heads 53 would, at worst, only have a very thin coating of cured resin on them. However, this thin coating is not problematic because it does not prevent the socket of the torque wrench from fitting over the bolt heads 53 when the bolts 52 are to be removed. Therefore, once the caps 69 are removed, no additional work is needed to remove resin from the bolt heads 53 before the bolts 52 can be removed.

Resin is also prevented from contacting the screw threads of the bolt 52 or entering the bushings 58 in the root inserts 50 by the conical seal 88, 90 and the gasket seal 92 on the respective sides of the root plate 48, as shown in Figure 7.

When the manufacturing process is complete and the resin has cured, the vacuum film 78 is removed and the caps 69 are removed from the bolt heads 53. Removing the caps 69 is an easy process and can be performed by hand, simply by grasping and pulling the caps 69.

The NBR material from which the caps 69 are made has advantageous non-stick properties, so the resin does not form strong mechanical or chemical bonds to the caps

69. This enables any cured resin on the caps 69 to be removed with little effort. As the caps 69 are flexible, they can be squeezed slightly, which causes resin to break off easily.

The material and hardness of the caps 69 ensures that the caps 69 are sufficiently durable and can withstand the pressures and temperatures experienced in the infusion and curing processes without incurring damage such as cracking. The caps 69 are designed to be reused multiple times.

As the caps 69 are relatively soft compared to the bolt heads 53, and may have rounded edges 106, the risk of tearing the vacuum film 78 is avoided.

The use of caps 69 to cover the bolt heads 53 presents numerous other advantages, including many advantages over the previously-described technique of using a secondary vacuum film 78 to cover the bolt heads 53. Firstly, the caps 69 prevent the bolt heads 53 from being contaminated with cured resin. This eliminates the need to manually chisel away resin from the bolts 52, thus saving several hours labour and significantly reducing the takt time of wind turbine blade production. The bolts 52 can be removed immediately after the caps 69 are removed as any resin on the bolt heads 53 is limited to a very thin film that can be accommodated within normal tolerance ranges of tools such as socket wrenches or spanners. The health and safety risks associated with manually removing resin are also avoided, so the caps 69 increase the safety of the manufacturing process. The caps 69 are easy to fit to the bolt heads 53 and easy to remove. The caps 69 are therefore convenient in comparison to a secondary vacuum bag, which can be time consuming to position correctly and seal. The caps 69 can be reused, whereas a secondary vacuum bag and seal must be disposed of after use. Accordingly, the caps 69 reduce wastage in the manufacturing process. The caps 69 are also relatively inexpensive to produce.

The above example relating to the manufacture of a root section using a male mould is used to illustrate one application of the caps 69 and is not intended to limit the scope of the invention. Root inserts 50 similar to those described above may also be incorporated into blade layups using a female mould, either a full-length blade layup or a root section layup. Alternatively the root inserts may be incorporated in a winding process where fibre is wound around a mandrel to form a root section of a blade. In both cases, the root inserts 50 may be secured to a root plate 48 in a similar way to that shown in Figure 7, and caps 69 may be used to prevent resin contamination of the bolt heads 53 in the same way.

The use of caps 69 to prevent resin contamination of bolts or other fasteners is also not limited to their use in connection with root inserts 50. It will be appreciated that caps 69 may be used to cover the heads 53 of any bolts or other fasteners that may be susceptible to resin contamination. For example, in some cases it may be desirable to temporarily secure other blade components during the blade manufacturing process. Such components may include spar caps, where it may be desirable to secure the spar caps in a predetermined position using fasteners. The caps 69 may be used to cover the head 53 of any such fastener that may be exposed to resin.

Many other modifications may be made to the examples described above without departing from the scope of the present invention as defined in the following claims.

Claims

1. A method of making at least a portion of a wind turbine blade, the method comprising:
   a. providing a tool shaped to form at least a portion of a wind turbine blade;
   b. providing fibrous reinforcing material on the tool;
   c. providing a blade component on the tool or on the fibrous reinforcing material;
   d. securing the blade component in a predetermined position relative to the tool using a fastener having a head and a shank;
   e. providing a cap shaped to fit snugly over the head of the fastener, and arranging the cap on the head of the fastener;
   f. covering the fibrous reinforcing material, the blade component, the fastener and the cap with a vacuum bag and sealing the vacuum bag to form a sealed region encapsulating the fibrous reinforcing material, the blade component, the fastener and the cap;
   g. optionally evacuating the sealed region;
   h. providing resin to the sealed region;
   i. curing the resin to integrate the fibrous reinforcing material and the blade component;
   j. removing the vacuum bag;
   k. removing the cap from the head of the fastener; and
   l. optionally removing the fastener from the blade component.

2. The method of Claim 1, wherein the blade component comprises a blade root insert having a threaded bore for use in attaching the blade to a wind turbine hub, and wherein the shank of the fastener is received within the threaded bore.

3. The method of Claim 2, further comprising attaching the blade root insert to a root plate using the fastener.

4. The method of Claim 3, further comprising providing a gasket between the root plate and the blade root insert.

5. The method of any preceding claim, wherein the cap is made from an elastomeric material.

6. The method of any preceding claim, wherein the cap is made from at least one of silicone rubber, nitrile butadiene rubber (NBR) and styrene-butadiene rubber (SBR).

7. The method of any preceding claim, wherein the cap is made from a combination of nitrile butadiene rubber (NBR) and styrene-butadiene rubber (SBR).

8. The method of any preceding claim, wherein the cap has a hardness on the Shore A scale of between 40 to 80, and preferably between 65 to 75.

9. The method of any preceding claim, wherein the cap defines a recess for receiving the head of the fastener, and wherein the recess has substantially the same shape as the head of the fastener.

10. The method of Claim 9, wherein the recess has a diameter that is equal to or less than a corresponding diameter of the head of the fastener, preferably the recess has a diameter that is approximately 0.1 mm less than the corresponding diameter of the head of the fastener.

11. The method of any preceding claim, wherein the cap comprises a side wall and an end wall together defining a recess for receiving the head of the fastener, and wherein the side wall and/or the end wall has a thickness of between 3 mm to 10 mm, preferably approximately 5 mm.

12. A kit of parts for use in the manufacture of a wind turbine blade, the kit comprising a plurality of fasteners each having a head and a threaded shank, and a plurality of caps configured to fit snugly over the heads of the fasteners, the fasteners being suitable for connecting a plurality of blade root inserts to a root plate used to support the root inserts in a predetermined position relative to a tool, the threaded shanks of the fasteners being suitable for mating with threaded bores of the root inserts, wherein each cap is made of an elastomeric material and comprises a side wall and an end wall together defining a recess for receiving the head of a respective fastener, the recess having substantially the same shape as the head of the fastener to be covered and the recess having a diameter that is equal to or less than a corresponding diameter of the head of the fastener.

13. The kit of Claim 12, wherein the recess has a diameter that is approximately 0.1 mm less than the corresponding diameter of the head of a fastener.

14. The kit of Claim 12 or Claim 13, wherein the caps are made from at least one of silicone rubber, nitrile butadiene rubber (NBR) and styrene-butadiene rubber (SBR).

15. The kit of any of Claims 12 to 14, wherein the caps have a hardness on the Shore A scale of between 40 to 80, and preferably between 65 to 75.

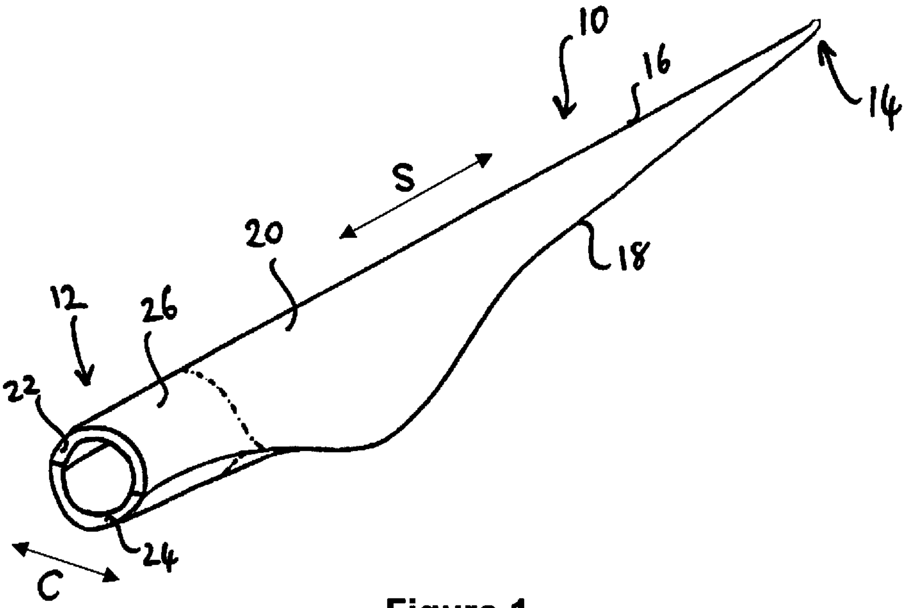

Figure 1

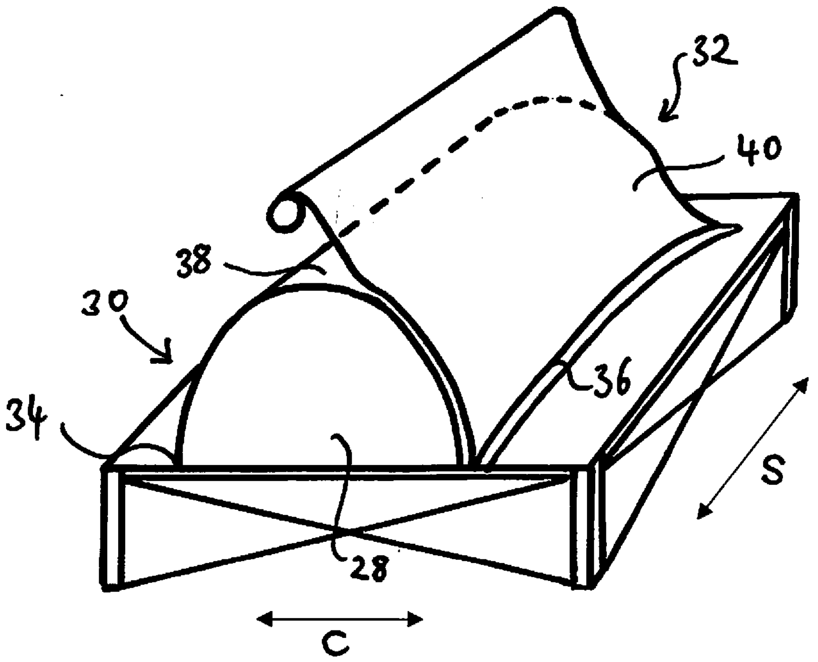

Figure 2

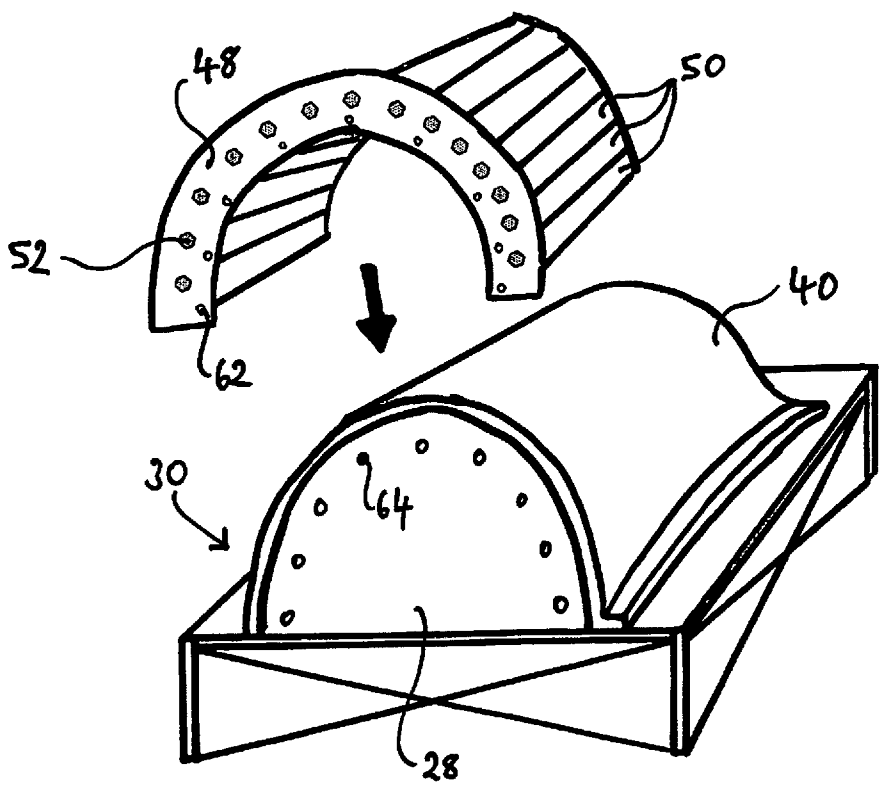

Figure 3

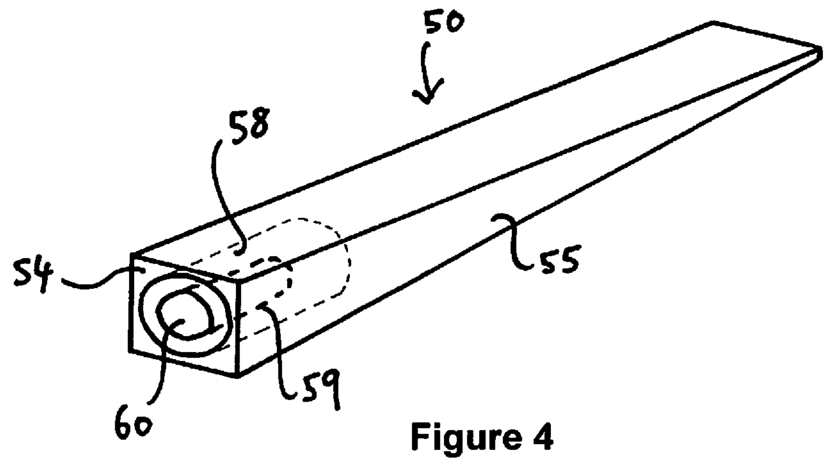

Figure 4

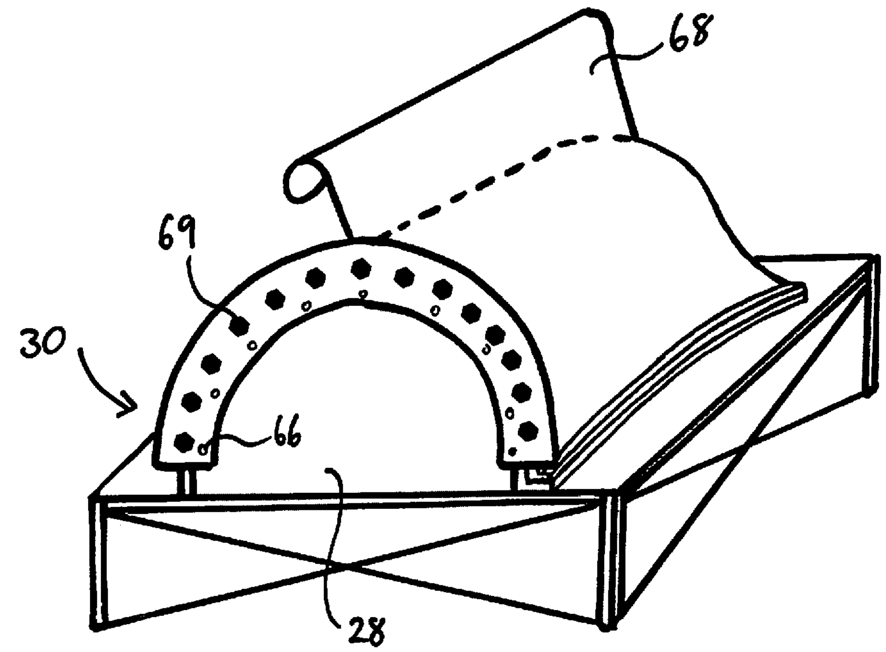

Figure 5

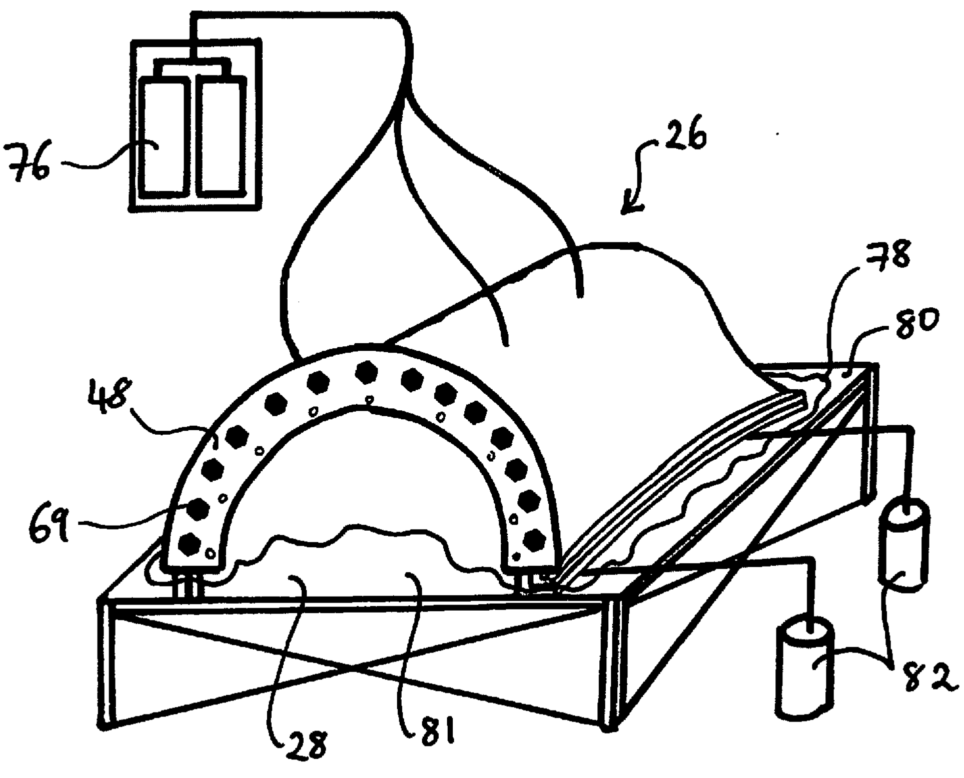

Figure 6

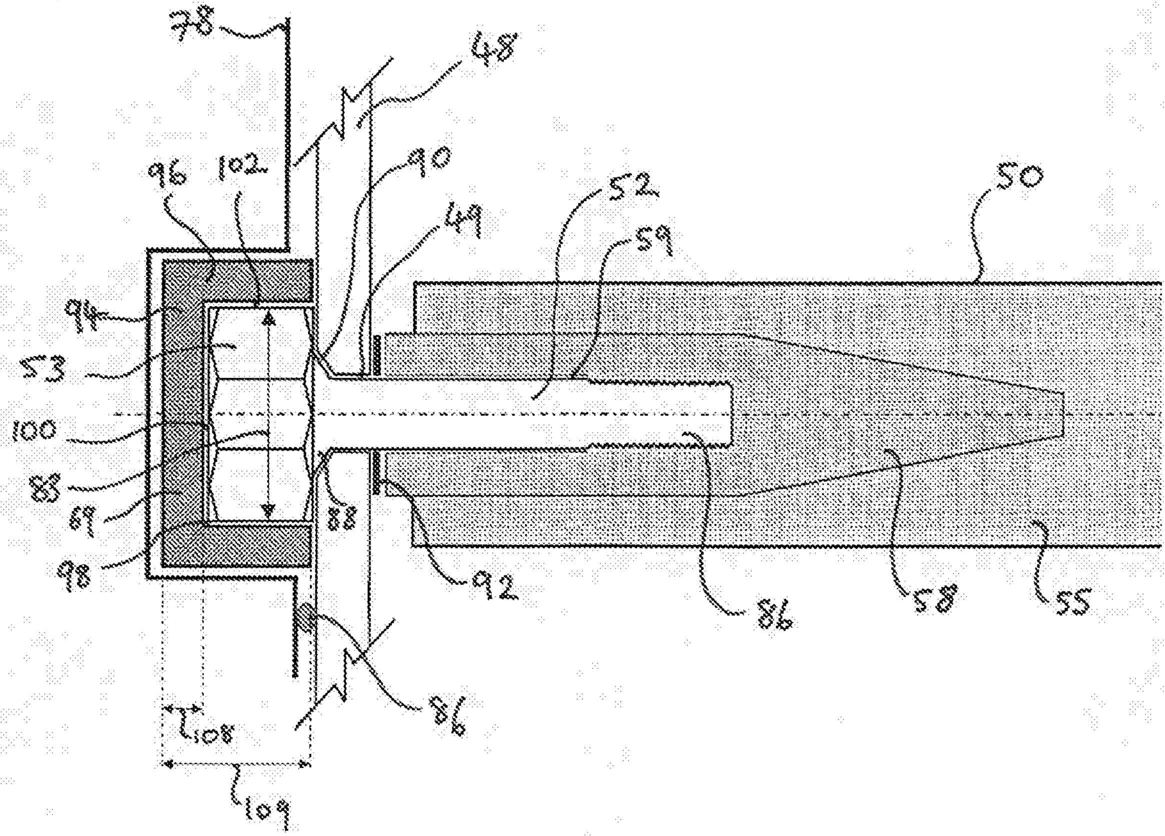

Figure 7

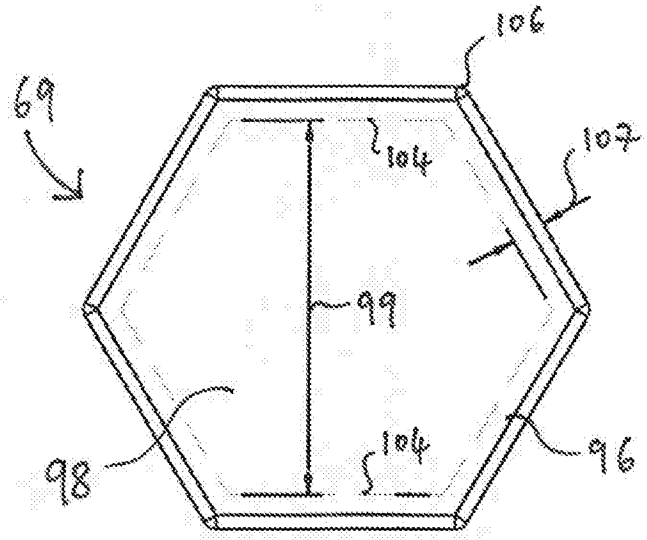

Figure 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2024/050127

A. CLASSIFICATION OF SUBJECT MATTER
INV. B29D99/00 B29C70/44 B29C70/72 B29C70/76 B29C33/12
B29C70/86 F03D1/06
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B29D B29C F03D B29L F16B

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 Y	JP 2021 127780 A (KYOWA RUBBER KK) 2 September 2021 (2021-09-02) figure 1 paragraphs [0015], [0031], [0034] -----	12-15 1-11
Y	CN 109 367 077 A (ZHUZHOU TIMES NEW MAT TECH CO) 22 February 2019 (2019-02-22) figures 1, 10 paragraphs [0001], [0024], [0033], [0036] -----	1-11

☐ 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
6 September 2024	19/09/2024

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	Gasner, Benoit

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/DK2024/050127

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2021127780 A	02-09-2021	JP 7399470 B2 JP 2021127780 A	18-12-2023 02-09-2021
CN 109367077 A	22-02-2019	NONE	