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(54) Title: WIND TURBINE BLADES COMPRISING GLASS FIBER STACKS

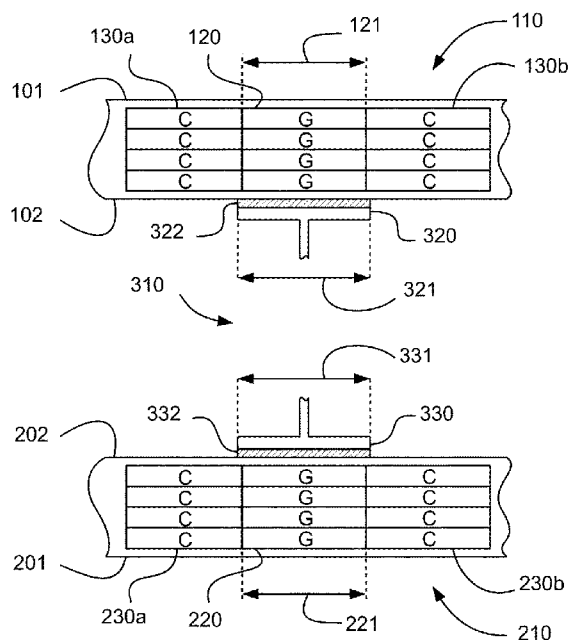


Figure 4

(57) Abstract: In a first aspect, a wind turbine blade is provided. The wind turbine blade comprises an upper blade shell part with an upper spar cap structure and a lower blade shell part with a lower spar cap structure. The upper spar cap structure and the lower spar cap structure comprise a first glass fiber stack comprising one or more glass fiber pultrusions. In a further aspect, a method for manufacturing a wind turbine blade according to any of the examples herein is provided. In yet a further aspect, a method to repair a wind turbine blade according to any of the examples herein is provided. In yet a further aspect, a wind turbine blade repaired with any of the methods to repair wind turbine blades herein is provided.

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Wind turbine blades comprising glass fiber stacks

The present disclosure relates to wind turbine blades comprising glass fiber stacks, methods for manufacturing wind turbine blades comprising glass fiber stacks, 5 methods for repairing wind turbine blades comprising glass fiber stacks, and wind turbine blades repaired with these repairing methods.

BACKGROUND

10 Modern wind turbines are commonly used to supply electricity to the electrical grid. Wind turbines of this kind generally comprise a rotor with a rotor hub and a plurality of wind turbine blades. The rotor is set into rotation under the influence of the wind on the blades. The rotation of the rotor shaft drives the generator rotor either directly ("directly driven") or through the use of a gearbox. The gearbox (if present), the 15 generator, and other systems are usually mounted in a nacelle on top of a wind turbine tower.

Wind turbine blades are generally made from fiber-reinforced polymers or plastics (FRP's), which are composite materials consisting of a polymer matrix and reinforced 20 with fibers. The fibers are usually glass or carbon and provide longitudinal stiffness and strength.

Wind turbine blades are commonly manufactured by joining two blade shell parts made from fiber-reinforced polymers, e.g. glass or carbon fiber reinforced polymers. 25 These two blade shell parts are first molded and then joined together, e.g. through an adhesive. For example, a pressure side blade shell part may be bonded to a suction side blade shell part through joining lines along the leading edge and the trailing edge.

30 These blade shell parts may be molded using a resin infusion technology or a prepreg technology. In resin infusion technology, fibers are placed in a mold and then, the resin is injected into the mold cavity under pressure. This resin fills the volume between the cavity, and then, the resin is cured or hardened. Examples of resin infusion technology may be Resin Transfer Molding (RTM) or Vacuum Assisted 35 Resin Transfer Molding (VARTM). In VARTM, the resin is injected under a vacuum or pressure lower than atmospheric.

A load-carrying structure may be arranged between the pressure side blade shell part and the suction side blade shell part. The load-carrying structure may comprise a reinforcing structure joined to opposing spar caps of the respective blade shell part. The spar caps may be embedded within the composite laminate materials of the blade shell parts or laminated to an inner surface of the blade shell. The spar caps are used to receive the reinforcing structure, e.g. a pair of opposing flanges, and to structurally reinforce the wind turbine blade. The spar caps provided in the blade shell parts typically increase the stiffness, buckling resistance, and strength of the wind turbine blade. The spar caps extend along a longitudinal length of the wind turbine blade.

Spar caps may be constructed of various materials, including glass fiber laminate composites and carbon fiber laminate composites. For example, glass fiber fabrics or carbon fiber fabrics may be employed for manufacturing spar caps. In order to increase the mechanical properties, pultruded composites may alternatively be used. Pultruded composites or pultrusions are fiber reinforcement materials that are impregnated with a resin and pulled through a heated stationary die such that resin cures and undergoes polymerization. Pultruded composites may comprise carbon fiber pultrusions and/or glass fiber pultrusions. As such, the pultrusion process is typically characterized by a continuous process that produces composite parts having a constant cross-section. Thus, a plurality of pultrusions can be vacuum infused together in a mold to form the spar caps. The pultrusions are prefabricated which allows for a high level of quality and better fiber configuration and homogeneity.

In recent times, there has been a trend to increase the size of wind turbine blades to capture more wind. Larger blades typically involve higher mechanical requirements. Furthermore, manufacturing complexity also increases with larger blades. Carbon fiber pultrusions offer a better stiffness/weight ratio and fatigue properties over glass fiber pultrusions. Accordingly, carbon fiber pultrusions may be used to achieve these high mechanical requirements. However, the high stiffness/weight ratio of the carbon fiber pultrusions does not allow subsequent machining, e.g. an abrupt stop of the unidirectional fiber, since cracks quickly propagate from holes or apertures performed in carbon fiber pultrusions. This renders repairment or operations more difficult. Furthermore, cutting tools for machining carbon fibers are subjected to great wear and are highly power-consuming. For these reasons, carbon fibers are not machined for subsequent mounting lightning receptors.

The present disclosure provides examples of systems and methods that at least partially resolve some of the aforementioned disadvantages.

SUMMARY

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In a first aspect, a wind turbine blade is provided. The wind turbine blade comprises an upper blade shell part, a lower blade shell part and a reinforcing structure between the upper blade shell part and the lower blade shell part.

10 The upper blade shell part comprises an upper outer layer defining an outer shape of the upper blade shell part and an upper inner layer defining an inner shape of the upper blade shell part. The upper blade shell part further comprises an upper spar cap structure embedded between the upper outer layer and the upper inner layer.

15 The lower blade shell part comprises a lower outer layer defining an outer shape of the lower blade shell part and a lower inner layer defining an inner shape of the upper blade shell part. The lower blade shell part further comprises a lower spar cap structure embedded between the lower outer layer and the lower inner layer.

20 Each of the upper spar cap structure and the lower spar cap structure comprises a plurality of pultrusions. Each of the pluralities of pultrusions comprises carbon fiber pultrusions defining a volume of carbon fiber pultrusions and glass fiber pultrusions defining a volume of glass fiber pultrusions. The ratio of the volume of carbon fiber pultrusions to the volume of glass fiber pultrusions is greater than 1. Each of the
25 pluralities of pultrusions comprises a first glass fiber stack comprising one or more glass fiber pultrusions.

The reinforcing structure comprises a first reinforcing beam arranged between the lower spar cap structure and the upper spar cap structure. The first reinforcing beam
30 comprises a web extending between an upper flange and a lower flange. The upper flange is joined to the upper blade shell part and the lower flange is joined to the lower blade shell part.

The first glass fiber stacks are aligned with the corresponding flange of the first
35 reinforcing beam so that the first glass fiber stack of the upper spar cap structure at least partially overlaps the upper flange, and the first glass fiber stack of the lower spar cap structure at least partially overlaps the lower flange.

According to this aspect, the volume of carbon fiber pultrusions is greater than the volume of glass fiber pultrusions. The spar cap structures are thus made mainly from carbon fiber pultrusions. Since the mechanical properties of carbon fiber pultrusions are greater than those of glass fiber pultrusions, acceptable mechanical properties may thus be achieved.

Furthermore, using a first glass fiber stack in each of the spar cap structures simplifies repairment operations. As the stiffness of glass fibers is lower than that of carbon fibers, the wear of cutting tools for machining glass fibers is significantly lesser than for machining carbon fibers. Equipment required for performing machining operations in glass fibers may be simplified and power consumption may be reduced. Safety risks of machining glass fibers are additionally reduced. Accordingly, contrary to carbon fiber pultrusions, glass fiber pultrusions may be machined. For example, perforations or holes may be drilled through the glass fiber pultrusions. The reduced stiffness and lower stress of the layers of one or more glass fiber components, when compared with layers of one or more carbon fiber components are more tolerant to damage upon perforations. This greater damage tolerance of glass fiber components may reduce the propagation of cracks from a hole performed in glass fiber components. An aperture may thus be performed through the whole first glass fiber stack in an easy manner.

In this disclosure, a glass fiber stack refers to a stack comprising one or more glass fiber pultrusions arranged on top of each other. The glass fiber stack is mainly formed by glass fiber pultrusions. The glass fiber stack may also comprise a minimum amount of pultrusions made from other types of fibers but in an amount that does not impede perforating the entire thickness of the glass fiber stack.

Manufacturing larger wind turbine blades may become more complex. Joining the reinforcing structure to the blade shell parts is a sensitive process that must be accurately controlled. For example, joint defects may occur when zones of the flanges of the first reinforcing beam are not completely joined, e.g. bonded, to the respective blade shell part. These joint defects must be detected and repaired. An adhesive may be employed for repairing the joint defect. The adhesive may be applied to the joint defect from inside the wind turbine, i.e. directly on the inner layer of the blade shell part. However, this operation may be complex, since some portions of the wind turbine blade are not accessible.

As explained before, carbon fiber pultrusions cannot be easily perforated, accordingly, the adhesive cannot be applied from outside the wind turbine blade through the carbon fiber pultrusions. However, as the first glass fiber stack of each wind turbine blade shell parts are aligned with the corresponding flange of the first reinforcing beam, a hole or aperture may be performed from outside the wind turbine blade through the first glass fiber stack to reach the joint defect. Consequently, the adhesive may be inserted through the aperture performed on the first glass fiber stack to repair the joint defect. Providing the glass fiber stack in the spar cap structure may thus allow for repairing wind turbine blades in a simplified manner.

As a result, wind turbine blades with joint defects may be easily repaired. This may reduce the scrap rate of wind turbine blades and increase blade manufacturing reliability. Manufacturing costs may thus be reduced.

Accordingly, the present disclosure aims at providing spar cap structures with the combination of the high mechanical properties of the carbon fiber pultrusions that provides stiffness with the low mechanical properties of the glass fiber pultrusions that allow apertures to be drilled for repairing joint defects.

In a further aspect, a method for manufacturing a wind turbine blade according to any of the examples herein is provided. The method comprises forming the upper blade shell part and the lower blade shell part. Forming each of the blade shell parts comprises stacking the plurality of pultrusions and laying the outer layer in a blade shell part mold. Then, the stack of the plurality of pultrusions is arranged on top of the outer layer, the inner layer is laid on top of the stack of the plurality of pultrusions, and the stack is bonded to the outer layer and to the inner layer to form the blade shell part.

The method further comprises joining the lower flange of the first reinforcing beam to the lower blade shell part, and the upper flange of the first reinforcing beam to the upper blade shell part to join the first reinforcing beam to the upper blade shell part and to the lower blade shell part, in such a way that the first glass fiber stack of the upper spar cap structure at least partially overlaps the upper flange and the first glass fiber stack of the lower spar cap structure at least partially overlaps the lower flange.

Advantages derived from this aspect may be similar to those mentioned regarding the

first aspect.

5 In yet a further aspect, a method for repairing a wind turbine blade according to any of the examples herein is disclosed. The method comprises detecting a joint defect between one of the flanges of the first reinforcing beam and one of the upper blade shell part and the lower blade shell part. In addition, the method comprises determining a joint defect zone in the corresponding blade shell part containing the joint defect.

10 The method further comprises forming one or more apertures in the defect zone through the first glass fiber stack to communicate a portion of the corresponding flange with an outside of the wind turbine blade, and inserting an adhesive through the one or more apertures to bond the corresponding flange to the corresponding blade shell part.

15 In a yet further aspect, a wind turbine blade repaired with the repairing method according to any of the examples herein is provided.

20 According to these aspects, a repaired wind turbine blade may be provided. As joint defects are repaired, the wind turbine blade may be delivered and installed in a wind turbine. The reliability of blade manufacturing may thus be increased, and scrap rates may be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

25 Non-limiting examples of the present disclosure will be described in the following, with reference to the appended drawings, in which:

30 Figure 1 illustrates a perspective view of a wind turbine according to one example;

Figure 2 shows a perspective view of a wind turbine blade according to one example;

Figure 3 shows a cross-sectional view of a wind turbine blade according to one example of the present disclosure;

35 Figure 4 schematically represents an upper spar cap structure and a lower spar cap structure according to an example of the present disclosure;

Figure 5 schematically represents an upper spar cap structure according to an example of the present disclosure;

- 5 Figure 6 shows a cross-sectional view of a wind turbine blade according to one example of the present disclosure;

Figure 7 schematically represents an upper spar cap structure according to an example of the present disclosure;

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Figure 8 is a block diagram of a method for manufacturing a wind turbine blade according to one example of the present disclosure;

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Figure 9 is a block diagram of a method for forming a blade shell part according to one example of the present disclosure;

Figure 10 is a block diagram of a method for repairing a wind turbine blade according to an example of the present disclosure;

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Figure 11A schematically represents a joint defect according to an example of the present disclosure;

Figure 11B schematically represents an aperture formed in the joint zone of the joint defect of figure 11A; and

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Figure 11C schematically represents the aperture of figure 10B filled with adhesive to repair the joint defect.

DETAILED DESCRIPTION OF EXAMPLES

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In these Figures, the same reference signs have been used to designate matching elements.

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Figure 1 illustrates a perspective view of one example of a wind turbine 1. As shown, the wind turbine 1 includes a tower 2 extending from a support surface 3, a nacelle 4 mounted on the tower 2, and a rotor 5 coupled to the nacelle 4. The rotor 5 includes a rotatable hub 6 and at least one wind turbine blade 7 coupled to and extending

outwardly from the rotor hub 6. For example, in the illustrated example, the rotor 5 includes three wind turbine blades 7. However, in an alternative embodiment, the rotor 5 may include more or less than three blades 7. Each wind turbine blade 7 may be spaced from the rotor hub 6 to facilitate rotating the rotor 5 to enable kinetic energy to be transferred from the wind into usable mechanical energy, and subsequently, electrical energy. For instance, the rotor hub 6 may be rotatably coupled to an electric generator positioned within the nacelle 4 or forming part of the nacelle to permit electrical energy to be produced.

- 10 Figure 2 illustrates an example of a wind turbine blade 7. The wind turbine blade 7 extends in a longitudinal direction or spanwise direction 37 from a blade root end 71 to a blade tip end 72. The blade 7 comprises a blade root region or portion 50 closest to the rotor hub, a profiled or an airfoil portion 52 furthest away from the rotor hub and a transition portion 51 between the blade root portion 50 and the airfoil portion 52.
- 15 The blade 7 comprises a leading edge 53 facing the direction of rotation of the blade 7 when mounted on the rotor hub, and a trailing edge 54 facing the opposite direction of the leading edge 53.

- The airfoil portion 52 has a shape designed to generate lift, whereas the blade root portion 50 has a circular or elliptical cross-section for structural considerations and easy mounting of the blade to the rotor hub. The diameter or the chord of the blade root portion 50 may be constant along the entire blade root portion 50. At the transition portion 51, the profile gradually changes from the circular or elliptical cross-section of the blade root portion 50 to the airfoil profile of the airfoil portion 52. The wind turbine blade 7 may be connected to the rotor hub through a blade root attachment portion 55.

- The wind turbine blade 7 comprises a blade shell 73. The blade shell 73 comprises an outer side or surface that defines the external shape of the blade, e.g. the outer shape at the blade root portion and the outer shape at the airfoil portion. The blade shell 73 also comprises an inner side or surface that defines the internal volume of the blade and faces a load-carrying structure (not shown). The blade shell 73 may be made of fiber-reinforced polymer or plastics, e.g. glass fiber and/or carbon fiber.

- 35 The blade shell may be formed by a plurality of blade shell parts. The plurality of blade shell parts may be joined together to form the blade shell. The blade shell parts may be formed and then joined according to any of the examples herein disclosed.

Resin infusion technology, e.g. RTM or VARTM, or prepreg technology may be used for manufacturing the blade shell parts.

5 In some examples, the blade shell comprises a lower side blade shell part and an upper blade shell part. The lower side blade shell may be a pressure side blade shell part. The upper blade shell part may be a suction side blade shell part. The lower side blade shell part may be joined to the upper side blade shell part along joining lines along the leading edge 53 and the trailing edge 54. Each of these blade shell parts may be manufactured in a mold and then joined together to define the entire
10 blade shell of the wind turbine blade 7. A reinforcing structure is arranged between the lower side blade shell part and the upper side blade shell part.

Figure 3 shows a cross-sectional view of a wind turbine blade according to one example of the present disclosure. A suction side blade shell part or upper blade shell
15 part 100, and a pressure side blade shell part or lower blade shell part 200 extend from the leading edge 53 to the trailing edge 54. The wind turbine blade 7 further comprises a chord line 38 between the leading edge 53 and the trailing edge 54. The chord line 38 extends in an edgewise direction or chordwise direction. A flapwise direction 39 is substantially perpendicular to the chord line 38. The upper blade shell
20 part 100 and the lower blade shell part 200 are joined, e.g. bonded, together along the leading edge 53 and the trailing edge 54.

The upper blade shell part 100 comprises an upper outer layer 101 and an upper inner layer 102. The upper outer layer 101 defines an outer shape of the upper blade
25 shell part 100 and the upper inner layer 102 defines an inner shape of the upper blade shell part 100. The upper outer layer 101 and the upper inner layer 102 may comprise glass fiber laminates. For example, one or more glass fiber laminates may be arranged to form the upper outer layer 101 and/or the upper inner layer 102. The fibers, e.g. glass fibers may be oriented bidirectionally to enhance the torsional
30 stiffness of the blade 7. In other examples, the fibers may be arranged unidirectionally. In further examples, the upper layers 101 and/or 102 comprise laminates with unidirectional fibers and laminates with bidirectional fibers.

The upper blade shell part 100 of this example comprises an upper spar cap
35 structure 110 embedded between the upper outer layer 101 and the upper inner layer 102. The upper spar cap 110 is thus arranged between the upper outer layer 101 and the upper inner layer 102. The upper spar cap structure 110 structurally reinforces

the upper blade shell part 100.

A core structure may be arranged between the upper outer layer 101 and the upper inner layer 102 in some parts of the upper blade shell part 100. For example, a core structure may extend a portion between the upper spar cap structure 110 and the leading edge. Additionally, or alternatively, a core structure may extend a portion between the upper spar cap structure 110 and the trailing edge 54. The core structure generally increases the thickness of the blade shell part so as to improve the stiffness without an excessive weight increase. The core structure may be made from a lightweight material such as balsa wood or polymer foam.

The lower blade shell part 200 may be manufactured like the upper blade shell part 100. As described with respect to the upper blade shell part 100, the lower blade shell part 200 comprises a lower outer layer 201 and a lower inner layer 202. The lower outer layer 201 and/or the lower inner layer 202 may comprise bidirectional glass fibers. A lower spar cap structure 210 is embedded between the lower outer layer 201 and the lower inner layer 202.

The upper spar cap structure 110 and the lower spar cap structure 210 of this example cross the flapwise direction 39. The spar cap structures 110 and 210 faces each other. The spar cap structures 110 and 210 may extend a length along the spanwise direction 37 of the wind turbine blade. The length of the spar cap structures may be greater than 90% of the entire length of the wind turbine blade.

The spar cap structures 110 and 210 comprise a plurality of pultrusions. The plurality of pultrusions of each spar cap structure 110 and 210 comprises carbon fiber pultrusions and glass fiber pultrusions. The volume of the carbon fiber pultrusions is greater than the volume of the glass fiber pultrusions. Accordingly, higher mechanical properties may be achieved. In some examples, the pultrusions are pultrusion plates. The width of the pultrusion plates is several times its thickness, for example, greater than ten times. In some examples, the pultrusion plates comprise a width between 20 mm and 300 mm and a thickness between 1 mm and 5 mm. In other examples, the pultrusions comprise other suitable cross-sectional shapes, e.g. a rectangular cross-section.

The pultrusions are arranged in stacks. Several pultrusions are thus arranged one on top of the other. In some examples, at least one of the first glass fiber stacks extend

in a direction parallel to the spanwise or lengthwise direction 37 of the wind turbine blade along a length of the corresponding spar cap structure 110 and 210. In some examples, the length of the pultrusions forming one stack varies along the spanwise direction forming a stepwise configuration. In further examples, some pultrusions of one stack may extend the entire length of the spar cap structure.

Each of the spar cap structures 110 and 210 comprises a first glass fiber stack having one or more glass fiber pultrusions. In some examples, the first glass fiber stack of the upper spar cap structure 110 and/or of the lower spar cap structure 210 comprises at least a volume of glass fiber pultrusions greater than 80% of the total volume of the pultrusions that forms the first glass pultrusions.

In other examples, the first glass fiber stack comprises pultrusions made from a different fiber material, e.g. carbon fiber pultrusions and/or aramid fiber pultrusions. The volume of these different fiber pultrusions when compared to the total volume of the first glass fiber stack is thus smaller than 20%, optionally smaller than 10%. The volume of pultrusions made from other types of fibers is thus relatively low when compared with the volume of glass fiber pultrusions. This very low volume of non-glass pultrusions within the first glass pultrusion does not impede perforating the entire thickness of the first glass fiber stack.

In some of these examples, the first glass fiber stack may be integrally formed from glass fiber pultrusions. In these examples, the first glass fiber stack is thus free from carbon fiber pultrusions or from other types of fiber pultrusions different from glass fiber pultrusions. This allows for even easier drilling through the first glass fiber pultrusions.

Apart from the first glass fiber pultrusions, the spar cap structures 110 and 210 comprise further stacks. These stacks may be formed by carbon fiber pultrusions or by a combination of glass and carbon fiber pultrusions, or other types of fiber pultrusions.

In some examples, a carbon conductive mesh may be arranged between the pultrusions that forms a stack. This carbon conductive mesh may be used for radar absorption purposes and/or for lightning protection purposes. Contrary to carbon fiber pultrusions, this carbon conductive mesh may be easily perforated due to its mesh configuration.

The wind turbine blade 7 comprises a reinforcing structure 300 arranged between the upper blade shell part 100 and the lower blade shell part 200. The reinforcing structure 300 provides stiffness to the wind turbine blade. The reinforcing structure 300 comprises a first reinforcing beam 310 arranged between the upper spar cap structure 110 and the lower spar cap structure 210. In further examples, the reinforcing structure comprises a first reinforcing beam and a second reinforcing beam.

The first reinforcing beam 310 of this example extends a length along the spanwise direction 37. The first reinforcing beam 310 may substantially extend between the root portion and the tip portion. The length of the first reinforcing beam 310 may correspond to the length of the spar cap structures 110 and 210.

The first reinforcing beam 310 comprises a web 340 extending between an upper flange 320 and a lower flange 330. The upper flange 320 of the first reinforcing beam 310 is joined to the upper blade shell part 100. The upper flange 320 is joined, e.g. bonded, to the upper inner layer 102 at the region of the upper spar cap structure 110. Similarly, the lower flange 330 is joined to the lower inner layer 202 at the region of the lower spar cap structure 210. In this example, the first reinforcing beam 310 and the spar cap structures 110 and 210 form the load-carrying structure of the wind turbine blade that serves to withstand loads applied to the wind turbine blade.

In this example, the first reinforcing beam 310 comprises a single web. However, in other examples, the first reinforcing beam 310 may comprise two webs extending between the flanges 320 and 330. This configuration may be generally known as a spar box configuration.

An adhesive layer may be arranged between the flanges 320 and 330 and the corresponding inner layer 102 and 202. The adhesive layers join the flanges 320 and 330 to the blade shell parts 100 and 200. The first reinforcing beam 310 may thus be bonded to the upper blade shell part 100 and to the lower blade shell part 200.

The first glass fiber stack of the upper spar cap structure 110 is arranged between the upper flange 320 of the first reinforcing beam 310 and the upper outer layer 101. This first glass fiber stack is thus aligned with the upper flange 320 so that this first glass fiber stack at least partially overlaps the upper flange. The upper flange 320 may be accessed from the outside of the wind turbine through the first glass fiber

stack of the upper spar cap structure 110. Similar to the upper spar cap structure 110, the first glass fiber stack of the lower spar cap structure 210 is aligned with the lower flange 330 to at least partially overlap the lower flange 330.

- 5 Figure 4 schematically represents an upper spar cap structure 110 and a lower spar cap structure 210 according to an example of the present disclosure. The upper spar cap structure 110 is arranged between the upper outer layer 101 and the upper inner layer 102 and the lower cap structure 210 is arranged between the lower outer layer 201 and the lower inner layer 202.

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The upper spar structure 110 and the lower spar structure 210 comprise a plurality of pultrusions. The pultrusions of this example are plates. The pultrusions are arranged in stacks.

- 15 The upper spar structure 110 of this example comprises a first glass fiber stack 120 arranged between two carbon fiber stacks 130a and 130b. The first glass fiber stack 120 of this example comprises several pultrusions of glass fibers arranged one on top of the other. In some examples, the first glass fiber stack 120 may comprise a plurality of glass pultrusions arranged next to each other.

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In some examples, the first glass fiber stack 120 may comprise glass fiber pultrusions and pultrusions made from other types of fiber. In these examples, the volume of glass fiber pultrusions is greater than 80% of the total volume of the pultrusions that form the first glass fiber stack 120. For example, the first glass fiber stack 120 may
25 comprise nine glass fiber pultrusions and a single carbon fiber pultrusion. This single carbon fiber pultrusion does not impede drilling the total thickness of the glass fiber stack 120.

- 30 The first glass fiber stack 120 of this figure extends embedded in the upper outer layer 101 and the upper inner layer 102 along a direction substantially parallel to the flapwise direction 39.

- In this figure, the first glass fiber stack 120 is formed by four glass fiber pultrusions. In some examples, the number of glass fiber pultrusions may vary along the spanwise
35 direction of the blade. The first glass fiber stack 120 may comprise any suitable number of glass fiber pultrusions.

The stacks 130a and 130b of this example consist of carbon fiber pultrusions. In other examples, the stacks 130a and 130b may comprise carbon fiber pultrusions and other types of fiber pultrusions, e.g. glass fiber pultrusions and/or aramid fiber pultrusions.

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In this example, the ratio of the volume of the carbon fiber pultrusions to the volume of glass fiber pultrusions is greater than 2. Or in other words, the volume of carbon fiber pultrusions is double that of glass fiber pultrusions.

- 10 Similar to the upper spar cap structure 110, the lower spar cap structure 210 of this example comprises a first glass fiber stack 220 integrally formed by a plurality of glass fiber pultrusions arranged between two carbon fiber stacks 230a and 230b. In this figure, the ratio between glass fiber pultrusions and carbon fiber pultrusions of the lower spar cap structure 210 is the same as in the upper spar cap structure 110.
- 15 As explained regarding the first glass fiber stack 220 of the lower spar cap structure 210 may comprise a minimum volume of non-glass fiber pultrusion.

- The upper flange 320 of this figure is bonded to the upper inner layer 102 through an adhesive layer 322. Loads may thus be transferred between the upper spar cap 110
- 20 and the first reinforcing beam 310. In this figure, an adhesive layer 332 is also arranged between the lower inner layer 202 and the lower flange 330 to join the first reinforcing beam 310 to the lower blade shell part 200.

- As can be seen in this figure, the upper flange 320 and the lower flange 330 are
- 25 respectively aligned with the first glass fiber stacks 120 and 220. The flanges 320 and 330 at least partially overlap the first glass fiber stacks 120 and 220. The flanges 320 and 330 are aligned with the glass fiber stacks 120 and 220 relative to a direction substantially parallel to the flapwise direction 39.

- 30 Referring to the upper spar cap structure 110, the first glass fiber stack 120 of this figure extends a stack width 121 in a direction substantially parallel to the chordwise direction 38. The upper flange 320 also extends an upper flange width 321. In this figure, the stack width 121 of the first glass fiber stack 120 overlaps the upper flange width 321. The first glass fiber stack 120 of this figure is thus aligned with the upper
- 35 flange width. A center line along a direction parallel to the flapwise direction 39 of the first glass fiber stack and of the upper flange width may substantially coincide. The width extension of the first glass fiber stack 120 is that comprised within the width

extension of the upper flange 320. The first glass fiber stack 120 of this example is arranged between the upper flange and the upper outer layer 101 in a direction substantially perpendicular to the chordwise direction 38.

5 The flange width 321 may be between 50 mm and 150 mm. In this example, the stack width 121 is smaller than the upper flange width 321. Accordingly, the proportion of the carbon fiber volume in the spar cap structure may be increased. Mechanical properties of the wind turbine blade may thus be improved. As the stack width 121 at least partially coincides with the upper flange width 321, the adhesive layer 322 may be accessed from outside the wind turbine blade 7 through the first glass fiber stack 120 in a direction perpendicular to the chordwise direction 38, i.e. parallel to the flapwise direction 39. An aperture may thus be performed through the upper outer layer 101, the first glass fiber stack 120 and the upper inner layer 102 to reach the adhesive layer 322 that bonds the upper flange 320 to the upper inner layer 102. Therefore, a spar cap structure with improved mechanical properties but ensuring access to the adhesive layer is provided.

In other examples, the stack width 121 may be greater or equal to the upper flange width 321, e.g. between 100% and 120% of the upper flange width 321.

20 As with respect to the upper spar cap structure 110, the lower flange width 331 is greater than the stack width 221. The stack width 221 of this example overlaps the lower flange width 331 so that the adhesive layer 332 may be accessed through the first glass fiber stack 220.

25 Figure 5 schematically represents an upper spar cap structure 110 according to an example of the present disclosure. It should be appreciated that a lower spar cap structure may be according to the example of this figure.

30 The upper spar cap structure 110 of this example comprises a plurality of stacks of pultrusions. The upper spar cap structure 110 of this example comprises a first glass fiber stack 120 formed by glass fiber pultrusions. The first glass fiber stack 120 is arranged between stacks of pultrusions. In this example, the spar cap structure 110 comprises carbon fiber stacks 130a, 130b, 130c and 130d which are integrally formed with carbon fiber pultrusions. The plurality of pultrusions may thus comprise a set of carbon fiber stacks. In this example, the first glass fiber stack 120 is thus between two carbon fiber stacks of the set of carbon fiber stacks.

In some examples, the spar cap structure 110 of this example may comprise hybrid stacks. Hybrid stacks may be formed by two or more different fiber materials. For example, a hybrid stack may be formed by glass and carbon fiber pultrusions.

5

In this example, the volume of the glass fiber pultrusions represents 20% of the total volume of the plurality of pultrusions and the volume of the carbon fiber pultrusions 80% of the total volume. In this figure, the ratio between the volume of the carbon fiber pultrusions and the glass fiber pultrusions is greater than 3.

10

In this example, the stack width 121 of the first glass fiber stack 120 is smaller than the upper flange width 321 of the upper flange 320. In this example, the stack width 121 is smaller than 80% of the upper flange width 321. The stack width 121 may thus be between 30 mm and 120 mm. This configuration may further improve the mechanical properties of the blade. As explained before, the lower spar cap structure may be according to the upper spar cap structure.

15

As the first glass fiber stack 120 overlaps the upper flange 320, the adhesive layer 322 may be accessed through the first glass fiber stack 120.

20

Figure 6 shows a cross-sectional view of a wind turbine blade according to one example of the present disclosure. The reinforcing structure 300 of this example comprises a first reinforcing beam 310 and a second reinforcing beam 350. The first reinforcing beam 310 and the second reinforcing beam 350 extend substantially parallel to each other and are arranged between the upper blade shell part 100 and the lower blade shell part 200.

25

The first reinforcing beam 310 may be according to any of the examples herein. The second reinforcing beam 350 may be according to any of the examples of first reinforcing beams 310. The second reinforcing beam 350 comprises a web 380 extending between the upper flange 360 and the lower flange 370.

30

The first reinforcing beam 310 and the second reinforcing beam 350 are arranged between the upper spar cap structure 110 and the lower spar cap structure 210. The upper flanges 320 and 360 are connected to the upper blade shell part 100 and the lower flanges 330 and 370 are connected to the lower blade shell part 200.

35

The plurality of pultrusions of the upper spar cap structure 110 and/or the lower spar cap structure 210 may comprise a second glass fiber stack comprising one or more glass fiber pultrusions. The second glass fiber stacks may be according to any of the examples herein regarding the first glass fiber stacks. For example, the second glass fiber stacks may be integrally or exclusively formed by glass fiber pultrusions. In other examples, the second glass fiber stack may also comprise a minimum amount of non-glass fiber pultrusions.

In some examples, the second glass fiber stacks are aligned with the corresponding flange 360 or 370 of the second reinforcing beam 350 so that the second glass fiber stack of the upper spar cap structure 110 at least partially overlaps the upper flange 360 of the second reinforcing beam 350 and the second glass fiber stack of the lower spar cap structure 210 at least partially overlaps the lower flange 370 of the second reinforcing beam 350.

Figure 7 schematically represents an upper spar cap structure 110 according to an example of the present disclosure. It should be appreciated that a lower spar cap structure may be according to the example of this figure. The upper spar cap structure 110 of this example extends between the first reinforcing beam 310 and the second reinforcing beam 350. In this example, the plurality of pultrusions extend side by side between the first reinforcing beam 310 and the second reinforcing beam 350.

In other examples, the upper spar cap structure may comprise two groups of pultrusions separated by laminates and/or a core structure. One of the groups of pultrusions is associated with one of the first reinforcing beam 310 and the other with the second reinforcing beam 350.

The upper spar cap structure 110 of this example comprises a first glass fiber stack 120 and a second glass fiber stack 140. Carbon fiber stacks 130a and 130b are arranged between the first glass fiber stack 120 and the second glass fiber stack 140. The carbon fiber stacks 130a and 130b are formed with carbon fiber pultrusions. In this figure, the upper spar cap structure 110 additionally comprises a pair of hybrid fiber stacks 150a and 150b. The hybrid fiber stacks 150a and 150b of this example comprises carbon and glass fiber pultrusions. In other examples, the hybrid fiber stacks may comprise pultrusions made from other combinations of suitable fibers.

In some examples, the spar cap structure 110 may comprise a first glass fiber stack

120, a second glass fiber stack 140 and a set of carbon fiber stacks. In some examples, a carbon fiber stack is arranged at each side of the first glass fiber stack 120 and/or of the second glass fiber stack.

- 5 In this example, the upper flange 320 of the first reinforcing beam 310 and the upper flange 360 of the second reinforcing beam 350 are bonded to the upper inner layer 102 through respective adhesive layers 322 and 362.

10 In this figure, the first glass fiber stack 120 is associated with the first reinforcing beam 310 and the second glass fiber stack 140 with the first reinforcing beam 310. The first glass fiber stack 120 is aligned with the upper flange 320 of the first reinforcing beam 310, and the second glass fiber stack 140 with the upper flange 360 of the second reinforcing beam 350.

- 15 In this example, the stack width 121 of the first glass fiber stack 120 is similar to the stack width 141 of the second glass fiber stack 140. In other examples, the width of the stacks may be different. Similarly, the upper flange width 321 of the first reinforcing beam 310 is similar to the upper flange width 361 of the second reinforcing beam 350; however, in other examples, the upper flange widths may be
20 different.

- In this example, the stack width 121 of the first glass fiber stack 120 is smaller than 80% of the upper flange width 321 of the first reinforcing beam 310. The stack width 141 of the second reinforcing beam 350 of this example is also smaller than 80% of
25 the upper flange width 361 of the second reinforcing beam 350. The glass fiber stacks 120 and 140 respectively overlap the upper flanges 320 and 360.

- Although not depicted in this figure, the lower spar cap structure and the lower flanges of the reinforcing beams may be as described with respect to the upper spar
30 cap structure.

- Figure 8 is a block diagram of a method for manufacturing a wind turbine blade according to one example of the present disclosure. The method 500 comprises forming the upper blade shell part 100 and the lower blade shell part 200, as
35 represented at block 510. Each of the upper blade shell part 100 and the lower blade shell part 200 is formed according to the method 510 illustrated in figure 8.

The method 500 further comprises joining the lower flange 330 of the first reinforcing beam 310 to the lower blade shell part 200 and the upper flange 320 of the first reinforcing beam 310 to the upper blade shell part 100, as represented at block 520. The first reinforcing beam 310 is joined to the upper blade shell part 100 and to the lower blade shell part 200, in such a way that the first glass fiber stack 120 of the upper spar cap structure 110 at least partially overlaps the upper flange 320; and the first glass fiber stack 220 of the lower spar cap structure 210 at least partially overlaps the lower flange 330.

10 The method may further comprise joining the upper blade shell part 100 and the lower blade shell part 200 together. The blade shell parts may be bonded together through bonding lines formed at the leading edge 53 and at the trailing edge 54.

15 The first reinforcing beam 310 is positioned in such a way the upper flange 320 is aligned with the first glass fiber stack 120 of the upper blade shell part 100 and the lower flange 330 is aligned with the first glass fiber stack 220 of the lower blade shell part 200. The upper flange 320 at least partially coincides with the first glass fiber stack 120 of the upper blade shell part 100 and the lower flange 330 at least partially coincides with the first glass fiber stack 220 of the lower blade shell part 200.

20 Joining the flanges 320, 330 with the corresponding blade shell part 100, 200 may comprise adhering or bonding the flanges 320, 330 to the corresponding inner layers 102, 202 of the blade shell parts 100, 200. An adhesive layer 322, 332 may thus be formed between the flanges 320, 330 and the inner layers 102, 202.

25 In some examples, the blade 7 comprises a first reinforcing beam 310 and a second reinforcing beam 350. The second reinforcing beam 350 may be joined to the blade shell parts 100, 200 according to any of the examples herein. For example, the flanges 360, 370 of the second reinforcing beam 350 are aligned with the second glass fiber stacks 140.

30 Referring to figure 9, a method 510 for forming each of the upper and lower blade shell parts 100, 200 is provided. The method 510 comprises stacking the plurality of pultrusions in different stacks, as represented at block 511. Stacking the plurality of pultrusions comprises forming the first glass fiber stack 120, 220 by stacking one or more glass fiber pultrusion one on the top of the other. Stacks of pultrusions may be arranged on both sides of the first glass fiber stack 120, 220. These stacks of

pultrusions may comprise carbon fiber pultrusions, hybrid fiber pultrusions and/or additional glass fiber pultrusions.

5 The method 510 further comprises laying the outer layer 101, 201 in a blade shell mold, as represented at block 512. Laying the outer layer 101, 201 in the blade shell mold may comprise laying one or more glass fiber laminates. These glass fiber laminates may comprise bidirectional glass fibers.

10 At block 513, arranging the stacks of the plurality of pultrusions on top of the outer layer 101, 201. The stacks may be pre-bonded before being arranged on top of the outer layer.

15 In some examples, adhesive may be used to bond the pultrusions that form the stacks. In further examples, the plurality of pultrusions is laid in a spar cap mold. Resin infusion may be used for bonding the pultrusions forming different stacks of pultrusions. Resin may thus be injected into the spar cap mold to fill the gaps between the pultrusions. Then, this resin is cured to form a prefabricated spar cap structure 110, 210. This may help to automatize the manufacturing process and arranging the stacks on the outer layer may be simplified. Accordingly, the spar cap
20 structure 110, 210 may be prefabricated before being arranged on top of the outer layer 101, 201 placed on the blade mold.

25 Then, the inner layer 102, 202 is laid on top of the stacks of the plurality of pultrusions, as represented at block 514. The inner layer 102, 202 may comprise one or more glass fiber laminates, e.g. having bidirectional glass fibers. In some examples, a core structure or a plurality of core structures may be placed on top of the outer layer in positions free of pultrusions. The core structures are placed adjacent to the pultrusions that form the spar cap structure 110, 210. The inner layer 102, 202 may then be laid on top of these core structures.

30 The method 510 further comprises bonding the stacks to the outer layer 101, 201 and to the inner layer 102, 202 to form the blade shell part 100, 200, as represented at block 515. In some examples, bonding the stacks to the outer layer and to the inner layer comprises molding the inner layer, the stacks and the outer layer together with
35 a resin infusion technology. Once the inner layer covers stacks and the outer layer, resin is injected into the mold cavity under pressure. This resin fills the volume between the stacks and the layers. Then, the resin is cured or hardened. Accordingly,

the stacks may be bonded to the inner layers and to the outer layers by using a resin infusion process. After curing, a blade shell part may be obtained.

5 Figure 10 is a block diagram of a method for repairing a wind turbine blade according to one example of the present disclosure. The wind turbine blade may be according to any of the examples herein.

10 The method 600 for repairing a wind turbine blade 7 comprises detecting a joint defect between one of the flanges 320, 360 of the first reinforcing beam 310 and one of the upper blade shell part 100 and the lower blade shell part 200, as represented at block 610.

15 A joint defect refers to a defect when two parts are not completely attached through the bonding surface or bonding line. These joint defects may occur between the flanges 320, 360 and the inner layers 102, 202. Examples of joint defects may be adhesive defects. Adhesive defects may occur between the flanges 320, 360 and the inner layers 102, 202 when the adhesive layer 322, 332 does not completely attach the flanges 320, 360 to the blade shell parts 100, 200. For example, when the adhesive layer 322, 332 does not extend along the flange widths 321, 331 and/or the thickness of the adhesive layer 322, 332 does not completely extend between the flanges 320, 330 and the inner layers 102, 202. A kissing bond may be an example of an adhesive defect.

25 A joint defect is schematically illustrated in figure 11A. This figure represents a joint defect 400 between the upper inner layer 102 and the upper flange 320 of the first reinforcing beam 310. The adhesive layer 322 does not extend a minimum length relative to the flange width. A gap is formed between a portion of the upper flange 320 and the upper inner layer 102. The adhesion between the upper flange 320 and the upper inner layer 102 is lower than required. This joint defect 400 may be detected from outside the wind turbine blade by using a suitable technique.

30 The joint defect may be detected by any suitable technique. For example, non-destructive techniques may be employed. Ultrasonic, thermographic, shearography, or digital X-ray techniques are examples of non-destructive techniques.

35 For example, detecting a joint defect may comprise detecting an adhesive defect by scanning or applying ultrasonic waves to the wind turbine blade from the outside of

the wind turbine blade.

Referring back to figure 10, determining a joint defect zone in the corresponding blade shell part 100, 200 containing the joint defect 400 is represented at block 620.

5 A joint defect zone containing the joint defect 400 may thus be delimited. This may allow analyzing the type and the severity of the joint defect 400. For example, the shape and the dimensions of the joint defect 400 may thus be determined. Non-destructive techniques may also be used to delimit the zone containing the joint defect 400.

10

For example, the length of the joint defect 400 along the spanwise direction of the wind turbine blade may be determined. The width of the joint defect 400 along the chordwise direction may also be determined. The joint zone may be marked for being repaired.

15

The method 600 further comprises forming one or more apertures in the defect zone through the first glass fiber stack to communicate a portion of the corresponding flange with an outside of the wind turbine blade.

20 Figure 11B schematically represents an aperture formed in the joint zone of the joint defect 400 of figure 11A. An aperture 410 is formed or drilled from outside the wind turbine blade. The aperture 410 passes through the upper outer layer 101, the first glass fiber stack 120 and the upper inner layer 102 to reach the joint defect 400. The upper flange 320 thus communicates with the outside of the wind turbine blade. The aperture 410 thus forms a channel or path through the blade shell part.

25

The aperture may comprise a substantially circular cross-section. For example, the aperture may comprise a diameter between 2 mm and 10 mm. These diameters minimize the risk of crack propagation while allowing adhesive to be inserted through the aperture.

30

Depending on the shape and the dimensions of the joint defect 400, a plurality of apertures 410 may be formed to communicate the joint defect 400 with the outside of the wind turbine blade. The apertures 410 may be separated in the lengthwise direction and/or in the chordwise direction. The minimum distance between two consecutive apertures in the joint zone may be between 5 and 30 mm, specifically between 10 and 15 mm. This may allow for minimizing the risk of crack propagation

35

while allowing the adhesive to fill the gap between the flange and the blade shell part.

Referring back to figure 10, the method 600 further comprises inserting an adhesive through the one or more apertures to bond the corresponding flange to the corresponding blade shell part, as represented at block 640. The gap formed between a portion of the flange 320, 330 and the inner layer 102, 202 may thus be filled with adhesive. This may improve the adherence between the flange 320, 330 and the inner layer 102, 202. The adhesive may be inserted from outside the wind turbine blade and may travel along the path defined by the aperture 410.

Figure 11C schematically represents the aperture 410 filled with adhesive to repair the joint defect 400. Figure 10C thus schematically represents a cross-sectional view of a portion of a repaired blade. Adhesive 420 of this figure fills the gap between the upper flange 320 and the upper inner layer 102. The adhesive 420 travels through the aperture defined across the upper outer layer 101, the first glass fiber stack 120 and the upper inner layer 102 to reach the joint defect 400. The adhesive 420 may be injected into the aperture 410 to reach the upper flange 320.

The adhesive may be a repair adhesive, such as epoxy adhesives or methyl methacrylate adhesives. In further examples, any suitable adhesive may be employed. In some examples, the adhesive used for repairing the joint defect may be different to the adhesive employed during the manufacturing of the wind turbine blade. In other examples, the same type of adhesive may be used for bonding the reinforcing structure to the blade shell parts and for repairing joint defects.

In this example, the conduit defined by the aperture 410 is substantially filled with the adhesive; however, in other examples, the conduit may only be partially filled.

In some examples, the aperture 410 may be closed or sealed. For example, a gel coat may be applied on the outer layer 101, 201 to close the aperture 410. Water tightness may thus be achieved.

The method of repairing wind turbines according to this disclosure allows for repairing wind turbine blades. Accordingly, a repaired wind turbine blade may be obtained. The repaired wind turbine blade comprises one or more apertures formed at the first glass fiber stack at least partially filled with adhesive.

This written description uses examples to disclose the invention, including the preferred embodiments, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims. Aspects from the various embodiments described, as well as other known equivalents for each such aspects, can be mixed and matched by one of ordinary skill in the art to construct additional embodiments and techniques in accordance with principles of this application. If reference signs related to drawings are placed in parentheses in a claim, they are solely for attempting to increase the intelligibility of the claim, and shall not be construed as limiting the scope of the claim.

CLAIMS

1. A wind turbine blade (7) comprising:
an upper blade shell part (100) comprising:
5 an upper outer layer (101) defining an outer shape of the upper blade shell part (100);
an upper inner layer (102) defining an inner shape of the upper blade shell part (100); and
an upper spar cap structure (110) embedded between the upper outer layer (101) and the upper inner layer (102);
10 a lower blade shell part (200) comprising:
a lower outer layer (201) defining an outer shape of the lower blade shell part (200);
a lower inner layer (202) defining an inner shape of the lower blade shell part (200); and
15 a lower spar cap structure (210) embedded between the lower outer layer (201) and the lower inner layer (202);
wherein each of the upper spar cap structure (110) and the lower spar cap structure (210) comprises a plurality of pultrusions, each of the pluralities of pultrusions comprising:
20 carbon fiber pultrusions defining a volume of carbon fiber pultrusions;
glass fiber pultrusions defining a volume of glass fiber pultrusions;
wherein the ratio of the volume of carbon fiber pultrusions to the volume of glass fiber pultrusions is greater than 1;
25 wherein each of the pluralities of pultrusions comprises a first glass fiber stack (120, 220) comprising one or more glass fiber pultrusions;
a reinforcing structure (300) comprising a first reinforcing beam (310) arranged between the lower spar cap structure (210) and the upper spar cap structure (110), the first reinforcing beam (310) comprising a web (340) extending
30 between an upper flange (320) and a lower flange (330); wherein the upper flange (320) is joined to the upper blade shell part (100) and the lower flange (330) is joined to the lower blade shell part (200); and
wherein the first glass fiber stacks (120, 220) are aligned with the corresponding flange (320, 330) of the first reinforcing beam (310) so that the first
35 glass fiber stack (120) of the upper spar cap structure (110) at least partially overlaps the upper flange (320) and the first glass fiber stack (220) of the lower spar cap structure (210) at least partially overlaps the lower flange (330).

2. The wind turbine blade (7) according to claim 1, wherein the ratio of the volume of carbon fiber pultrusions to the volume of glass fiber pultrusions is greater than 2, specifically greater than 3.

5

3. The wind turbine blade (7) according to any of claims 1 - 2, wherein the first glass fiber stacks (120, 220) extend a stack width (121, 221) in a direction substantially parallel to the chordwise direction (38);

wherein the upper flange (320) and the lower flange (330) of the first reinforcing beam (310) respectively extend an upper flange width (321) and a lower flange width (331) in a direction substantially parallel to the chordwise direction (38); and

wherein the stack width (121) of the first glass fiber stack (120) of the upper spar cap structure (110) is smaller or equal to the upper flange width (321) and/or the stack width (221) of the first glass fiber stack (220) of the lower spar cap structure (210) is smaller or equal to the lower flange width (331).

4. The wind turbine blade (7) according to claim 3, wherein the stack width (121) of the first glass fiber stack (120) of the upper spar cap structure (110) is smaller than 80% of the upper flange width (321) and/or the stack width (221) of the first glass fiber stack (220) of the lower spar cap structure (220) is smaller than 80% of the lower flange width (331).

5. The wind turbine blade (7) according to any of claims 3 - 4, wherein the stack width (121) of the first glass fiber stack (120) of the upper spar cap structure (110) overlaps the upper flange width (321) and/or the stack width (221) of the first glass fiber stack (220) of the lower spar cap structure (210) overlaps the lower flange width (331).

6. The wind turbine blade (7) according to any of claims 1 - 5, wherein each of the plurality of pultrusions comprising comprises a set of carbon fiber stacks (130a, 130b, 130c, 130d) and wherein the first glass fiber stacks (120, 220) are arranged between two carbon fiber stacks of the set of carbon fiber stacks (130a, 130b, 130c, 130d).

35

7. The wind turbine blade (7) according to any of claims 1 - 6, wherein the upper blade shell part (100) comprises an adhesive layer (322) between the upper flange (320) of the first reinforcing beam (310) and the upper inner layer (102) to join the first reinforcing beam (310) to the upper blade shell part (100); and/or

wherein the lower blade shell part (200) comprises an adhesive layer (332) between the lower flange (330) of the first reinforcing beam (310) and the lower inner layer (202) to join the first reinforcing beam (310) to the lower blade shell part (200).

5 8. The wind turbine blade (7) according to any of claims 1 – 7, wherein the reinforcing structure (300) comprises a second reinforcing beam (350) arranged between the lower spar cap structure (210) and the upper spar cap structure (110), the second reinforcing beam (350) comprising a web (380) extending between an upper flange (360) and a lower flange (370); wherein the upper flange (360) is
10 connected to the upper blade shell part (100) and the lower flange (370) is connected to the lower blade shell part (200).

9. The wind turbine blade according (7) to claim 8, wherein the plurality of pultrusions of the upper spar cap structure (110) and the plurality of pultrusions of the
15 lower spar cap structure (210) comprises a second glass fiber stack (140) comprising one or more glass fiber pultrusions; and

wherein the second glass fiber stacks (140) are aligned with the corresponding flange (360, 370) of the second reinforcing beam (350) so that the second glass fiber stack (140) of the upper spar cap structure (110) at least partially
20 overlaps the upper flange (360) of the second reinforcing beam (350), and the second glass fiber stack (140) of the lower spar cap structure (210) at least partially overlaps the lower flange (370) of the second reinforcing beam (350).

10. The wind turbine blade (7) according to claim 9, wherein each of the upper
25 spar cap structure (110) and the lower spar cap structure (210) comprises one or more carbon fiber stacks (130a, 130b, 130c, 130d) arranged between the first glass fiber stack (120, 220) and the second glass fiber stack (140).

11. The wind turbine blade (7) according to any of claims 1 – 10, wherein the first
30 glass fiber stacks (120, 220) extend in a direction parallel to the lengthwise direction (37) of the wind turbine blade (7) along a length of the corresponding spar cap structure (110, 210).

12. The wind turbine blade (7) according to any of claims 1 – 11, wherein one or
35 more of the first glass fiber stacks (120, 220) comprises at least a volume of glass fiber pultrusions greater than 80% of the total volume of the pultrusions that forms the one or more of the first glass fiber stacks (120, 220)

13. A method (500) for manufacturing a wind turbine blade (7) according to any of

claims 1 -12, comprising:

forming (510) the upper blade shell part (100) and the lower blade shell part (200); wherein forming each of the blade shell parts (100, 200) comprises:

stacking (511) the plurality of pultrusions in different stacks;

5 laying (512) the outer layer (101, 201) in a blade shell part mold;

arranging (513) the stacks of the plurality of pultrusions on top of the outer layer (101, 201); and

laying (514) the inner layer (102, 202) on top of the stacks of the plurality of pultrusions;

10 bonding (515) the stacks to the outer layer (101, 201) and to the inner layer (102, 202) to form the blade shell part (100, 200); and

joining (520) the lower flange (330) of the first reinforcing beam (310) to the lower blade shell part (200) and the upper flange (320) of the first reinforcing beam (310) to the upper blade shell part (100) to join the first reinforcing beam (310) to the upper
15 blade shell part (100) and to the lower blade shell part (200), in such a way that the first glass fiber stack (120) of the upper spar cap structure (110) at least partially overlaps the upper flange (320), and the first glass fiber stack (220) of the lower spar cap structure (210) at least partially overlaps the lower flange (330).

20 14. A method (600) for repairing a wind turbine blade (7) according to any of claims 1 -12, comprising:

detecting (610) a joint defect (400) between one of the flanges (320, 330) of the first reinforcing beam (310) and one of the upper blade shell part (100) and the lower blade shell part (200);

25 determining (620) a joint defect zone in the corresponding blade shell part (100, 200) containing the joint defect (400);

forming (630) one or more apertures (410) in the defect zone through the first glass fiber stack (120, 220) to communicate a portion of the corresponding flange (320, 330) with an outside of the wind turbine blade (7); and

30 inserting (640) an adhesive (420) through the one or more apertures (410) to bond the corresponding flange (320, 330) to the corresponding blade shell part (100, 200).

15. A wind turbine blade repaired with the method (600) according to any of
35 claims 13 – 14.

FIGURES

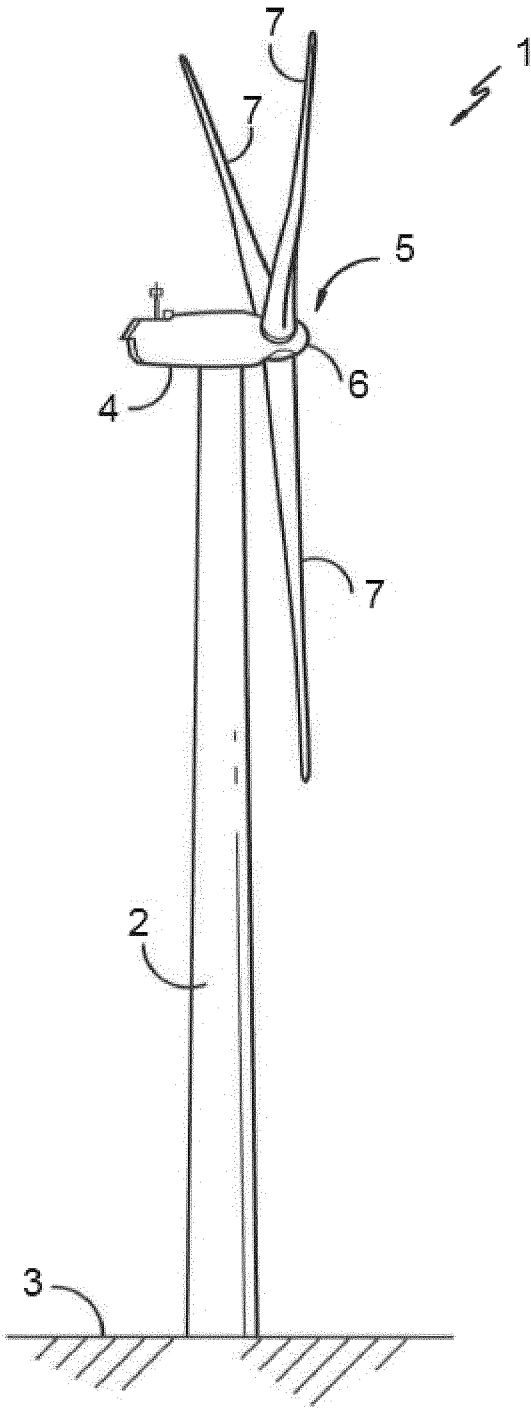


Figure 1

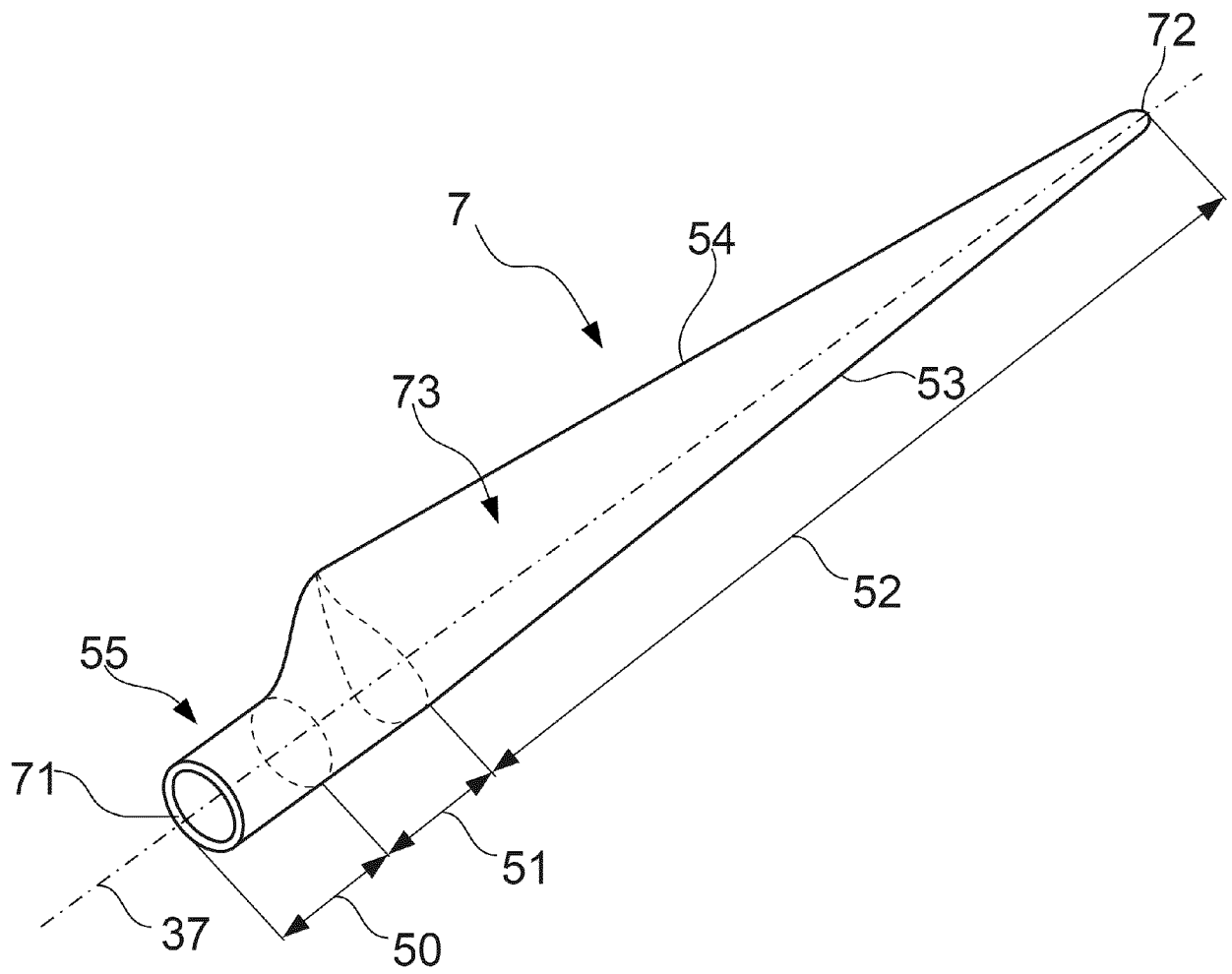


Figure 2

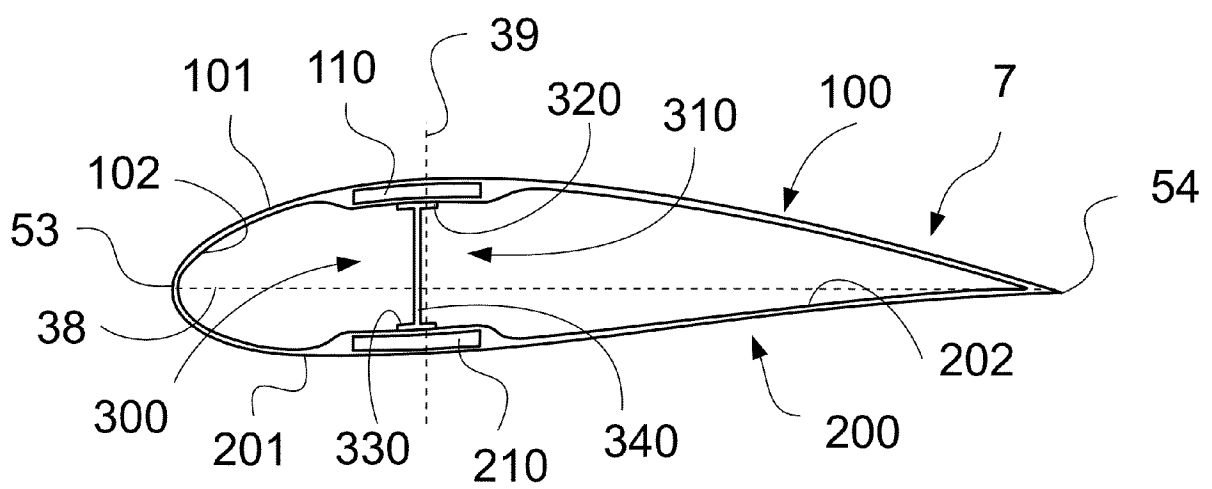


Figure 3

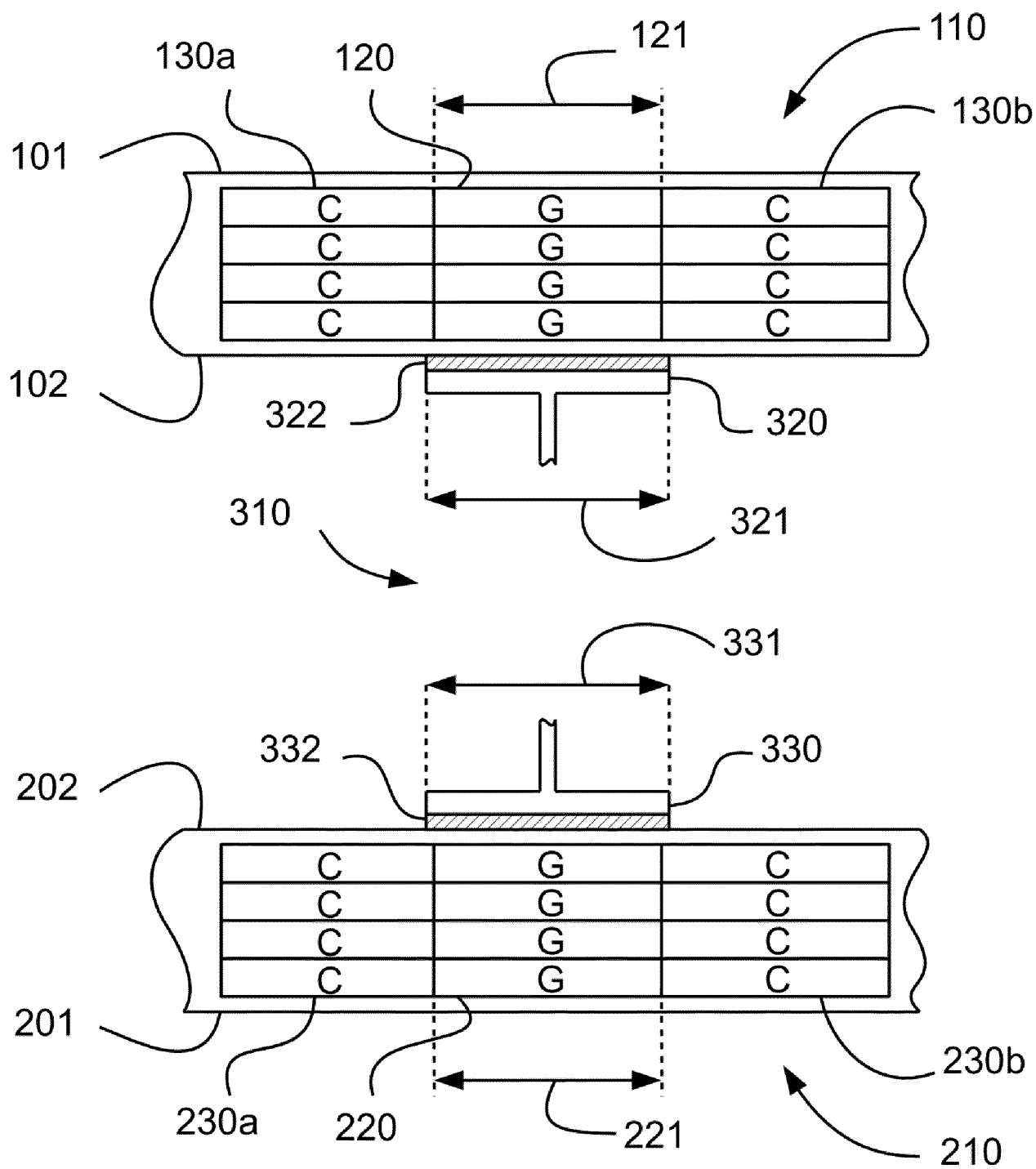


Figure 4

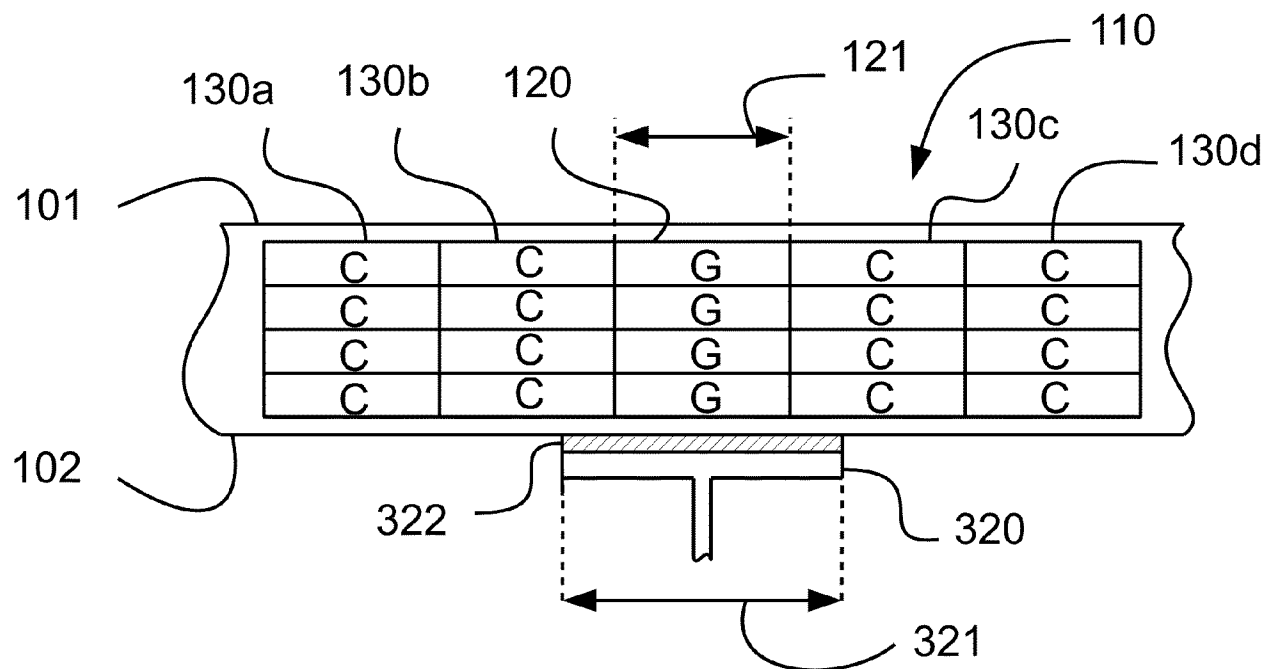


Figure 5

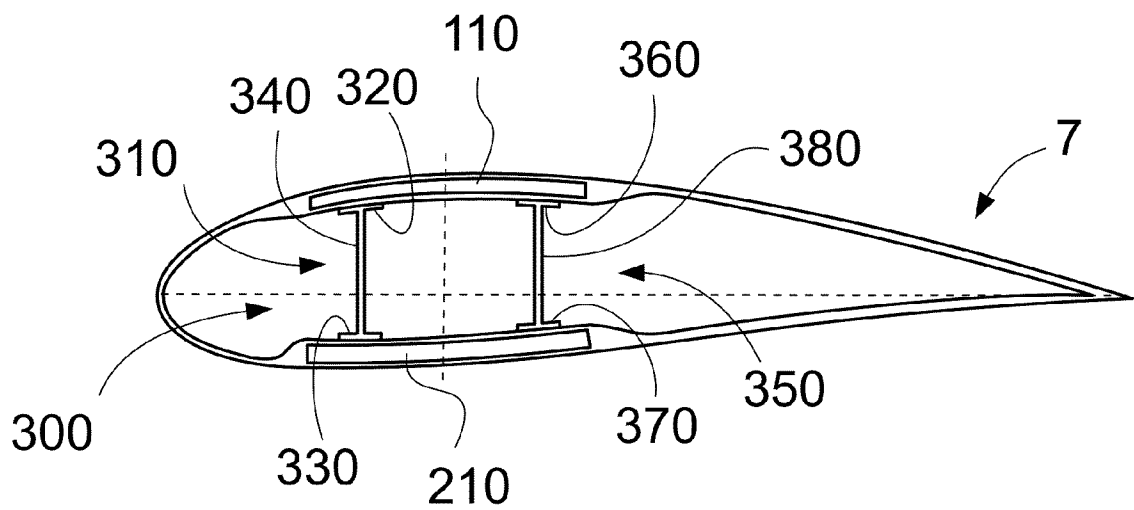


Figure 6

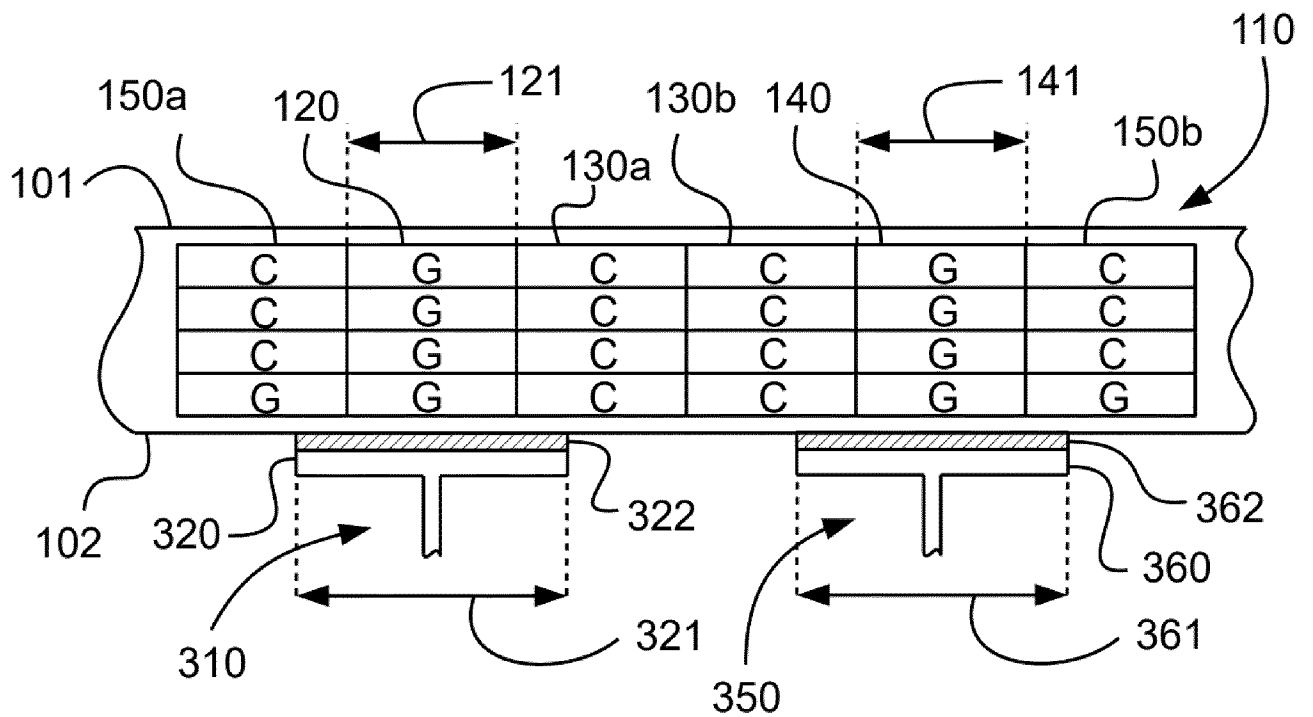


Figure 7

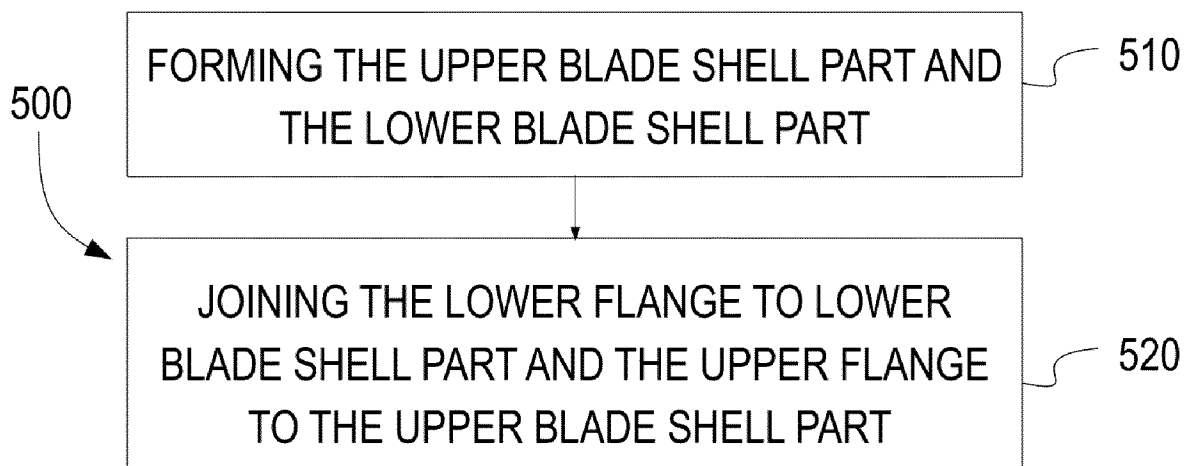


Figure 8

6/7

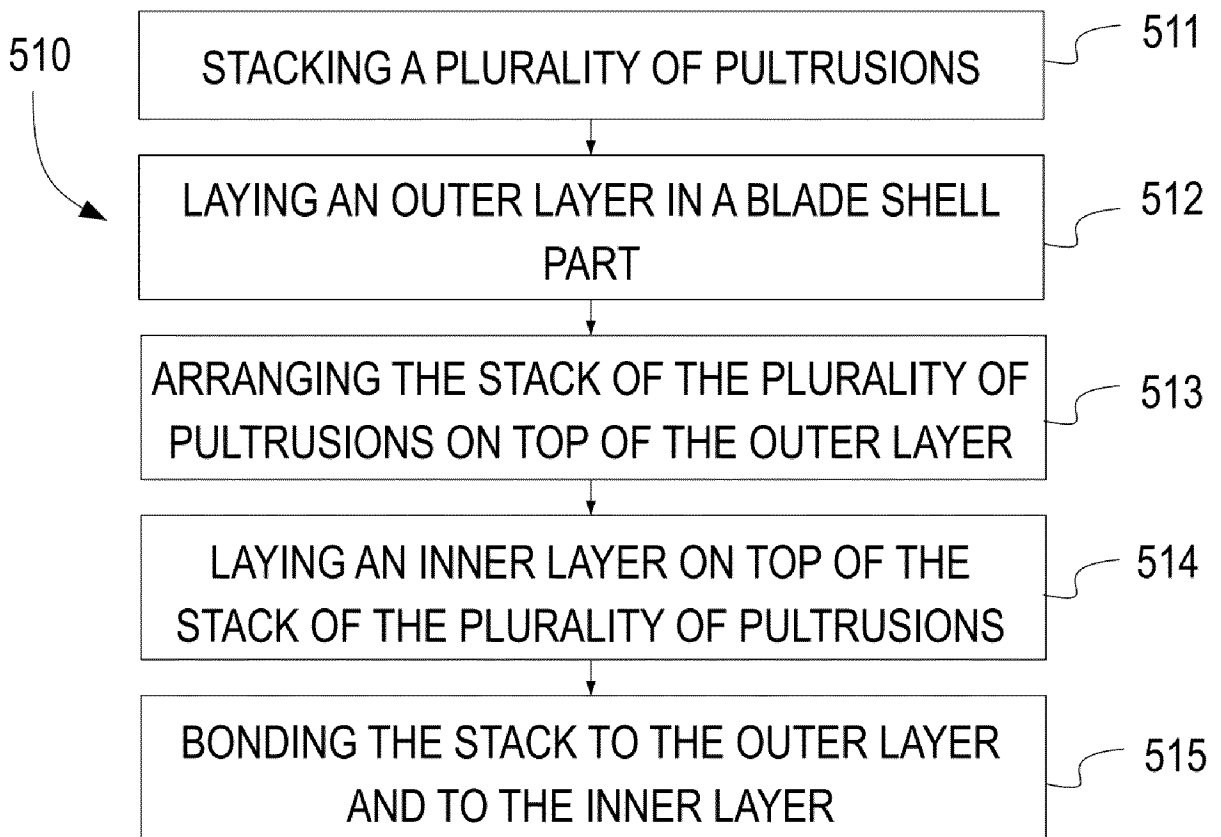


Figure 9

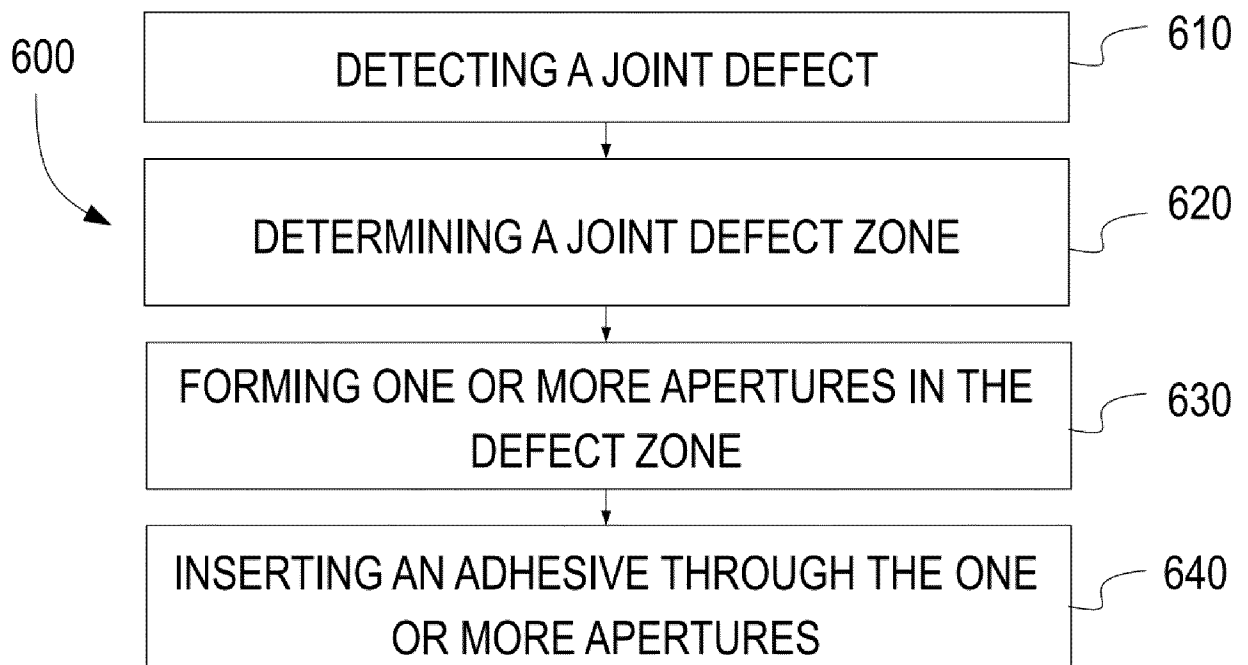


Figure 10

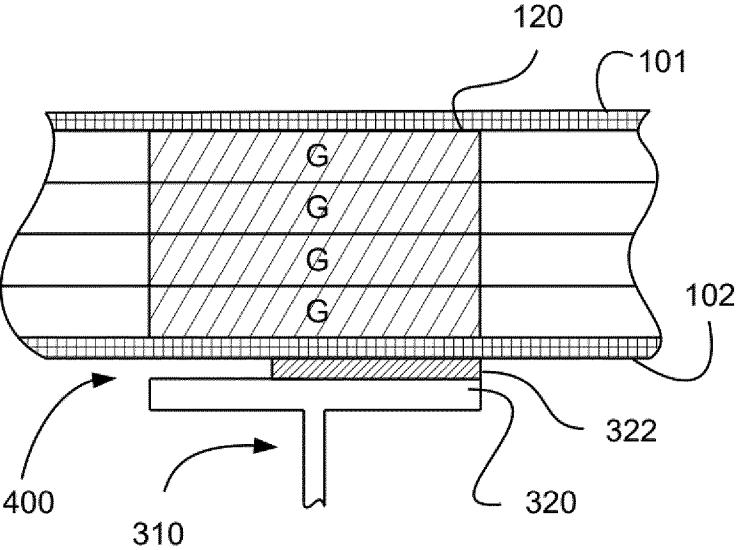


Figure 11A

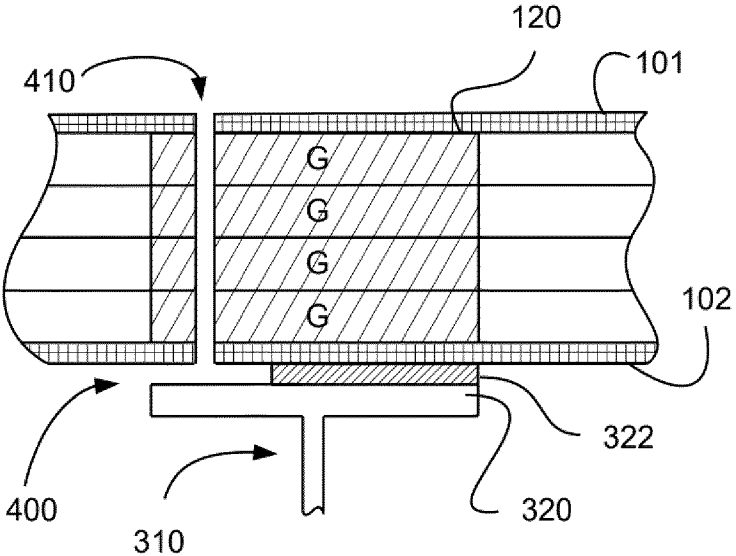


Figure 11B

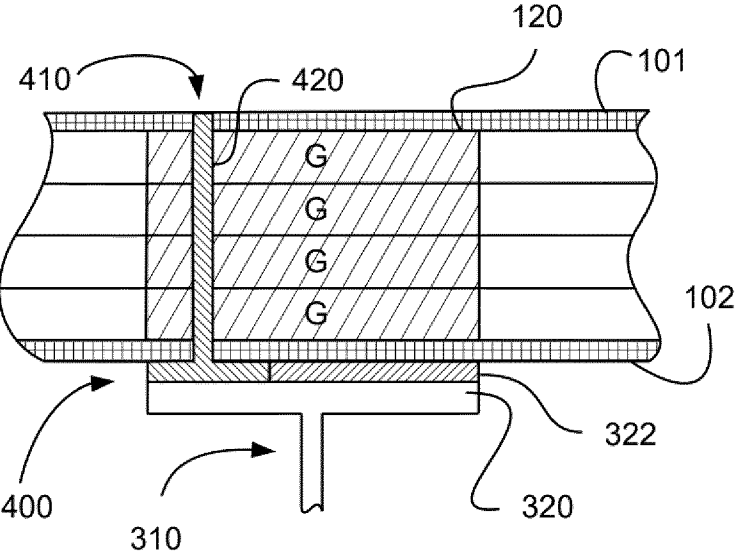


Figure 11C

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2024/070115

A. CLASSIFICATION OF SUBJECT MATTER

INV. F03D1/06 F03D80/50
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)

F03D B29D B29L B29C

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**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2022/332074 A1 (ATUTXA BRIONES MIKEL [ES] ET AL) 20 October 2022 (2022-10-20) paragraph [0011]; figures 1-3 paragraph [0014] - paragraph [0018] paragraph [0033] - paragraph [0047] -----	1 - 15
Y	CN 116 006 392 A (SINOMA WIND POWER BLADE PINGXIANG CO LTD) 25 April 2023 (2023-04-25) claims 6,8; figure 2 -----	1 - 15
A	EP 4 105 007 A1 (LM WIND POWER AS [DK]) 21 December 2022 (2022-12-21) paragraph [0048] - paragraph [0052]; figures 1-5 paragraph [0068] - paragraph [0080] ----- - / - -	1 - 15



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

19 September 2024

Date of mailing of the international search report

01/10/2024

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INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2024/070115

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2024/070115

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