US 20180147683A1

(19) **United States**

(12) **Patent Application Publication**

Bellanger et al.

(10) **Pub. No.: US 2018/0147683 A1**

(43) **Pub. Date: May 31, 2018**

(54) **CHAMFERING OF LAMINATE LAYERS**

(71) Applicant: **Vestas Wind Systems A/S**, Aarhus N. (DK)

(72) Inventors: **Yohann Bellanger**, Cowes (GB); **Christopher Thomson**, Portsmouth (GB)

(21) Appl. No.: **15/884,431**

(22) Filed: **Jan. 31, 2018**

Related U.S. Application Data

(62) Division of application No. 13/641,636, filed on Mar. 29, 2013, now Pat. No. 9,914,191, filed as application No. PCT/DK2011/050287 on Jul. 19, 2011.

(60) Provisional application No. 61/413,078, filed on Nov. 12, 2010.

(30) **Foreign Application Priority Data**

Jul. 30, 2010 (GB) 1012868.4

Publication Classification

(51) **Int. Cl.**

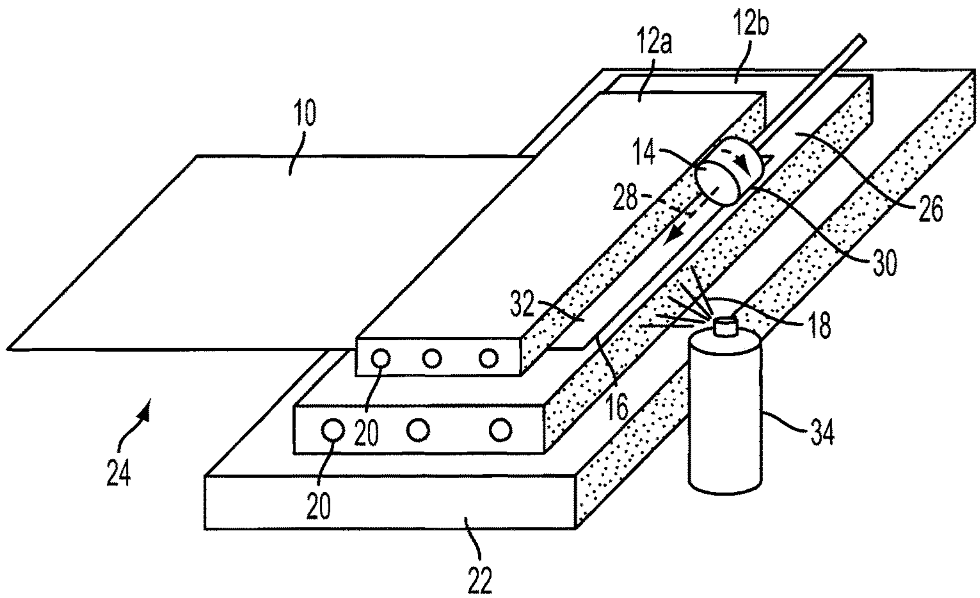
B23Q 11/10	(2006.01)
F04D 29/38	(2006.01)
B24B 55/02	(2006.01)
B24B 9/20	(2006.01)
B29C 70/54	(2006.01)
B24B 41/06	(2012.01)
B29C 35/16	(2006.01)

(52) **U.S. Cl.**

CPC ***B23Q 11/10*** (2013.01); ***F04D 29/38*** (2013.01); ***B24B 55/02*** (2013.01); ***B23Q 11/1053*** (2013.01); ***B24B 9/20*** (2013.01); *B29C 2035/165* (2013.01); ***B29C 70/54*** (2013.01); ***B24B 41/068*** (2013.01); *Y10T 29/54* (2015.01); *Y10T 29/49995* (2015.01); ***B29C 70/545*** (2013.01)

(57) **ABSTRACT**

A method of machining a fibrous sheet for a composite structure is described. The sheet comprises a resin matrix having a glass transition temperature, wherein the method comprises cooling the sheet substantially to maintain the temperature of the matrix below its glass transition temperature during machining.



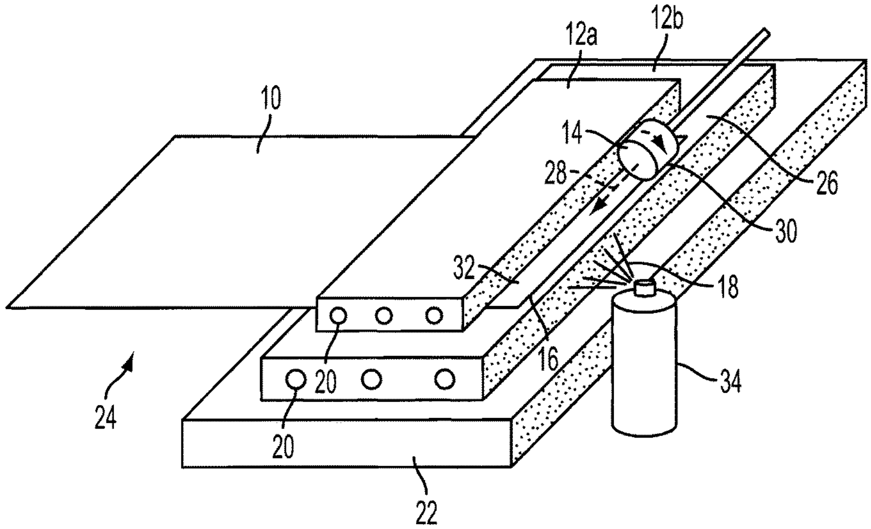


FIG. 1

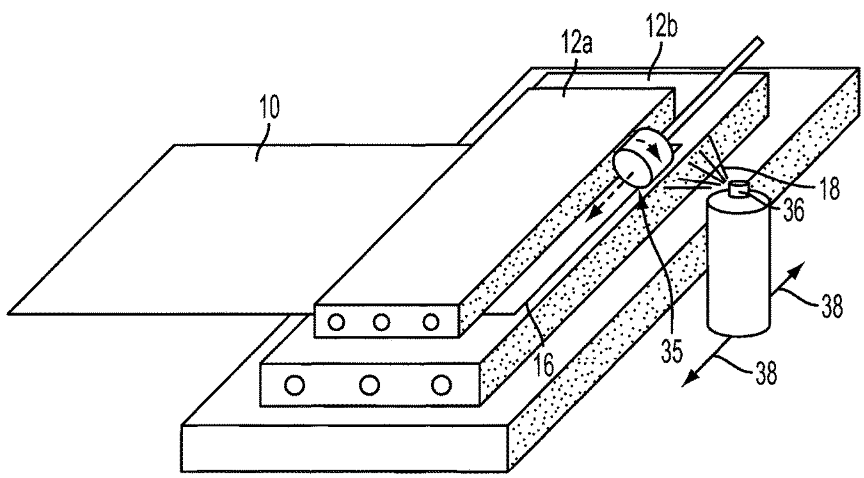


FIG. 2

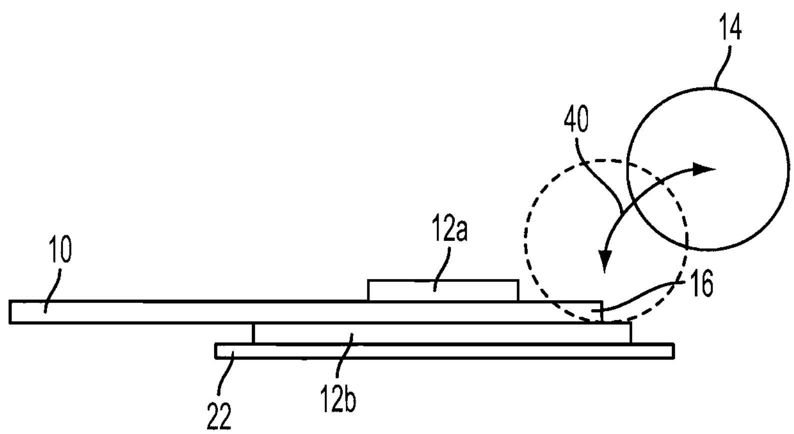


FIG. 3

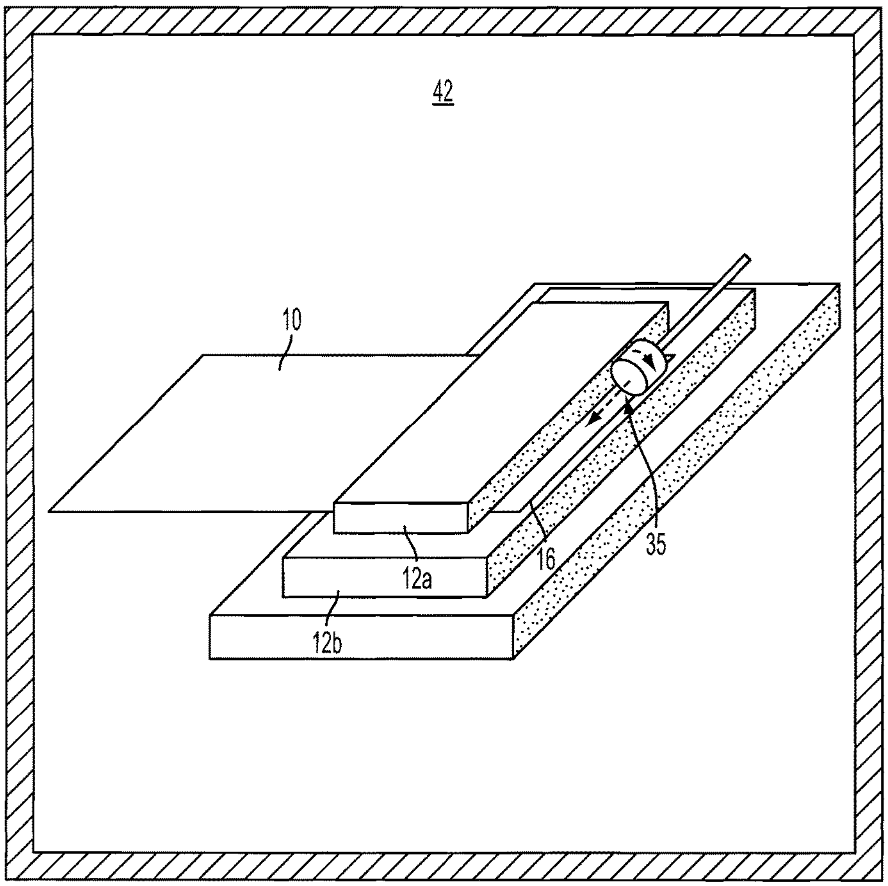


FIG. 4

CHAMFERING OF LAMINATE LAYERS

[0001] This invention relates to techniques for chamfering layers or plies used in composite structures, such as wind turbine blades.

[0002] Composite structures typically comprise one or more plies, each ply being a fibre-reinforced sheet that may comprise a thermoplastic or thermosetting resin matrix. The fibres may be pre-impregnated with the matrix as a 'prepreg' or the matrix may be impregnated into a fibre sheet during fabrication of a composite structure, for example during lay-up or injection-moulding procedures. Alternatively, the fibre-reinforced sheet may be pre-impregnated on just one side by a resin foil, i.e., a 'semi-preg'.

[0003] Plies are commonly laid atop one another in a layered or laminated arrangement. Single-ply composite structures are also possible, with single-thickness plies abutting in edge-to-edge relationship or overlapping at their edges. The plies are commonly supported by a foam core to define a skin on or around the core.

[0004] In some circumstances, it is desirable to chamfer an edge of a ply. For example, plies may abut edge-to-edge in a composite structure and it is desirable to maximize the surface area of the interface between the abutting plies. This is because the shear strength at the interface is a small fraction—possibly as little as 5%—of the tensile strength of the plies themselves. The alternative of overlapping abutting plies leads to stress concentration and disadvantageously kinks the load path extending from one ply to another. Also, where plies define the external surface of a composite structure, an overlap between the plies makes a smooth finish difficult to achieve.

[0005] It is also well known to taper a composite structure by reducing the number of plies from one location to another across the structure. Such tapering is common in aerofoil members such as wind turbine blades, which taper in both the spanwise direction from blade root to blade tip and in the chordwise direction from leading edge to trailing edge. To achieve this, some plies may be terminated or 'dropped' inward of an extremity of the structure, leaving other continuous plies to extend further toward that extremity.

[0006] Plies are preferably dropped in a staggered or interleaved manner to make the transition as gradual as possible. However, each dropped ply introduces a region of weakness in view of discontinuity between the neighboring plies, with the possibility of resin concentrations or gas pockets in any gaps between plies, especially at the edge of dropped plies. Here, edge chamfering is helpful to minimize gaps, to straighten the load path and to maximize the surface area of the interface between plies. This allows thicker plies to be used, which facilitates the lay-up process because fewer layers are then required in the laminate to achieve a required overall thickness.

[0007] Plies for use in composite structures are difficult to chamfer efficiently, accurately and repeatably, particularly with the shallow taper angle that is desirable to maximize the surface area of the edge interface. The plies are flexible and compressible and so tend to move unpredictably under the forces applied by the chamfering process. Also, the plies may degrade with heat generated by the chamfering process. This is a particular problem with prepregs, if the matrix cures or otherwise transforms with heat. For example, heat generated during chamfering may cause the thermoplastic matrix to soften or melt and clog the chamfering tool. If the matrix softens or melts, it is also possible for the chamfering tool to drag the ply unpredictably, possibly distorting it and so undermining the accuracy of cutting.

[0008] Some examples of ply-tapering tools are disclosed in EP 1786617. These include finger cutters akin to hair trimmers, but finger cutters are not suitable for cutting prepregs in which the fibres are embedded in a matrix because the matrix prevents the fingers from penetrating between the fibres. EP 1786617 also discloses milling cutters with inclined faces, turning about an axis orthogonal to a plane containing the edge being tapered. When configured as shown in EP 1786617, milling cutters impart heat to the ply that may degrade the ply and melt its matrix if the ply is a thermoplastic prepreg; this is also a problem suffered by abrading techniques proposed elsewhere in the art, using a belt sander or the like. Also, when configured as shown in EP 1786617, milling cutters impart a side force to the ply, parallel to the tapered edge, that tends to distort the ply and so undermines the accuracy of cutting. This is also a problem suffered by knife-cutting techniques proposed elsewhere in the art.

[0009] It is against this background that the present invention has been made.

SUMMARY OF THE INVENTION

[0010] In accordance with the present invention, there is provided a method of machining a fibrous sheet for a composite structure, the sheet comprising a resin matrix having a glass transition temperature, wherein the method comprises: providing a fibrous sheet at a first temperature; supporting the sheet for machining; and cooling at least part of the sheet to a second temperature below the first temperature, substantially to maintain the temperature of the matrix below its glass transition temperature during machining.

[0011] The resin becomes hard and brittle when cooled, which makes it easier to machine. Generally, the resin becomes harder and more brittle with decreasing temperature. Therefore, it is preferable to cool the material to the lowest temperature possible within realistic practical and economic constraints.

[0012] The glass transition temperature of the uncured resin may also be referred to in the art as the 'cold T_g' or the 'uncured T_g', and is an intrinsic property of the resin that will vary from material to material. Put simply, the cold/uncured T_g is the glass transition temperature of a matrix that has reacted at ambient temperature, and hence exhibits a relatively low degree of cross-linking. Material suppliers such as Gurit™ can provide details of the cold/uncured T_g of the materials that they supply. However, as a matrix ages, some additional cross linking will occur, causing the cold T_g to increase slightly with time. The T_g of the uncured resin in typical prepreg or semi-preg materials used in the construction of modern wind turbine blades is generally below 0° C., for example around −2° C. In comparison, when a matrix is cured at an elevated temperature, it will exhibit a relatively high degree of cross-linking, resulting in the cured matrix having a much higher T_g, typically well in excess of 100° C.

[0013] The inventive concept encompasses a method of making a composite structure, comprising: tapering an edge of a fibrous reinforcement in accordance with the above machining method; and incorporating the sheet into a composite structure with the tapered edge lying against or beside at least one other fibrous reinforcement sheet.

[0014] The present invention also provides an apparatus for machining a fibrous sheet for a composite structure, the apparatus comprising: a support for the sheet; a machining tool movable relative to the support; and a cooling system for cooling the sheet.

[0015] The inventive concept also encompasses a composite structure such as a wind turbine blade produced by the above methods or apparatus.

[0016] Optional features of the present invention are set out in the sub claims appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] In order that the invention may be more readily understood, reference will now be made, by way of example, to the accompanying drawings in which:

[0018] FIG. **1** is a schematic perspective view of an apparatus for machining a prepreg or semi-preg ply, in which refrigerant is applied to the ply prior to machining;

[0019] FIG. **2** is a schematic perspective view of the apparatus of FIG. **1**, in which the refrigerant is applied to the machining site during the machining process;

[0020] FIG. **3** is a schematic side view showing a machining tool being moveable towards and away from an edge of a ply along an arc-shaped path; and

[0021] FIG. **4** shows the apparatus of FIG. **1** located within a climate-controlled environment.

DETAILED DESCRIPTION

[0022] Referring to FIG. **1**, a prepreg ply **10** is clamped between refrigerated steel blocks **12***a*, **12***b*, and a grinding wheel **14** is arranged to translate across a free edge **16** of the ply **10** to remove material from that edge to create a chamfer. Refrigerant **18** is applied locally to the free edge **16** of the ply **10** during the chamfering operation. The apparatus and chamfering technique are described in further detail below.

[0023] The prepreg ply **10** comprises a sheet of glass fibre fabric, which has been impregnated with a thermoset matrix, which in this example is pre-catalysed epoxy resin. The glass fibre fabric consists of two layers and is commonly referred to as 'triax'. The first layer includes a set of unidirectional (ud) fibres, whilst the second layer is a layer of 'biax', which has a first set of unidirectional fibres oriented at an angle of +45° relative to the fibres in the first layer, and a second set of unidirectional fibres oriented at an angle of −45° relative to the fibres in the first layer.

[0024] The steel blocks **12***a*, **12***b* are oblongs and include internal refrigeration channels **20**. A refrigerant is pumped through the channels **20** to cool the blocks **12***a*, **12***b* to a temperature of −50° C., and then continuously pumped through the channels **20** to maintain the temperature of the blocks **12***a*,**12***b* at −50° C. Alternatively, the blocks **12***a*, **12***b* may be placed in a refrigerator at −50° C. for several hours prior to the chamfering operation. In this way, the refrigeration channels **20** may not be required.

[0025] The steel blocks **12***a*, **12***b* are placed one on top of the other, with the lower steel block **12***b* being located on an insulating foam block **22** to reduce heat transfer from a work surface **24** to the cold blocks **12***a*, **12***b*. An end portion of the prepreg ply **10** is sandwiched between the steel blocks **12***a*, **12***b* and the blocks are clamped together by a clamp (not shown) to hold the ply **10** firmly in place. The upper block **12***a* is set back from the lower block **12***b* by approximately 40 mm to define an elongate ledge **26**. The free edge **16** of the ply **10** extends from between the steel blocks **12***a*, **12***b* onto this ledge **26**.

[0026] The grinding wheel **14** is arranged to traverse along the ledge **26** in a direction parallel to the exposed free edge **16** of the ply **10** as indicated by the arrow **28** in FIG. **1**. The grinding wheel **14** has an abrasive cylindrical outer surface **30**, which rotates about an axis parallel to the free edge **16** of the ply **10**, i.e., parallel to its direction of translation **28** across the ply **10**. In use, the grinding wheel **14** is angled slightly with respect to the surface **32** of the ply **10** and traversed across the free edge **16** to create a chamfer of a desired gradient. A shallow chamfer gradient in the range of 1:20 to 1:10 i.e., approximately 2.8° to 6° is particularly desirable.

[0027] Prior to chamfering commencing, the free edge **16** of the ply **10** is sprayed with tetrafluoroethane refrigerant (R134a) from a spray can **34**. It will of course be appreciated that other suitable refrigerants may be used for this purpose, for example liquid nitrogen or liquid carbon dioxide. Spraying the free edge **16** of the ply **10** with refrigerant cools the ply **10** to well below the glass transition temperature (T_g) of the uncured epoxy resin in the prepreg. Typically the T_g of the uncured epoxy is around −2° C. Maintaining the temperature of the resin below its uncured T_g during chamfering ensures that the resin remains hard during the chamfering process. This prevents the resin from becoming tacky and contaminating or clogging the abrasive surface **30** of the grinding wheel **14**, which would otherwise occur if chamfering was conducted at room temperature. The cold steel blocks **12***a*, **12***b* ensure that any heat generated during the chamfering operation is channeled away from the ply **10**.

[0028] Experimental tests have shown that a single application of the R134a refrigerant to the free edge **16** of the ply **10** prior to chamfering is sufficient to keep the temperature of the ply **10** below the T_g of the uncured resin. However, if necessary, the refrigerant may be applied repeatedly or continuously during chamfering to keep the temperature of the ply **10** below the T_g of the uncured resin. Applying the refrigerant continuously has the advantage that a flow of refrigerant will carry heat away from the worksite. In the example shown in FIG. **2**, the refrigerant **18** is applied during machining and is applied locally at the machining site **35**. A nozzle **36** supplying the refrigerant **18** may be arranged to move in tandem with the grinding wheel **14** as represented by the arrows **38** in FIG. **2**. Applying the refrigerant **18** locally at the machining site **35** is advantageous because it concentrates the refrigerant **18** at the point where heat is generated.

[0029] In order to assist heat dissipation from the free edge **16** of the ply **10**, rather than being translated across the ply **10** in a single motion, the grinding wheel **14** may be pressed against the free edge **16** of the ply **10** in a series of pressing operations across the width of the ply **10**. This is represented schematically in FIG. **3**, which shows the grinding wheel **14** being moveable towards and away from the free edge **16** of the ply **10**, i.e., in and out of contact with the free edge **16**, along an arc-shaped path **40**. Refrigerant is continuously applied to the free edge **16** so that cooling continues between presses, i.e., whilst the grinding wheel **14** is moved out of contact with the free edge **16** of the ply **10**.

[0030] Whilst not shown in the above figures, the humidity of the air surrounding the apparatus is controlled to prevent condensation from forming on the cold ply **10** or elsewhere on the apparatus itself.

[0031] Referring to FIG. **4**, rather than applying refrigerant directly to the free edge **16** of the prepreg ply **10**, the entire apparatus is located in a climate-controlled environment **42** that is sufficiently cold to maintain the epoxy below its uncured glass transition temperature during the chamfering process. Of course, it is also possible to apply refrigerant directly to the chamfering site **35** if necessary when the apparatus is located in a climate-controlled environment **42** such as this. In this example, refrigerant channels have been removed from the blocks **12***a*, **12***b*, however it will be appreciated that such channels may be used in combination with a climate-controlled environment **42**.

[0032] It will be appreciated that many modifications may be made to the techniques described above without departing from the scope of the present invention as defined by the accompanying claims. For example, it will be appreciated that the prepreg ply described by way of example above may be substituted for a semi-preg ply or other fibrous ply comprising a resinous matrix material. Also, whilst triax is described by way of example, it will be appreciated that the invention is not limited to the use of triax. Indeed, the fibres in the ply may have any other orientation, for example the fibres may all be unidirectional (ud). In addition, whilst a grinding wheel has been described above, it will be appreciated that the invention may be used in connection with any other machining tool or technique.

1. An apparatus for machining a fibrous sheet for a composite structure, the apparatus comprising:

a support for the sheet;

a machining tool movable relative to the support; and

a cooling system for cooling the sheet.

2. The apparatus of claim **1**, wherein the cooling system comprises one or more cooled surfaces against which the sheet is supported before or during machining.

3. The apparatus of claim **2**, comprising opposed cooled surfaces between which the sheet may be sandwiched.

4. The apparatus of claim **1**, wherein the cooling system comprises a supply for supplying coolant to the sheet before or during machining.

5. The apparatus of claim **4**, wherein the supply is arranged to move relative to the support in tandem with the machining tool.

6. The apparatus of claim **1**, wherein the cooling system comprises an enclosure for holding the sheet within a cooled environment.

* * * * *