Title: METHOD AND APPARATUS FOR CHAMFERING OF LAMINATE LAYERS

Abstract: A method apparatus of tapering an edge of a fibrous reinforcement sheet (14) for a composite structure is described. The method includes supporting the sheet against a support (12) and creating a tapered edge by relative translational movement of a cutting tool (16) with respect to the supported sheet. A cutting element (18) of the tool is acutely angled with respect to the supported sheet to develop an inclined cutting plane (32) during the relative translational movement between the tool and the sheet. The sheet (14) has an inner side lying against a supporting surface (20) of the support and the cutting plane (32) projected through the sheet intersects the inner side of the sheet.
This invention relates to techniques for chamfering layers or plies used in composite structures, such as wind turbine blades.

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'.

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.

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 maximise 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.

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.

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 neighbouring 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 minimise gaps, to straighten the load path and to maximise 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.

Plies for use in composite structures are difficult to chamfer efficiently, accurately and repeatably, particularly with the shallow taper angle that is desirable to maximise 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.

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.

It is against this background that the present invention has been made.
Summary of the invention

In accordance with the present invention, there is provided a method of tapering an edge of a fibrous reinforcement sheet for a composite structure, the method comprising:

supporting the sheet against a support; and creating a tapered edge by relative translational movement of a cutting tool with respect to the supported sheet, a cutting element of the tool being acutely angled with respect to the supported sheet to develop an inclined cutting plane during said relative translational movement between the tool and the sheet; wherein closing movement between the cutting element of the tool and the sheet is in the cutting plane; and the sheet has an inner side lying against a supporting surface of the support and the cutting plane projected through the sheet intersects the inner side of the sheet.

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

The present invention also provides an apparatus for tapering an edge of a fibrous reinforcement sheet for a composite structure, the apparatus comprising: a support for supporting the sheet; and a cutting tool capable of relative translational movement with respect to the supported sheet, a cutting element of the tool being acutely angled with respect to the supported sheet to develop an inclined cutting plane during said relative translational movement between the tool and the sheet; wherein the sheet has an inner side lying against a supporting surface of the support and the cutting plane projected through the sheet intersects the inner side of the sheet.

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

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

The present invention is advantageous because it allows a tapered edge having a relatively shallow gradient to be created in a fibrous reinforcement sheet. The invention is suitable for creating tapered edges in fibrous sheets of various thickness, including very thin sheets such as single plies. For example, using the techniques of the present
invention, it is possible to create a tapered edge having a gradient of 1:20 to 1:10, i.e. 2.8° to 6°, in a single fibrous ply having a thickness of 0.5 mm. The tapered edge is also referred to herein as a 'chamfered edge'.

5 Brief description of the drawings

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:

10 Figure 1 is an end view of a chamfering apparatus in accordance with a first embodiment of the present invention, in which a prepreg ply is draped over a cylindrical roller of circular cross section eccentrically mounted on an axle, and an ultrasonic knife for creating a chamfered cut through the ply is arranged near an outer surface of the roller;

15 Figure 2 is an end view of a chamfering apparatus in accordance with a second embodiment of the present invention, in which a prepreg ply is draped over an eccentric cylindrical roller of elliptical cross section, and an ultrasonic knife for creating a chamfered cut through the ply is arranged near an outer surface of the roller;

20 Figure 3 is a side view of a chamfering apparatus in accordance with a third embodiment of the present invention, in which a prepreg ply is stretched over a cylinder and an ultrasonic knife for creating a chamfered cut through the ply is supported adjacent to the cylinder;

25 Figure 3A shows the apparatus of Figure 3 with the ultrasonic knife oriented to cut a chamfer of shallowest gradient;

30 Figure 4 is a schematic side view of a chamfering apparatus in accordance with a fourth embodiment of the present invention, in which an air gap is provided in the cylinder for cooling purposes; and

35 Figure 5 is a side view of a chamfering apparatus in accordance with a fifth embodiment of the present invention, in which a prepreg ply is stretched over a
support of rhomboidal cross section, and an ultrasonic knife for creating a chamfered cut through the ply is supported adjacent to the support.

Detailed description

Referring to Figure 1, a chamfering apparatus 10 in accordance with a first embodiment of the present invention includes a cylindrical roller 12 of circular cross section supporting a prepreg ply 14. An ultrasonic knife 16 including a blade 18 is arranged adjacent to the roller 12. The blade 18 is oriented approximately tangentially to a cylindrical outer surface 20 of the roller 12 in order to create a chamfered cut through and across the prepreg ply 10. In practice, the relative dimensions of the ultrasonic knife 16 and the roller 12 would be different: the roller 12 would be significantly smaller than the ultrasonic knife 16 in relative terms. The apparatus and chamfering technique are described in further detail below.

The prepreg ply 14 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.

The prepreg ply 14 is draped over the roller 12 such that an inner surface 22 of the ply 14 lies against the cylindrical outer surface 20 of the roller 12. A clamp 24 bears against an outer surface 26 of the ply 14, to clamp the ply to the roller 12 at a point 28 ahead of a cutting location 30. In this way, the ply 14 is partially wound around the roller 12 so that the ply 14 is curved at the cutting location 30 in conformity with the curvature of the roller 12. The cutting location 30 is defined by the intersection of a longitudinal axis 32 of the cutting blade 18 with the inner surface 22 of the ply 14. The longitudinal axis 32 defines a cutting plane through the ply 14.

In this example, the ply 14 is clamped to the roller 12 on a side of the roller 12 substantially opposite the cutting blade 18. However, it will be appreciated that the ply 14 may be fixed to the roller 12 at a location closer to, or further from the cutting location 30 in other examples. The ply 14 is held in tension on the roller 12 by virtue of a tensioning
rod 34 that extends across the ply 14. When the ply 14 is clamped and tensioned in this way, the cutting location 30 is between the clamp 24 and the tensioning rod 34.

The roller 12 is mounted eccentrically on an off-centre cylindrical axle 36. The axle 36 extends through the roller 12, parallel to a central cylindrical axis 38 of the roller 12. When viewed in cross-section, as in Figure 1, the axle 36 is offset from the cylindrical axis 38 of the roller 12. The axle 36 is arranged to turn in a clockwise direction when viewed from the end shown in Figure 1. The roller 12 is fixed to the axle 36, so that as the axle 36 turns, the clearance between the blade 18 and the surface 20 of the roller 12 decreases due to the eccentricity of the roller 12. In this way, the eccentric roller 12 acts as a cam, causing the prepreg ply 14 to be brought towards the blade 18.

The ultrasonic knife 16 shown in Figure 1 is generally known in the art, but will be described briefly to assist the understanding of the present invention. The ultrasonic knife 16 includes a transducer 40, an output element 42, a horn 44 and the cutting blade 18 described above. The transducer 40 is energized by a high frequency alternating current, typically in the range 20 to 40 kHz, supplied via lines 46 from an audio amplifier 48. The transducer 40 converts the alternating current into vibratory motion at the same frequency as the current. The vibratory motion is imparted to the output element 42, which vibrates along the longitudinal axis 32. The horn 44, which serves to amplify the vibrations generated by the transducer 40, is coupled to the output element 42 and has a cross section that tapers progressively along the longitudinal axis 32, from a large diameter end 50 attached to the output element 42, to a small diameter 52 end that holds the cutting blade 18.

The following technique is used to create a chamfered edge in the prepreg ply 14. Firstly, the ply 14 is draped over the eccentric roller 12 and clamped to the outer cylindrical surface 20 of the roller 12 by the clamp 24 as described above. Next, the ultrasonic knife 16 is arranged adjacent to the ply 14 on the roller 12 with the cutting blade 18 spaced slightly apart from the ply 14. The knife 16 is oriented such that the longitudinal axis 32, which defines the direction of vibration of the blade 18, is substantially tangential to the cylindrical outer surface 20 of the roller 12 at the cutting location 30. The transducer is then supplied with alternating current at a frequency of 20 kHz which causes the cutting blade 18 to oscillate along the longitudinal axis 32 at a corresponding ultrasonic frequency of 20 kHz as described above.
Once the apparatus 10 has been arranged as above, the eccentric roller 12 is turned clockwise about the axle 36 so that the clamped end 54 of the ply 14 is advanced slightly towards the cutting blade 18. The eccentricity of the roller 12 causes the ply 14 to be brought towards the ultrasonic cutting blade 18. The roller 12 is turned clockwise until the blade 18 makes contact with the ply 14. Turning of the roller 12 is automated by means of a stepper motor (not shown), but the roller 12 may alternatively be turned by hand. Once turned, the roller 12 is locked in position to maintain a given distance and angle of cut.

Once the prepreg ply 14 has been brought into contact with the cutting blade 18, the blade 18 is traversed across the width of the ply 14 in a direction, in this example, that is substantially parallel to the cylindrical axis 38 of the roller 12, i.e. perpendicular to the plane of the page in Figure 1. As the blade 18 moves across the ply 14, material is removed from the ply 14 to create the beginning of a chamfered cut through the ply 14.

Multiple passes of the cutting blade 18 across the ply 14 are employed to create the chamfered cut. Once the blade 18 has been traversed across the width of the ply 14, the stepper motor is used to turn, or 'index', the roller 12 clockwise by a further increment. Again, due to the eccentricity of the roller 12, turning the roller 12 in this way brings the outer cylindrical surface 20 of the roller 12 closer to the cutting blade 18 so that the blade 18 penetrates deeper into the ply 14. The blade 18 is then passed across the ply 14 again to progress the chamfered cut across the width of the ply 14. Instead of indexing the roller 12 between successive passes, the blade 18 may alternatively be moved towards the ply 14 between passes along the longitudinal axis 32 so that the blade 32 cuts deeper into the ply 14.

The above process of indexing the roller 12 or advancing the blade 18 towards the ply 14 and then traversing the blade 18 across the ply 14 is repeated until the blade 18 has cut through the thickness of the ply 14 to create a chamfered edge. It is also possible to cut through the thickness of the ply 14 in a single traverse if required.

As the blade 18 cuts through the ply 14, heat is generated in the ply 14 due to frictional forces between the blade 18 and the fibres. Heat is also generated in the roller 12 due to friction between the blade 18 and the roller 12 as the blade 18 cuts through the ply 14 against the roller 12. If excessive heat is generated, there is a risk that the fibres of the ply 14 may burn and/or that the resin may melt against the roller 12. To mitigate the
effects of heating, the roller 12 includes a plurality of internal refrigerant tubes 56 through which a refrigerant is pumped to cool the roller. As shown in Figure 1, the refrigerant tubes 56 are provided adjacent the cutting location 30.

The gradient of the chamfer can be controlled in number of ways. For example, the inclination of the blade 18 relative to the cylindrical outer surface 20 of the roller 12 can be varied; positioning the blade 18 so that its longitudinal axis 32 is tangential to the outer surface 20 of the roller 12 at the cutting location 30 creates the shallowest gradient of chamfer. Yet shallower gradients of chamfer can be created by increasing the cross-sectional diameter of the roller 12.

Figure 2 shows a second embodiment of the present invention, which comprises an eccentric roller 58 of elliptical cross section. In this example, the roller 58 is centrally mounted on the axle 36. The eccentricity of the roller 58 causes the ply 14 to be brought towards the blade 18 as the roller 58 is turned clockwise. Aside from the geometrical differences, the operation of this apparatus to create a chamfered cut is as described above with respect to the first embodiment.

Referring now to Figure 3, in a third embodiment of the present invention a prepreg ply 14 is stretched over a fixed cylinder 60 and a pair of clamps 61a,61b are used to clamp the ply 14 to a work surface 62 on both sides of the cylinder 60. In this way, a curvature in conformity with part of the curvature of the surface 64 of the cylinder 60 is developed in the ply 14, in a region between the clamps 61a,61b. A rod 66 is located across the width of the ply 14 at a location between the cylinder 60 and the clamp 61b on a 'non-cutting side' 67 of the cylinder 60. The rod 66 bears against the ply 14 so that the ply 14 is held in tension between the clamps 61a,61b. The clamp on a 'cutting side' 68 of the cylinder 60 is spaced apart from the cylinder 60 in the plane of the work surface 62 so that the ply 14 lifts away from the cylinder 60 towards that clamp 61a to form a clearance zone 70 adjacent the surface 64 of the cylinder 60 in the form of a gap between an inner surface 72 of the ply 14 and the cylinder 60. At the point where the ply lifts away from the cylinder 60, the inner surface 72 of the ply 14 is substantially tangential to the surface 64 of the cylinder 60, as represented by the dotted line 74 in Figure 3.

An ultrasonic knife 16 having a cutting blade 18 is positioned at one end of the cylinder 60, adjacent the clearance zone 70. The knife 16 is oriented with respect to the ply 14 such that a longitudinal axis 32 of the cutting blade 18 intersects the tangent line 74 of
the inner surface 72 of the ply 14 at the point where the ply 14 lifts away from the cylinder 60. The longitudinal axis 32 defines a cutting plane through the ply 14. In the most extreme example, shown schematically in Figure 3A, the longitudinal axis 32 of the blade 18 is aligned with the tangent line 74 of the inner surface 72 of the ply 14 at the point where the ply 14 lifts away from the cylinder 60. Orienting the blade 18 in this way provides the shallowest possible chamfer gradient, i.e. the smallest chamfer angle.

It can be seen from the dashed line 32 defining the longitudinal axis of the cutting blade 18 in Figures 3 and 3A, that the cutting blade 18 penetrates an outer surface 76 of the ply 14 at a point where the ply is supported by the cylinder 60, i.e. where the outer surface 76 of the ply 14 is in alignment with the surface 64 of the cylinder 60 lying orthogonally below. The cutting blade 18 penetrates the inner surface 72 of the ply 14 at or close to the point where the ply 14 lifts away from the cylinder 60 such that the blade 18 extends into the clearance zone 70 between the cylinder 60 and the ply 14 when a chamfering cut through the ply 14 is performed, as described below. As described previously, the point at which the blade 18 penetrates the inner surface 72 of the ply 14 will be referred to hereafter as the 'cutting location'.

Referring still to Figure 3, to create a chamfered cut through the ply 14, the ultrasonic blade 18 is set to vibrate at 20 kHz and then traversed across the full width of the ply 14. In this example, the blade 18 is advanced across the ply 14 in a direction substantially parallel to a longitudinal axis 78 of the cylinder 60, i.e. in a direction perpendicular to the plane of the page in Figure 3. As the blade 18 cuts through the ply 14, the tip of the blade 18 extends into the clearance zone 70 between the cylinder 60 and the ply 14 at the cutting location 30 as mentioned above.

Having a clearance zone 70 is advantageous because it allows the blade 18 to cut through the ply 14 without making contact with the cylinder 60. This prevents the blade 18 from becoming blunt and prevents the cylinder 60 from becoming hot as a result of friction between the blade 18 and the cylinder 60 that would otherwise occur if the blade 18 cut against the cylinder 60. As heat is inevitably generated in the ply 14 due to friction between the blade 18 and the ply 14, the cylinder 60 includes a plurality of internal refrigerant tubes 56 through which a refrigerant is pumped to cool the cylinder 60, and hence to cool the ply 14.
The blade 18 is able to cut through the thickness of the ply 14 in a single pass. In this example, the ply 14 is 1.2 mm thick, but these techniques may be employed to create a chamfered cut through plies of other thicknesses. It will be appreciated that multiple passes of the blade 18 across the ply 14 may be employed if required to cut through the thickness of the ply 14. If multiple passes are employed, relative movement of the knife 16 and cylinder 60 towards one another may be required between successive passes to cause the blade 18 to penetrate deeper into the ply 14. This can be achieved, for example, by advancing the knife 16 parallel to the longitudinal axis 32 of the blade 18 towards the ply 14.

In a fourth embodiment of the invention, which is shown in Figure 4, an air gap is provided behind the ply 14 by virtue of a recess 80 machined in the surface 64 of the cylinder 60 adjacent the cutting location 30. The recess 80 extends longitudinally, along the length of the cylinder 60, parallel to the cylinder's longitudinal axis 38. The recess 80 defines a clearance zone into which the blade 18 extends as it penetrates the inner surface 72 of the ply 14. Cooling fluid, such as air or a refrigerant, is pumped along the recess 80 to cool the cylinder 60 and the ply 14 at the cutting location 30.

The inclination of the blade 18 relative to the inner surface 72 of the ply 14 defines the gradient of the chamfered or 'tapered' edge of the ply 14 that is created by the cut. A shallow chamfer gradient in the range of 1:20 to 1:10, i.e. approximately 2.8° to 6°, is particularly desirable when the ply 14 is to be incorporated in a composite structure, for example in a wind turbine blade.

Whilst the ply 14 is stretched over a cylinder 60 in the examples shown in Figures 3 and 3A, it will be appreciated that in other examples of the invention, the cylinder 60 may be replaced by a supporting structure having a different shape. For example, referring to Figure 5, in a further embodiment of the invention, the ply 14 is stretched over a support 82 of rhomboidal cross section. The ply 14 lifts away from the support 82 at an edge 84 of the support 82 to define a clearance zone 86 between the inner surface 72 of the ply 76 and the support 82. The ultrasonic knife 16 is arranged adjacent the clearance zone 86 and oriented such that the longitudinal axis 32 of the blade 18 extends through the thickness of the ply 14. The ply 14 is supported by the support 82 at the point where the blade 18 encounters the outer surface 76 of the ply 14, i.e. at this point, the outer surface 76 is in alignment with a supporting surface 88 of the support 82 lying orthogonally below. The ply 14 is unsupported at the point where the blade 18 penetrates the inner
surface 72 such that the blade 18 extends into the clearance zone 86 during the cutting operation.

Figure 5 is included by way of example to illustrate that the invention is not limited to cylindrical supports. However, a cylinder or other convex-curved support is preferred because the smooth outer contour of a cylinder or other curved support prevents the ply 14 from creasing or being subjected to high local stresses, which may occur with certain types of ply 14 when stretched over a sharp edge of a support structure as in Figure 5. Cylindrical or other such convex-curved supports are also preferred because they curve away from the blade 18 on both sides of the cutting location 30. This allows the blade 18 to be positioned at a more acute angle with respect to the inner surface 72 of the ply 14 (as compared to the rhomboidal support of Figure 5, for example) because a sufficient clearance is provided behind the cutting location 30 to accommodate the relatively wide horn 44 of the ultrasonic knife 16.

Many modifications may be made to the process described above without departing from the scope of the present invention as defined by the accompanying claims. For example, whilst prepreg plies have been described above, it will be appreciated that the invention is equally suitable for chamfering other plies, for example semi-preg plies or dry plies for use in resin infusion techniques. 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).

Whilst an ultrasonic knife has been described by way of example, it will be appreciated that other suitable cutting means may be employed. In addition, whilst in the examples described above the knife is moved relative to the support, it will be appreciated that the support may instead be moved relative to the cutting means to bring the ply into contact with the cutting means. Further it will also be appreciated that other cutting methods may be employed, for example laser or water-jet cutting techniques.
Claims

1. A method of tapering an edge of a fibrous reinforcement sheet for a composite structure, the method comprising:

   - supporting the sheet against a support; and
   - creating a tapered edge by relative translational movement of a cutting tool with respect to the supported sheet, a cutting element of the tool being acutely angled with respect to the supported sheet to develop an inclined cutting plane during said relative translational movement between the tool and the sheet;

   wherein closing movement between the cutting element of the tool and the sheet is in the cutting plane; and

   - the sheet has an inner side lying against a supporting surface of the support and the cutting plane projected through the sheet intersects the inner side of the sheet.

2. The method of Claim 1, wherein the sheet is held under tension against the support.

3. The method of Claim 1 or Claim 2, wherein the cutting plane projected through the sheet is substantially tangential with the supporting surface.

4. The method of Claim 1 or Claim 2, wherein the cutting plane projected through the sheet intersects the inner side of the sheet in a clearance zone adjacent the supporting surface where there is a gap between the inner side of the sheet and the support.

5. The method of Claim 4, wherein the cutting plane intersects an outer side of the sheet in alignment with the supporting surface lying orthogonally below the outer side of the sheet on the line of intersection with the cutting plane.

6. The method of Claim 4 or Claim 5, wherein the clearance zone is defined by holding part of the sheet under tension away from the support.
7. The method of any of Claims 4 to 6, wherein the clearance zone is defined by a recess in the support.

8. The method of any of Claims 4 to 7, wherein cooling is applied to the sheet via the clearance zone.

9. The method of any preceding claim, wherein cooling is applied to the sheet via the support.

10. The method of any preceding claim, wherein the supporting surface is convex-curved about an axis of curvature substantially parallel to the cutting plane.

11. The method of Claim 10, wherein the support has an effective radius that is varied by turning the support about an axis of rotation substantially parallel to the cutting plane to advance the sheet toward the tool in a direction substantially orthogonal to the tapered edge.

12. The method of Claim 11, wherein the supporting surface moves eccentrically with respect to the axis of rotation as the support turns.

13. The method of any preceding claim, comprising relative movement between the tool and the sheet to advance the tool across the sheet in a direction substantially parallel to the tapered edge.

14. The method of any preceding claim, comprising relative movement between the tool and the sheet to advance the tool toward the sheet in a direction substantially orthogonal to the tapered edge.

15. The method of Claim 13 or Claim 14, comprising repeating said movements to cut through the sheet in a succession of cuts.

16. The method of Claim 15, wherein the movements defined in Claim 13 and Claim 14 are used in alternation.

17. The method of any preceding claim, wherein the cutting tool is an ultrasonic knife.
18. A method of making a composite structure, comprising:

tapering an edge of a fibrous reinforcement sheet in accordance with any preceding claim; and

incorporating the sheet into a composite structure with the tapered edge lying against or beside at least one other fibrous reinforcement sheet.

19. The method of Claim 18, wherein the cooperating fibrous reinforcement sheets each have a tapered edge and the tapered edges abut one another.

20. Apparatus for tapering an edge of a fibrous reinforcement sheet for a composite structure, the apparatus comprising:

a support for supporting the sheet; and

a cutting tool capable of relative translational movement with respect to the supported sheet, a cutting element of the tool being acutely angled with respect to the supported sheet to develop an inclined cutting plane during said relative translational movement between the tool and the sheet;

wherein the sheet has an inner side lying against a supporting surface of the support and the cutting plane projected through the sheet intersects the inner side of the sheet.

21. The apparatus of Claim 20, comprising a tensioner for holding the sheet in tension against the support.

22. The apparatus of Claim 20 or Claim 21, wherein the cutting plane projected through the sheet is substantially tangential with the supporting surface.

23. The apparatus of Claim 20 or Claim 21, wherein the cutting plane projected through the sheet intersects the inner side of the sheet in a clearance zone adjacent the supporting surface where there is a gap between the inner side of the sheet and the support.
24. The apparatus of Claim 23, wherein the cutting plane intersects an outer side of the sheet in alignment with the supporting surface lying orthogonally below the outer side of the sheet on the line of intersection with the cutting plane.

25. The apparatus of Claim 23 or Claim 24, wherein the clearance zone is defined by holding part of the sheet under tension away from the support.

26. The apparatus of any of Claims 23 to 25, wherein the clearance zone is defined by a recess in the support.

27. The apparatus of any of Claims 23 to 26 and having cooling means arranged to cool the sheet via the clearance zone.

28. The apparatus of any of Claims 20 to 27, wherein the support has cooling means.

29. The apparatus of any of Claims 20 to 28, wherein the supporting surface is convex-curved about an axis of curvature substantially parallel to the cutting plane.

30. The apparatus of Claim 29, wherein the support has an effective radius that is variable by turning the support about an axis of rotation substantially parallel to the cutting plane to advance the sheet toward the tool in a direction substantially orthogonal to the tapered edge.

31. The apparatus of Claim 30 and being arranged such that the supporting surface moves eccentrically with respect to the axis of rotation as the support turns.

32. The apparatus of any of Claims 20 to 31, wherein the cutting tool is an ultrasonic knife.

33. A composite structure such as a wind turbine blade, produced by the method of any of Claims 1 to 19 or by use of the apparatus of any of Claims 20 to 32.
A. CLASSIFICATION OF SUBJECT MATTER
INV. B29C70/54 B26D3/02 B26D7/08
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)
B29C B26D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<tr>
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<td>WO 2008/086802 Al (LM GLASFIBER AS [DK]: BOERSTING DENNIS ANDRE [DK])</td>
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X Further documents are listed in the continuation of Box C. X See patent family annex.

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Date of the actual completion of the international search: 13 December 2011

Date of mailing of the international search report: 21/12/2011

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