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1306762.4 15 April 2013 (15.04.2013) GB(71) Applicant: **THE UNIVERSITY OF BRISTOL**
[GB/GB]; Senate House, Tyndall Avenue, Bristol, BS8
1TH (GB).(72) Inventors: **YU, HaNa**; c/o The University of Bristol,
Queens Building, Advanced Composites Centre for Innova-
tion & Science, Bristol, BS8 1TR (GB). **POTTER, Kev-**
in; c/o The University of Bristol, Queens Building, Ad-
vanced Composites Centre for Innovation & Science, Bris-
tol, BS1 1TR (GB).(74) Agent: **RIBEIRO, James**; c/o Withers & Rogers LLP, 4
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(54) Title: METHOD AND APPARATUS FOR ALIGNING DISCONTINUOUS FIBRES

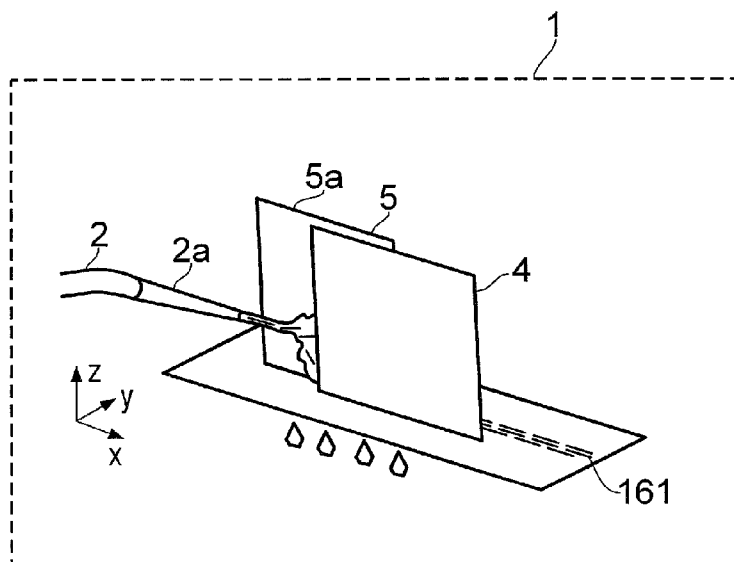


FIG. 1

(57) Abstract: A method of manufacturing a
fibre preform with aligned discontinuous fibres.
A jet of liquid containing discontinuous fibres is
directed onto an alignment surface from a noz-
zle so that the jet meets the alignment sur-
face at an oblique angle and is deflected by the
alignment surface into a channel between an op-
posed pair of channel surfaces. The fibres move
along the channel after the jet has been deflected
into the channel by the alignment surface. The
liquid is removed from the fibres to provide the
fibre preform which may optionally be impreg-
nated with matrix to form a composite tape. At
least some of the fibres have a length greater
than a spacing between the channel surfaces.

Method and apparatus for aligning discontinuous fibres

FIELD OF THE INVENTION

The present invention relates to a method and apparatus for aligning discontinuous fibres in the manufacture of a fibre preform.

5 BACKGROUND OF THE INVENTION

Several techniques exist for the manufacture of aligned discontinuous fibre composites, typically involving hydraulic, electrical, magnetic, or pneumatic means, each technique having specific benefits relating to either fibre type, fabrication time or orientation level.

- 10 Composites can achieve high specific strength and stiffness through fibre alignment. Continuous fibre reinforced composite has a high specific stiffness and strength and yet is susceptible to brittle fracture due to limited ductility. Aligned discontinuous short fibre composites can also achieve high performance provided the fibre aspect ratio is sufficiently high to give sufficient load transfer capability. Complex structural
- 15 shapes not easily fabricated using continuous fibres can be produced. The discontinuity of fibres provides scope to create a ductile or pseudo-ductile response under loading by deformation and slip at fibre discontinuities. However, the degree of ductile or pseudo-ductile response is limited by the degree of fibre alignment.

- US6066235 describes a wet lay process for manufacture of highly-oriented fibrous
- 20 mats having fibres in the region of 10-60mm in length. A thickened solution containing suspended fibres is introduced into the headbox of a wetlay machine. The solution is applied to a moving belt through which suction is applied inducing a flow aligning the fibres along the stream line near the moving belt.

- US3617437 describes a wet processing method of manufacturing a composite material
- 25 using a converging flow to achieve a good degree of fibre alignment in fibres of short length. The method described includes the steps of dispersing fibres in a viscous liquid and passing the suspension through an orifice to at least partially align the fibres. The partially aligned suspension is then laid upon a surface moving relative to

the orifice and withdrawing the viscous liquid through a permeable surface at a velocity such that fibre alignment is maintained.

The use of a high-viscous working fluid, such as glycerine, limits manufacturing time and therefore cost effectiveness. However, in the presently known methods, any
5 reduction in processing time tends to be at the expense of fibre alignment levels.

There is therefore a need for a discontinuous fibre processing method capable of producing high performance ductile composite materials which can be deformed without significant loss in performance and without catastrophic failure having reducing manufacturing time whilst simultaneously achieving a high level of fibre
10 alignment. Such materials provide greater reliability and safety, together with reduced design and maintenance requirements and longer service life.

SUMMARY OF THE INVENTION

A first aspect of the invention provides apparatus for aligning discontinuous fibres, the apparatus comprising an alignment surface; a nozzle oriented at an oblique angle to
15 the alignment surface; and an opposed pair of channel surfaces with a channel between them, wherein the nozzle is arranged such that in use it directs a jet of liquid containing discontinuous fibres onto the alignment surface so that the jet of liquid is deflected by the alignment surface into the channel, and wherein the apparatus is further arranged such that in use the fibres move along the channel after the jet has
20 been deflected into the channel by the alignment surface. Typically the nozzle is arranged such that in use the jet of liquid meets the alignment surface at an oblique angle (which may be the same as the oblique angle of the nozzle or it may be slightly different).

A second aspect of the invention provides a method of manufacturing a fibre preform
25 with aligned discontinuous fibres, the method comprising: directing a jet of liquid containing discontinuous fibres onto an alignment surface from a nozzle so that the jet meets the alignment surface at an oblique angle and is deflected by the alignment surface into a channel between an opposed pair of channel surfaces, wherein the fibres move along the channel after the jet has been deflected into the channel by the
30 alignment surface; and removing the liquid from the fibres to provide the fibre

preform, wherein at least some of the fibres have a length greater than a spacing between the channel surfaces.

The present invention provides an improved degree of alignment compared with known methods of aligning discontinuous fibres. Typically the alignment of the fibres
5 is achieved by three processes which operate one after the other. Firstly the fibres become partially aligned by the action of the nozzle as the jet is formed. Secondly the fibres become further aligned by the action of the alignment surface on the jet. Thirdly the fibres become further aligned by the action of the opposed pair of channel surfaces as they move along the channel.

10 The invention is well suited to a liquid with a low viscosity - for instance less than 100cps, less than 50cps, or less than 10cps. This enables the process to run quicker than one with a high-viscous working fluid such as glycerine. The liquid preferably comprises water, either pure water or an aqueous solution.

Preferably the jet of liquid meets the alignment surface at an average speed greater
15 than 1.5 m/s, greater than 1.6m/s or greater than 1.7m/s.

Preferably the jet of liquid meets the alignment surface at an average speed less than 4m/s.

Preferably the jet of liquid meets the alignment surface at an average speed greater than 1.5m/s and less than 4m/s.

20 Typically the apparatus comprises a pump arranged to feed the liquid containing discontinuous fibres to the nozzle. Typically the pump is arranged to feed the liquid into the nozzle at a sufficiently high rate to ensure that the jet of liquid meets the alignment surface at an average speed greater than 1.5 m/s, greater than 1.6m/s or greater than 1.7m/s.

25 Typically the pump is arranged to feed the liquid into the nozzle at a sufficiently high rate to ensure that the jet of liquid meets the alignment surface at an average speed greater than 1.5 m/s and less than 4m/s.

The channel may have a non-uniform width, but more preferably a spacing between the channel surfaces (which defines the width of the channel) remains substantially constant along a length of the channel.

5 The nozzle is preferably inclined down at an angle to the horizontal. This causes the jet to be deflected down towards a base of the channel and thus ensures that the jet is fully captured within the channel. The nozzle is preferably inclined down at an acute angle to the horizontal which is greater than 10° and less than 45° .

10 Typically the channel has a base between the channel surfaces which extends lengthwise along a channel axis and supports the fibres as they move along the channel, and the nozzle is oriented at an oblique angle to the channel axis.

The alignment surface may lie in a different plane to both channel surfaces, but more preferably it is coplanar with a respective one of the channel surfaces.

15 The alignment surface and the channel surfaces may be provided by three separate parts, but more typically the apparatus comprises first and second plates, wherein the first plate provides the alignment surface and each plate provides a respective one of the channel surfaces.

20 The nozzle may be arranged such that in use it directs the jet of liquid containing discontinuous fibres over the second plate, or through a hole in the second plate. This prevents the liquid from backflowing out of the channel in the wrong direction. In one embodiment the second plate has a main part with a first height, and a fence part with a lower height than the main part. The nozzle is arranged such that in use it directs the jet of liquid containing discontinuous fibres over the fence part of the second plate.

The first and second plates may be staggered so that the first plate has a part which extends beyond the second plate and provides the alignment surface.

25 The fibres may be moved along the channel only under the force of gravity and/or the force of the jet. However more preferably the channel has a moveable base between the opposed pair of channel surfaces which supports the fibres as they move along the channel, and the apparatus further comprises a drive motor for moving the base relative to the channel surfaces to convey the fibres along the channel. A conveyor

belt may receive the fibres from the moving channel base. In this case the conveyor belt may be moved at a faster speed than the channel base so that the fibres stretch as they transfer from the channel base to the conveyor belt.

5 The apparatus may be provided with a tank coupled to the nozzle, the tank containing fibres dispersed in a liquid, at least some of the fibres having a length greater than a spacing between the channel surfaces.

Typically a spacing between the channel surfaces can be adjusted.

10 The apparatus may have means for removing the liquid from the fibres, such as a vacuum device, either as they move through the channel or after they have moved through the channel. The channel may have a permeable base between the opposed pair of channel surfaces which supports the fibres as they move along the channel, and the vacuum device is coupled to the permeable base so that it removes the liquid from the fibres in the channel through the permeable base as they move along the channel. The permeable base is preferably permeable across a full width of the channel
15 between the opposed pair of channel surfaces so that the vacuum device applies a vacuum across the full width of the channel.

An impregnation station may be provided for impregnating the fibres with a matrix material to provide an impregnated fibre preform. Alternatively the apparatus may produce a non-impregnated fibre preform.

20 The apparatus may be replicated with one or more further alignment surfaces, nozzles, and opposed channel surfaces; and an impregnation station for impregnating the fibres from all of the channels with a matrix material so that they are bound together in a single preform. The fibres from the two or more of the channels may have different material properties so the resultant preform is a hybrid with two or more distinct strips
25 with different material properties.

The apparatus may have a fence which closes an inlet of the channel. The fence may be inclined at an acute angle to the opposed channel surfaces, or may run at right angles to the opposed channel surfaces.

Typically the nozzle has an outlet width, and at least some of the fibres have a length greater than the outlet width of the nozzle. The nozzle may have an elongate shape, or it may be circular.

Typically the nozzle has a maximum outlet width, and at least some of the fibres have
5 a length greater than the maximum outlet width of the nozzle.

Typically the nozzle has a minimum outlet width, and at least some of the fibres have a length greater than the minimum outlet width of the nozzle.

The maximum outlet width of the nozzle is typically less than 3mm, less than 2mm, or less than 1mm. The minimum outlet width of the nozzle is typically less than 3mm,
10 less than 2mm, or less than 1mm.

Preferably the jet meets the alignment surface at an acute angle to a line normal to the alignment surface. This acute angle is typically greater than 10°. The acute angle is typically less than 45°.

Preferably the nozzle is inclined at an acute angle to a line normal to the alignment
15 surface. This acute angle is typically greater than 10°. The acute angle is typically less than 45°.

Any of the desirable or optional features discussed herein in relation to first and subsequent aspects of the invention can be applied to any aspect, either individually or in any combination.

20 BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 shows an orientation head;

Figure 2a is a top view of the orientation head of Figure 1;

25 Figure 2b is a side view of the orientation head of Figure 1;

Figure 3 is a side view of an orientation head showing alignment of the fibres in use;

Figure 4 shows an orientation head with three plates and two nozzles;

Figure 5a is a top view of the orientation head of Figure 4;

Figure 5b is a side view of the orientation head of Figure 4;

Figure 6 is a schematic representation of a system for manufacturing prepreg tape
5 using the orientation head of Figure 4;

Figure 7 shows a preform manufactured by the orientation head of Figure 4;

Figure 8 shows apparatus for manufacturing a two-part hybrid preform;

Figures 9 and 10 show two-part hybrid preforms manufactured by the apparatus of
Figure 8;

10 Figures 11 and 12 show an alternative orientation head;

Figure 13 is a top view of part of the orientation head of Figure 1 illustrating the
problem of escaping backflow;

Figures 14 and 15 show an alternative orientation head;

Figure 16 is a top view of part of the orientation head of Figure 14 showing the
15 prevention of escape of the backflow;

Figures 17 and 18 show a further alternative orientation head;

Figure 19 is a top view of part of the orientation head of Figure 17 showing the
prevention of escape of the backflow;

Figure 20 shows apparatus for manufacturing a three-part hybrid preform;

20 Figures 21 and 22 show three-part hybrid preforms manufactured by the apparatus of
Figure 20;

Figure 23 is a side view of an orientation head with an arbitrary number of orientation
plates;

Figure 24 is a top view of the orientation head of Figure 23;

Figure 25 shows alternative apparatus for manufacturing a three-part hybrid preform;

Figure 26 shows a hybrid preform manufactured by the apparatus of Figure 25;

Figure 27 is an isometric view of an alternative orientation head;

Figure 28 is an enlarged view A of one end of the orientation head of Figure 27;

5 Figure 29 is an enlarged view B of the other end of the orientation head of Figure 27;

Figure 30 shows a probability distribution of fibre angle in a preform; and

Figure 31 shows a probability distribution of fibre angle in a prepreg composite tape.

DETAILED DESCRIPTION OF EMBODIMENT(S)

Referring to Figures 1-3, there is shown an orientation head 1 for aligning
 10 discontinuous fibres. A nozzle 2 is oriented at an oblique angle to two parallel plates 4,5. The plates are staggered in the direction of flow (x direction) so that the plate 5 has a protruding part 5a extending beyond the plate 4 in the -x direction. The plates 4,5 have the same length so that the plate 4 also has a protruding part extending beyond the plate 5 in the +x direction.

15 In use as shown in Figure 1, the nozzle 2 directs a jet of liquid 2a onto the protruding part 5a of the plate 5 so that the jet is deflected into a channel 7 between the plates as shown in Figures 2a and 2b. Note that as shown in Figure 2a the jet 2a impacts the protruding part 5a of the plate outside the channel 7 (just upstream of its inlet) but optionally the nozzle may be repositioned and reoriented so that the jet 2a impacts the
 20 plate 5 inside the channel 7.

The plates 4,5 are oriented vertically (parallel to the zx plane) and spaced apart in the y direction by a distance d1 labelled in Figure 2a. The opposed faces of the plates 4,5 define the sides of the channel 7 so the distance d1 defines the width of the channel 7. The plates 4,5 are parallel so the width d1 remains substantially constant along the
 25 length of the channel. The channel also has a base 7a between the plates 4,5 which extends lengthwise along the channel axis and lies in the (horizontal) xy plane.

The nozzle 2 is inclined with respect to the channel axis so that when viewed from above (as shown in Figure 2a) the jet 2a meets the plate 5 at an acute angle θ to the channel axis (or equivalently at an angle $90-\theta$ to a line normal to the face of the plate 5). The acute angle θ is typically in the range of 70° to 90° , for example 80° , so the minimum value of θ is 70° . Similarly the nozzle is inclined down so that when viewed from the side (as shown in Figure 2b) the jet 2a meets the plate 5 at an acute angle ϕ to the vertical (z-direction) or equivalently at an angle $(90-\phi)$ to the horizontal. The acute angle ϕ is typically in the range of 45° to 90° , for example 60° , so the minimum value of ϕ is 45° .

The outlet of the nozzle 2 is spaced apart from the plates 5 and positioned at a height about 10mm above the channel base 7a. Thus the liquid flies as an unsupported jet 2a across an air gap before impacting with the plate 5.

The jet 2a contains discontinuous fibres 10 in suspension as shown in Figure 3 which are roughly aligned with the flow direction of the jet. Note that in Figure 3 the first plate 4' is modified compared with the plate 4 shown in Figure 1, being shorter than the second plate 5 in the z-direction. The jet 2a follows a trajectory 11 as it impacts the plate 5. Depending on the speed and angle of the jet this trajectory may be straight as shown or slightly curved. The protruding part 5a of the plate which deflects the jet provides an alignment surface which imparts a momentum change on the fibres 10 tending to align them with the plane of the alignment surface on impact.

On impact the jet 2a is deflected to follow a path 2b towards the opposed plate 4 as shown in Figures 2a and 2b which guides them along the channel. Most (or all) of the fibres have a length greater than the width d_1 of the channel 7 so that they become further aligned with the flow direction along the length of the channel as shown in Figure 3. Preferably the width d_1 is at least $1/3$ shorter than the average fibre length. The average fibre length typically lies within the range of 0.1mm to 5mm. The total range of fibre lengths within the jet is quite tightly grouped around the average, typically varying by about $\pm 10\%$ from the average.

Referring to Figures 2b and 3, the channel base 7a is formed by a conveyor belt 12 of permeable material which is slidably mounted on a water suction plate 13 with a vacuum chamber 14 and vacuum port 15 coupled to a vacuum device (not shown in

Figure 2b). The conveyor belt 12 supports the oriented fibres 10 while the liquid is removed through it by the action of the vacuum.

Referring to Figures 4 and 5, there is shown an orientation head 1' which is identical to the orientation head 1 except that it has an additional nozzle 3 which directs a jet 3a
5 onto a projecting part 6a of a third plate 6 spaced from the plate 5 by a distance d2. The jet 3a is deflected at 3b towards the plate 5 along a channel 8 with a base 8a between the plates 5,6. The conveyor belt 12', suction plate 13' and vacuum chamber 14' are widened compared with items 12-14 to accommodate the double width. Each channel 7,8 outputs a respective strip 7b,8b of aligned fibres as shown in Figure 4
10 which merge together to form an aligned preform.

The orientation head 1' shown in Figure 4 is used in a system shown in Figure 6. The system includes a water trap tank 20 supplying a tank 21 with water. The fibres are fed into the tank 21 via a fibre inlet 22. The tank 21, containing a mix of fibres 10 dispersed in water 23, is coupled to the nozzles 2,3 via a water pump 24. The action
15 of the pump 24 causes the fibre/water mixture to accelerate as it passes through the outlet of the nozzle, this acceleration having an alignment effect on the fibres which tends to roughly align them in the direction of flow of the jet. Each nozzle 2,3 has an inwardly tapering conical shape terminating in a circular outlet with a diameter less than the fibre length. The jet from the nozzle is a continuous stream as shown in
20 Figure 4 rather than a spray. The rate of flow from the pump 24 is arranged to feed the liquid into the nozzle at a sufficiently high rate to ensure that the jet of liquid meets the alignment surface at an average speed (i.e., an average taken across the width of the jet) which is greater than 1.5 m/s. In the case of a circular nozzle with a nozzle width (diameter) of 2mm, then an average jet speed of 1.8m/s can be used. In
25 the case of a circular nozzle with a nozzle width (diameter) of 1mm or less, then an average jet speed between 1.5m/s and 4m/s has been found to work well. Preferably the jet has small-scale turbulent flow so as not to induce too much drag force on the parallel plates.

The vacuum port 15' is coupled to a vacuum device 25 via a vacuum line 26 which
30 passes through the water trap tank 20 so that the water in the vacuum line 26 is returned to the water trap tank.

The aligned fibre preform output from the channels 7,8 on the conveyor belt 12' is transferred to a drying and impregnation station 30. The conveyor belt 12' is driven at a velocity V1 by a motor 27 with variable speed. The station 30 comprises a conveyor belt 31 which receives the preform from the conveyor belt 12 and is also driven by a motor 28 with a variable speed at a velocity V2 which is greater than V1. These motors 27,28 for the conveyor belts 12', 31 are controlled individually and an encoder can be used to give feedback to the motors. This difference in velocity stretches the fibres and provides a further alignment effect. The fibres on the belt 31 are heated by a heater 32 to dry them, and then a resin film 33 is fed from a roll 34 into contact with the heated fibres, melting and impregnating the preform to form pre-impregnated (prepreg) composite tape 36 which is wound onto a roll 35.

Figure 7 shows a preform 40 manufactured by the system of Figure 6. The preform contains carbon fibres 41 randomly mixed with glass fibres 42.

Figure 8 shows an alternative apparatus for use with the orientation head 1' in manufacturing a two-part hybrid preform of the kind shown in Figures 9 and 10. The apparatus of Figure 8 has a first tank 46 containing fibres 47 suspended in liquid 48, and a second tank 49 containing fibres 50 suspended in liquid 51. Liquid from each tank is fed to the orientation head 1' via a respective pump 52,53. The preform has one half containing fibres from the first tank 46 and another half containing fibres from the second tank 49. Thus by selection of the fibre and liquid in the tanks the two half strips 7b,8b of the preform can have different properties. Thus for example in the preform 54 of Figure 9 one half contains carbon fibres 55 and the other half contains glass fibres 56; and in the preform 60 of Figure 10 one half contains fibres 61 suspended in water and the other half contains fibres 62 suspended in a dilute sizing solution.

The hybrid preforms of Figures 7, 9 and 10 are designed to obtain pseudo-ductility or ductility by the fracture control of the composites. The critical fibre length (l_c) of carbon/epoxy composites is determined by eqn. (1):

$$s_c = \sigma_f / 2\tau_i = l_c / d_f \quad (1)$$

where d_f is the diameter of the fibres, σ_f is the tensile strength of the fibres and τ_i is the shear strength or the shear yield stress of the interface or the frictional shear stress at the interface. Fibres which are shorter than the critical length cannot be broken by stressing the composite. On the other hand, fibre breakage occurs and leads to the whole composite's rupture rather than slip between the fibres and the matrix when the fibre is longer than the critical fibre length.

Carbon/epoxy composites have typically high modulus, but low failure strain (around 1.5% in continuous fibre reinforced composites) and glass/epoxy composites have relatively low modulus but high failure strain (over 2% in continuous fibre reinforced composites). In the case of continuous fibre reinforced composites, a hybrid composite with glass and carbon fibres shows pseudo-ductility provided the glass fibres can hold out the applied stress after all carbon fibres fail. The same symptom can be expected in the case of the aligned short fibre composites shown in Figures 7, 9 and 10. Furthermore, the manufacturing process allows finer hybridization of the carbon/glass fibres.

In the case of Figure 10 the dilute sizing solution containing the fibres 62 increases the surface interface characteristics of the fibres 62 compared with the fibres 61 contained in pure water. Thus the fibres 61 may have better fibre pull-out properties than the fibres 62. Using pure water as a working fluid, it can be assumed there is no sizing material on the fibre. On the other hand, a working fluid with a small amount of sizing materials (such as waterborne epoxy, silane coupling agent etc.) can improve the interface properties (the shear yield stress of the interface) between the fibre and matrix, which means that it is possible to control the critical fibre length of the composite.

Figures 11 and 12 show an orientation head 70 which is similar to the orientation head 1' but with orientation plates 71-73 having different lengths so they all terminate at the same x position at the outlet of the channels.

A potential backflow problem with the orientation head 1 is shown in Figure 13. The majority of the liquid from jet 2a flows along the channel but part of it may provide a backflow 2c which runs along the base and flows out of the channel inlet. The orientation head 80 of Figures 14-16 solves this problem by providing the first two

plates with fences 81,82 extending in the -x direction. The fences 81,82 have a lower height than the plates so that the jets 2a,3a can pass over the top of them. The fences 81,82 prevent the backflow 2c from escaping the channels in the -y direction. Another solution to the backflow problem is shown in Figures 17-19. In this case an inclined
5 fence 85 closes the channels at their inlet end and prevents the backflow 2c from escaping the channel in the -x direction as well as the -y direction.

Figure 20 shows an alternative system including an orientation head 90 for manufacturing a three-part hybrid preform of the kind shown in Figures 21 and 22. Note that the head 90 has four plates and three channels/nozzles in contrast to the head
10 1' which has only three plates and two channels/nozzles. A first tank 91 contains fibres 92 suspended in liquid 93, and a second tank 94 contains fibres 95 suspended in liquid 96. Liquid from tank 91 is fed to a nozzle 97 via a first water pump 98, and liquid from tank 94 is fed to two nozzles 100,101 via a second water pump 102. Each nozzle directs a jet into a respective channel between a pair of orientation plates. The
15 preform has a central tow containing fibres from the first tank 91, and two outer tows each containing fibres from the second tank 94. Thus by selection of the fibre and liquid in the tanks the tows can have different properties. Thus for example the preform 110 of Figure 21 has an inner tow with carbon fibres 111 and outer tows containing glass fibres 112; and in the preform 120 of Figure 22 the central tow
20 contains short fibres 121 with a low average length L and the outer tows contain long fibres 122 with an average length which is greater than L.

The orientation head can have any number of orientation plates. By way of example Figures 23 and 24 show an orientation head with two sets of three orientation plates, and an arbitrary number of additional plates between the two sets. The y position of
25 each plate can be adjusted so that the channel width d1, d2 between each adjacent pair of opposed surfaces can be adjusted as required for different fibre lengths.

The two faces of each plate are parallel planes, and the lower edge of each plate lies transverse to these parallel planes. As shown in Figure 23 there is a small gap between this lower edge of each plate and the conveyor belt 12'' to enable the
30 conveyor belt 12'' to be moved. When several preform strips (for instance the strips 7b,8b shown in Figure 4) merge together after exiting the channels 7,8, a small gap

will be present between them if the plate 5 between the channels 7,8 is thick. The thickness of the plate 5 must be sufficiently high to ensure that it has sufficient bending stiffness to withstand the momentum of the jet 2a.

A way of adapting the lower edge of the plate 5 to minimise the gap between the strips 7b,8b whilst maintaining the plate's bending stiffness is shown in the enlarged part of Figure 23. The lower part of the plate 5 is shown with two alternative shapes. On the left-hand side the plate is shown with inwardly tapered planar faces 132, 133 terminating at a planar lower edge 134. On the right-hand side the plate is shown with inwardly tapered planar faces 135, 136 terminating at a curved lower edge 137. Thus the width of the plate at its lower edge 134,137 (which governs the size of the gap between the strips 7b,8b) is smaller than the average thickness of the plate (which governs its bending stiffness).

Figure 25 shows an alternative system for feeding the orientation head 90 to produce a three-part hybrid preform of the kind shown in Figure 26. Liquid from tank 91 is fed either to nozzle 97 via the first water pump 98 or to the two nozzles 100,101 via the second water pump 102, depending on the position of a switch 141. Similarly, liquid from tank 94 is fed either to nozzle 97 via the first water pump 98 or to the two nozzles 100,101 via the second water pump 102, depending on the position of a switch 142. The preform has a central tow containing fibres from the first pump 98, and two outer tows each containing fibres from the second pump 102. Thus by selection of the fibre and liquid in the tanks, and the positions of the switches 141, 142, different parts of the preform can have different properties. Thus for example the preform of Figure 26 has a left section 145 and a right section 146. The left section 145 has an inner tow with glass fibres 150 and outer tows containing carbon fibres 151, and the right section 146 has an inner tow with carbon fibres 152 and outer tows containing glass fibres 153.

Figures 27-29 show an orientation head 160 according to a further embodiment of the invention. The head 160 has eleven plates which are mounted at each end in a slot in a bracket 161,162 as shown in detail in Figure 28. The spacing between the plates can be adjusted by selecting the slots in the brackets 161,162 which are used to mount the plates. Each plate has a decreasing number of holes through which a jet 2a,3a can be

directed to impact the adjacent plate as shown in Figure 29. Thus the first plate has ten holes 163 as shown in Figure 27, the next plate has nine holes 164, the next plate has eight holes and so on. The eleventh plate has no holes.

5 Figure 30 is a graph showing a spread of fibre angles in a preform manufactured by one of the orientation heads described above. About 80% of the fibre angles are in the range of $\pm 3^\circ$. Figure 31 shows a spread of fibre angles in a composite tape manufactured by one of the systems described above. About 65% of the fibre angles are in the range of $\pm 3^\circ$ and about 90% are in the range of $\pm 7^\circ$.

10 Composite tape manufactured according to the present invention with 3mm carbon fibres at a volume fraction between 40% and 55% have been shown to have a relatively high tensile modulus (between 80 and 120 GPa), tensile strength (800-1600 MPa) and %strain at break (1-1.4%).

15 The method described above provides a continuous and low cost process with fast fabrication times. The method is not limited to a particular type of fibre, although lengths in the range of 0.1mm to 5mm are typical, and provides a high alignment level (over 50% of the fibre angles being in the range of $\pm 3^\circ$). The method is suited for using recycled fibres and can be used to produce hybrid preforms.

20 Although the invention has been described above with reference to one or more preferred embodiments, it will be appreciated that various changes or modifications may be made without departing from the scope of the invention as defined in the appended claims.

Claims

1. Apparatus for aligning discontinuous fibres, the apparatus comprising an alignment surface; a nozzle oriented at an oblique angle to the alignment surface; and an opposed pair of channel surfaces with a channel between them,
5 wherein the nozzle is arranged such that in use it directs a jet of liquid containing discontinuous fibres onto the alignment surface so that the jet of liquid is deflected by the alignment surface into the channel, and wherein the apparatus is further arranged such that in use the fibres move along the channel after the jet has been deflected into the channel by the alignment surface.
- 10 2. The apparatus of claim 1 wherein a spacing between the channel surfaces remains substantially constant along a length of the channel.
3. The apparatus of claim 1 or 2 wherein the nozzle is inclined down at an angle to the horizontal.
- 15 4. The apparatus of any preceding claim wherein the channel has a base between the channel surfaces which extends lengthwise along a channel axis and supports the fibres as they move along the channel, and the nozzle is oriented at an oblique angle to the channel axis.
5. The apparatus of any preceding claim comprising first and second plates, wherein the first plate provides the alignment surface and each plate provides a
20 respective one of the channel surfaces.
6. The apparatus of claim 5 wherein the nozzle is arranged such that in use it directs the jet of liquid containing discontinuous fibres onto the alignment surface through a hole in the second plate.
- 25 7. The apparatus of any preceding claim wherein the channel has a moveable base between the opposed pair of channel surfaces which supports the fibres as they move along the channel, and the apparatus further comprises a drive motor for moving the base relative to the channel surfaces to convey the fibres along the channel.

8. The apparatus of claim 7 further comprising a conveyor belt for receiving the fibres from the channel base; and a drive system for moving the conveyor belt at a faster speed than the channel base so that the fibres stretch as they transfer from the channel base to the conveyor belt.
- 5 9. The apparatus of any preceding claim further comprising a tank coupled to the nozzle, the tank containing fibres dispersed in a liquid, at least some of the fibres having a length greater than a spacing between the channel surfaces.
- 10 10. The apparatus of any preceding claim further comprising means for removing the liquid from the fibres, either as they move through the channel or after they have moved through the channel.
11. The apparatus of claim 10 wherein the means for removing the liquid is a vacuum device.
- 15 12. The apparatus of claim 11 wherein the channel has a permeable base between the opposed pair of channel surfaces which supports the fibres as they move along the channel, and the vacuum device is coupled to the permeable base so that it removes the liquid from the fibres in the channel through the permeable base as they move along the channel.
- 20 13. The apparatus of any preceding claim further comprising an impregnation station for impregnating the fibres with a matrix material.
- 25 14. The apparatus of any preceding claim further comprising a second alignment surface; a second nozzle oriented at an oblique angle to the second alignment surface; and a second opposed pair of channel surfaces with a second channel between them, wherein the apparatus is arranged such that in use the second nozzle directs a second jet of liquid containing discontinuous fibres onto the second alignment surface so that the second jet of liquid is deflected by the second alignment surface into the second channel, and the fibres then move along the channel; and an impregnation station for impregnating the fibres from the first and second channels with a matrix material so that they are bound together in a single piece.

15. The apparatus of claim 14 further comprising a first tank coupled to the first nozzle and a second tank coupled to the second nozzle.
16. The apparatus of any preceding claim further comprising a fence, wherein the nozzle is arranged such that in use it directs the jet of liquid containing discontinuous fibres onto the alignment surface over the fence.
17. A method of manufacturing a fibre preform with aligned discontinuous fibres, the method comprising: directing a jet of liquid containing discontinuous fibres onto an alignment surface from a nozzle so that the jet meets the alignment surface at an oblique angle and is deflected by the alignment surface into a channel between an opposed pair of channel surfaces, wherein the fibres move along the channel after the jet has been deflected into the channel by the alignment surface; and removing the liquid from the fibres to provide the fibre preform, wherein at least some of the fibres have a length greater than a spacing between the channel surfaces.
18. The method of claim 17 further comprising conveying the fibres along the channel by carrying them on a support which moves relative to the channel walls.
19. The method of claim 17 or 18 wherein the nozzle has an outlet width, and at least some of the fibres have a length greater than the outlet width of the nozzle.
20. The method of any of claims 17 to 19 further comprising: directing a second jet of liquid containing discontinuous fibres onto a second alignment surface from a second nozzle so that the second jet meets the second alignment surface at an oblique angle and is deflected by the second alignment surface into a second channel between a second opposed pair of channel surfaces, wherein the fibres move along the second channel after the second jet has been deflected into the second channel by the second alignment surface; and removing the liquid from the fibres to provide the fibre preform, wherein at least some of the fibres have a length greater than a spacing between the channel surfaces, and impregnating the fibres from the first and second

channels with a matrix material so that they are bound together in a single preform.

21. The method of claim 20 wherein the fibres from the first channel are different from the fibres from the second channel.
- 5 22. The method of any of claims 17 to 21 wherein the jet meets the alignment surface at an average speed greater than 1.5 m/s.
23. A fibre preform manufactured by the method of claim 21.

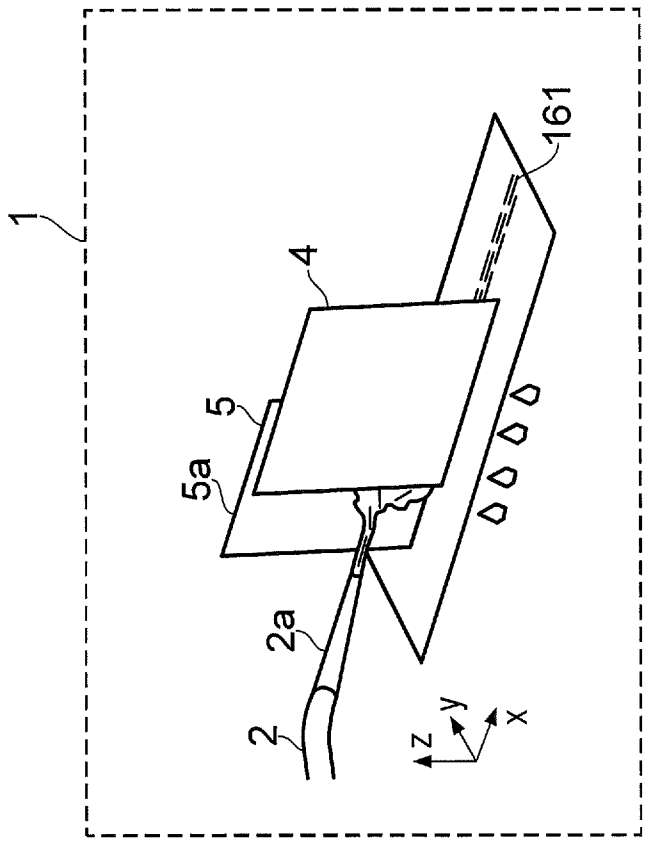


FIG. 1

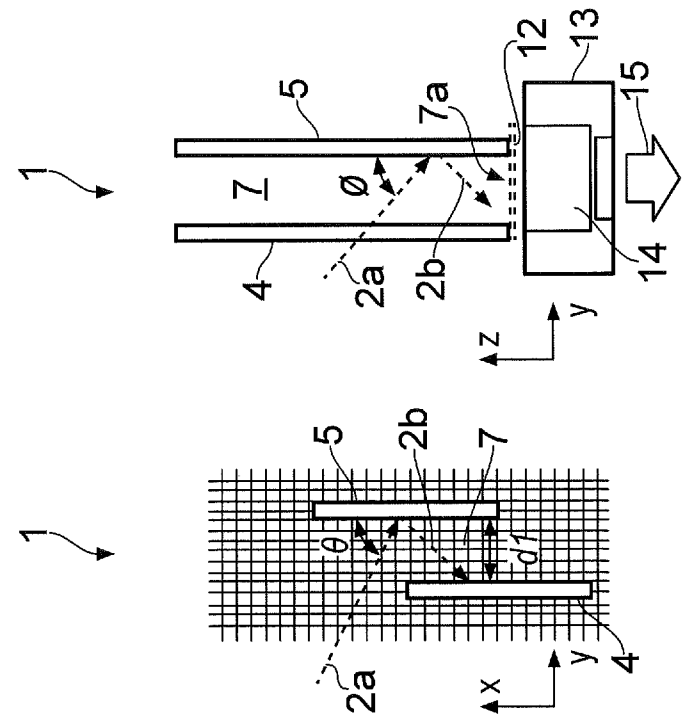


FIG. 2a

FIG. 2b

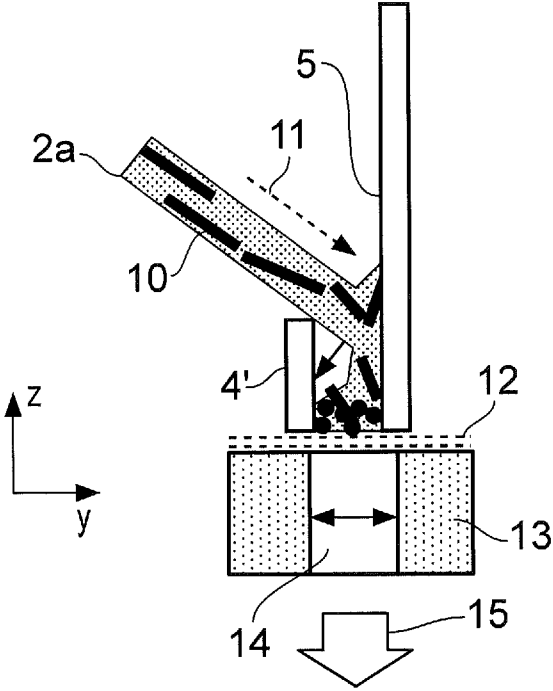


FIG. 3

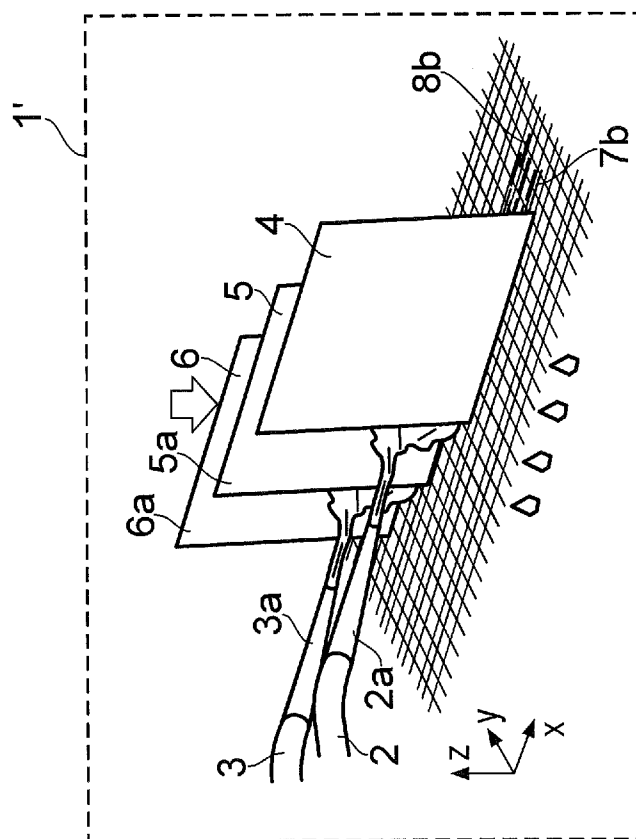


FIG. 4

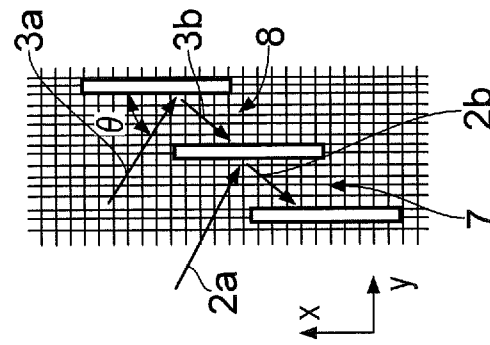


FIG. 5a

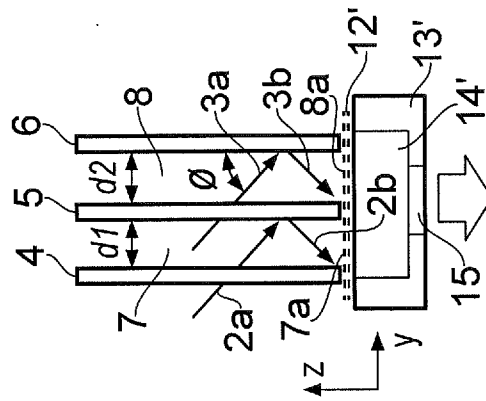
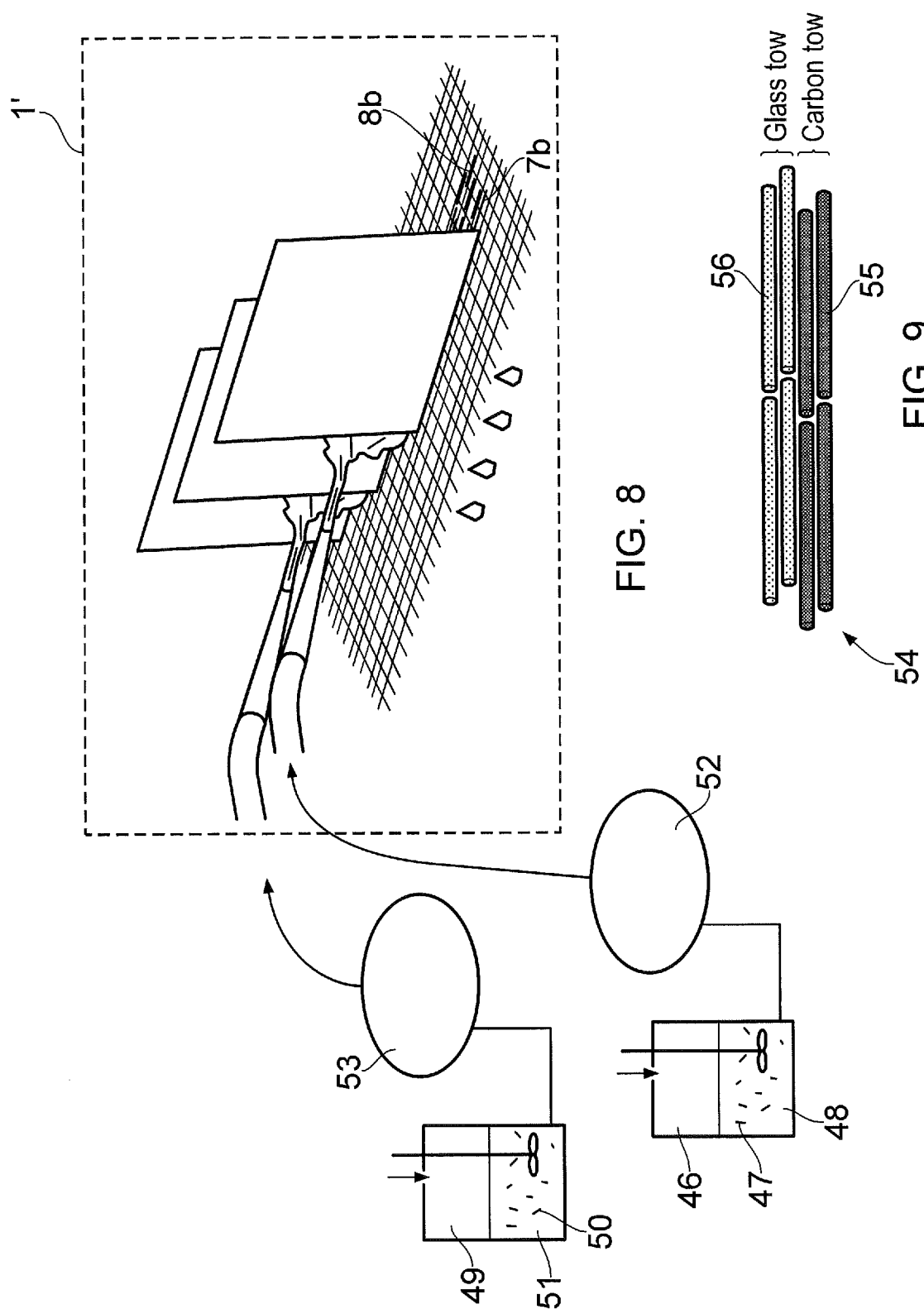


FIG. 5b



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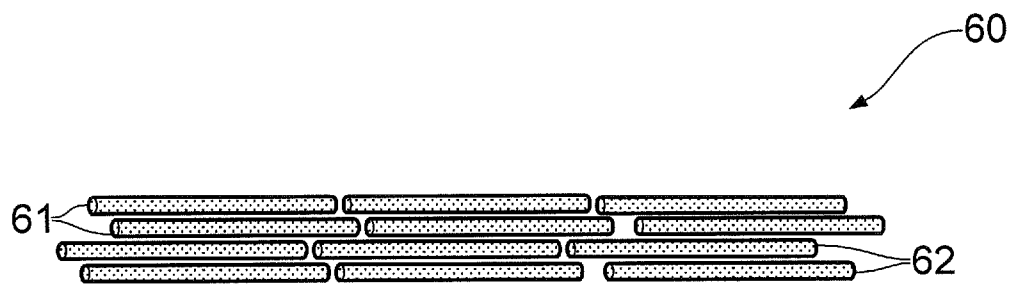


FIG. 10

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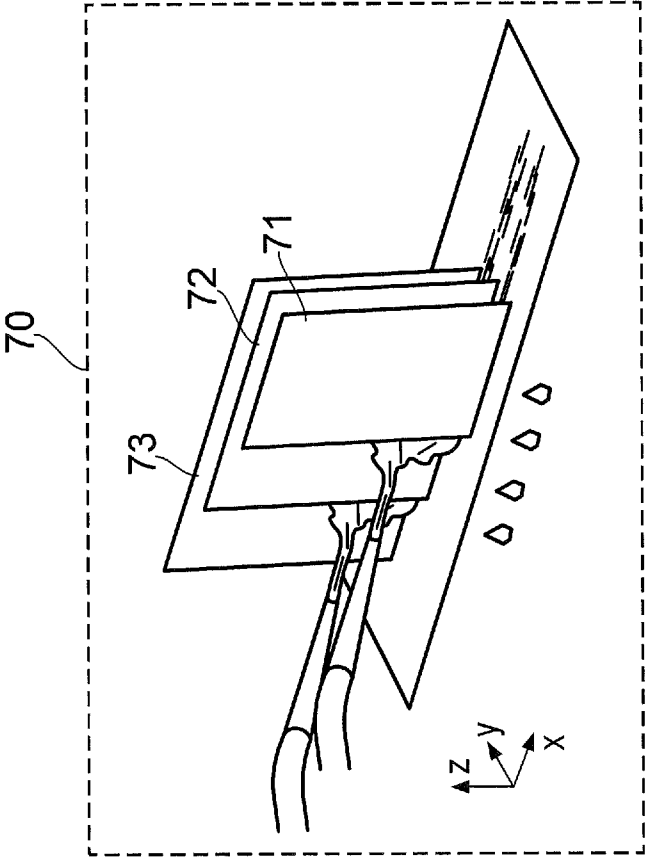


FIG. 11

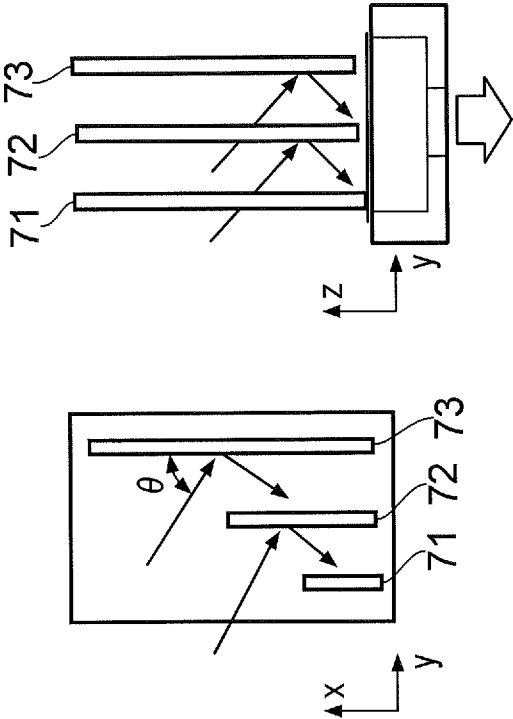


FIG. 12a

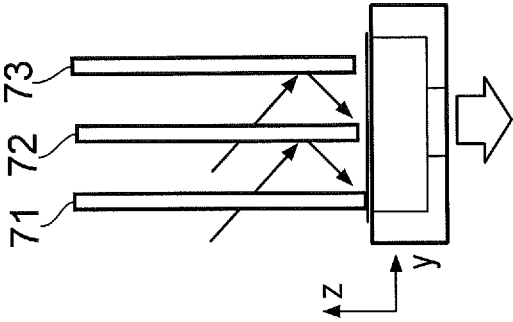


FIG. 12b

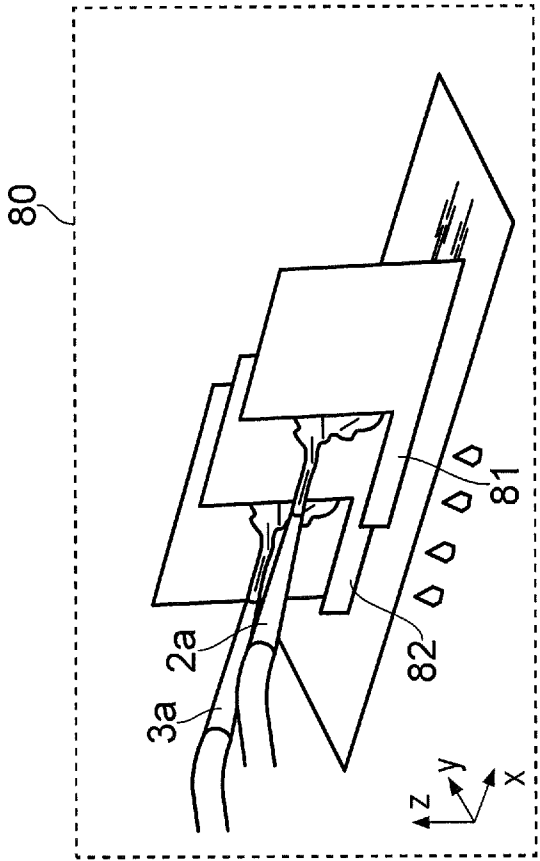


FIG. 14

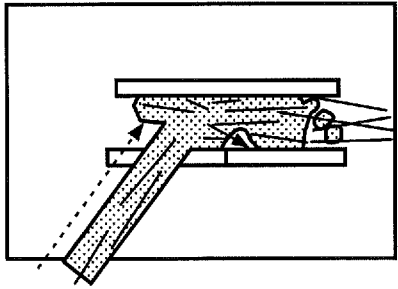
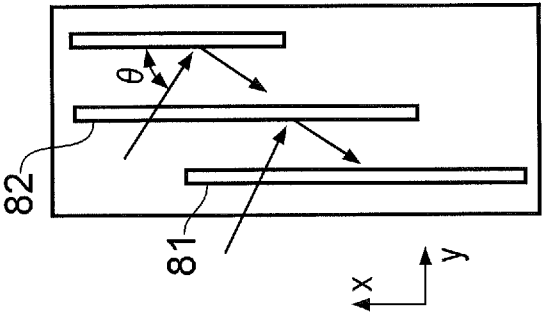


FIG. 16

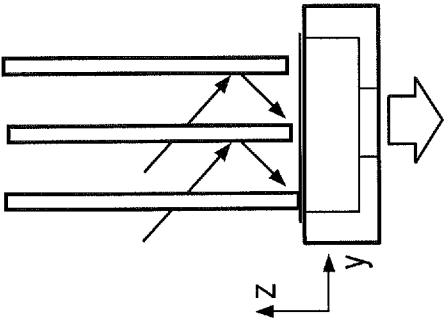


FIG. 15b

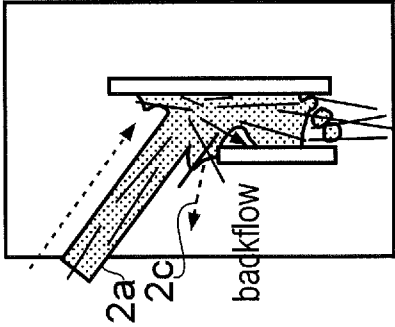
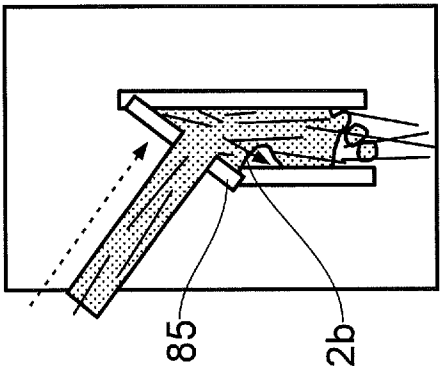
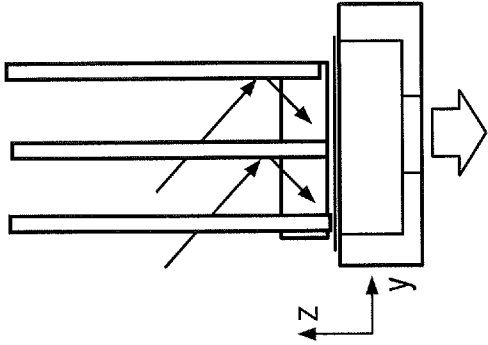
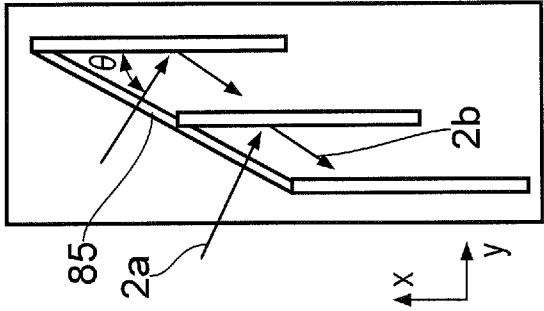
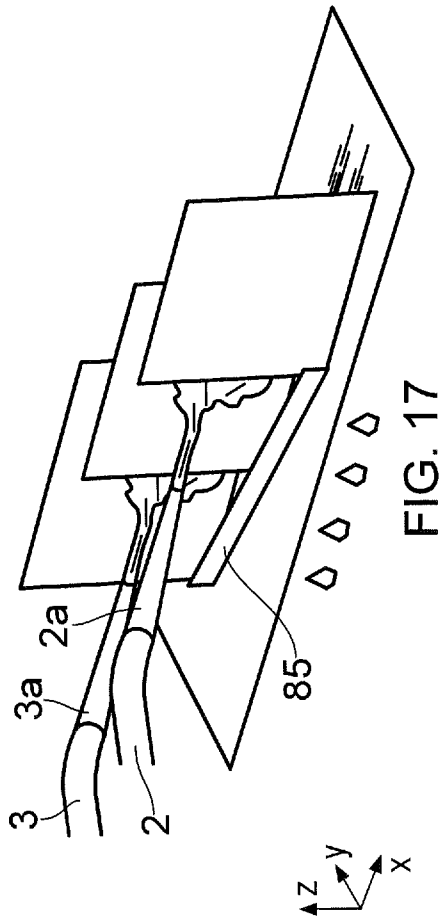


FIG. 13



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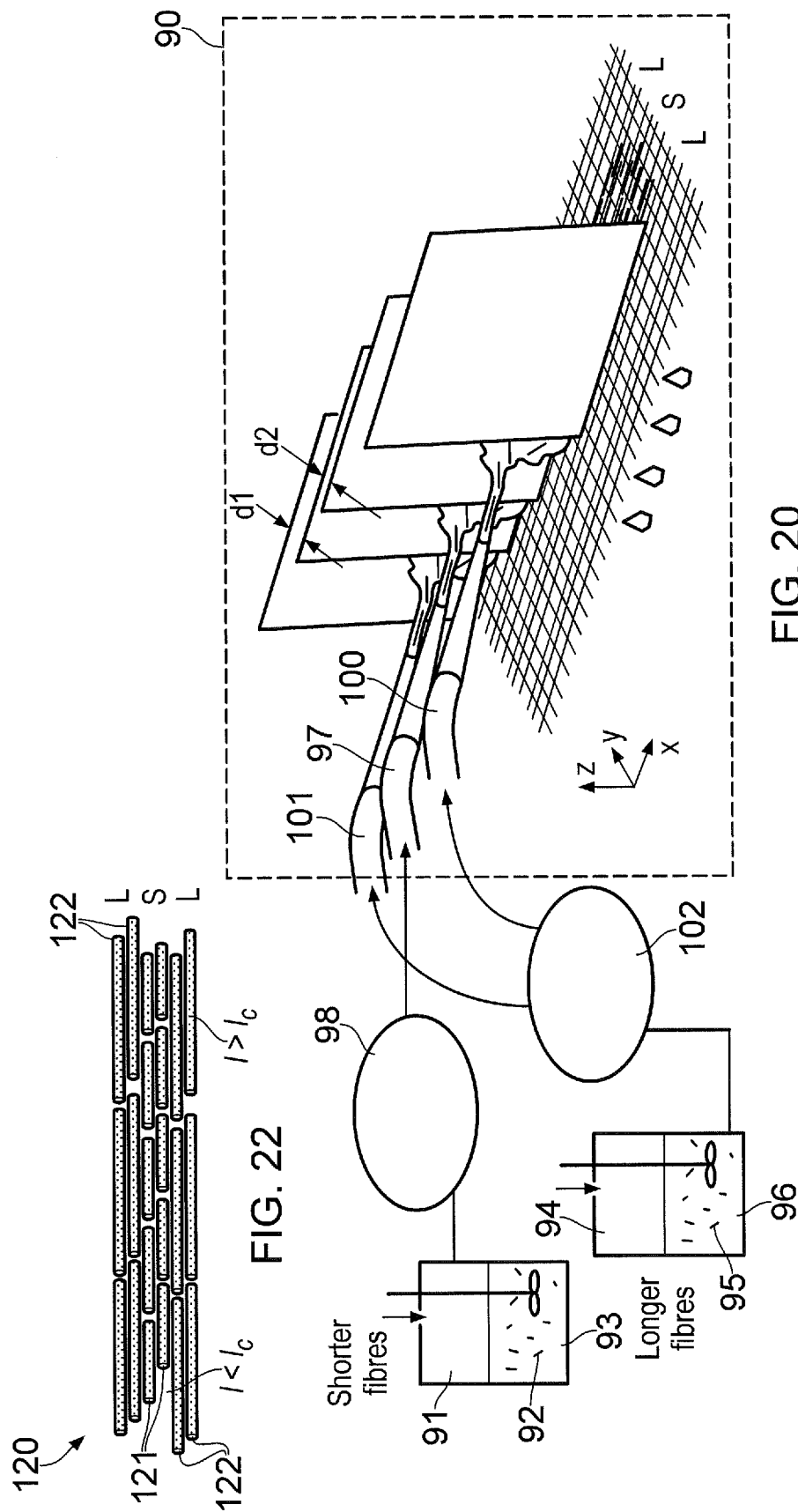
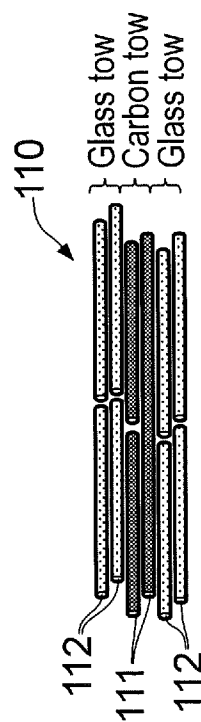
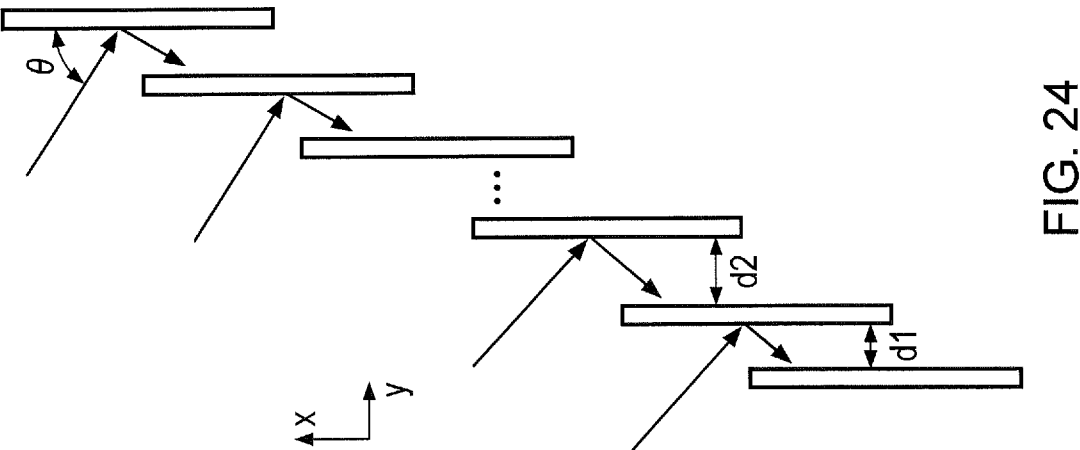
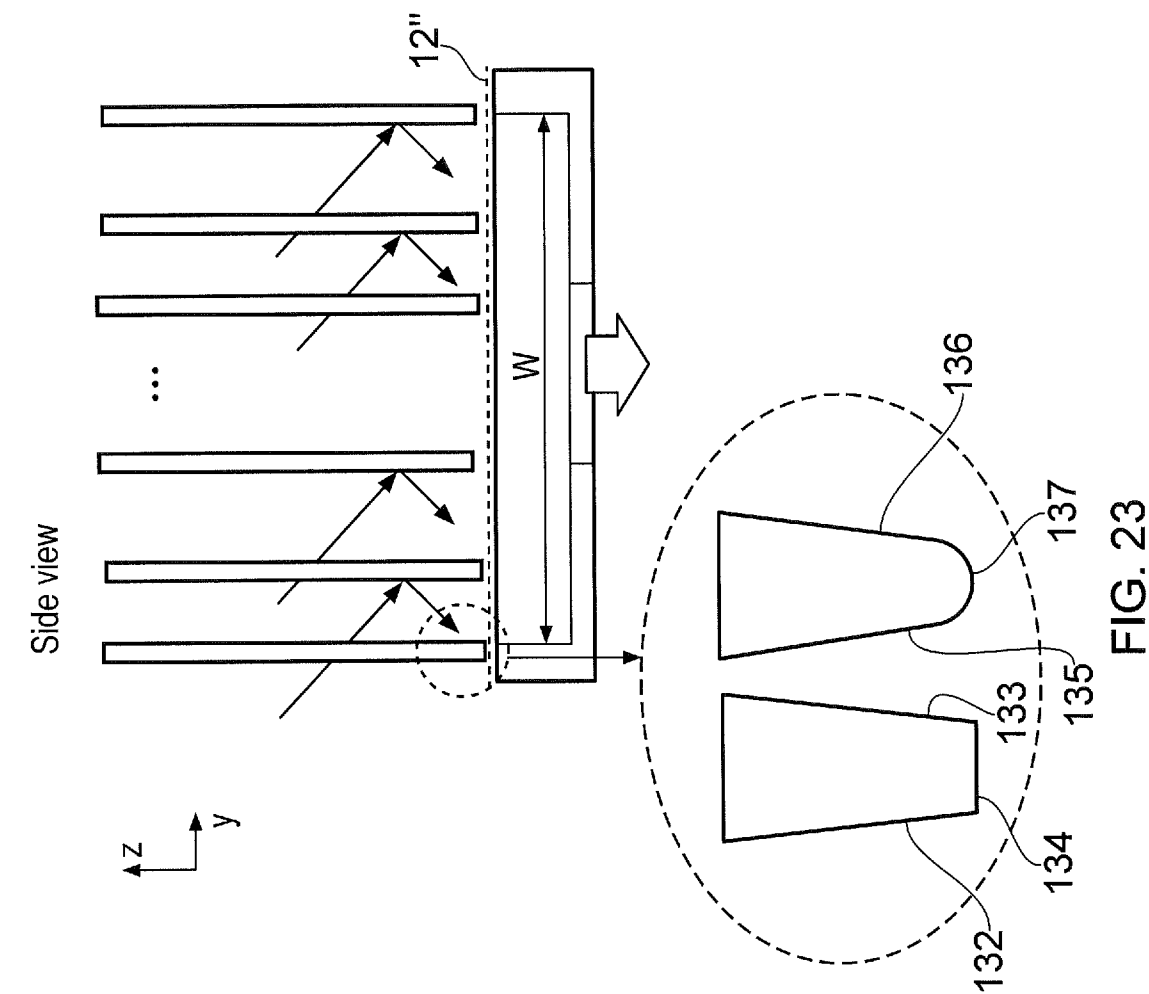


FIG. 20



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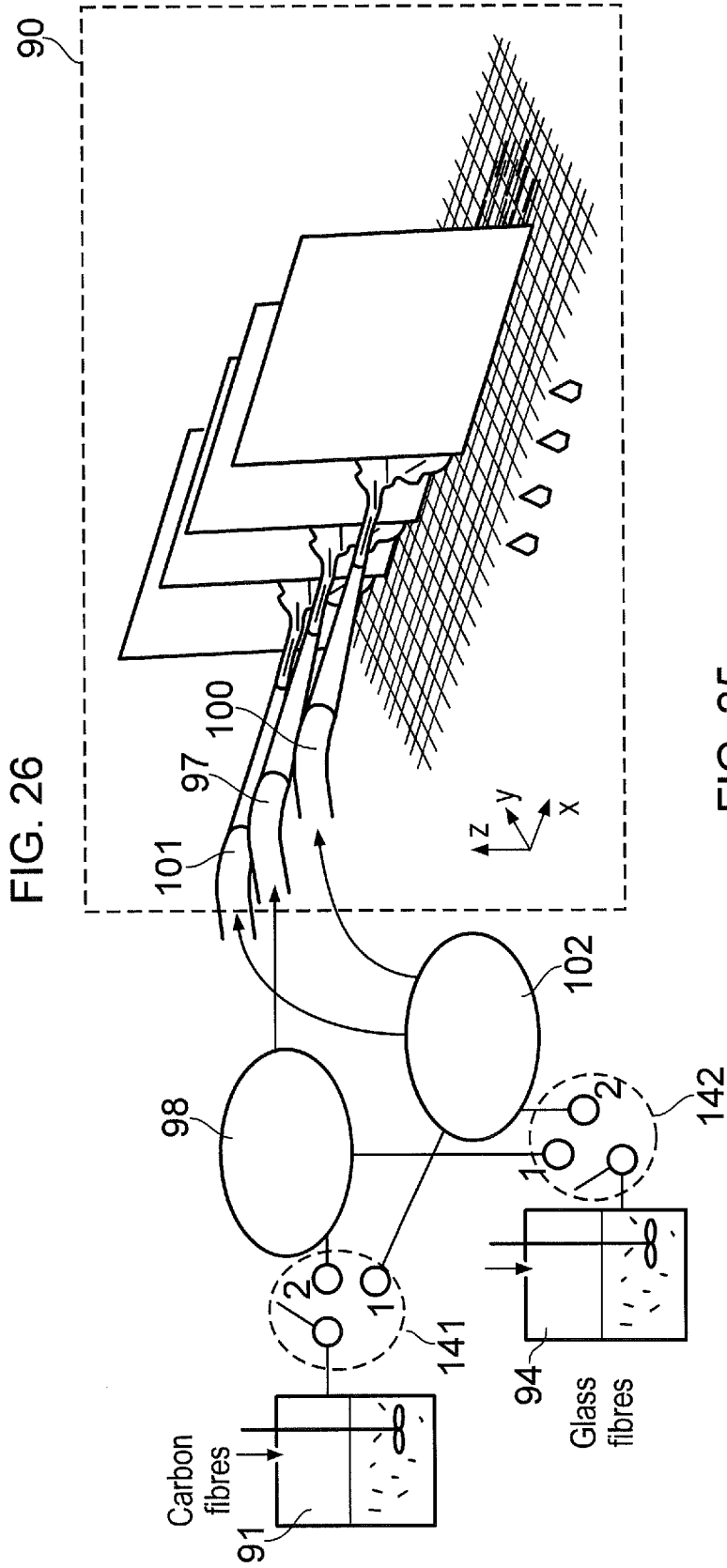
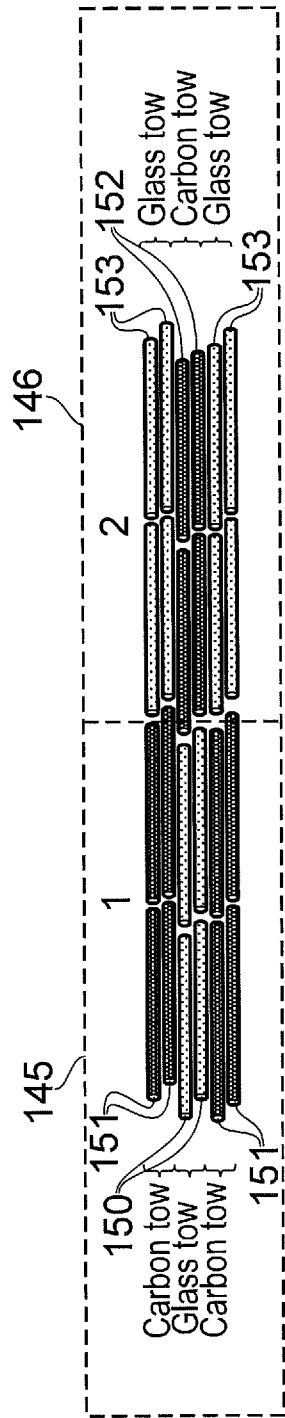


FIG. 26

FIG. 25

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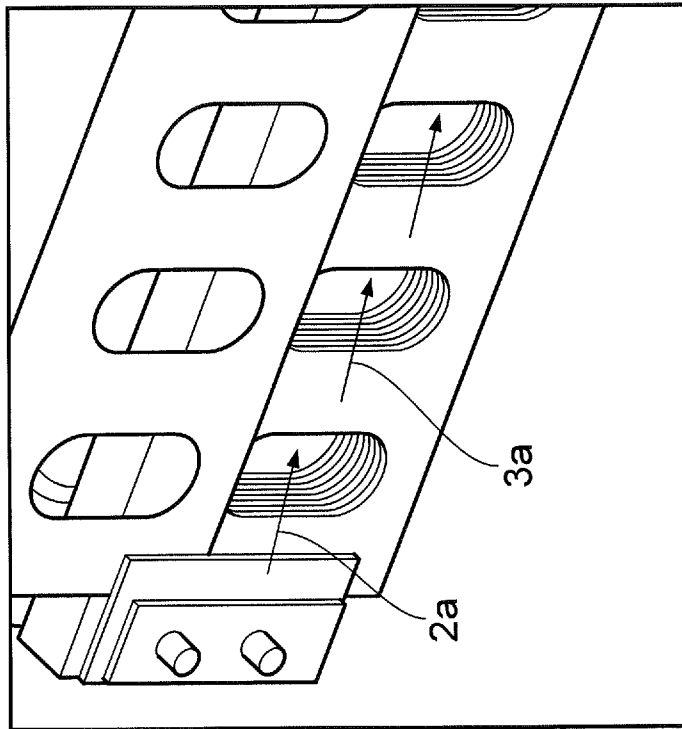


FIG. 29

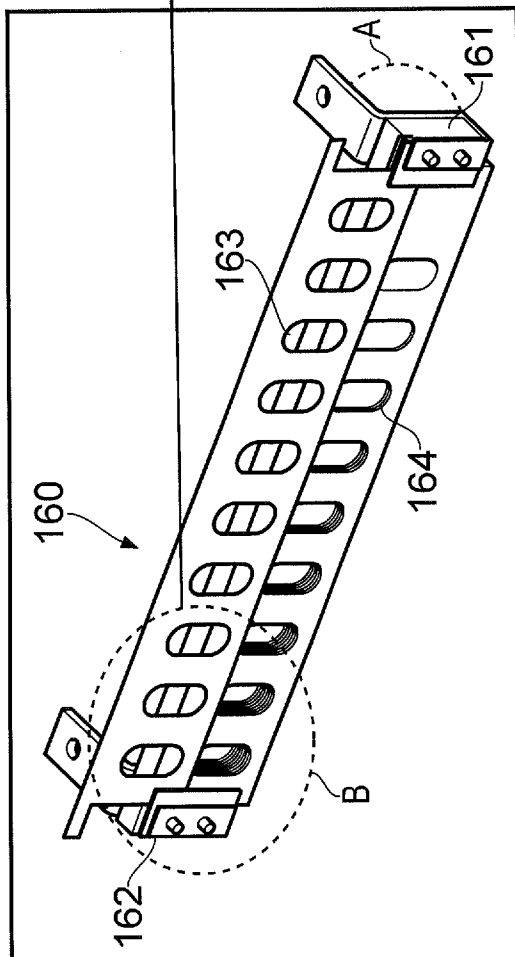


FIG. 27

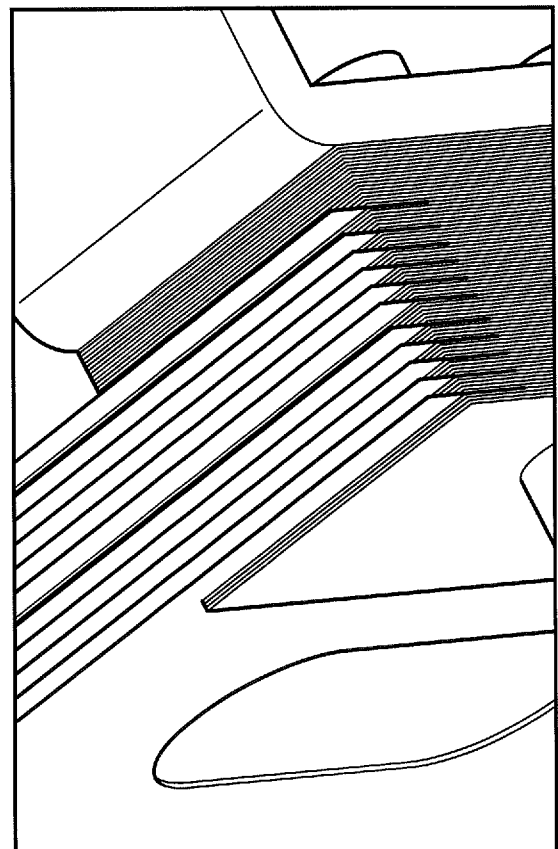


FIG. 28

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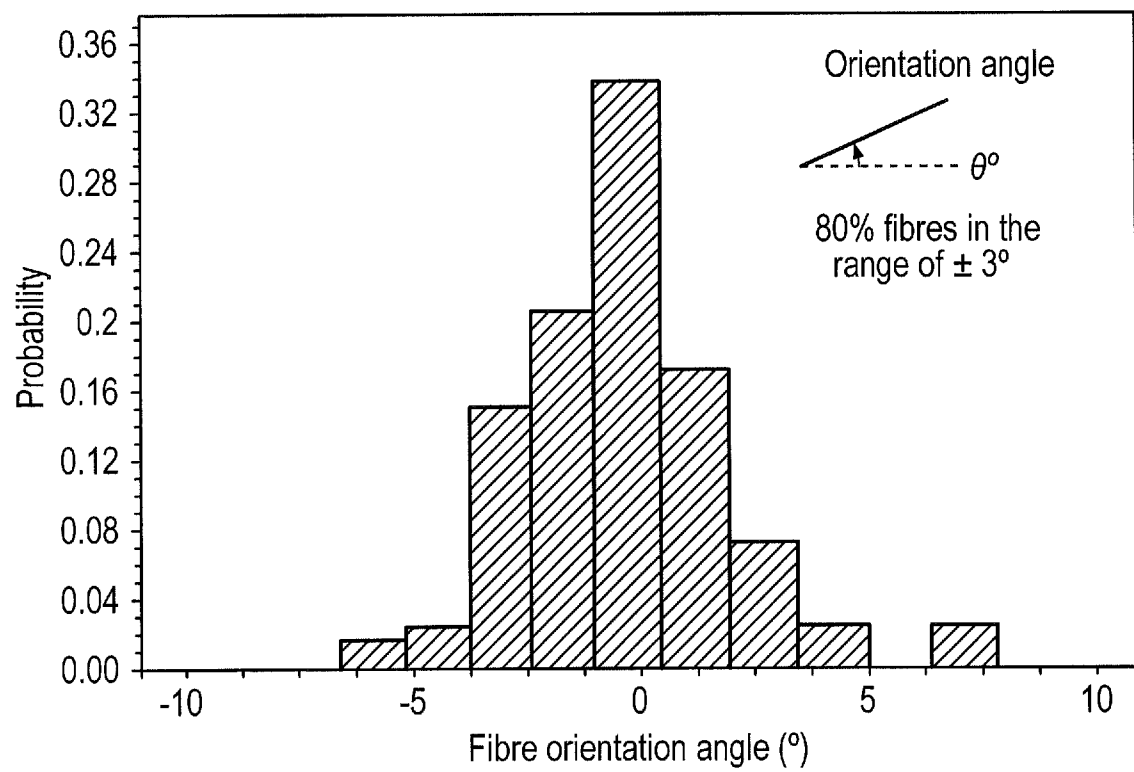


FIG. 30

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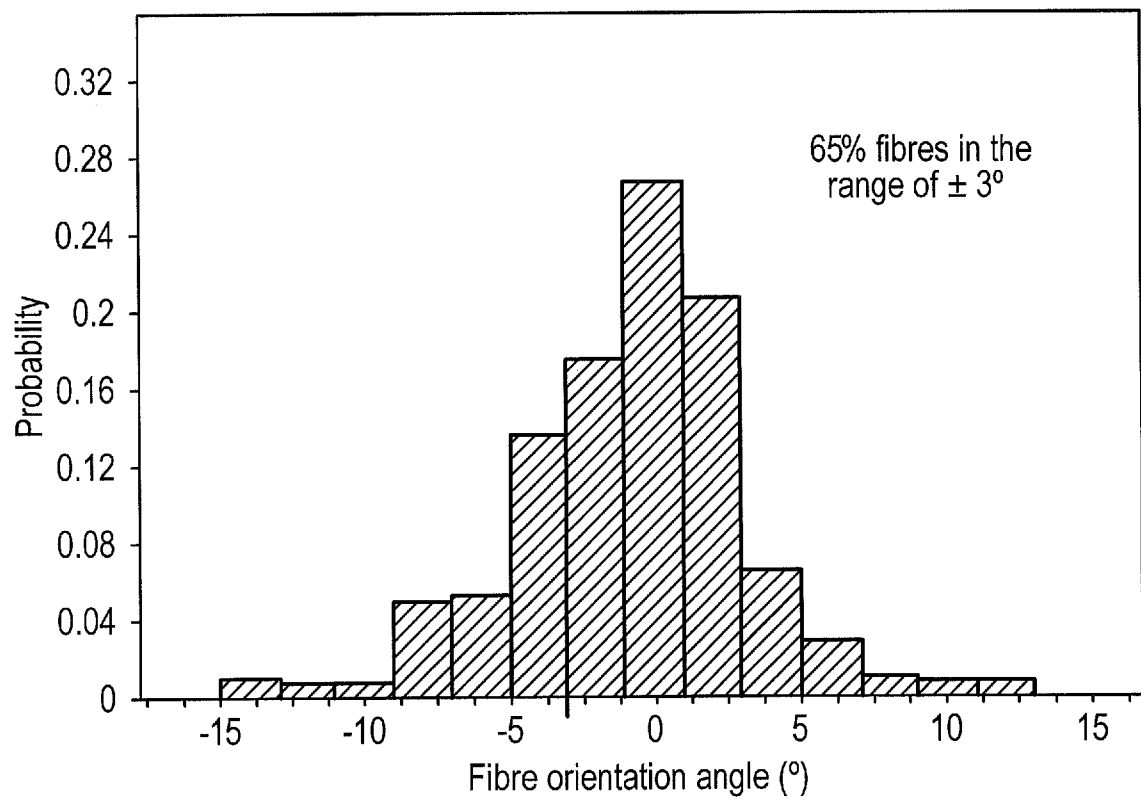


FIG. 31

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2014/051053

A. CLASSIFICATION OF SUBJECT MATTER
 INV. D04H1/74
 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)

D04H D21F D21J D01D B28B D01G

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 888 340 A (VYAKARNAM MURTY N [US] ET AL) 30 March 1999 (1999-03-30)	23
A	column 6, lines 19-62 -----	1-22
X	US 3 617 437 A (BAGG GREVILLE EUAN GORDON ET AL) 2 November 1971 (1971-11-02)	23
A	column 1, lines 59-69 column 2, lines 37-75 -----	1-22
A	US 6 066 235 A (SCHEINBERG STEPHEN P [US]) 23 May 2000 (2000-05-23)	1-23
	column 4, lines 3-24; figure 1 -----	
A	US 4 392 903 A (ENDO TADAKAZU [JP] ET AL) 12 July 1983 (1983-07-12)	1-23
	column 5, lines 14-65 -----	



Further documents are listed in the continuation of Box C.



See patent family annex.

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

26 June 2014

Date of mailing of the international search report

07/07/2014

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 NL - 2280 HV Rijswijk
 Tel. (+31-70) 340-2040,
 Fax: (+31-70) 340-3016

Authorized officer

Lanniel, Geneviève

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2014/051053

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