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Proprietor: Cytec Technology Corp.
Wilmington, DE 19801 (US)

Inventors:
• JUNKER, Shawn, Walden
Rockwall, TX 75087 (US)

• POH, Shaun, Michael
Huntington Beach, CA 92646 (US)

• YEE, Ping
Monterey Park, CA 91754 (US)

• ROGERS, Scott, Alfred
Placentia, CA 92870 (US)

• VANHORNE, Thomas, A.
Greenville, TX 75401-7965 (US)

Representative: Cockerton, Bruce Roger et al
Carpmaels & Ransford LLP
One Southampton Row
London WC1B 5HA (GB)

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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to uniformly spreading continuous multiple filament fiber bundles and unidirectionally arranging in parallel for the continuous production of prepregs having reduced gaps and improved fiber-resin distribution. More specifically, the invention relates to apparatus as described in the claims using tension control throughout the apparatus and higher differential speeds between the surface periphery of driven rollers and the line speed (or running speed) of the fiber bundle, and methods for using same to achieve prepreg material used for fabricating articles of fiber-reinforced plastics that has a uniform thickness and few defects in appearance.

2. Description of the Related Art

Prepregs, in which reinforcing fibers are impregnated with a matrix resin, are well known in the art and are broadly used in various industrial/high performance fields, such as for aircraft and automobile materials, medical materials, and formed materials for sports and leisure (e.g., fishing rods, golf club shafts, badminton rackets, tennis rackets, etc.).

Producing more uniform prepregs with less thickness irregularity is preferable and critical to overall product quality. In order to achieve this, it is necessary to open (i.e., spread) the reinforcing fiber bundle before impregnating it with a matrix resin when forming a prepreg, for reducing the thickness of the reinforcing fiber bundle and for letting the matrix resin sufficiently fill the clearances between the single fibers of the reinforcing fiber bundle.

Accordingly, the technique for efficiently and properly opening or spreading the raw reinforcing fiber bundles is critical for producing a prepreg having uniform thickness, reduced gaps between fibers, and proper fiber-resin distribution. Various apparatus and methods for spreading fiber bundles and/or making prepregs are known in the art and include, for example, those described in U.S Patent Nos. 4,495,017; 5,042,122; 5,182,839; and 6,743,392.

Additionally, it is generally known that tension is the prime mover for spreading fiber bundles containing multiple filaments. Thus, higher tension typically creates wider spread of the fibers in the bundle. However, too high a tension makes impregnation difficult due to decreased permeability of the fiber in relation to the resin, roping of the fibers, and damaging the fibers (thereby causing fuzz) or breaking the fiber. Increased tension also increases forces and torques throughout the apparatus which leads to increased process costs.

Accordingly, the apparatus and methods for spreading multiple adjacent fiber bundles having multiple filaments for the continuous production of prepreg require further improvement. Apparatus and methods that uniformly spread continuous multiple filament fiber bundles and unidirectionally arrange the spread fibers in parallel for the continuous production of prepregs having reduced gaps and improved fiber-resin distribution would be a useful advance in the art and could find rapid acceptance in the industry.

SUMMARY OF THE INVENTION

It has now been discovered that continuous multiple filament fiber bundles can be uniformly spread at lower tensions thereby increasing permeability to resins, decreasing gaps from roping, and decreasing fuzz due to damage thereby providing a superior prepreg product and ultimately a superior article of manufacture made therefrom. Such improvements are achieved by strategic use of tension control throughout the spreading apparatus. This advance drives the tension of the fiber bundles very high and then drops it down low such that by using moderate tensions throughout the entire apparatus the fiber spread is increased without the use of extremely high tensions that were otherwise thought necessary to achieve such objectives. Additionally, use of higher differential speeds between the driven roller bars and the running fiber bundle has also been shown to improve fiber spreading mechanics.

Accordingly, in one aspect the invention provides an apparatus as described in the claims for producing a spread fiber bundle having a tension control module that includes a tension building unit configured as a series of static bars and a tension reducing unit configured as a series of driven rollers, wherein the static bars and driven rollers are configured perpendicular to the direction of a running fiber bundle that makes direct wrapping contact with the surface of the series of static bars and driven rollers, and wherein the peripheral surface speed of the driven rollers is operated at least three times the line speed of the running fiber bundle.

In another aspect, the invention provides methods as described in the claims for producing a spread fiber bundle using an apparatus as described herein by running a fiber bundle in direct wrapping contact with the surface of a series of static bars and/or driven rollers, and controlling tension of the fiber through the apparatus by operating the driven rollers at a higher differential speed in relation to the speed of the running fiber bundle, thereby spreading the fiber bundle.

Described in detail herein also is the production of prepreg. Accordingly, in another aspect methods for the continuous production of rolled prepreg unidirectionally arranged and having uniform distribution between fibers by integrating an apparatus as described herein as part of a composite processing machine, running a plurality of adjacent fiber bundles in direct wrapping contact with the surface of a series of static bars and/or driven
rollers, spreading the plurality of adjacent fiber bundles by operating the driven rollers at a higher differential speed in relation to the speed of the running fiber bundle, and impregnating the spread fiber bundles with a predetermined amount of resin are described.

[0011] In other aspects, producing a prepreg by impregnating a pre-determined amount of resin into a spread fiber bundle produced according to the methods described in detail herein.

[0012] In another aspect, prepreg materials produced according to the methods described in detail herein, as well as articles of manufacture made from the prepregs made according to those methods.

[0013] In another aspect, a composite processing system having two or more fiber spreading devices are described herein in detail, wherein each spreader device is situated in a different path and receives a different set of a plurality of adjacent fiber bundles.

[0014] These and other objects, features and advantages of this invention will become apparent from the following detailed description of the various aspects of the invention taken in conjunction with the accompanying Figures and Examples.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 provides a profile view of an apparatus according to one embodiment, wherein a single fiber bundle having multiple filaments is seen making direct wrapping contact with the surface of a series of static bars and driven rollers to provide an optimally tensioned and uniformly distributed spread fiber.

FIG. 2 is a perspective view of an apparatus according to another embodiment of the invention that provides a tension mediating unit as part of the apparatus.

FIG. 3 is a perspective view of another embodiment of the apparatus as a component of a composite processing machine. Such equipment can be used in performing the methods for continuous production of rolled prepreg. In the particular embodiment depicted, two fiber spreading devices according to the invention are located in separate paths and are available to each receive a set of multiply adjacent fiber bundles wound on multiple spools which are positioned on one or more tension creel (not shown). The fiber spreading devices are located downstream from the tension creel and upstream from a composite processing system, such as a prepreg processing machine having an impregnation means.

DETAILED DESCRIPTION OF CERTAIN EMBODIMENTS OF THE INVENTION

[0016] The present invention provides an apparatus as described in the claims for producing a spread fiber bundle by strategic use of tension control throughout the spreading device and use of higher differential speeds as between the driven rollers and the line speed of the fiber bundle, along with methods for producing spread fibers and prepregs and articles of manufacture therefrom. As summarized above, it has been discovered that the fiber spreading mechanics known in the art can be greatly improved by strategic use of tension control throughout the spreading apparatus and the use of higher differential speeds between roller bar surface and line speed of the fiber. Tension is the main factor in spreading multiple filament fiber bundles, but it is also the main factor (e.g., too high a tension) in roping, reducing permeability to resin impregnation, and defects such as fluff (also called fuzz balls), pilling gaps, fiber disorder, etc. The increase, maintaining, and then reducing tension through the spreading cycle provides the necessary means to combat roping and other undesirable fiber properties, but also to maximize spreading, thereby opening the fiber bundle and controlling (i.e., increasing or decreasing) the permeability to resin impregnation. As the ratio of the surface speed of the roller bar to the linear speed/running speed of the fiber bundle increases beyond 2 times, significant gains in spreading are seen. The gains decay with a logarithmic behavior however. Improvements to the mechanics of fiber spreading ultimately lead to improvements in prepreg products and articles manufactured therefrom, as uniformity of thickness and occurrence of gaps, along with fiber-resin distribution, are critical to overall product quality.

Apparatus

[0017] Accordingly, in one aspect the invention provides an apparatus as described in the claims for producing a spread fiber bundle having a tension control module that includes a tension building unit configured as a series of static bars and a tension reducing unit configured as a series of driven rollers, wherein the static bars and driven rollers are configured perpendicular to the direction of a running fiber bundle that makes direct wrapping contact with the surface of the series of static bars and driven rollers, and wherein the driven rollers of the tension building unit are operated such that their peripheral surface speed is at least three times the line speed of the running fiber bundle.

[0018] The fiber bundles used in apparatus according to the present invention are those composed of a large number of single filaments (e.g., 6K/bundle, 12K/bundle, or more) and preferably they are yarns or tows composed of bundles of continuous long filaments. For example, the fiber bundles can include, but are not limited to, organic fibers such as fibers of polyamide, polyester, poly-
The fiber bundle includes a plurality of filaments that are arranged as a paralleled reinforcing fiber that can be wound on a spool. The spools of fiber can be placed on a tension creel such that the plurality of reinforcing fiber bundles can be arranged by a comb or raker at regularly spaced intervals as it is presented to the apparatus. As used herein the term "running fiber bundle" has its ordinary meaning known to those of ordinary skill in the art and refers to fibers that are being pulled from a spool on a tension creel, for example, by a pull-drum or take-up roll, through the apparatus. In certain embodiments, the running fiber bundle can include multiple adjacent bundles. In other embodiments, two or more sets of multiple adjacent fiber bundles can be provided in separate paths to be spread by a corresponding number of fiber spreader devices according to the invention.

Increasing tension of the fiber bundle before the drive rolls maximizes fiber spreading without requiring undue increase in tension. In the present invention, tension is initially increased through the use of the tension builder unit. In certain embodiments, the tension builder includes a member chosen from a tension creel; one or more driven roller operating at a slower speed than the linear speed of the running fiber bundle (i.e., a slow speed roll); one or more static bar (i.e., a fixed type bar that does not rotate); and combinations thereof. In some embodiments, the tension builder unit can be provided by a series of slow speed driven rollers and static bars. In other embodiments, the tension builder unit can be provided for by one or more static bars.

In certain embodiments, the apparatus can include a tension mediating section located downstream from the tension building section and having a series of static bars and one or more driven roller operating at a faster speed than the linear speed of the running fiber bundle (i.e., a fast or high speed roller). This section can serve to adjust the tension of the fiber bundle downward on the driven rollers while building the tension of the fiber bundle back up as the fiber comes in direct wrapping contact with the surface of the static bars, thereby further opening/spreading the fiber bundle with every repeated cycle. In some embodiments, the tension mediating section can have high speed driven rollers and static bars in alternating positions. In other embodiments, the high speed driven rollers can sandwich one or more of the static bars. The static bars and driven rollers of the fiber spreading apparatus can be arranged in either a horizontal or vertical alignment so long as the running fiber bundle is in direct wrapping contact with the surface of driven rollers and the static bars.

The apparatus according to the invention also includes a tension reducing section/unit having a series of high speed driven rollers that help reduce tension in the running fiber bundle. As used herein the term "series" has its ordinary meaning known to those of skill in the art and refers to two or more of the object of which it modifies.

The running speed of the fiber bundle (i.e., transfer speed) can range from 2 m/min. to 20 m/min., with a preference of 2 to 10 m/min. In some embodiments, the peripheral surface speed of the high speed driven rollers ranges from 3 to 100 times the speed of the running fiber bundle. For example, in certain embodiments the peripheral surface speed of the high speed rollers can range from 3 to 50 times the speed of the running fiber bundle; 3 to 25 times the speed of the running fiber bundle; or 3 to 10 times the speed of the running fiber bundle.

The static bars and driven rollers (or spreader bodies as they are sometimes called), having at least a part of the curved surface of a column or cylinder, are solid or hollow columns or cylinders, and also a part of a curved surface cut off from a column or cylinder of a large diameter may be used. The material is not particularly specified, but it is preferable to select one which has a small frictional coefficient, is not extremely deformed or abraded by the friction with the fiber bundles, and does not oxidize with sharp crystalline structures. Usually, stainless steel is used, but a static bar or driven roller made of a metal covered with a synthetic resin such as teflon, etc., iron, copper, etc. and inorganic substances such as glass, alumina, etc. can be used. The diameter, number, type of combination and spatial arrangement are selected considering the balance between the spread width and the damage of the fiber bundles, and therefore they cannot be determined definitely, but for fiber bundles having a high modulus of elasticity, spreader bodies with a large diameter are used, and it is desirable that the number, type of combination and spatial arrangement of the spreader bodies should be selected taking account of the contact length between the fiber bundles and the curved surfaces, and the pressing force against the spreader bodies caused by the tension. The type of spreader bodies (whether they are of fixed type (i.e., static), or whether they are of driving type, which gives a
differential peripheral speed in the travelling direction of the fiber bundles, exerts a great influence on the spreading effects (the spread width and damage of the fiber bundles). Therefore, in carrying out the process of the present invention, it is desirable, taking the above-mentioned effects into consideration to use the various types of rollers singly or in combination of two or more types. Furthermore, the tension and speed of the fiber bundles should be, of course, uniform in order that any disorder of the fiber bundles does not occur, and they are selected in relation with the spreading effects.

[0025] The use of a surface finish on both the static bars and driven rollers can also be included on the apparatus according to the present invention, thereby further reducing the tension required to open the fiber bundle and achieve a particular fiber width. The static bars and driven rollers can be made from stainless steel, for example, and sanded in the axial direction with sandpaper of various grit. For example, in some embodiments the static bars and driven rollers bars can have a surface finish imparted by sanding with 180 grit to 400 grit sandpaper, and preferably with 180 grit to 220 grit. In still other embodiments, some spreader bodies can be surface finished with one grit size while other spreader bodies are surface finished with a different grit size. Similarly, the spreader bodies can also have different surface finishes. In some embodiments, for example, the spreader bodies may be both dimpled and sanded, or some dimpled and some sanded. In other embodiments, the spreader bodies can be surface finished by whatever means known to those of ordinary skill in the art which reduces the coefficient of friction of the fiber on the spreader bodies and simultaneously spreads the fiber bundle at lower tensions.

[0026] Additionally, it may be desirable to arrange the position of the unidirectional fiber bundles, which are in parallel and adjacent with one another, by making the fiber bundles pass through a comb-like structure called a rake. In some embodiments, such a rake can be positioned downstream from the creel and upstream from the tension building unit such that the fiber bundles are positioned within a width corresponding to the final width of the prepreg sheet. In other embodiments, another rake can be positioned between the tension building unit and the tension reducing unit. If there is more than one set of multiple adjacent fiber bundles running in separate paths, there can be a rake in each path for each set of multiple adjacent fiber bundles to pass through. In such a case, the rakes for each set of multiple adjacent fiber bundles can be slightly off-set so that the spread bundles from each set are arranged in such a way as to reduce the incidence of gaps and promote uniform fiber-resin distribution.

[0027] An apparatus as described in the claims according to the present invention can also include a heating source positioned to heat the reinforcing fiber bundle. The heating source can be provided by any means including, but not limited to, conduction, convection, or radiation means. Heating the reinforcing fiber bundle can be advantageous in order to soften the sizing agent or oil that may be deposited thereon, and to generally enhance efficiency of the spreading action by reducing the co-efficient of friction between the fiber and spreader bodies (i.e., static bars and driven rollers). In some embodiments, the heating source can be provided as an indirect heating source such as by blown gas or by radiant heat. In other embodiments, the static bars and/or driven rollers themselves can be heated such that the contact surface of the roller bar becomes heated. It is preferable that the running fiber bundle is exposed to a heating temperature range from 50° to 250° C (depending on the fiber sizing used), with 70° to 180° C being most common.

[0028] In some embodiments, the fiber spreading apparatus of the present invention can be a singular component. In certain embodiments, the apparatus can be a component of a composite processing machine such as, for example, a prepreg processing machine. In such an assembly, the apparatus according to the invention can be located downstream from a tension creel containing spools of fiber bundles and upstream from an impregnation system. In certain embodiments, two or more fiber spreading devices can be integrated into a prepreg processing machine, such as where there are two or more sets of multiple adjacent fiber bundles running in separate paths. In other embodiments, the fiber spreading apparatus according to the invention can be a component of a weaver loom and can be located downstream from a tension creel and upstream from a composite processing machine.

[0029] Certain embodiments of the invention will be described below in reference to the drawings.

[0030] FIG. 1 shows a perspective view of an apparatus according to the invention as described above. In FIG. 1, a fiber spreading device 10 is depicted and includes a tension building section 2 and tension reducing section 3, wherein a single running fiber bundle 1 supplied by a spool of fiber as on a tension creel (not shown) travels in the direction of the arrow and enters the tension building section 2 in direct wrapping contact with the surface of a series of static bars 2a en route to the tension reducing section 3, which contains a series of high speed driven rollers 3a with which the fiber bundle maintains its direct wrapping contact. The high speed driven rollers are independently rotated by a drive motor 3b or other means known to those of skill in the art. As depicted, the fiber spreading device 10 drives the tension of the running fiber bundle 1 very high via a series of static bars 2a in the tension building unit 2 and then drops the tension of the fiber bundle down low via a series of high speed driven rollers 3a in the tension reducing unit 3, thereby spreading/opening the fiber bundle more with each alternation of a high speed driven roller and without the use of extremely high tensions. Immediately downstream of the fiber spreading device 10 and ready to receive the now open fiber bundle is a composite processing machine or impregnation system (not shown) known to those of ordinary skill in the art. Though the fiber spreading device
Methods

[0032] In another aspect, methods for producing a spread fiber bundle by running a fiber bundle through an apparatus as described in detail herein, and operating the driven rollers of the apparatus at a differential speed in relation to the speed of the running fiber bundle, thereby controlling the tension of the fiber throughout the apparatus and spreading/opening the fiber bundle are described.

[0033] In a method of producing the spread fiber bundle, various fibers can be used in producing a spread fiber bundle as described above. These fibers can also have various tensile strengths and elasticities depending on the fiber used. The final spread width of the fiber can be up to 4 times the original width of the fiber bundle and more typically will be up to 3.5 times the original width. Typically bobbins or spools having fiber bundle wound around them and installed on a tension creel will serve as the supply of running fiber. The tension can be changed on the creel as desired for stabilizing the spread state of the fiber bundle. In one embodiment at least one static bar and/or driven roller will be heated. In another embodiment, the running fiber bundle per se will be heated, such as by a radiant heater. In certain embodiments for methods of producing a spread fiber bundle, a rake can be positioned between the tension creel and fiber spreading apparatus so that any multiple adjacent fibers are uniformly spaced.

[0034] In another aspect, methods for the continuous production of rolled prepreg unidirectionally arranged and having uniform distribution between fibers are described. In certain embodiments, the method can be achieved by integrating a fiber spreading apparatus as described herein in detail as part of a composite processing machine well known to those of skill in the art, running a set of a plurality of adjacent fiber bundles so as to make direct wrapping contact with a series of static bars and/or driven rollers, thereby spreading the fiber bundles, and impregnating the spread fiber bundles with a pre-determined amount of resin to form a prepreg sheet. For example, one set of a plurality of adjacent fiber bundles can include 2 or more fiber bundles, and typically between 5 and 20 fiber bundles. A second set can include an equal number of fiber bundles to the first set.

[0035] In certain embodiments, the prepreg can be produced from two or more sets of a plurality of adjacent fiber bundles moving in separate paths (i.e., a 2-pattern or 2-path spread). In such embodiments, a corresponding number of fiber spreading devices according to the invention can be integrated into a composite processing system. Figure 3 and Example 1 describe and exemplify such an embodiment, but other multiple path embodiments are also contemplated by the invention.

[0036] In a method for producing the rolled prepreg, the resin used and the resin impregnation method are not especially limited as numerous resins and methods/apparatus for impregnation are known to those skilled in the art. Examples of the resins that can be used include, but are not limited to, thermosetting resins such as epoxy resins (e.g., bisphenol A epoxy resin, phenol novolak epoxy resin, cresol novolak epoxy resin, glycidylamine epoxy resin, alicyclic epoxy resin, urethane modified epoxy resin, and brominated bisphenol A epoxy resin), vinyl ester resins, unsaturated polyester resins and phenol resins, thermoplastic resins such as polyester resins, polyethylene resins, polycarbonate resins, polyether resins, and polyamide resins, etc.

[0037] Although one resin can be used, two or more resins can be used together. Additionally, a liquid resin or a solid resin can be used and deposited on the fibers...
Referring to FIG. 3, where corresponding elements are assigned common identifiers, and which depicts two fiber spreading devices according to the invention as integrated components in a composite processing system for carrying out the continuous prepreg producing method according to the invention, it is shown that two sets of a plurality of adjacent fiber bundles 31 (such as T650-35, a 12K filament/bundle fiber supplied by Cytec Carbon Fibers (South Carolina) and having a standard spread modulus of 145 gsm) are running in a 2-pattern spread at a line speed of approximately 2-5 m/min. (i.e., 2 m/min., 3 m/min., 4 m/min., or 5 m/min. as determined by the speed of a pull roll (not shown) of the composite processing system) as they are unwound from bobbins set on a tension creel (not shown), set uniformly by a low wrap angle static bar 32, and are metered with a comb 33. The tow tension of the fiber bundles 31 is increased as the plurality of adjacent fiber bundles make direct wrapping contact with a series of static bars provided by the tension building unit 34a of the fiber spreading apparatus according to the invention 34, and which contain a surface morphology applied by 180 grit sandpaper in the axial direction. The sizing on the fiber bundles is preheated with a radiant heater 35a positioned near the tension building unit 34a. The tow tension of the running fiber bundles is managed as they make direct wrapping contact with a series of driven rollers provided by a tension mediating unit 34b of the fiber spreading apparatus according to the invention 34, and which contain a surface morphology applied by 180 grit sandpaper in the axial direction. The driven rollers are rotated in the direction of the running fiber bundle at various speeds ranging from 0.5 to 11 times than line speed (i.e., the speed of the running fiber bundles) to increase and then reduce tension levels just below the fiber limitations. The web of tow is then heated again with a radiant heater 35b before finally reducing tension of the fiber bundles by placing them in direct wrapping contact with a series of high speed driven rollers provided by a tension reducing unit 34c of the fiber spreading apparatus according to the invention 34, and which contain a surface morphology applied by 180 grit sandpaper in the axial direction. The tension reducing unit 34c is located within close proximity to a nip roller 38 carrying a resin film 39 which film is placed on the spread fiber, which is then (resin film on spread fiber together) pulled in between the nip rollers 38 and compacted at 35 grams per square meter per set of fiber bundles.

In certain embodiments of the method for producing a continuous rolled prepreg, a fiber bundle spacing means such as a rake or comb will be positioned between the tension creel and the fiber spreading apparatus and between the fiber spreading apparatus and the composite processing machine in order to maintain uniformity between the fiber bundles. In certain embodiments, the method will include multiple spacing means such as when there are multiple sets of a plurality of adjacent fiber bundles. In these instances the spacing means proximate to the composite processing system can be slightly off-set with one another in order to ensure that as the fiber bundles exit the spreader device and enter the composite processing system the fiber bundles overlap slightly with each other before they are compacted by the nip rollers in order to further reduce gaps between fibers and promote fiber-resin distribution. The spacing means can be substantially the width corresponding to that of the prepreg sheet.

In a further aspect, articles of manufacture composed of a prepreg are described herein in detail. The articles can include any composite article made from pre-impregnated fibers or fiber sheets such as aerospace or high performance industrial, automotive, or leisure materials. In a final aspect, composite processing system having two or more fiber spreading devices according to the invention described herein, wherein each device is situated in a different path and able to receive a set of a plurality of adjacent fiber bundles are described.

Example 1: Production of a Prepreg Sheet Having Low Fiber Areal Weight (FAW) of 70 grams per square meter (gsm).

Example 2: Referring to FIG. 3, where corresponding elements are assigned common identifiers, and which depict two fiber spreading devices according to the invention as integrated components in a composite processing system for carrying out the continuous prepreg producing method according to the invention, it is shown that two sets of a plurality of adjacent fiber bundles 31 (such as T650-35, a 12K filament/bundle fiber supplied by Cytec Carbon Fibers (South Carolina) and having a standard spread modulus of 145 gsm) are running in a 2-pattern spread at a line speed of approximately 2-5 m/min. (i.e., 2 m/min., 3 m/min., 4 m/min., or 5 m/min. as determined by the speed of a pull roll (not shown) of the composite processing system) as they are unwound from bobbins set on a tension creel (not shown), set uniformly by a low wrap angle static bar 32, and are metered with a comb 33. The tow tension of the fiber bundles 31 is increased as the plurality of adjacent fiber bundles make direct wrapping contact with a series of static bars provided by the tension building unit 34a of the fiber spreading apparatus according to the invention 34, and which contain a surface morphology applied by 180 grit sandpaper in the axial direction. The sizing on the fiber bundles is preheated with a radiant heater 35a positioned near the tension building unit 34a. The tow tension of the running fiber bundles is managed as they make direct wrapping contact with a series of driven rollers provided by a tension mediating unit 34b of the fiber spreading apparatus according to the invention 34, and which contain a surface morphology applied by 180 grit sandpaper in the axial direction. The driven rollers are rotated in the direction of the running fiber bundle at various speeds ranging from 0.5 to 11 times than line speed (i.e., the speed of the running fiber bundles) to increase and then reduce tension levels just below the fiber limitations. The web of tow is then heated again with a radiant heater 35b before finally reducing tension of the fiber bundles by placing them in direct wrapping contact with a series of high speed driven rollers provided by a tension reducing unit 34c of the fiber spreading apparatus according to the invention 34, and which contain a surface morphology applied by 180 grit sandpaper in the axial direction. The tension reducing unit 34c is located within close proximity to a nip roller 38 carrying a resin film 39 which film is placed on the spread fiber, which is then (resin film on spread fiber together) pulled in between the nip rollers 38 and compacted at 35 grams per square meter per set of fiber bundles.

The following examples are provided to assist one skilled in the art to further understand certain embodiments of the present invention. These examples are intended for illustration purposes and are not to be construed as limiting the scope of the various embodiments of the present invention.

Example 1: Production of a Prepreg Sheet Having Low Fiber Areal Weight (FAW) of 70 grams per square meter (gsm).

Example 2: Referring to FIG. 3, where corresponding elements are assigned common identifiers, and which depict two fiber spreading devices according to the invention as integrated components in a composite processing system for carrying out the continuous prepreg producing method according to the invention, it is shown that two sets of a plurality of adjacent fiber bundles 31 (such as T650-35, a 12K filament/bundle fiber supplied by Cytec Carbon Fibers (South Carolina) and having a standard spread modulus of 145 gsm) are running in a 2-pattern spread at a line speed of approximately 2-5 m/min. (i.e., 2 m/min., 3 m/min., 4 m/min., or 5 m/min. as determined by the speed of a pull roll (not shown) of the composite processing system) as they are unwound from bobbins set on a tension creel (not shown), set uniformly by a low wrap angle static bar 32, and are metered with a comb 33. The tow tension of the fiber bundles 31 is increased as the plurality of adjacent fiber bundles make direct wrapping contact with a series of static bars provided by the tension building unit 34a of the fiber spreading apparatus according to the invention 34, and which contain a surface morphology applied by 180 grit sandpaper in the axial direction. The sizing on the fiber bundles is preheated with a radiant heater 35a positioned near the tension building unit 34a. The tow tension of the running fiber bundles is managed as they make direct wrapping contact with a series of driven rollers provided by a tension mediating unit 34b of the fiber spreading apparatus according to the invention 34, and which contain a surface morphology applied by 180 grit sandpaper in the axial direction. The driven rollers are rotated in the direction of the running fiber bundle at various speeds ranging from 0.5 to 11 times than line speed (i.e., the speed of the running fiber bundles) to increase and then reduce tension levels just below the fiber limitations. The web of tow is then heated again with a radiant heater 35b before finally reducing tension of the fiber bundles by placing them in direct wrapping contact with a series of high speed driven rollers provided by a tension reducing unit 34c of the fiber spreading apparatus according to the invention 34, and which contain a surface morphology applied by 180 grit sandpaper in the axial direction. The tension reducing unit 34c is located within close proximity to a nip roller 38 carrying a resin film 39 which film is placed on the spread fiber, which is then (resin film on spread fiber together) pulled in between the nip rollers 38 and compacted at 35 grams per square meter per set of fiber bundles.
combined at the nip sets of multiply adjacent fiber bundles, and then are not used. The tow web (or fiber bundles) is spread without gaps or fuzz.

A prepreg sheet with a standard fiber areal weight (FAW) of 145 grams per square meter (gsm).

[0044] A prepreg sheet having a FAW of 145 gsm is made as in Example 1. However, only two static bars are used in the tension building section 34a and only two driven rollers are used in each of the tension managing section 34b (low speed driven rollers and/or high speed driven rollers) and tension reducing section 34c (high speed driven rollers) of the fiber spreading device according to the invention 34. Heaters 35a and 35b are not used. The tow web (or fiber bundles) is spread to a FAW of 72.5 gsm for each of the upper and lower sets of multiply adjacent fiber bundles, and then combined at the nip 38 to make a highly impregnated, uniformly spread prepreg sheet having a FAW of 145 gsm without gaps or fuzz.

Various patent and/or scientific literature references have been referred to throughout this application. In view of the above description and the examples, one of ordinary skill in the art will be able to practice the disclosure as claimed without undue experimentation.

Although the foregoing description has shown, described, and pointed out the fundamental novel features of the present teachings, it will be understood that various omissions, substitutions, and changes in the form of the detail of the apparatus as illustrated, as well as the uses thereof, may be made by those skilled in the art, without departing from the scope of the present teachings. Consequently, the scope of the present teachings should not be limited to the foregoing discussion, but should be defined by the appended claims.

**Claims**

1. An apparatus for producing a spread fiber bundle comprising:

   a) a tension control module comprising:

   i) a tension building unit comprising a series of static bars configured to increase tension in a running fiber bundle moving in a traveling direction; and

   ii) a tension reducing unit comprising a series of driven rollers configured to reduce tension in the running fiber bundle, each driven roller being independently rotatable,

   wherein the tension reducing unit is positioned downstream from the tension building unit along the traveling direction of the running fiber bundle such that, during operation, the running fiber bundle makes direct wrapping contact with the surface of said static bars prior to making direct wrapping contact with said driven rollers, and wherein the peripheral surface speed of the driven rollers is at least three times the speed of the running fiber bundle.

   b) a managing section

   c) a tension reducing unit comprising a series of driven rollers configured to reduce tension in the running fiber bundle, each driven roller of the tension reducing unit being independently rotatable, wherein the second tension reducing unit is positioned downstream from the tension building unit along a traveling direction of the second running fiber bundle such that during operation, the second running fiber bundle makes direct wrapping contact with the surface of the static bars of said second tension building unit prior to making direct wrapping contact with the surface of the driven rollers of said second tension reducing unit.

   1. An apparatus according to claim 1, further comprising a spool of fiber for supplying the running fiber bundle, wherein the spool of fiber is positioned upstream from the tension building unit along the traveling direction of the running fiber bundle.

   2. An apparatus according to claim 1, further comprising a series of driven rollers, each driven roller of the tension reducing unit being independently rotatable, wherein the second tension reducing unit is positioned downstream from the tension building unit along a traveling direction of a second running fiber bundle such that during operation, the second running fiber bundle makes direct wrapping contact with the surface of the static bars of said second tension building unit prior to making direct wrapping contact with the surface of the driven rollers of said second tension reducing unit.

   3. An apparatus according to claims 1 or 2, wherein the running fiber bundle comprises multiple adjacent bundles.

   4. An apparatus according to any of the preceding claims further comprising a second tension control module in a different path than that of said tension control module, said second tension control module comprising a second tension building unit comprising a series of static bars, and a second tension reducing unit comprising a series of driven rollers, each driven roller of the second tension reducing unit being independently rotatable, wherein the second tension reducing unit is positioned downstream from the tension building unit along a traveling direction of a second running fiber bundle such that during operation, the second running fiber bundle makes direct wrapping contact with the surface of the static bars of said second tension building unit prior to making direct wrapping contact with the surface of the driven rollers of said second tension reducing unit.

   5. An apparatus according to any of the preceding claims, wherein the final spread width of the running fiber bundle exiting the tension reducing unit is up to 3.5 times the original width of the fiber bundle.

   6. An apparatus according to any of the preceding claims, wherein the tension building unit further comprising one or more low speed driven rollers operating at a slower speed than the speed of the running fiber bundle.

   7. An apparatus according to any of the preceding claims further comprising a tension mediating unit comprising a series of alternating driven rollers and static bars positioned between the tension building unit and the tension reducing unit along the traveling direction of the running fiber bundle.

   8. An apparatus according to any one of the preceding claims, further comprising a separate drive motor for...
independently rotating each of the driven rollers such that the peripheral surface speed of the driven rollers ranges from 3 to 100 times the speed of the running fiber bundle.

9. An apparatus according to any of the preceding claims wherein the static bars and/or driven rollers contain a sanded surface finish.

10. An apparatus according to any of the preceding claims further comprising at least one rake situated upstream from the tension building unit or between the tension building unit and the tension reducing unit.

11. An apparatus according to any of the preceding claims further comprising at least one heating source positioned to heat the running fiber.

12. A method for producing a spread fiber bundle using an apparatus according to any one of claims 1-11 comprising:

   a) running a fiber bundle through the apparatus of any one of claims 1-11 such that the fiber bundle makes direct wrapping contact with the surface of the series of static bars prior to making direct wrapping contact with the series of driven rollers; and
   b) controlling tension of the fiber bundle through the apparatus by operating the driven rollers at a peripheral surface speed that is at least three times the speed of the running fiber bundle, thereby spreading the fiber bundle.

13. A method for the continuous production of rolled prepreg unidirectionally arranged in parallel and having uniform distribution between fibers, the method comprising:

   a) integrating an apparatus according to any one of claims 1-11 as part of a composite processing machine;
   b) running a set of a plurality of adjacent fiber bundles through the apparatus of any one of claims 1-11 such that the fiber bundles make direct wrapping contact with the surface of the series of static bars prior to making direct wrapping contact with the series of driven rollers of the apparatus;
   c) spreading the plurality of adjacent fiber bundles by operating the driven rollers at a peripheral surface speed that is at least three times the speed of the running fiber bundles; and
   d) impregnating the spread fiber bundles with a pre-determined amount of resin.

14. A method according to claim 13, wherein step (a) further comprises integrating a second apparatus according to any one of claims 1-11 to the composite processing machine in a different path than the first apparatus, and wherein step (b) further comprises running a second set of a plurality of adjacent fiber bundles through the second apparatus such that the fiber bundles make direct wrapping contact with the surface of the series of static bars prior to making direct wrapping contact with the series of driven rollers of the second apparatus.

15. A method according to claim 13 or 14 further comprising uniformly spacing the plurality of adjacent fiber bundles prior to the impregnating step with a spacing means, and the spacing means are offset from one another when there are multiple sets of fiber bundles.

16. A composite processing system comprising two or more fiber spreading apparatuses according to any one of claims 1-11, wherein each apparatus is situated in a different path and able to receive a set of a plurality of adjacent fiber bundles.

Patentansprüche

1. Vorrichtung zum Herstellen eines verteilten Faserbündels, die Folgendes umfasst:

   ein Spannungssteuermodul, umfassend:
   i) eine Spannungsaufbaueinheit, die eine Reihe von statischen Stangen umfasst, die zum Erhöhen der Spannung in einem laufenden Faserbündel, das sich in Förderrichtung bewegt, konfiguriert ist; und
   ii) eine Spannungsreduzierungseinheit, die eine Reihe von angetriebenen Laufrollen umfasst, die zum Reduzieren der Spannung in dem laufenden Faserbündel konfiguriert ist, wobei jede angetriebene Laufrolle unabhangig drehbar ist,

wobei die Spannungsreduzierungseinheit stromabwärts der Spannungsaufbaueinheit entlang der Förderrichtung des laufenden Faserbündels angeordnet ist, sodass während des Betriebs des laufenden Faserbündels einen direkten Umhulungskontakt mit der Oberfläche der statischen Stangen vor Herstellen eines direkten Umhulungskontakts mit den angetriebenen Laufrollen herstellt, und wobei die Umfangsüberflächen-drehzahl der angetriebenen Laufrollen mindestens das Dreifache der Drehzahl des laufenden Faserbündels beträgt.

2. Vorrichtung nach Anspruch 1, ferner umfassend ei-
ne Faserspule zum Zuführen zu dem laufenden Faserbündel, wobei die Faserspule stromaufwärts der Spannungsaufbaueinheit entlang der Förderrichtung des laufenden Faserbündels angeordnet ist.

3. Vorrichtung nach Anspruch 1 oder 2, wobei das laufende Faserbündel mehrere benachbarte Bündel umfasst.

4. Vorrichtung nach einem der vorherigen Ansprüche, ferner umfassend ein zweites Spannungsteuermodule auf einem anderen Förderweg als dem des Spannungsteuermoduls, wobei das zweite Spannungsteuermodule eine zweite Spannungsaufbaueinheit umfasst, die eine Reihe von statischen Stangen umfasst, und wobei die zweite Spannungsreduziereneinheit eine Reihe von angetriebenen Laufrollen umfasst, wobei jede der angetriebenen Laufrollen der zweiten Spannungsreduziereneinheit unabhängig drehbar ist, wobei die zweite Spannungsreduziereneinheit stromabwärts der zweiten Spannungsaufbaueinheit entlang der Förderrichtung eines zweiten laufenden Faserbündels angeordnet ist, sodass während des Betriebs das zweite laufende Faserbündel einen direkten Umhüllungskontakt mit der Oberfläche der statischen Stangen der zweiten Spannungsaufbaueinheit herstellt, bevor der Umhüllungskontakt mit der Oberfläche der angetriebenen Laufrollen der zweiten Spannungsreduziereneinheit hergestellt wird.

5. Vorrichtung nach einem der vorherigen Ansprüche, wobei die endgültige Verteilungsbreite des laufenden Faserbündels, das aus der Spannungsaufbaueinheit austritt, das bis zu 3,5-fache der ursprünglichen Breite des Faserbündels beträgt.

6. Vorrichtung nach einem der vorherigen Ansprüche, wobei die Spannungsaufbaueinheit ferner eine oder mehrere angetriebene Laufrollen mit geringer Drehzahl umfasst, die bei einer geringeren Drehzahl als der Drehzahl des laufenden Faserbündels betrieben werden.

7. Vorrichtung nach einem der vorherigen Ansprüche, ferner umfassend eine Spannungsschichtungseinheit, umfassend eine Reihe von abwechselnd angetriebenen Laufrollen und statischen Stangen, die zwischen der Spannungsaufbaueinheit und der Spannungsreduziereneinheit entlang der Förderrichtung des laufenden Faserbündels angeordnet sind.

8. Vorrichtung nach einem der vorherigen Ansprüche, ferner umfassend einen separaten Antriebsmotor zum unabhängigen Drehen jeder der angetriebenen Laufrollen, sodass die Umfangsüberflächendrehzahl der angetriebenen Rollen zwischen dem 3- bis 100-fachen der Drehzahl des laufenden Faserbündels beträgt.

9. Vorrichtung nach einem der vorherigen Ansprüche, wobei die statischen Stangen und/oder angetriebenen Laufrollen einen geschmirgelten Oberflächenabschluss aufweisen.

10. Vorrichtung nach einem der vorherigen Ansprüche, ferner umfassend mindestens eine Neigung, die stromaufwärts der Spannungsaufbaueinheit oder zwischen der Spannungsaufbaueinheit und der Spannungsreduziereneinheit angeordnet ist.

11. Vorrichtung nach einem der vorherigen Ansprüche, ferner umfassend mindestens eine Wärmequelle, die zur Erwärmung der laufenden Faser angeordnet ist.

12. Verfahren zum Herstellen eines verteilten Faserbündels durch Verwenden der Vorrichtung nach einem der Ansprüche 1 bis 11, wobei das Verfahren Folgendes umfasst:
   a) Durchlaufenlassen eines Faserbündels durch die Vorrichtung nach einem der Ansprüche 1 bis 11, sodass das Faserbündel einen direkten Umhüllungskontakt mit der Oberfläche der Reihe von statischen Stangen herstellt, bevor der Umhüllungskontakt mit der Oberfläche der angetriebenen Laufrollen hergestellt wird; und
   b) Steuern der Spannung des Faserbündels mittels der Vorrichtung durch Betreiben der angetriebenen Laufrollen mit einer Umfangsüberflächendrehzahl, die mindestens das Dreifache der Drehzahl des laufenden Faserbündels beträgt, wodurch das Faserbündel verteilt wird.

13. Verfahren zum kontinuierlichen Herstellen eines gewalzten Prepreg, das unidirektional parallel angeordnet ist und eine einheitliche Verteilung zwischen den Fasern aufweist, wobei das Verfahren Folgendes umfasst:
   a) Integrieren einer Vorrichtung nach einem der Ansprüche 1 bis 11 als Teil einer Verbundstoffverarbeitungsmaschine; und
   b) Durchlaufenlassen eines Satzes mehrerer benachbarter Faserbündel durch die Vorrichtung nach einem der Ansprüche 1 bis 11, sodass die Faserbündel einen direkten Umhüllungskontakt mit der Oberfläche der Reihe von statischen Stangen herstellen, bevor sie einen direkten Umhüllungskontakt mit der Reihe von angetriebenen Laufrollen herstellen; und
   c) Verteilen der mehreren benachbarten Faserbündel durch Betreiben der angetriebenen Laufrollen mit einer Umfangsüberflächendrehzahl,
die mindestens das Dreifache der Drehzahl der laufenden Faserbündel beträgt; und
d) Imprägnieren der verteilten Faserbündel mit einer vorbestimmten Menge Harz.

14. Verfahren nach Anspruch 13, wobei Schritt (a) ferner das Integrieren einer zweiten Vorrichtung nach einem der Ansprüche 1 bis 11 in die Verbundstoffverarbeitungsmaschine in einem anderen Förderweg als die erste Vorrichtung umfasst, und wobei Schritt (b) ferner das Durchlaufvolllassen eines zweiten Satzes mehrerer benachbarter Faserbündel durch die zweite Vorrichtung umfasst, sodass die Faserbündel einen direkten Umhüllungs kontakt mit der Oberfläche der Reihe von statischen Stangen herstellen, bevor sie einen direkten Umhüllungskontakt mit der Reihe von angetriebenen Laufrollen der zweiten Vorrichtung herstellen.

15. Verfahren nach Anspruch 13 oder 14, ferner umfassend das einheitliche Beabstanden der mehreren benachbarten Faserbündel vor dem Imprägnierschritt mit Abstandsmitteln, wobei die Abstandsmittel voneinander versetzt sind, wenn mehrere Sätze Faserbündel vorliegen.

16. Verbundstoffverarbeitungssystem, umfassend zwei oder mehrere Faserverteilungsvorrichtungen nach einem der Ansprüche 1 bis 11, wobei jede Vorrichtung in einem anderen Förderweg angeordnet ist und einen Satz mehrerer benachbarter Faserbündel aufnehmen kann.

Revendications

1. Appareil pour produire un faisceau de fibres étalé comprenant :

   un module de contrôle de tension comprenant :

   i) une unité d’augmentation de tension comprenant une série de barres statiques configurées pour augmenter la tension dans un faisceau de fibres mobile bougeant dans une direction de déplacement ; et

   ii) une unité de réduction de tension comprenant une série de rouleaux entraînés configurées pour réduire la tension dans le faisceau de fibres mobile, chaque rouleau entraîné pouvant tourner indépendamment,

   dans lequel l’unité de réduction de tension est positionnée en aval de l’unité d’augmentation de tension le long de la direction de déplacement du faisceau de fibres mobile de telle sorte que, en fonctionne-ment, le faisceau de fibres mobile établit un contact d’enroulement direct avec la surface desdites barres statiques avant d’établir un contact d’enroulement direct avec lesdits rouleaux entraînés, et dans lequel la vitesse de surface périphérique des rouleaux entraînés représente au moins trois fois la vitesse du faisceau de fibres mobile.

2. Appareil selon la revendication 1, comprenant en outre une bobine de fibre pour fournir le faisceau de fibres mobile, la bobine de fibre étant positionnée en amont de l’unité d’augmentation de tension le long de la direction de déplacement du faisceau de fibres mobile.

3. Appareil selon la revendication 1 ou 2, dans lequel le faisceau de fibres mobile comprend de multiples faisceaux adjacents.

4. Appareil selon l’une quelconque des revendications précédentes comprenant en outre un deuxième module de contrôle de tension sur un chemin différent de celui dudit module de contrôle de tension, ledit deuxième module de contrôle de tension comprenant une deuxième unité d’augmentation de tension comprenant une série de barres statiques, et une deuxième unité de réduction de tension comprenant une série de rouleaux entraînés, chaque rouleau entraîné de la deuxième unité de réduction de tension pouvant tourner indépendamment, dans lequel la deuxième unité de réduction de tension est positionnée en aval de la deuxième unité d’augmentation de tension le long d’une direction de déplacement d’un deuxième faisceau de fibres mobile de telle sorte qu’en fonctionnement, le deuxième faisceau de fibres mobile établit un contact d’enroulement direct avec la surface des barres statiques de ladite deuxième unité d’augmentation de tension avant d’établir un contact d’enroulement avec la surface des rouleaux entraînés de ladite deuxième unité de réduction de tension.

5. Appareil selon l’une quelconque des revendications précédentes, dans lequel la largeur d’étalage finale du faisceau de fibres mobile sortant de l’unité de réduction de tension représente jusqu’à 3,5 fois la largeur initiale du faisceau de fibres.

6. Appareil selon l’une quelconque des revendications précédentes, dans lequel l’unité d’augmentation de tension comprend en outre un ou plusieurs rouleaux entraînés à faible vitesse fonctionnant à une vitesse plus lente que la vitesse du faisceau de fibres mobile.

7. Appareil selon l’une quelconque des revendications précédentes comprenant en outre une unité d’ajustement de tension comprenant une série de rouleaux entraînés et de barres statiques en alternance posi-
tionnée entre l’unité d’augmentation de tension et l’unité de réduction de tension le long de la direction de déplacement du faisceau de fibres mobile.

8. Appareil selon l’une quelconque des revendications précédentes, comprenant en outre un moteur d’ entraînement distinct pour faire tourner indépendamment chacun des rouleaux entraînés de telle sorte que la vitesse de surface périphérique des rouleaux entraînés représente de 3 à 100 fois la vitesse du faisceau de fibres mobile.


10. Appareil selon l’une quelconque des revendications précédentes comprenant en outre au moins un râteau situé en amont de l’unité d’augmentation de tension ou entre l’unité d’augmentation de tension et l’unité de réduction de tension.

11. Appareil selon l’une quelconque des revendications précédentes comprenant en outre au moins une source de chauffage positionnée pour chauffer la fibre mobile.

12. Procédé de production d’un faisceau de fibres étalé à l’aide d’un appareil selon l’une quelconque des revendications 1 à 11 comprenant :

   a) le passage d’un faisceau de fibres à travers l’appareil de l’une quelconque des revendications 1 à 11 de telle sorte que le faisceau de fibres établisse un contact d’enroulement direct avec la surface de la série de barres statiques avant d’établir un contact d’enroulement direct avec la série de rouleaux entraînés ; et
   b) le contrôle de la tension du faisceau de fibres à travers l’appareil par le fonctionnement des rouleaux entraînés à une vitesse de surface périphérique qui représente au moins trois fois la vitesse du faisceau de fibres mobile, pour étaler ainsi le faisceau de fibres.

13. Procédé de production continue d’un préimprégné enroulé disposé unidirectionnellement en parallèle et ayant une distribution uniforme entre fibres, le procédé comprenant :

   a) l’intégration d’un appareil selon l’une quelconque des revendications 1 à 11 comme partie d’une machine de transformation composite ;
   b) le passage d’un ensemble d’une pluralité de faisceaux de fibres adjacents à travers l’appareil de l’une quelconque des revendications 1 à 11 de telle sorte que les faisceaux de fibres établissent un contact d’enroulement direct avec la surface de la série de barres statiques avant d’établir un contact d’enroulement direct avec la série de rouleaux entraînés de l’appareil ;
   c) l’étalonnage de la pluralité de faisceaux de fibres adjacents par le fonctionnement des rouleaux entraînés à une vitesse de surface périphérique qui représente au moins trois fois la vitesse des faisceaux de fibres mobiles ; et
   d) l’imprégnation des faisceaux de fibres étalés avec une quantité prédéterminée de résine.

14. Procédé selon la revendication 13, dans lequel l’étape (a) comprend en outre l’intégration d’un deuxième appareil selon l’une quelconque des revendications 1 à 11 à la machine de transformation composite sur un chemin différent du premier appareil, et dans lequel l’étape (b) comprend en outre le passage d’un deuxième ensemble d’une pluralité de faisceaux de fibres adjacents à travers le deuxième appareil de telle sorte que les faisceaux de fibres établissent un contact d’enroulement direct avec la surface de la série de barres statiques avant d’établir un contact d’enroulement direct avec la série de rouleaux entraînés du deuxième appareil.

15. Procédé selon la revendication 13 ou 14 comprenant en outre l’espacement uniforme de la pluralité de faisceaux de fibres adjacents avant l’étape d’imprégnation avec des moyens d’espacement, les moyens d’espacement étant décalés les uns par rapport aux autres quand il y a de multiples ensembles de faisceaux de fibres.

16. Système de transformation composite comprenant au moins deux appareils d’étalonnage de fibres selon l’une quelconque des revendications 1 à 11, chaque appareil étant situé sur un chemin différent et susceptible de recevoir un ensemble d’une pluralité de faisceaux de fibres adjacents.
REFERENCES CITED IN THE DESCRIPTION

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