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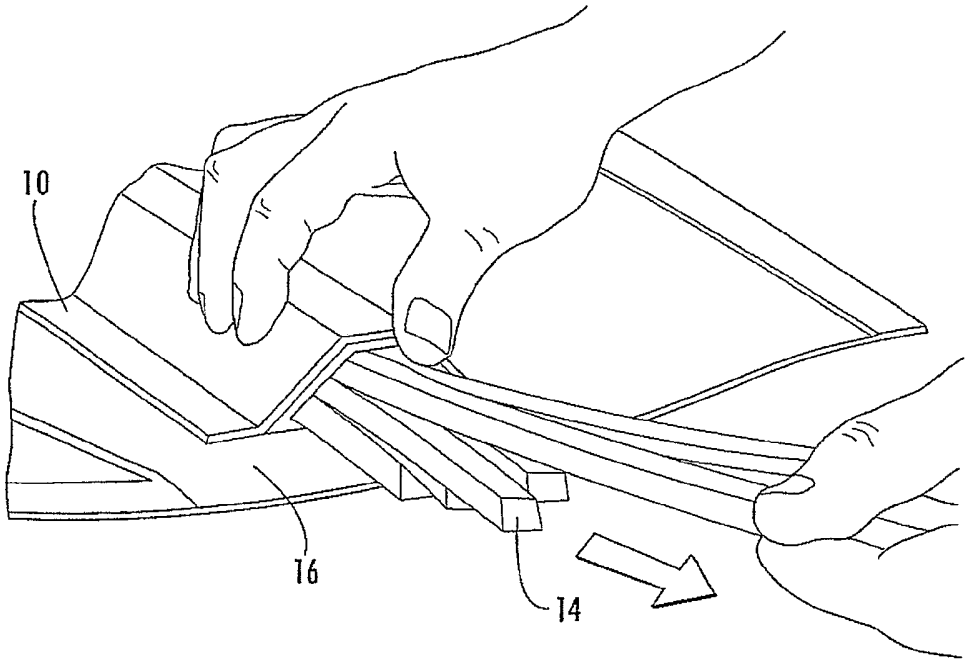
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(54) **Title:** CO-CURED STRINGERS AND ASSOCIATED MANDREL AND FABRICATION METHOD



(57) **Abstract:** A co-cured composite stringer and associated apparatus and method are provided. The co-cured composite stringer includes a stringer and a mandrel positioned within a channel defined in the stringer. A plurality of strips are positioned within an opening of the mandrel, and a substrate layer, such as aircraft skin, is positioned adjacent to the stringer. During application of the substrate layer to the stringer, the mandrel and plurality of strips support the stringer.

WO 2005/105402 A1

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

CO-CURED STRINGERS AND ASSOCIATED MANDREL AND FABRICATION METHOD

BACKGROUND OF THE INVENTION

1) Field of the Invention

The present invention relates to stringers and, more particularly, to a collapsible mandrel having reinforcing strips therein that may be employed to co-cure stringers, as well as an associated fabrication method.

2) Description of Related Art

Aircraft utilize a variety of elements for reinforcement due to the application of bending, torsional, shear, and direct loading on the aircraft. One of the basic reinforcing structures used within aircraft include stringers (also termed stiffeners and longerons), which typically run spanwise within the wing. Stringers may be fabricated into various cross sections, such as I-beams, Z, and "hat" sections. Stringers are typically a lightweight composite formed into a tape or fabric, which includes using a plurality of fibers embedded in a matrix of resin or adhesive to support and bond the fibers together (i.e., pre-impregnated or "prepreg"). A lay-up method is typically used to form the stringers, wherein the skin, typically also formed as a prepreg, is applied to a stringer using sufficient head pressure. Autoclaving or a similar method is then used to cure the stringer and the aircraft skin together.

There are a variety of mandrels used to co-cure stringers. For example, there are hollow mandrels that, when vented to an autoclave, press from the inside out. However, the hollow mandrels cannot support the tape head rolling over the stringers. Another type of mandrel includes hard rubber mandrels placed between the skin and stringer, but this mandrel has proved to be difficult to remove from long stringers following curing. There are also expendable mandrels that may be dissolved after curing, but this mandrel requires a messy and impractical dissolution process. Finally, there is a re-usable elastomeric mandrel system (REMS), which is essentially a rubber shaped mandrel full of ceramic beads. In spite of this design, the REMS is impractical to use with longer stringer lengths.

Further, U.S. Patent No. 5,368,807 to Lindsay discloses a method for vacuum bag molding fiber reinforced resin matrix composites without requiring the use of a mandrel.

The method includes laying prepreg stiffener hat sections on the inside portion of a rigid portion of a vacuum bag. An elastomeric tube is inserted within each of the stiffener sections, and may be inflated to conform to the shape of the stiffener. A sealing wedge is placed on the end of each of the stiffeners to hold and seal the elastomeric tube to the rigid portion of the vacuum bag. Following curing, the wedge is removed, and a vacuum drawn on the elastomeric tube is used to collapse the tube for removal from the vacuum bag.

Lindsay shows the stringers or longerons arranged linearly, but does not permit arranging and co-curing the stringers in a variety of other contours, as would be desirable. In addition, the rigid vacuum bag only supports the stringer during autoclaving but does not support the stringer during laying up of the aircraft skin. Thus, the aircraft skin in Lindsay is not capable of being applied over a recessed area of a "hat-shaped" stringer such that the elastomeric tube does not have to withstand the head pressure of tape laying aircraft skin to the stringer, where the head pressure may also cause collapse of the aircraft skin within the recess or of the stringer itself.

It would therefore be advantageous to provide a mandrel used in co-curing stringers that may withstand the pressure applied during lay-up. Also, it would be advantageous to provide a stringer and mandrel that may be formed into various shapes prior to co-curing. Finally, it would be advantageous to provide a mandrel that may be easily removed following co-curing.

BRIEF SUMMARY OF THE INVENTION

The invention addresses the above needs and achieves other advantages by providing a composite stringer that may be supported by a collapsible mandrel during lay-up and co-curing. The composite stringer is fabricated in part with the support of a mandrel and reinforcing strips during application and curing of the substrate layer to the stringer. The mandrel and reinforcing strips may be removed following co-curing of the composite stringer and reused to fabricate additional stringers.

In one embodiment, the co-cured composite stringer includes a stringer and a mandrel positioned within a channel defined in the stringer. A plurality of strips are positioned within an opening of the mandrel, and a substrate layer, such as uncured pre-

impregnated skin, is positioned adjacent to the stringer. During application of the substrate layer to the stringer, the mandrel and plurality of strips support the stringer.

In variations of the present invention, the co-cured composite stringer includes a plurality of strips stacked horizontally and vertically within the opening of the mandrel such that each of the strips may slide with respect to one another. The plurality of strips are preferably positioned within the opening of the mandrel such that the strips substantially conform to the shape of the mandrel. In addition, the plurality of strips are pliable such that the mandrel and strips are capable of bending to a desired contour. The plurality of strips may be rectangular in shape and comprise a polymeric material (e.g., nylon). The stringer may be an uncured pre-impregnated reinforcing material, such as an epoxy graphite, while the mandrel may be an elastomeric material. In another advantageous embodiment of the present invention, the mandrel and plurality of strips are capable of withstanding at least 90 psi of head pressure.

In another aspect of the present invention, a collapsible lay-up mandrel assembly is provided that comprises a mandrel defining an opening therethrough, and a plurality of strips slidably positioned within the opening of the mandrel.

The present invention further provides a method of fabricating co-cured stringers. The method includes providing a stringer that defines a channel therein. A plurality of strips are positioned within a mandrel, and the mandrel is then positioned within the channel of the stringer. The method also includes applying a substrate layer to the stringer. The mandrel and plurality of strips are capable of supporting the stringer during application of the substrate layer, which may include head pressures of at least 90 psi. Finally, the stringer and the substrate layer are cured such that the stringer and substrate layer are attached.

In additional embodiments of the present invention, the method further includes bending the plurality of strips and mandrel to a desired contour. The plurality of strips may also be slid from the the mandrel following application of the substrate layer. Applying a vacuum to the mandrel following removal of the plurality of strips may be employed to remove the mandrel.

The present invention therefore provides a co-cured composite stringer that may be formed into a variety of contours and lengths. An uncured substrate layer is applied to an uncured stringer such that the substrate layer may be co-cured to the stringer. The

mandrel and strips are used to retain a desired shape of the stringer during laying of the substrate layer to the stringer and during co-curing. In addition, the mandrel and strips may be manipulated to various configurations prior to application of the substrate layer, and may be removed and reused following co-curing. A variety of materials may be used for individual elements in embodiments of the present invention to fabricate co-cured stringers that provide various degrees of reinforcement to the substrate layer.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

Figure 1 is a perspective view of a plurality of co-cured stringers having strips positioned within a respective mandrel according to one embodiment of the present invention;

Figure 2 is an enlarged cross-sectional view of one of the co-cured stringers shown in **Figure 1**;

Figure 3 is a perspective view of a stringer illustrating that each strip is removable from the mandrel of one embodiment of the present invention; and

Figure 4 is an enlarged cross-sectional view of a stringer with the strips removed and vacuum applied to the mandrel of one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, this invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

Referring now to the drawings and, in particular to **Figure 1**, there is shown a substrate **16** having a plurality of stringers **10** arranged thereon. The stringers **10** are capable of being arranged in a variety of positions, for example, longitudinally along the span of an aircraft wing or contoured to a specific curvature. Additionally, the stringers **10** could be any number of dimensions to accommodate a variety of reinforcement

applications. The term "stringer" is not meant to be limiting and could be any stiffener, longeron, or reinforcing member that is used to provide support to another structure, such as an aircraft skin. Furthermore, the stringers **10** could be useful to support structures other than aircraft skins or wings, such as with marine, construction, or automotive structures, where a lightweight reinforcement is desired. Thus, the substrate **16** could be any suitable material that that is capable of being reinforced by the stringers **10**. For purposes of example, however, reference will be made to an aircraft skin as the substrate **16**.

The stringers **10** are generally fabricated by applying an aircraft skin **16** to the stringer and co-curing the aircraft skin and underlying stringer together. In order to ensure that the stringer **10** maintains its shape during laying of the aircraft skin **16**, a mandrel **12** is positioned between the stringer and the aircraft skin. In addition, a number of strips **14** are positioned within the mandrel **12** to also provide reinforcement during lay-up of the aircraft skin **16**. The stringers **10** shown in **Figures 1-2** are "hat" shaped as known to those skilled in the art, although various shapes could be used in additional embodiments of the present invention, such that various mandrel **12** shapes could also be utilized.

The composite material used for each of the stringers **10** and aircraft skin **16** is generally a lightweight material, such as an uncured pre-impregnated reinforcing tape or fabric (i.e., "prepreg"). The tape or fabric typically includes a plurality of fibers such as graphite fibers that are embedded within a matrix material, such as a polymer, e.g., an epoxy or phenolic. The tape or fabric could be unidirectional or woven depending on the degree of reinforcement desired. Thus, the prepreg tape or fabric is generally laid onto a mandrel or mold to preform the tape or fabric into the desired shape of the stringer **10** as defined by the mandrel or mold. The stringers **10** could be any suitable dimension to provide various degrees of reinforcement, and could be comprised of any number of plies of prepreg tape or fabric. Similarly, the aircraft skin **16** could be various sizes and thicknesses for both individual and multiple plies depending on the weight and amount of support desired.

In one embodiment, each stringer **10** is preformed and generally defines a channel or recess. Further, each preformed stringer **10** is typically uncured. A mandrel **12** is positioned within the channel of the stringer **10**. The mandrel **12** has a shape that

substantially conforms to the corresponding channel defined by the stringer **10** such that the mandrel may provide support to the stringer during subsequent lay up of the aircraft skin **16**. Also, the mandrel **12** defines an opening, such as a lengthwise opening, such that a plurality of longitudinally extending strips **14** may be inserted within the opening to provide reinforcement to the mandrel.

The mandrel **12** of the illustrated embodiment has a trapezoidal shape to conform to a hat-shaped stringer **10**, although the mandrel could have any number of other shapes to conform to differently shaped stringers. Similarly, the mandrel **12** could be various dimensions so long as the mandrel defines an opening that enables strips **14** to be inserted therethrough. The mandrel **12** may be formed of any elastomeric material, such as Teflon® (E.I. du Pont de Nemours and Company)coated silicone or hard rubber, but is preferably pliable to enable the mandrel to conform to various configurations. Thus, the mandrel **12** may be bent somewhat to fit within and conform with channels defined by a preformed stringer **10** that may not be linear, such as curved or piecewise linear channels. In addition, the mandrel **12** may be fabricated with any suitable technique, such as with extrusion or casting.

As shown in **Figure 2**, the strips **14** are inserted within the opening defined in the mandrel **12**. The strips **14** are advantageously pliable and may slide with respect to one another. Because the strips **14** are pliable and individually capable of sliding axially within the mandrel **12**, the strips can have a variety of cross-sectional shapes, as shown in **Figure 1**. The greater the number of strips **14**, *i.e.*, smaller cross section, the more flexible the mandrel **12** is, such that more complex contours may be achieved with a greater number of strips. The collection of strips **14** substantially conform to the shape of the opening defined by the mandrel **12** such that there are no gaps between the strips and the mandrel. **Figure 2** demonstrates that the strips **14** may be arranged horizontally and vertically with respect to one another, as well as adjacent to each other, although the strips could be arranged in any number of configurations within the mandrel **12**. Furthermore, although some of the strips **14** are shown as being rectangular, the strips could be any number of dimensions and cross-sectional shapes that may complement the shape of the opening defined by the mandrel **12**, as well as any number of lengths depending on the structure to be reinforced.

In the embodiment of the present invention shown in **Figure 2**, there are outer strips **14** that contact the surface of the mandrel **12**, while interior strips contact other adjacent strips but do not contact any surface of the mandrel. The widest strips **14** in the mandrel **12**, the top two strips shown in **Figure 2**, are generally split into two separate strips to aid in the removal of the strips from the mandrel following curing. However it is understood that the strips **14** shown in **Figure 2** could be arranged within the mandrel **12** in any desired configuration with any number and dimension of strips. The interior strips **14** are generally easier to remove and are thus removed first, although the strips could be removed in any order desired.

The strips **14** are preferably a polymeric material, such as nylon that is capable of withstanding the temperatures associated with co-curing. However, the material used for the strips **14** depends on the temperature used in co-curing to prevent deformation of the strips by heating the strips above their melting temperature, as well as the configuration of the strips arranged within the mandrel **12**, such that various materials could be used in variations of the present invention in additional embodiments. The strips **14** may have a coefficient of thermal expansion that is higher than the surrounding stringer **10** and aircraft skin **16** such that the strips expand when heated to apply additional pressure during curing, but also contract upon cooling to aid in removal of the strips from the mandrel **12**. The strips **14** could be fabricated through extrusion, molding, or any other suitable process.

A method of fabricating co-cured stringers **10** is illustrated in the flowchart shown in **Figure 5**. After each of the stringers **10** is preformed in an uncured state, the stringers are typically first placed in a trough section of a lay-up mandrel that defines a shape corresponding to that of the preformed stringers. The stringers **10** are uncured so that the prepreg may be cured at the same time that the stringer is cured to the aircraft skin **16**. Next, the mandrel **12**, having the strips **14** inserted within the mandrel as described above, is placed within a respective channel or recess defined by the stringers **10**. The strips **14** could also be inserted within the mandrel **14** after the mandrel is positioned in the channel or recess of the stringer **10**, as opposed to already being assembled within the mandrel. As a result of their pliability, the mandrel **12** and strips **14** could be bent or otherwise arranged within the channel or recess of the stringer **10** in

any number of configurations, such that the mandrel and strips need not be custom-made for a particular stringer shape or contour.

The aircraft skin **16** is generally applied over the mandrel **12** and exposed portions of the stringer **10** with pressure being applied, such as a head pressure of about 90 psi. The mandrel **12** and strips **14** are capable of withstanding this head pressure to ensure that the aircraft skin **16** and stringer **10** maintain their shape and are not undesirably deformed. The aircraft skin **16** is applied as a tape or fabric such that a sufficient amount of tape or fabric of the aircraft skin contacts the stringer **10** to allow the stringer to cure to the aircraft skin **16** during autoclaving. Laying the aircraft skin **16** onto the stringer **10** and mandrel **12** is preferably automated, although it is understood that hand-laying techniques could also be employed in alternative embodiments of the present invention. It is also understood that additional techniques, as known to those skilled in the art, could be utilized in applying the aircraft skin **16** to the stringer **10**. In this regard, in one alternative of the present invention, the mandrel **12** could be placed on the aircraft skin **16** and prepreg applied over the mandrel such that the stringer could be formed over the mandrel and applied directly to the aircraft skin.

The stringer **10** and aircraft skin **16** are generally co-cured with autoclaving, as known to those skilled in the art, which generally involves the application of heat and pressure under vacuum. It is understood that other techniques could be used to co-cure the stringer **11** and the aircraft skin **16**, such as with a vacuum bag, as known to those skilled in the art.

Following co-curing of the stringer **10** and the aircraft skin **16**, each of the strips **14** may be removed, as illustrated in **Figure 3**. Thus, the strips **14** are capable of being removed individually by hand. As discussed above, the strips **14** that do not contact any surface of the mandrel **12** are typically removed first. After each of the strips **14** have been removed from the mandrel **12**, the mandrel is subjected to a vacuum to collapse it slightly so that the mandrel can be removed from each of the stringers **10**. The mandrel **12** is also capable of being removed from the co-cured stringer **10** by hand without the application of a vacuum. **Figure 4** illustrates a cross section of a mandrel under vacuum, which demonstrates that the edges buckle slightly to enable easy removal of the mandrel. Each of the strips **14** and mandrel **12** may thus be reused during subsequent co-curing of additional stringers **10**. Although **Figure 3** illustrates the strips **14** capable of being

removed by hand, it is understood that other techniques of removing both the strips and the mandrel could be employed, such as with an automated machine.

In alternative embodiments of the present invention, the stringer **10** could be pre-cured prior to being cured to the aircraft skin **16**, or vice versa. In addition, both the stringer **10** and aircraft skin **16** could be pre-cured and attached together. Furthermore, it is understood that the stringers **10** could be shaped in a lay-up mandrel rather than being in an uncured and preformed shape such that the stringer is molded into a hat section in the same lay-up mandrel that laying up of the aircraft skin takes place. Also, it is understood that the aircraft skin **16** could be laid over the "hat-shaped" side of the stringer **10** (i.e., the side opposite to the channel or recess) in addition to over the channel or recess and co-cured to the stringer such that the aircraft skin is co-cured to both sides of the stringer. Alternatively, the aircraft skin **16** could be laid over the "hat-shaped" side of the stringer **10** only and subsequently co-cured to the stringer. Thus, the mandrel **12** and strips **14** would support the stringer **10** if the aircraft skin is applied in either manner.

Therefore, the combination of the mandrel **12** and strips **14** provide reinforcement during application of the aircraft skin **16** and autoclaving. Thus, the mandrel **12** and strips **14** prevent the stringers **10** from buckling when the aircraft skin **16** is laid over the recessed area of the stringers. The stringers **10** may be fabricated in any number of dimensions depending on the type of support and configuration desired. In addition, the mandrel **12** and strips **14** may be advantageously bonded to the aircraft skin **16** in one autoclave cure cycle and removed following co-curing and reused for additional curing.

Many modifications and other embodiments of the invention set forth herein will come to mind to one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

THAT WHICH IS CLAIMED:

1. A co-cured composite stringer comprising:

a stringer, the stringer defining a channel therein;

a mandrel positioned within the channel of the stringer, wherein the mandrel defines an opening therethrough;

a plurality of strips slidably positioned within the opening of the mandrel; and

a substrate layer positioned adjacent to the stringer, wherein the mandrel and plurality of strips are capable of supporting the stringer during application of the substrate layer to the stringer.

2. A co-cured composite stringer according to Claim 1, wherein the plurality of strips are stacked horizontally and vertically within the opening of the mandrel such that each of the strips may slide with respect to one another.

3. A co-cured composite stringer according to Claim 1, wherein the plurality of strips are positioned within the opening of the mandrel such that the strips substantially conform to the shape of the mandrel.

4. A co-cured composite stringer according to Claim 1, wherein the plurality of strips are pliable such that the mandrel and strips are capable of bending to a desired contour.

5. A co-cured composite stringer according to Claim 1, wherein the each of the plurality of strips is rectangular in shape.

6. A co-cured composite stringer according to Claim 1, wherein the plurality of strips comprise a polymeric material.

7. A co-cured composite stringer according to Claim 6, wherein the plurality of strips comprise nylon.

8. A co-cured composite stringer according to Claim 1, wherein the stringer comprises uncured pre-impregnated reinforcing material.

9. A co-cured composite stringer according to Claim 8, wherein the pre-impregnated reinforcing material comprises uncured epoxy graphite.

10. A co-cured composite stringer according to Claim 1, wherein the mandrel and plurality of strips are capable of withstanding at least 90 psi of head pressure.

11. A co-cured composite stringer according to Claim 1, wherein the mandrel comprises an elastomeric material.

12. A co-cured composite stringer according to Claim 1, wherein the substrate layer comprises uncured pre-impregnated aircraft skin.

13. A collapsible lay-up mandrel assembly comprising:
a mandrel defining an opening therethrough; and
a plurality of strips slidably positioned within the opening of the mandrel.

14. A collapsible lay-up mandrel assembly according to Claim 13, wherein the plurality of strips are stacked horizontally and vertically within the opening of the mandrel.

15. A collapsible lay-up mandrel assembly according to Claim 13, wherein the plurality of strips are positioned within the opening of the mandrel such that the strips substantially conform to the shape of the mandrel.

16. A collapsible lay-up mandrel assembly according to Claim 13, wherein the plurality of strips are pliable such that the mandrel and strips are capable of bending to a desired contour.

17. A collapsible lay-up mandrel assembly according to Claim 14, wherein the each of the plurality of strips is rectangular in shape.

18. A collapsible lay-up mandrel assembly according to Claim 14, wherein the plurality of strips comprise a polymeric material.

19. A collapsible lay-up mandrel assembly according to Claim 18, wherein the plurality of strips comprise nylon.

20. A collapsible lay-up mandrel assembly according to Claim 13, wherein the mandrel and plurality of strips are capable of withstanding at least 90 psi of head pressure.

21. A collapsible lay-up mandrel assembly according to Claim 13, wherein the mandrel comprises an elastomeric material.

22. A method of fabricating co-cured stringers comprising:

providing a stringer, the stringer defining a channel therein;

positioning a plurality of strips within a mandrel;

positioning the mandrel within the channel defined in the stringer;

applying a substrate layer to the stringer, wherein the mandrel and plurality of strips are capable of supporting the stringer during the applying of the substrate layer; and

curing the stringer and the substrate layer such that the stringer and substrate layer are attached.

23. The method according to Claim 22, further comprising bending the plurality of strips and mandrel to a desired contour.

24. The method according to Claim 22, wherein applying comprises applying the substrate layer at a head pressure of at least 90 psi.

25. The method according to Claim 22, wherein applying comprises applying uncured pre-impregnated reinforcing material.

26. The method according to Claim 23, further comprising removing the plurality of strips by sliding the strips from the mandrel following curing.

27. The method according to Claim 26, further comprising applying a vacuum to the mandrel following removing the plurality of strips.

28. The method according to Claim 27, further comprising removing the mandrel following applying the vacuum.

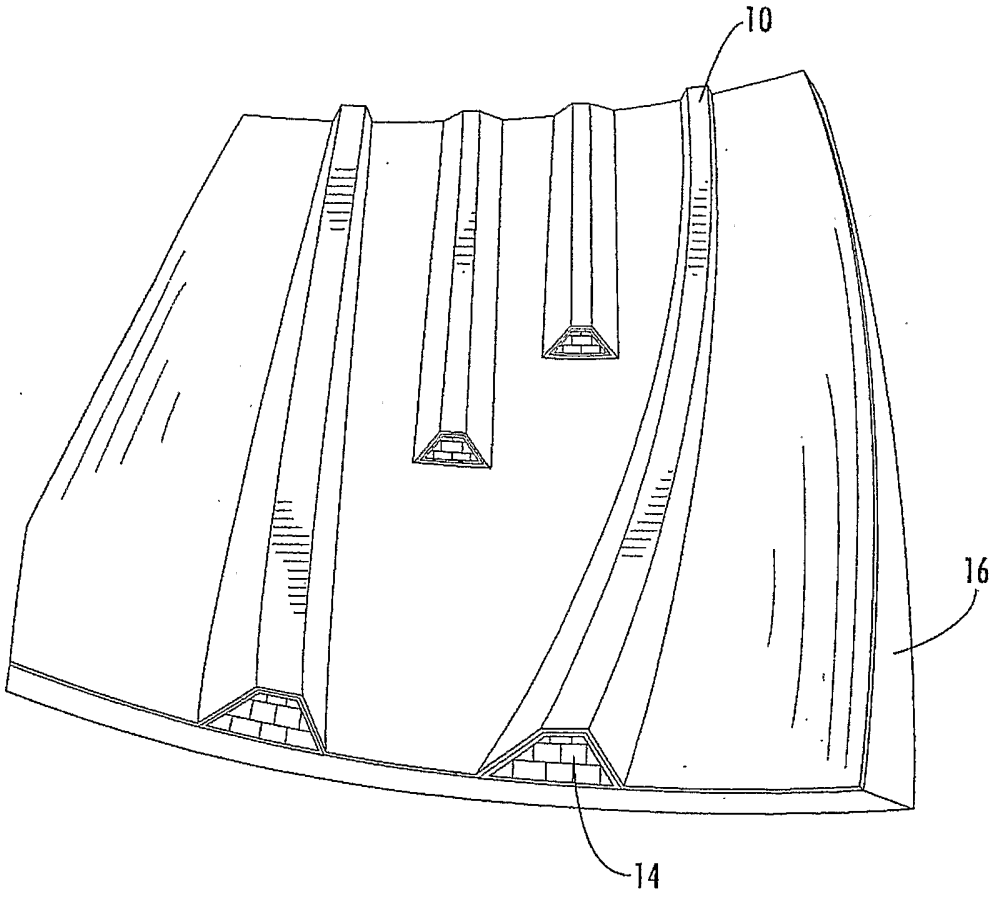


FIG. 1

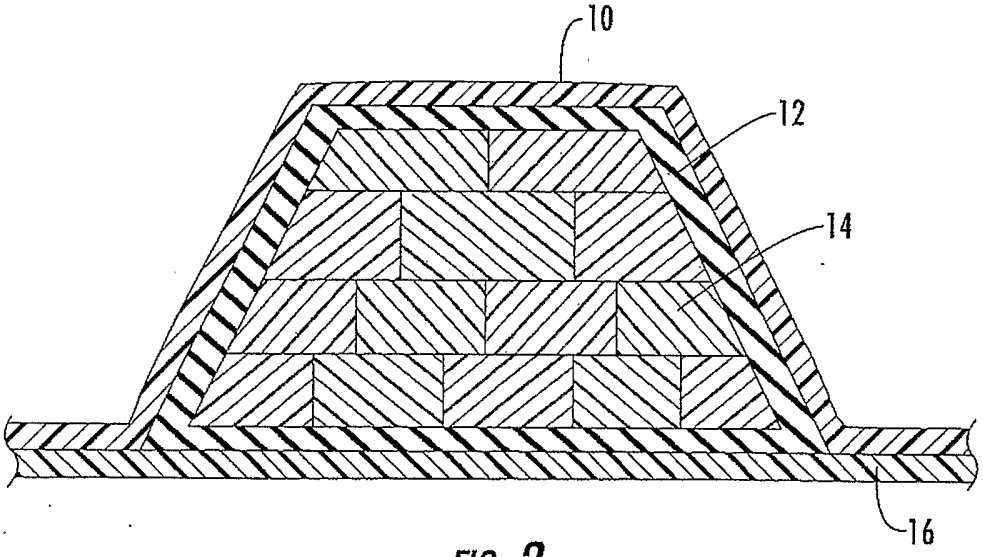


FIG. 2

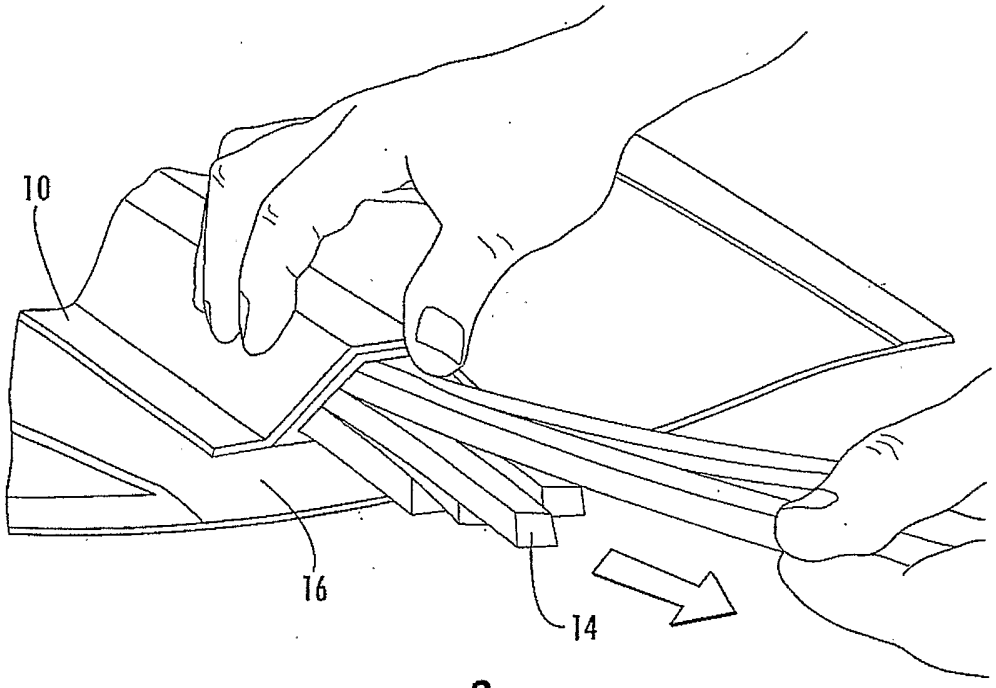


FIG. 3

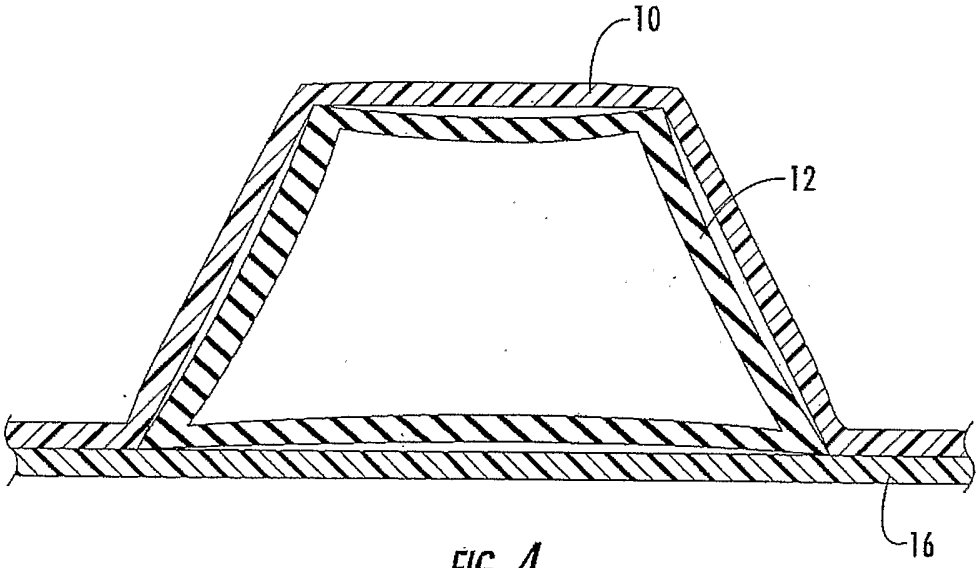


FIG. 4

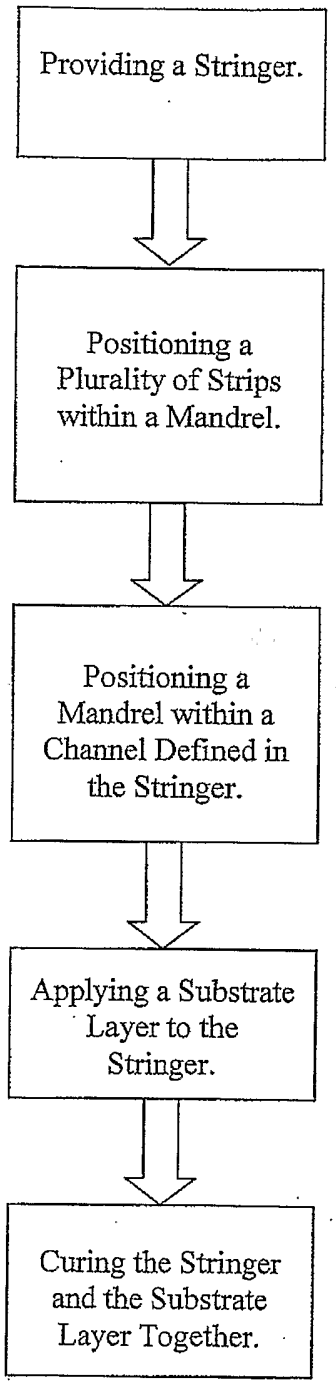

Providing a Stringer.
Positioning a Plurality of Strips within a Mandrel.
Positioning a Mandrel within a Channel Defined in the Stringer.
Applying a Substrate Layer to the Stringer.
Curing the Stringer and the Substrate Layer Together.

FIG. 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/006572

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B29C33/48 B29C70/44

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)
IPC 7 B29C

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, PAJ, 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 5 387 098 A (WILLDEN ET AL) 7 February 1995 (1995-02-07)	1,3-6, 8-13, 15-18, 20-26
Y	column 2, line 41 - column 3, line 19; claims	27,28
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☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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13 June 2005	20/06/2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Van Wallene, A

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US2005/006572

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US 3629030 A	21-12-1971	NONE	