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Bland

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(54) **METHOD FOR FABRICATING HIGHLY CONTOURED COMPOSITE STIFFENERS WITH REDUCED WRINKLING**

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B29C 70/34 (2006.01)
B32B 5/02 (2006.01)

(52) **U.S. Cl.**
USPC **264/258**; 428/174

(58) **Field of Classification Search**
None
See application file for complete search history.

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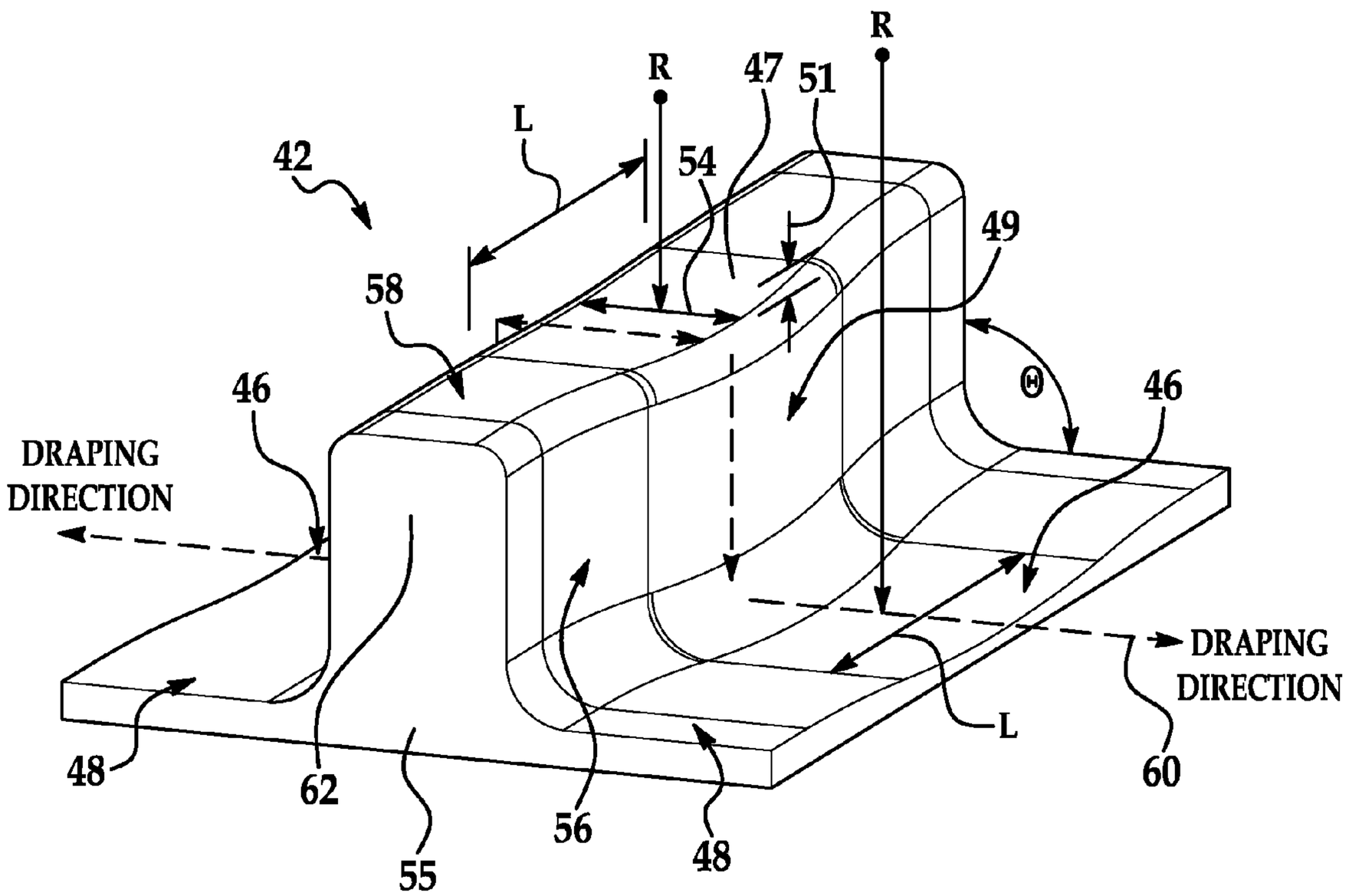
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(57) **ABSTRACT**

A mandrel having an out-of-plane curvature and a corresponding in-plane change in mandrel geometry is used to fabricate substantially wrinkle-free, fiber reinforced stiffeners having an out-of-plane curvature.

12 Claims, 7 Drawing Sheets



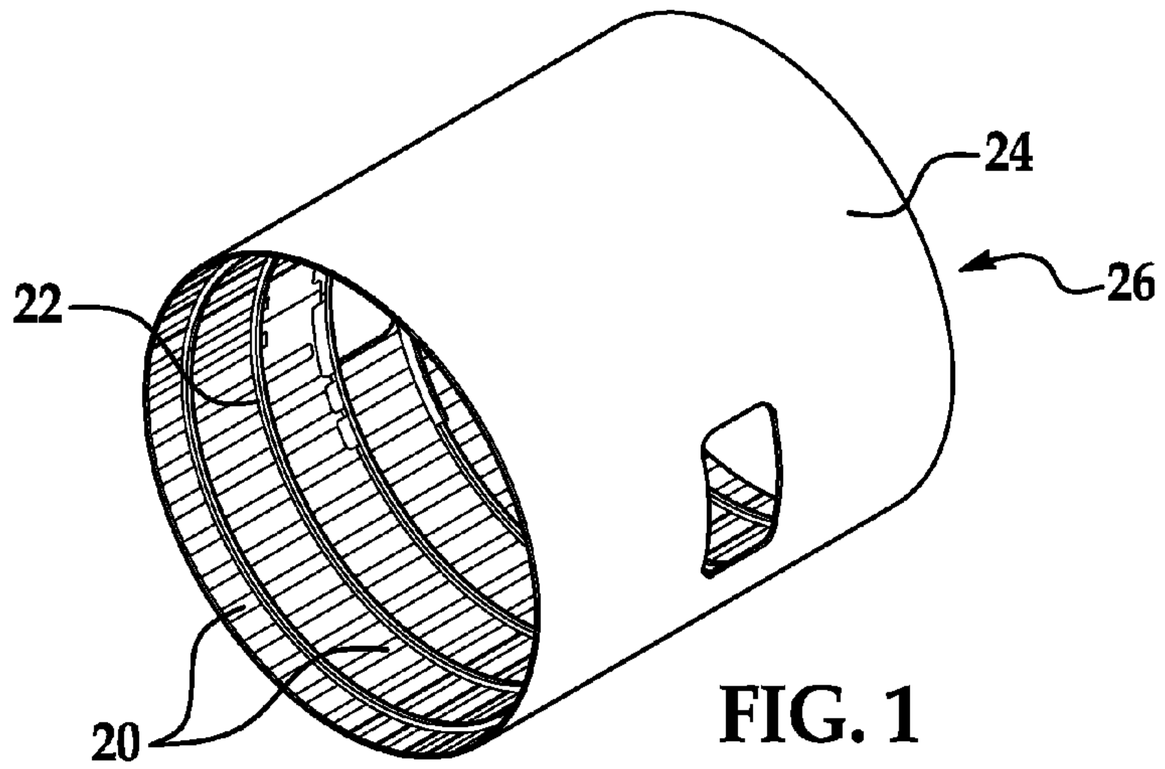


FIG. 1

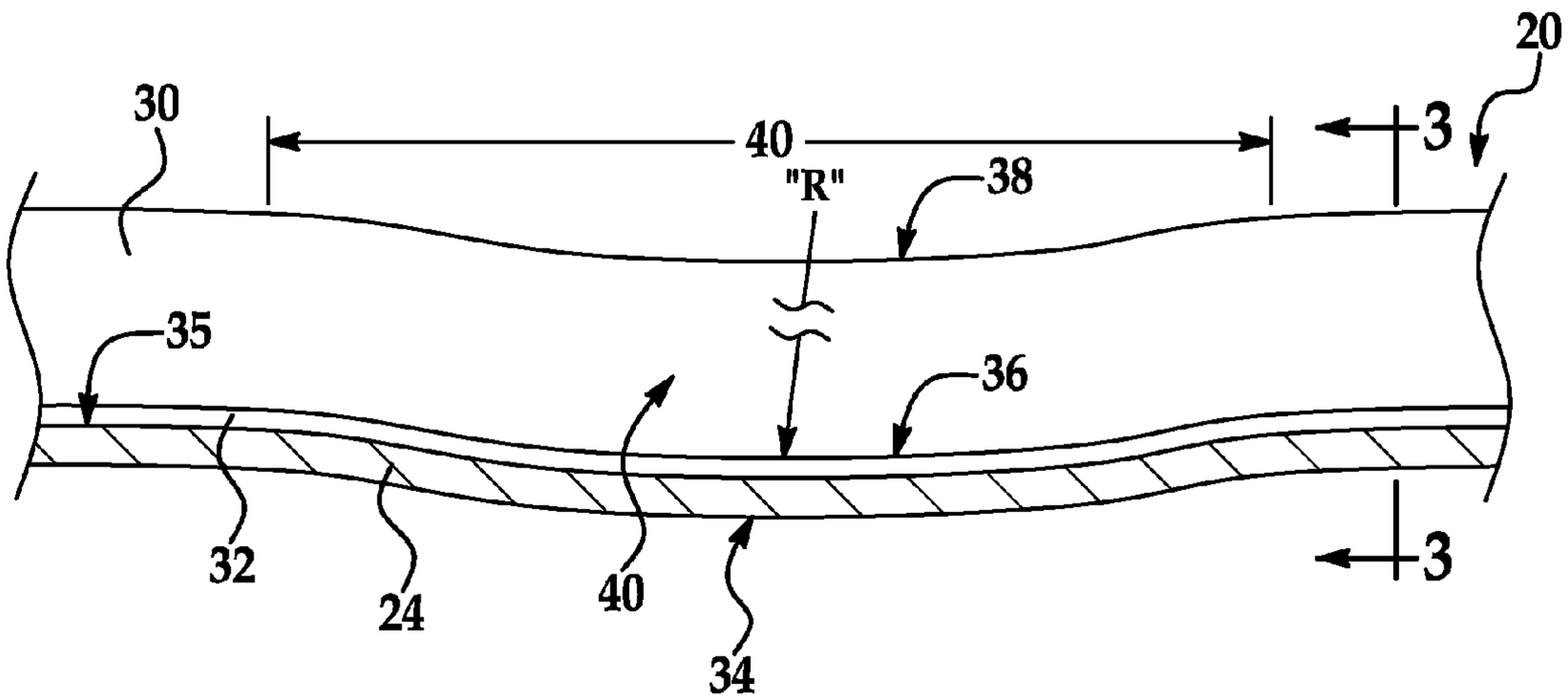


FIG. 2

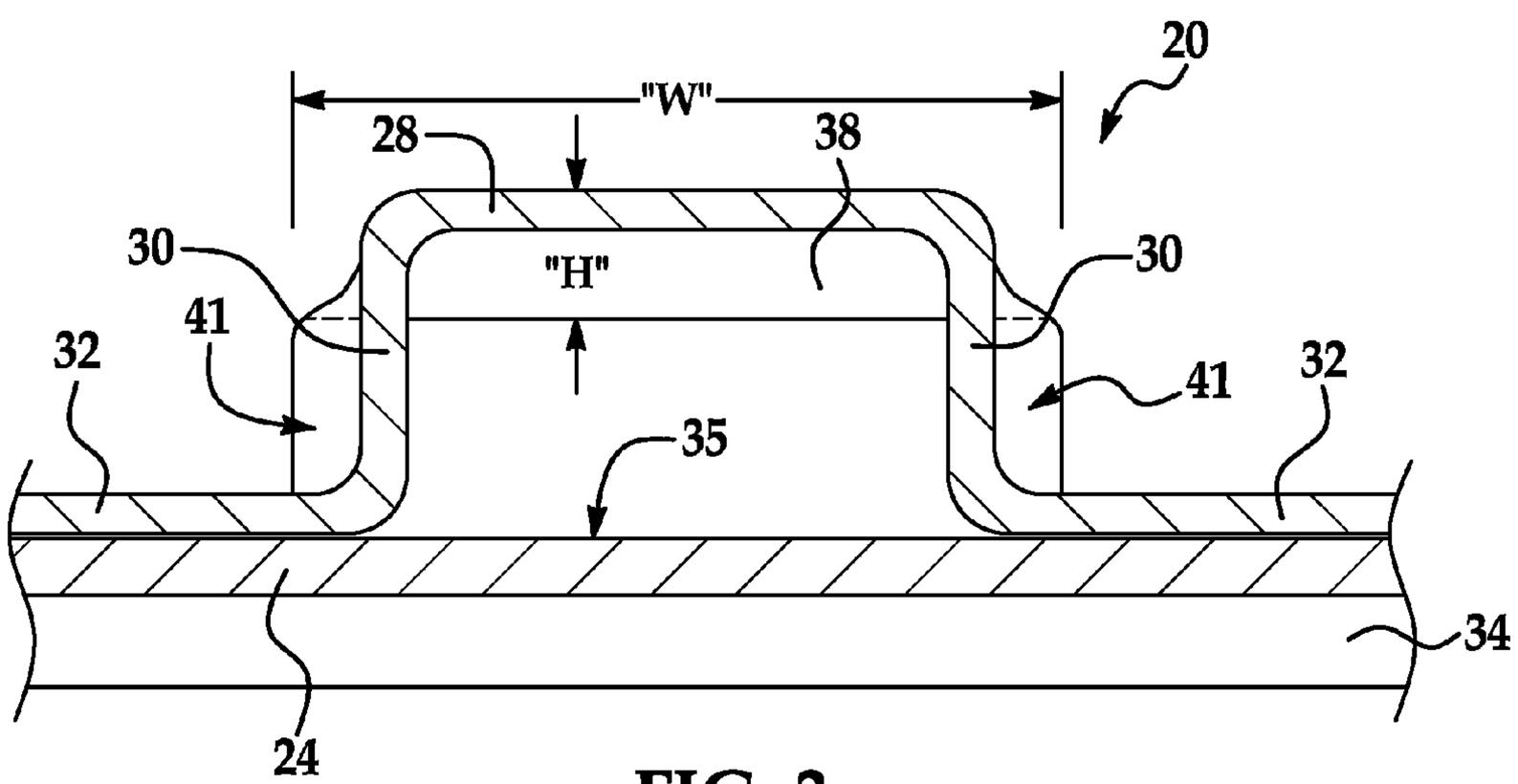


FIG. 3

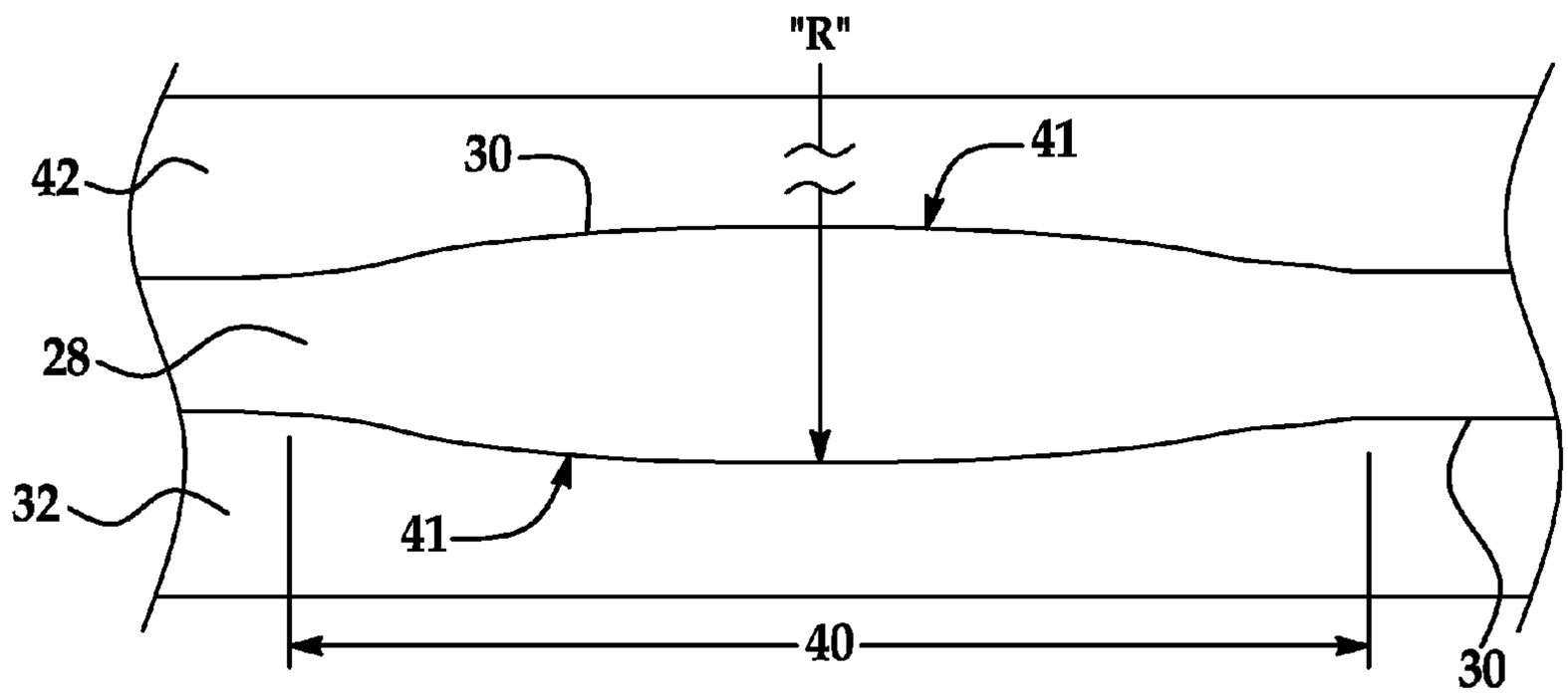


FIG. 4

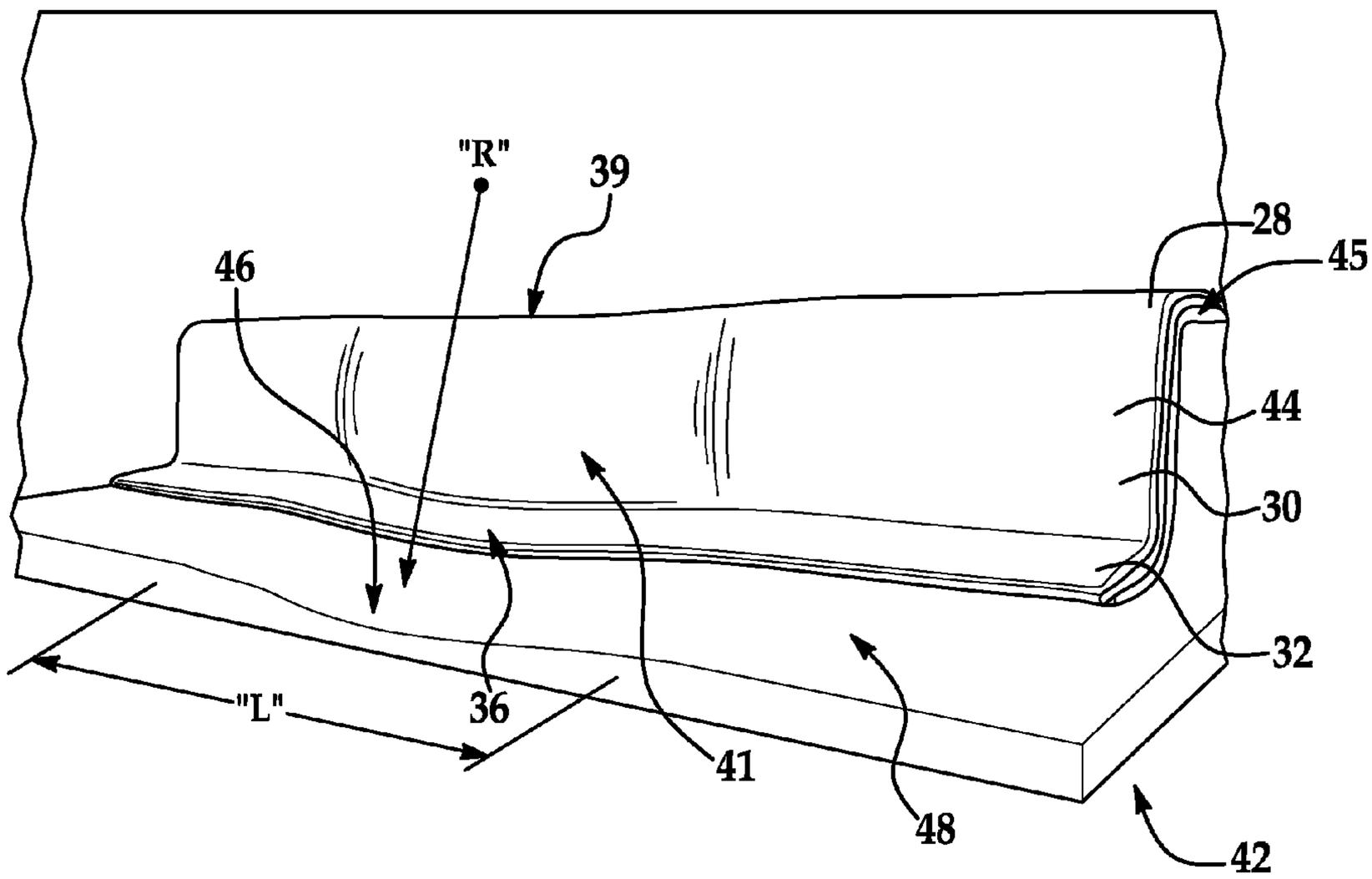


FIG. 5

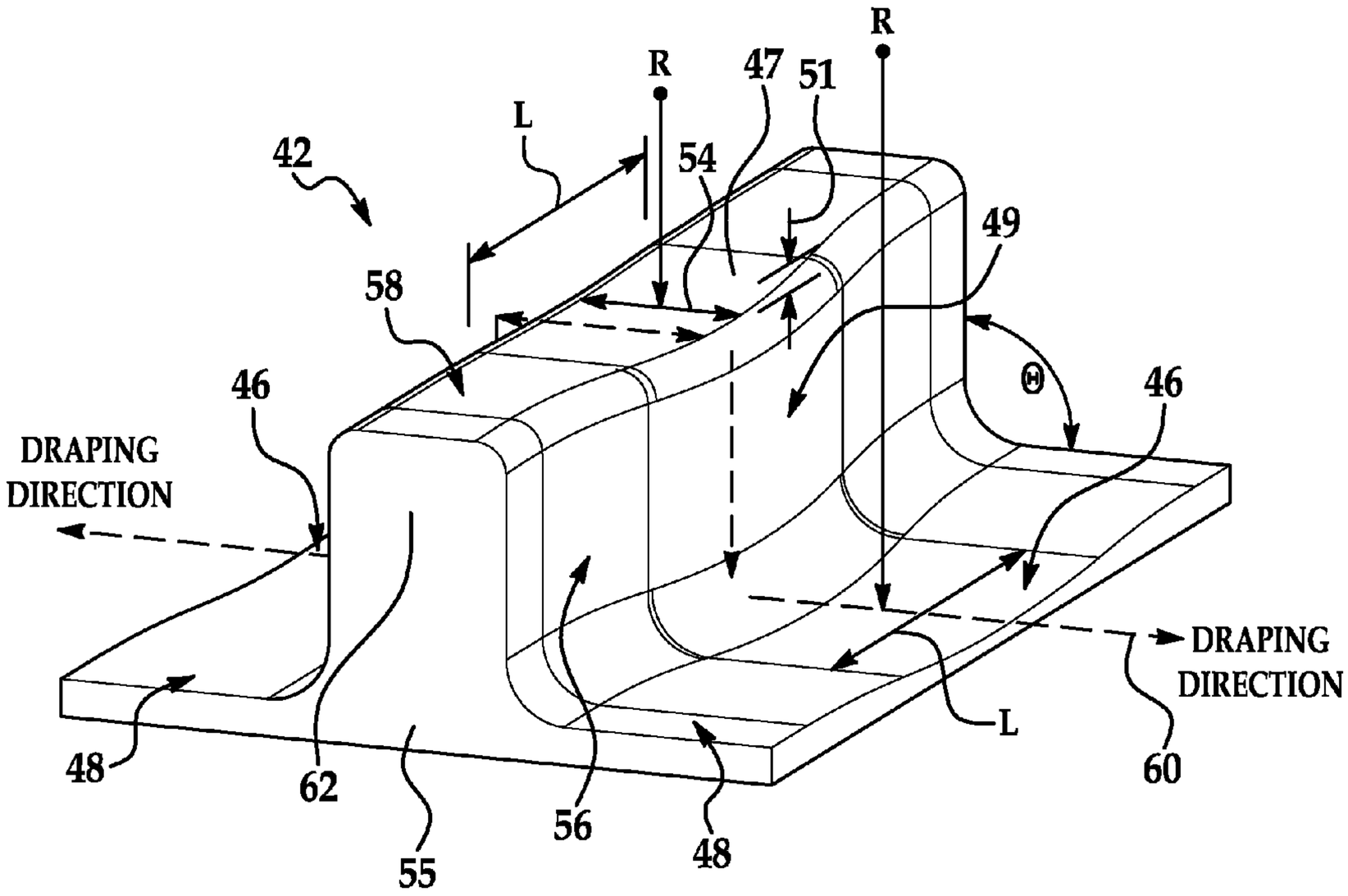

R
R
47
51
L
42
54
49
58
46
46
DRAPING
DIRECTION
Θ
DRAPING
DIRECTION
L
48
62
55
56
48
60

FIG. 6

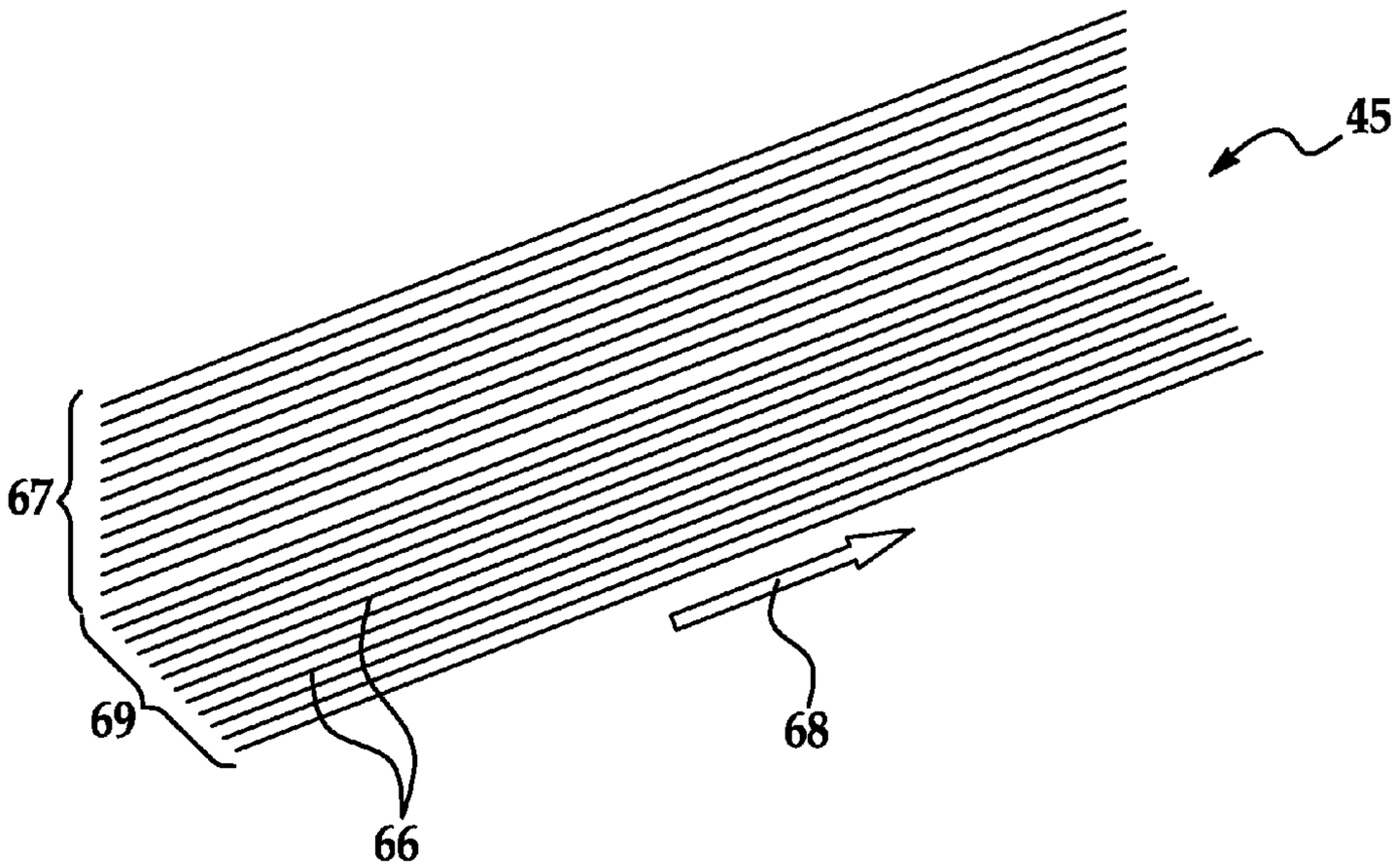

45
67
69
66
68

FIG. 7

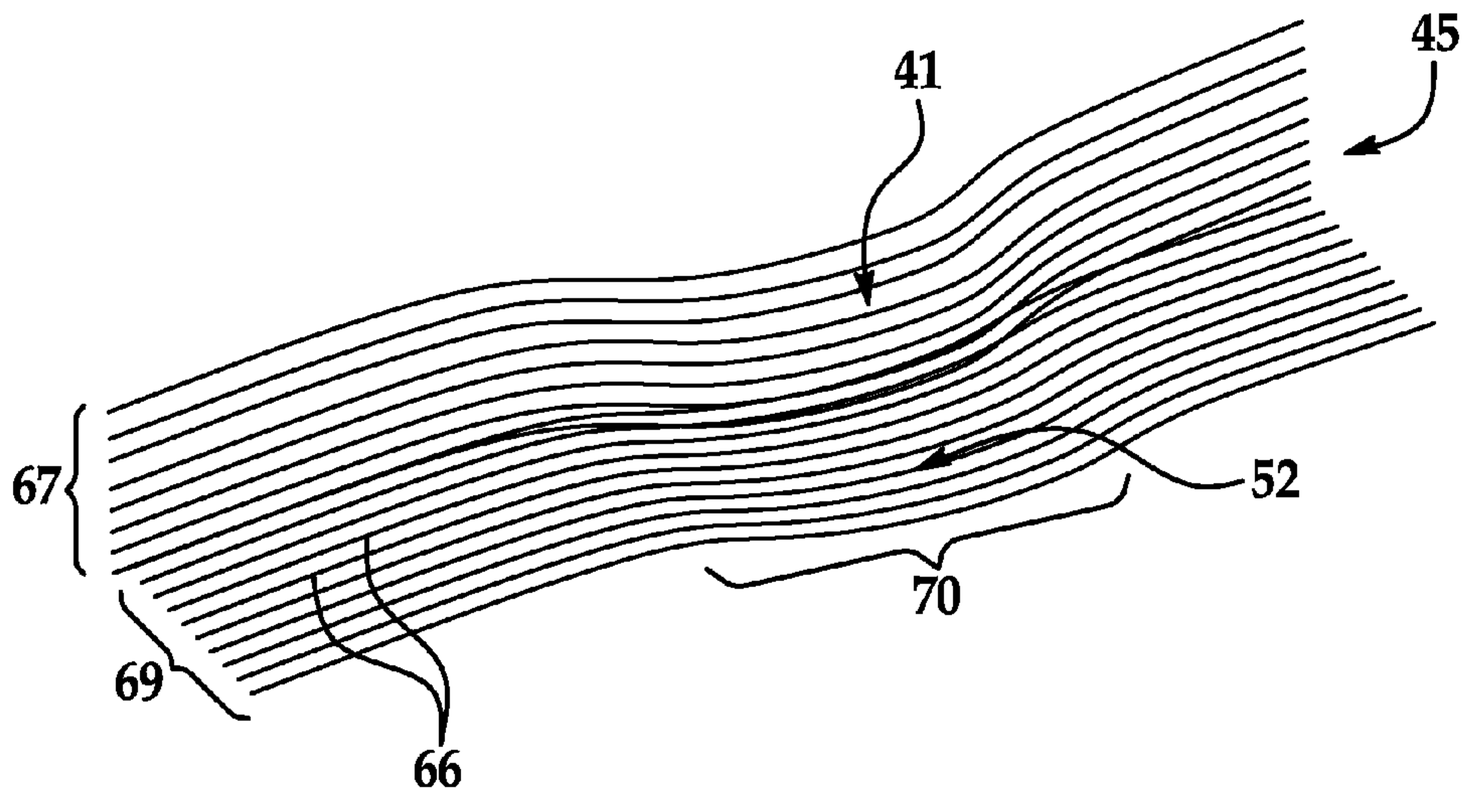


FIG. 8

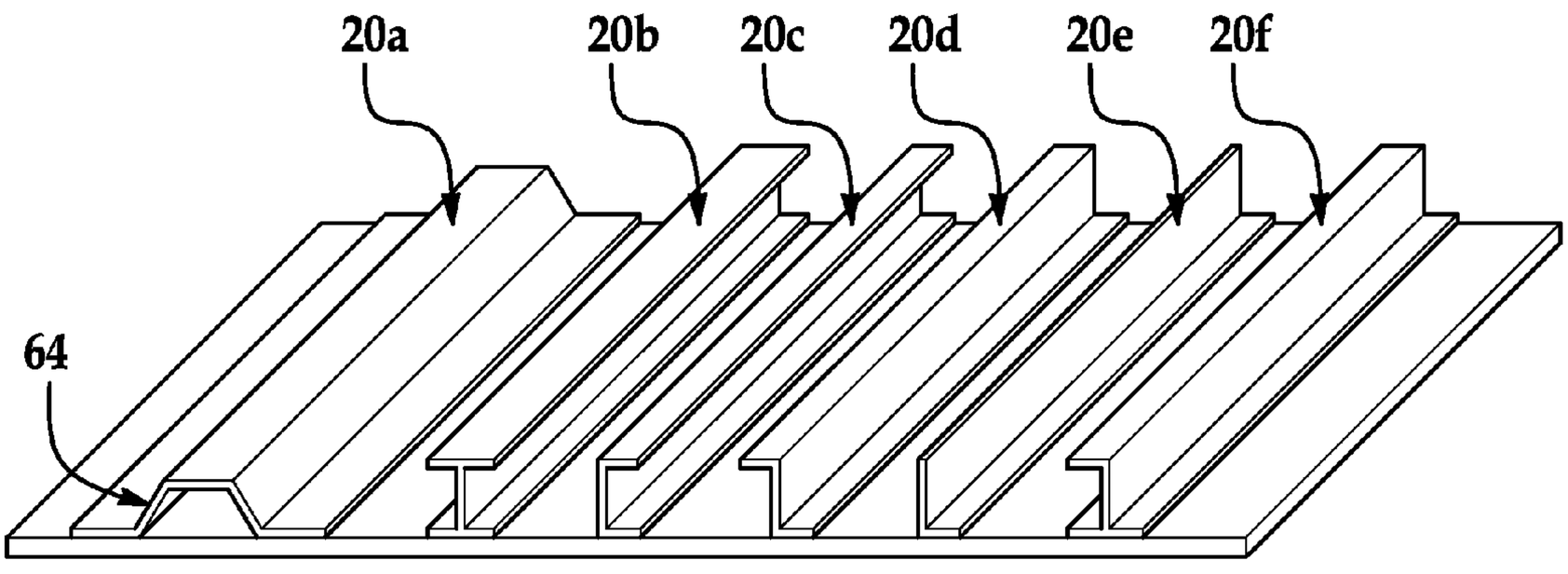


FIG. 9

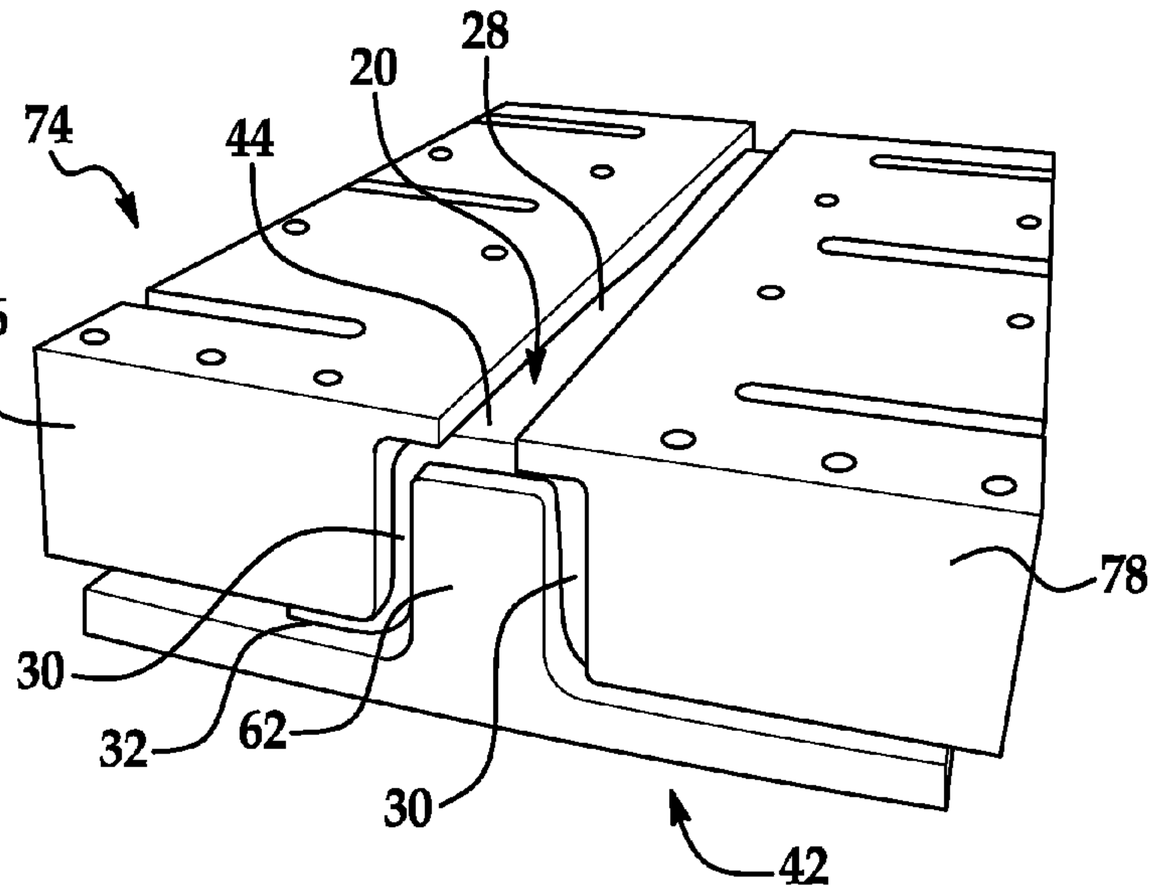

28
20
74
44
76
78
30
32
62
30
42

FIG. 10

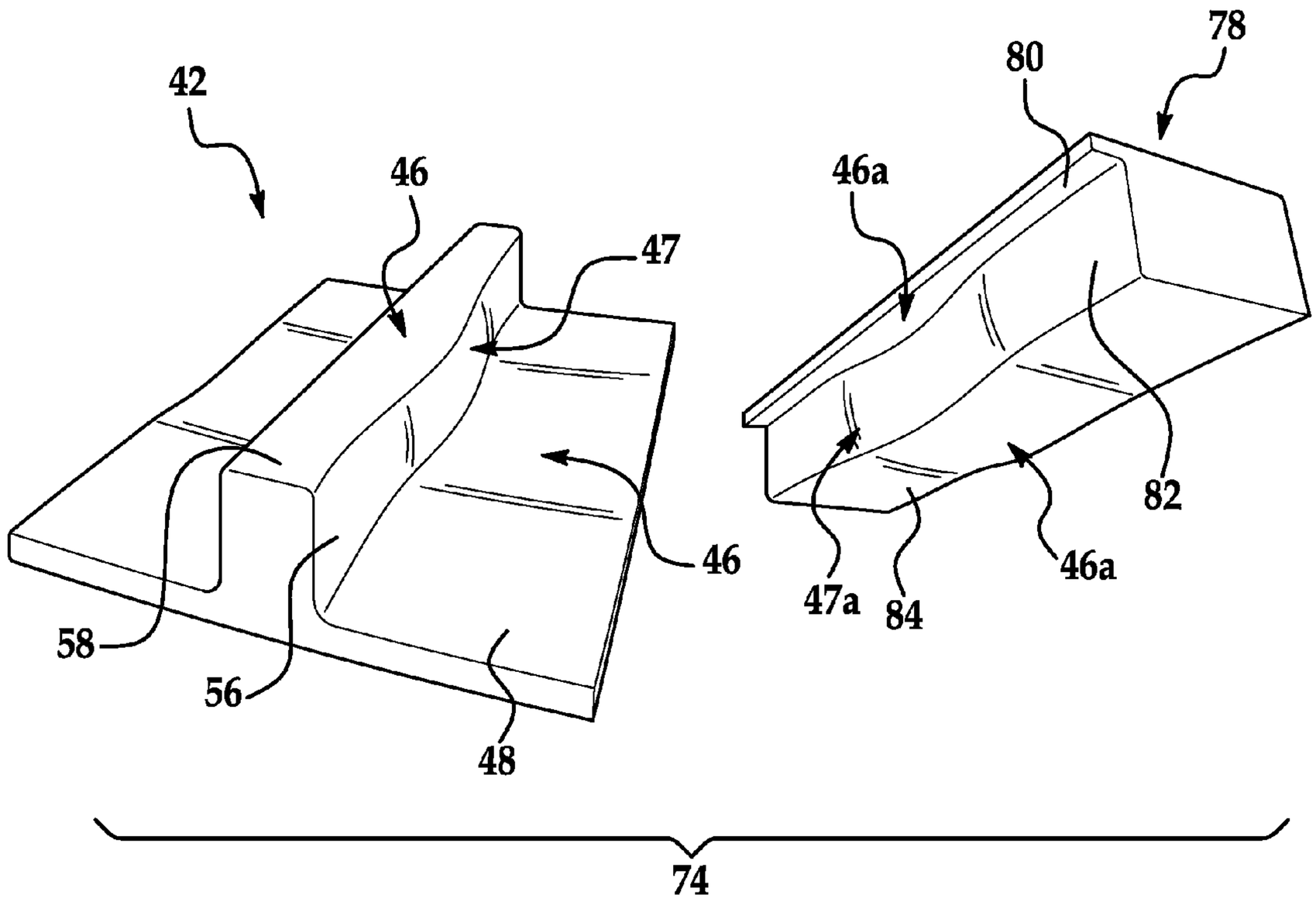

42
46
47
78
80
46a
82
46
47a
84
46a
58
56
48
74

FIG. 11

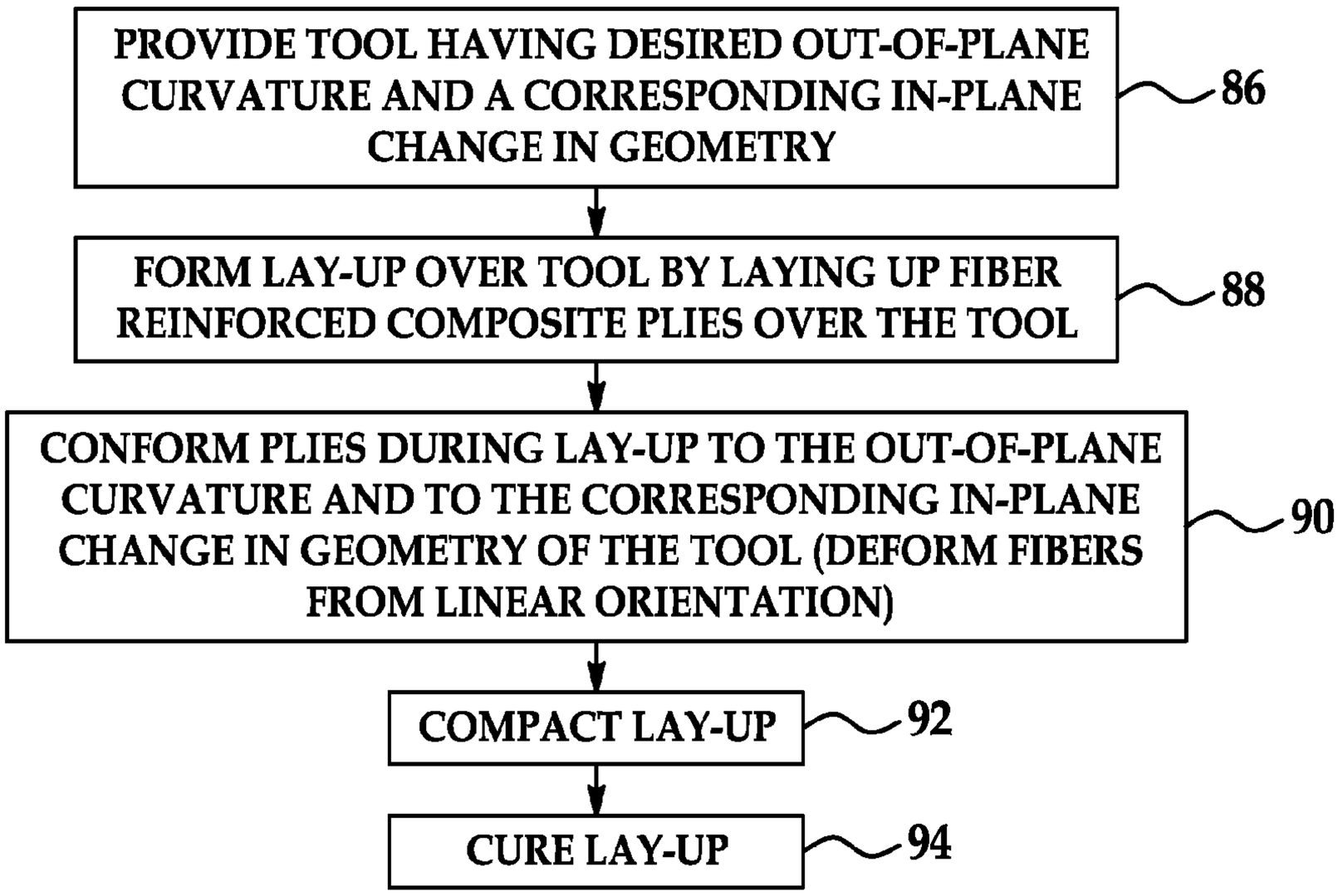

PROVIDE TOOL HAVING DESIRED OUT-OF-PLANE CURVATURE AND A CORRESPONDING IN-PLANE CHANGE IN GEOMETRY
86
FORM LAY-UP OVER TOOL BY LAYING UP FIBER REINFORCED COMPOSITE PLIES OVER THE TOOL
88
CONFORM PLIES DURING LAY-UP TO THE OUT-OF-PLANE CURVATURE AND TO THE CORRESPONDING IN-PLANE CHANGE IN GEOMETRY OF THE TOOL (DEFORM FIBERS FROM LINEAR ORIENTATION)
90
COMPACT LAY-UP
92
CURE LAY-UP
94

FIG. 12

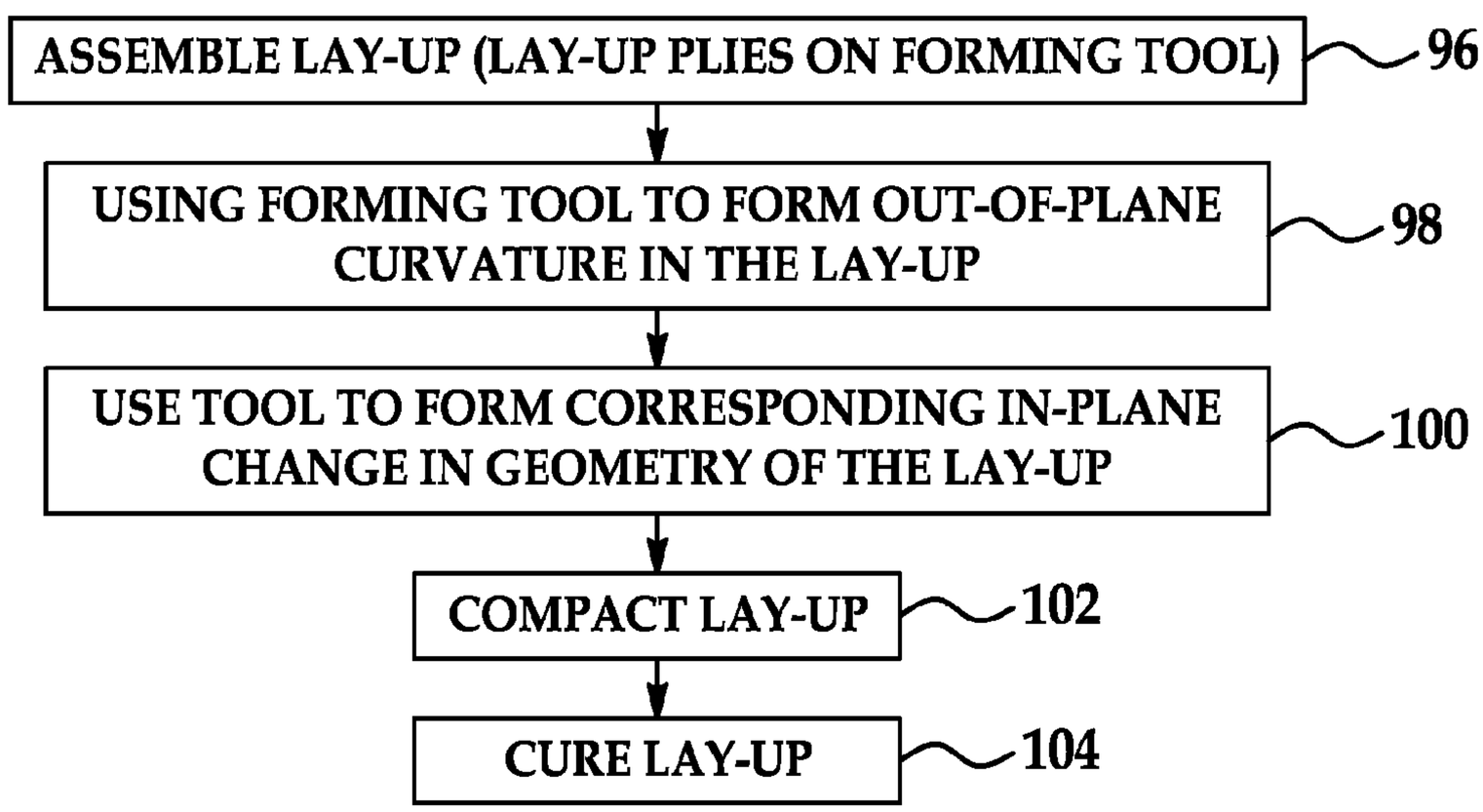

ASSEMBLE LAY-UP (LAY-UP PLIES ON FORMING TOOL)
96
USING FORMING TOOL TO FORM OUT-OF-PLANE CURVATURE IN THE LAY-UP
98
USE TOOL TO FORM CORRESPONDING IN-PLANE CHANGE IN GEOMETRY OF THE LAY-UP
100
COMPACT LAY-UP
102
CURE LAY-UP
104

FIG. 13

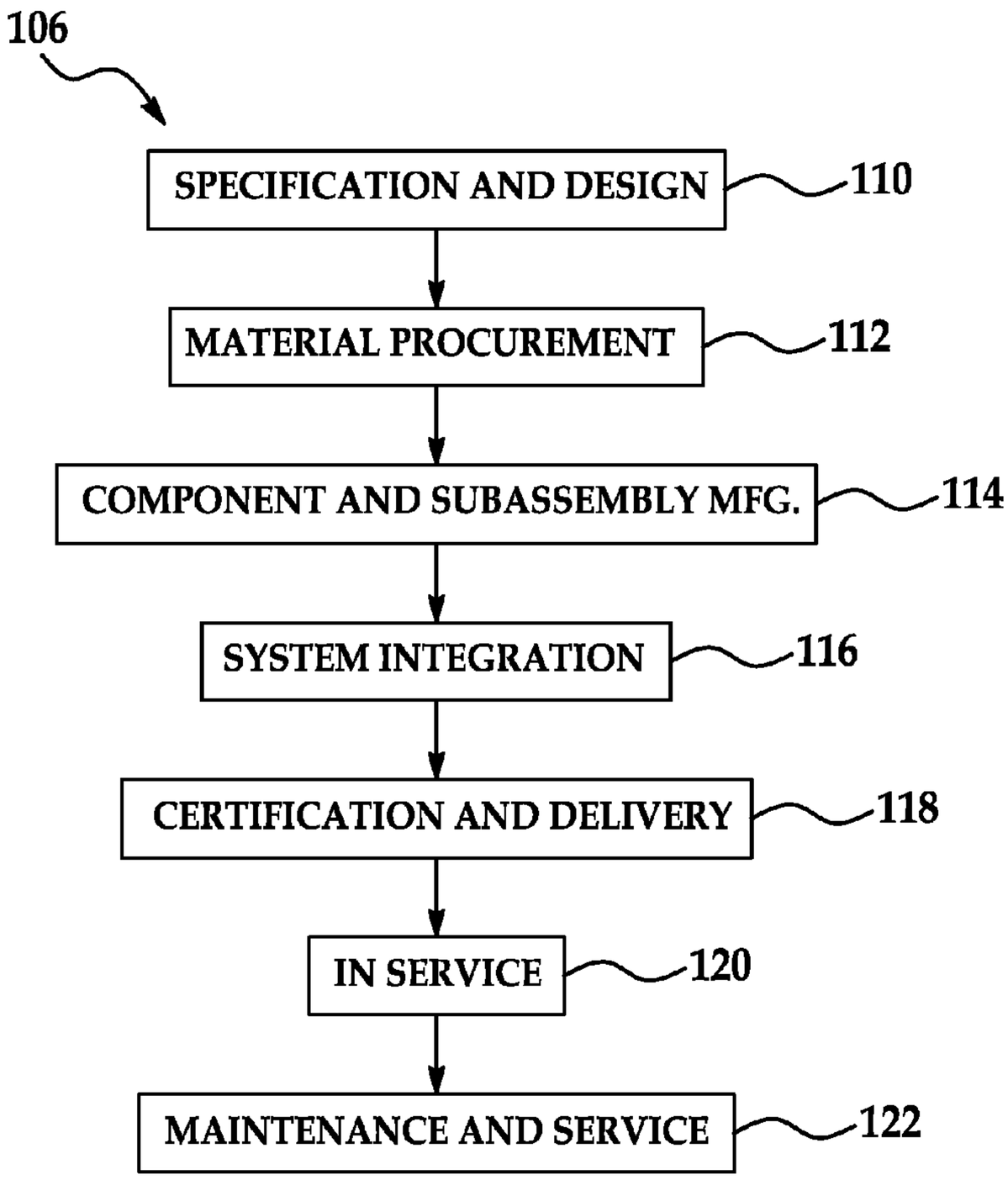

106
SPECIFICATION AND DESIGN
110
MATERIAL PROCUREMENT
112
COMPONENT AND SUBASSEMBLY MFG.
114
SYSTEM INTEGRATION
116
CERTIFICATION AND DELIVERY
118
IN SERVICE
120
MAINTENANCE AND SERVICE
122

FIG. 14

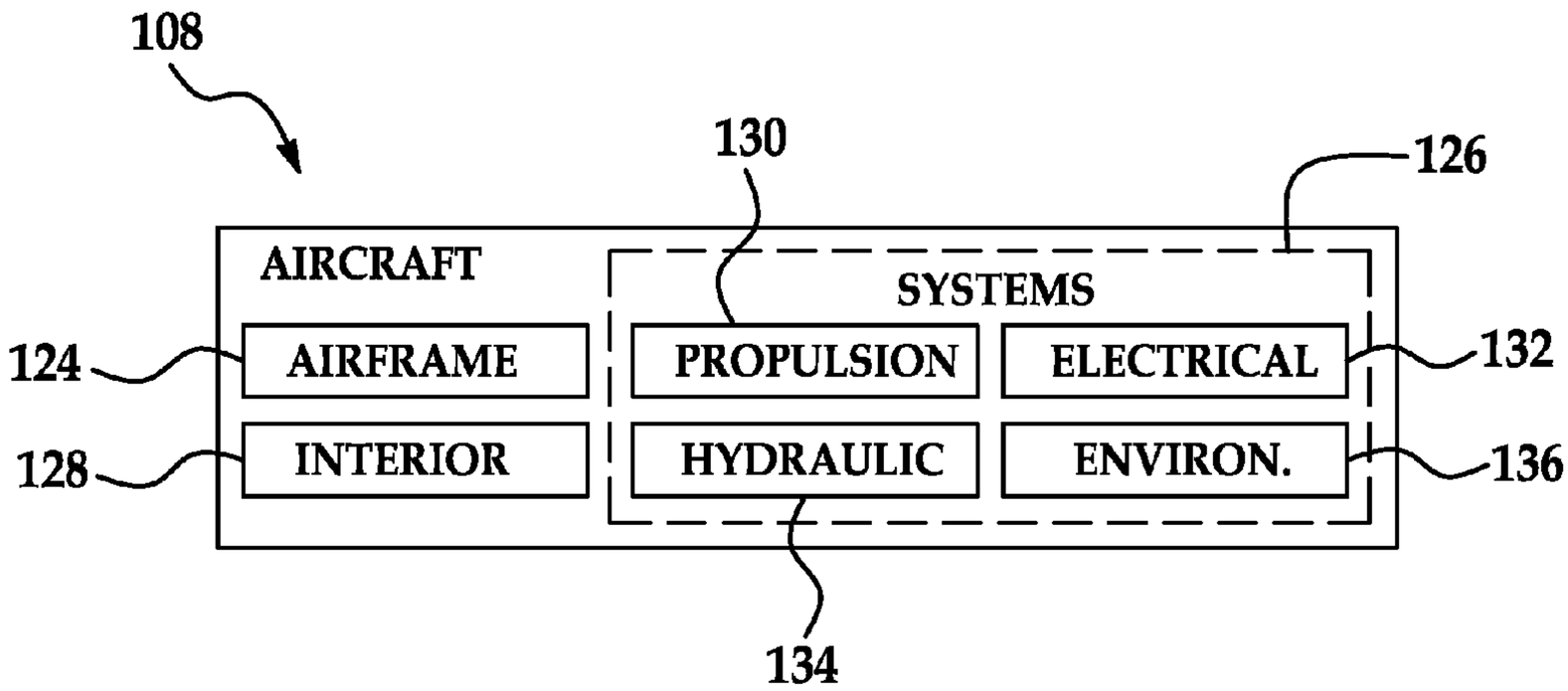

108
130
126
AIRCRAFT
SYSTEMS
124
AIRFRAME
PROPULSION
ELECTRICAL
132
128
INTERIOR
HYDRAULIC
ENVIRON.
136
134

FIG. 15

METHOD FOR FABRICATING HIGHLY CONTOURED COMPOSITE STIFFENERS WITH REDUCED WRINKLING

TECHNICAL FIELD

This disclosure generally relates to processes for fabricating composite structures, and deals more particularly with a method and apparatus for fabricating highly contoured, fiber reinforced composite stiffeners with reduced wrinkling.

BACKGROUND

During the process of laying up plies of unidirectional fiber reinforced pre-preg to form a composite laminate, such as a stiffener, wrinkles may sometimes form in one or more of the plies. Wrinkles are undesirable because they may result in voids or discontinuities in the cured laminate. Wrinkling may be due to, without limitation, a ply being deformed during the lay-up process and/or to relatively high friction between the unidirectional reinforcing fibers caused by the tackiness of the uncured resin. Wrinkling may be particularly problematic where a stack of unidirectional pre-preg plies is formed over a highly contoured tool surface.

In the past, in order to avoid wrinkling in contoured areas, pre-preg plies were cut into sections. The sections were then spliced together and individually placed on a contoured forming tool in order to achieve a desired curvature. However cutting and splicing the plies in this manner may have an undesirable effect on the properties of the cured part. In order to compensate for these potentially reduced properties, additional plies or doublers were sometimes required which may result in an increase in the thickness and weight of the stiffener. The cutting and splicing technique described above is also time consuming and labor intensive, results in material waste and may induce undesirable preload in the cured part. Also, when there is a need to add plies to the IML (inner mold line) it is necessary to add these plies gradually, at a specific rate, so that the contour of the IML is not too severe.

Accordingly, there is a need for a method and apparatus for fabricating highly contoured, fiber reinforced composite parts, such as stiffeners which may substantially reduce or eliminate ply wrinkling during the lay-up process, and which avoids the need for cutting and splicing plies.

SUMMARY

According to the disclosed embodiments, a method and apparatus are provided for fabricating highly contoured, fiber reinforced composite stiffeners, such as stringers, in which the reinforcing fibers are continuous throughout areas of curvature in the stiffener, and ply wrinkling is substantially reduced or eliminated. Ply wrinkling is avoided by tailoring the geometry of a lay-up mandrel to accommodate the stiffener's material characteristics. The material characteristics are accommodated by selectively widening or narrowing parts of the mandrel, depending upon the geometry of the stiffener part. These geometrical changes in the mandrel adjust the mandrel contour without requiring a change in the thickness of the stiffener part. Also, the disclosed method may allow increasing the allowable contour in areas where plies may need to be added, so that the rate at which the plies can be increased which may reduce the parasitic weight caused by past constraints on contour.

The tailored shape of the mandrel allows the fibers, especially the zero degree fibers, to traverse high contoured areas continuously and substantially without wrinkling. Structural properties of the cured stiffener may not be degraded since the higher stiffness plies, i.e. the zero degree plies of the composite, are not required to be cut and spliced, but rather extend continuously throughout the length of the stiffener's curvatures. Higher production rates may be realized using the disclosed fabrication method since the plies may not need to be altered (cut and spliced) as they are being laid up. Also, larger variations in stiffener contour may be accommodated, which in turn may permit more complex and weight efficient stiffener designs to be realized.

According to one disclosed embodiment, a method is provided of fabricating a substantially wrinkle-free fiber reinforced composite stiffener having an out-of-plane curvature. The method comprises providing a tool having the desired out-of-plane curvature and a corresponding in-plane curvature, forming a lay-up over the tool and compacting the layup. Forming the layup includes laying up a plurality of fiber reinforced plies over the tool and conforming the plies to the out-of-plane curvature and to the corresponding in-plane curvature of the tool. Conforming the plies to the out-of-plane curvature includes allowing the fibers in each of the plies to deform generally from a nominal linear orientation to a deformed orientation determined by the out-of-plane curvature. Compacting the lay-up includes compacting each of the plies to substantially eliminate any wrinkles in the ply and to set the deformed fiber orientation into the ply.

According to another disclosed embodiment, a method is provided of fabricating a substantially wrinkle-free, fiber reinforced composite stringer having a hat-shaped cross section and an out-of-plane curvature along its length. The method comprises assembling a layup by laying up fiber reinforced composite plies on a forming tool and using the forming tool to form the out-of-plane curvature in the layup. The method further comprises using the tool to form a corresponding in-plane curvature in the layup. In one embodiment, the hat-shaped stringer includes a cap, sides and bottom flanges, and the out-of-plane curvature is formed in the flanges of the stringer. The corresponding in-plane curvature is formed in the sides of the stringer.

According to another embodiment, a method is provided of making a mandrel for laying up a substantially wrinkle-free fiber reinforced composite stiffener having an out-of-plane curvature. The method comprises forming at least one out-of-plane curvature in a mandrel body, and forming an in-plane curvature in the mandrel body substantially corresponding to the out-of-plane for compensating for the effects of the out-of-plane curvature on composite plies laid up over the mandrel body. The at least one out-of-plane curvature is formed in a first tool face on the mandrel body, and the in-plane curvature is formed in a second tool face adjacent the first tool face.

According to a further embodiment, apparatus is provided for forming a substantially wrinkle-free fiber reinforced composite stiffener having an out-of-plane curved section along its length. The apparatus comprises a mandrel on which fiber reinforced composite plies may be formed. The mandrel has a first tool face including a section substantially matching the out-of-plane curved section of the stiffener, and a second tool face that includes a section having an in-plane curved section substantially corresponding to the out-of-plane curve section in the first tool face. The first and second tool faces extend traverse and are contiguous to each other.

According to still another embodiment, apparatus is provided for fabricating a fiber reinforced, substantially wrinkle-free composite stringer having an out-of-plane curvature. The apparatus comprises a stringer mandrel having an out-of-plane curvature and a corresponding in-plane change in mandrel geometry.

BRIEF DESCRIPTION OF THE ILLUSTRATIONS

FIG. **1** is an illustration of a perspective view of a section of an airplane fuselage.

FIG. **2** is an illustration of a longitudinal sectional view of a stringer used in the fuselage of FIG. **1**, and having an out-of-plane curvature conforming to a curvature in the fuselage skin.

FIG. **3** is an illustration of a sectional view taken along the line **3-3** in FIG. **2**.

FIG. **4** is an illustration of a plan view of the stringer shown in FIGS. **2** and **3**.

FIG. **5** is an illustration of a perspective view of a mandrel having a stringer layup formed thereon.

FIG. **6** is an illustration of an isometric view of the mandrel shown in FIG. **5**.

FIG. **7** is an illustration of a perspective view of a portion of a single ply, showing the position of the fibers having been laid up on, but not yet conformed to the geometry of the mandrel shown in FIG. **6**.

FIG. **8** is an illustration similar to FIG. **7**, but showing the ply fibers having been conformed to the geometry of the mandrel following compaction.

FIG. **9** is an illustration of a perspective view showing examples of stiffener shapes that may be formed using the disclosed method and apparatus.

FIG. **10** is an illustration of a perspective view of a set of tooling compacting the layup shown in FIG. **5**.

FIG. **11** is an illustration of a perspective view of the mandrel and one of the compaction tools shown in FIG. **10**.

FIG. **12** is an illustration of a flow diagram of one method of forming a stiffener having an out-of-plane curvature.

FIG. **13** is an illustration of another method of forming a stiffener having an out-of-plane curvature.

FIG. **14** is a flow diagram of aircraft production and service methodology.

FIG. **15** is a block diagram of an aircraft.

DETAILED DESCRIPTION

Referring to FIGS. **1-4**, the disclosed embodiments relate to a method and apparatus for fabricating unidirectional fiber reinforced composite laminate stiffeners **20** having an out-of-plane curvature **36** along one or more sections **40** along their length, including stiffeners **20** having compound contours. The stiffeners **20** may be used in a variety of applications. For example, FIG. **1** illustrates an airplane fuselage **26** having an outer skin **24** attached to spaced apart, barrel frames **22** and longitudinally extending, circumferentially spaced stiffeners **20** sometimes referred to as stringers **20**. The stringers **20** are attached to and function to stiffen the skin **24**. As will be discussed below, the skin **24** may have one or more undulations or curvatures **34** (FIGS. **2** and **3**) to which the stringers **20** may be required to conform.

Referring particularly to FIGS. **2**, **3** and **4**, in the illustrated example, the stringer **20** used to stiffen the skin **24** is hat-shaped in cross section, although other cross sectional shapes are possible, as will be discussed in more detail below. The stringer **20** comprises a generally flat cap **28** connected by sidewalls **30** to laterally extending flanges **32** that substantially conform and are secured to the inside surface **35** of the skin **24** by any suitable means. In the illustrated embodiment, the sidewalls **30** extend substantially normal to the cap **28** and flanges **32**, however, in other examples the sidewalls **30** may be inclined relative to the cap **28** and/or flanges **32**. The flanges **32** include an out-of-plane curvature **36** extending along section **40** of the stringer **20**, which substantially matches the curvature **34** in the skin **24**, so that the flanges **32** substantially conform to the skin **24** in the section **40** of curvature. As used herein, "out-of-plane curvature" refers curvatures which are not substantially within the plane of the plies in the flanges **32**, or within planes that extend parallel to the plane of plies in the flanges **32**.

During the ply layup and forming process, the out-of-plane curvature **36** in the flanges **32** causes the plies in the flanges **32** to place tension on plies in the sidewalls **30** along section **40**. This tension ordinarily would tend to cause the plies in the sidewalls **30** to draw away from the forming tool (not shown) resulting in ply wrinkles during the forming process and prior to curing, particularly where the stringer is fabricated by forming an flat stack of plies over a contoured tool (not shown), in part because friction between the pre-preg plies make it more difficult for the plies to move relative to each other and to conform to the contours of the tool.

In order to accommodate such material characteristics of the plies and reduce or eliminate ply wrinkling (not shown in FIGS. **2** and **3**), the plies are laid up and formed in a manner that results in the stringer **20** having in-plane changes in geometry corresponding to the out-of-plane curvature **36**. In the illustrated embodiment these in-plane changes in geometry comprise an outward curvature **41** of the sidewalls **30** within section **40**, immediately adjacent the out-of-plane curvature **36**. The outward curvature **41** of the sidewalls **30** has a radius of curvature "R" (FIG. **4**) substantially matching the radius of curvature "R" (FIG. **2**) of the out-of-plane curvature **36**, so that sidewall curvature **41** is essentially a mirror image of the flange curvature **36**. As a result, the sidewalls **30** extend smoothly through section **40** of the stringer **20**, without substantial wrinkling.

As a result of the in-plane sidewall curvature **41**, the cap **28** is provided with a downward curvature **38** of radius "R" resulting in a reduction in the height "H" of the cap **28** and a contoured widening "W" along the section **40**. This contouring of the cap **28** reflects the in-plane changes in the sidewalls **30**.

FIG. **5** illustrates a tool mandrel **42** on which a multi-ply, pre-preg laminate lay-up **44** may be formed as part of the process of fabricating the stringer **20** shown in FIGS. **2-4**. Unidirectional fiber reinforced plies **45** are laid up by draping them over the mandrel **42** to form the layup **46**. In one embodiment, an ordered flat stack (not shown) of pre-preg plies is laid up according to a predefined ply schedule (not shown) which may specify the number, order and fiber orientation of the plies in the stack. The flat ply stack is then draped over the tool mandrel **42** in the direction shown by the arrow **60** in FIG. **6**, and conformed to the contours of the mandrel **42**.

The tool mandrel **42** includes a bottom tool face **48** having an out-of-plane curvature **46** which corresponds in length "L" and radius "R" to the out-of-plane curvature **36** in the flanges **32** of the cured stringer **20**. FIG. **5** also illustrates the corresponding in-plane changes in geometry of the stringer lay-up **44**, comprising the in-plane, outward curvature **41** of the sidewalls **30**. In effect, the inner mold line (IML) contour of the mandrel **42** is rotated +/−90 degrees so that its contour is reflected in the cap **28** and sidewalls **30** of the stringer **20** (FIG. **2***a*

Referring now to FIG. **6**, the mandrel **40** comprises a mandrel body **55** having a top tool face **58**, side tool faces **56** and bottom tool faces **48** which respectively form the IML of the cap **28**, sidewalls **30** and flanges **32** of the stringer **20** (FIG. **3**). Each of the bottom tool faces **48** has a curvature **46** of radius "R" and length "L", as previously described in connection with FIG. **5**. The mandrel **42** also has an in-plane change in

geometry, corresponding to the out-of-plane curvature **46** along the length "L" of the out-of-plane curvature **46**. This in-plane change in geometry comprises an outward curvature **49** in the side tool faces **56** which substantially matches the radius "R" and length "L" of the out-of-plane curvature in the bottom tool faces **48**. The top tool face **58** includes a downwardly curved section which substantially matches the radius "R" and length "L" of the out-of-plane curvature in the bottom tool faces **48**. The curvature **49** in the side tool faces **56** results in an increase in the width **54** of the top tool face along the length "L", as well as a reduced height shown by the numeral **51**.

The in-plane change in geometry of the mandrel **42** that is needed to compensate for the affects on the ply material caused by the out-of-plane curvature **46** is determined by the location, geometry and dimensions of the out-of-lane curvature **46**. In the illustrated embodiment, the out-of-plane curvature **46** has a radius "R" and extends along a length "L" of the mandrel **42**, consequently, an in-plane plane change in mandrel geometry is required that also has a radius "R" and length "L", formed in a manner that compensates for the "pull" on the ply material overlying the mandrel side tool face **56**. This pull on the ply material is caused by the ply material being drawn down into the curvature **46** in the adjacent bottom tool face **48** during the forming process. The side tool faces **56** are curved in the direction that the material is being pulled as a result of being drawn down into the out-of-plane curvature **46**, i.e., the tool faces **56** are curved outwardly in the illustrated example to generally match the outward displacement of the ply material caused by ply material "pull" generated on the bottom tool faces **48** by the out-of-plane curvature **46**. The amount of change in the in-plane geometry required to compensate for the affects on ply material caused by an out-of-plane curvature may also depend in part on the angle θ between two adjacent sides of a forming tool, such as the adjacent tool faces **48** and **56** on mandrel **42**.

Referring now to both FIGS. **7** and **8**, FIG. **7** illustrates two portions **67**, **69** of a ply **45** with unidirectional fibers **66** having a zero degree fiber orientation after being draped over the mandrel **42** shown in FIG. **5**, but before being compacted to conform to the features of the mandrel **42**. The zero degree fibers **66** extend substantially parallel to each other prior to being pressed against the mandrel **42**. At this point, one portion **67** of the ply **45** overlies one of the side tool faces **56**, and the other portion **69** overlies one of the bottom tool faces **48**. Referring to FIG. **8**, during compaction, the fibers **66** are deformed so as to conform to the out-of-plane curvature **46** (FIG. **6**) on the bottom tool face **48**, resulting in a section **70** of the fibers **66** assuming the downward curvature shown at **52** which substantially matches the out-of-plane curvature **46** of the mandrel **42** shown in FIG. **6**. Similarly, the fibers **66** in the ply portion **67** are deformed during compaction to assume an outward curvature **41** substantially matching the curvature of the side tool face of the mandrel **42** shown in FIG. **6**. During the compaction process, the fibers **66** deform generally from a nominal linear orientation shown in FIG. **6** to the deformed orientations **52**, **41** shown in FIG. **8** which are respectively determined by the out-of-plane curvature **46** on the bottom tool face **48** of the mandrel **42** of FIG. **6** and the corresponding change in geometry **49** in the side tool face **56** of the mandrel **42**.

The hat-shaped stringer **20** described above is merely illustrative of a wide range of stiffener configurations that may be formed using the disclosed method and apparatus. For example, as shown in FIG. **9**, the disclosed method and apparatus may be employed to produce at least portions of substantially wrinkle free stiffeners that may be used as stringers or for other purposes, which have cross sections corresponding to a modified hat **20***a* having inclined sidewalls **64**, an "I" **20***b*, a "C" **20***c*, a "Z" **20***d*, an "L" **20***d* and a "J" **20***e*.

FIGS. **10** and **11** show additional details of tooling **74** used to form and compact the stringer layup **44**. A pair of compaction tools **76**, **78** is used to compact the layup **44** against the mandrel **42**. Compaction may be achieved, for example and without limitation, by using conventional vacuum bag and/or autoclave processing. As best seen in FIG. **11**, each of the compaction tools **78** includes a flange **80**, sidewall **82** and bottom **84** which respectively compact and apply pressure to the cap **28**, sidewalls **30** and flanges (FIG. **3**) of the stringer layup **44**. The flange **80** and bottom **84** each include an out-of-plane curvature **46***a* that respectively correspond to the curvatures **46** in the top tool face **58** and bottom tool face **48** of the mandrel **42**. Similarly, the side **82** of the compaction tool **78** includes a curved section **47***a* that substantially matches that of the side tool faces **56** of the mandrel **42**.

Attention is now directed to FIG. **12** which illustrates the steps of a method of fabricating a substantially wrinkle-free, fiber reinforced composite stiffener, such as the previously discussed stringer **20**. Beginning at step **86**, a tool **42** is provided having the desired out-of-plane curvature **46** and corresponding in-plane change in geometry **47**. Then at step **88**, a layup **44** is formed over the tool **42** by laying up successive plies **45** (FIG. **5**) of unidirectional fiber reinforced pre-preg, with fiber orientations corresponding to a desired ply schedule (not shown). Alternatively, the layup **44** may be pre-formed as a flat stack (not shown) of ordered plies **45**, and the ply stack may be formed over the tool **42**. Each of the plies **45**, or the ply stack is laid by draping the ply **45** (or stack) over the mandrel **42** in the direction **60** shown in FIG. **5**. At step **90**, each of the plies **45** or the ply stack is conformed to the tool faces on the mandrel **42**, including the out-of-plane curvature **46** and the corresponding in-plane curvature **49** which represents the in-plane change in geometry **47** of the mandrel **42**. At step **92**, the layup **44** is compacted which may include the use of compaction tools **76**, (FIGS. **10** and **11**) and vacuum bag processing. Finally, at step **94**, the layup **44** is cured.

FIG. **13** illustrates another embodiment of a method for fabricating a stringer having an out-of-plane curvature **46**. Beginning at **96**, a layup **44** (FIG. **5**) is assembled by successively laying up plies **45** of unidirectional fiber pre-preg on a suitable forming tool, such as the mandrel **42**, or by laying up the plies **45** as an order flat stack of the plies. Then at **98**, the tool **42** is used to form an out-of-plane curvature in the layup **44**, and at **100**, the tool **42** is used to form a corresponding in-plane curvature and change in geometry **41** in the layup **44**. At step **102**, the layup **44** is compacted, and is cured at step **104**.

Referring next to FIGS. **14** and **15**, embodiments of the disclosure may be used in the context of an aircraft manufacturing and service method **106** as shown in FIG. **14** and an aircraft **108** as shown in FIG. **15**. During pre-production, exemplary method **106** may include specification and design **110** of the aircraft **108** and material procurement **112**. During production, component and subassembly manufacturing **114** and system integration **116** of the aircraft **108** takes place. The disclosed method and apparatus may be used to fabricate highly contoured stiffeners that are integrated into subassemblies used in step **114**. Thereafter, the aircraft **108** may go through certification and delivery **118** in order to be placed in service **120**. While in service by a customer, the aircraft **108** may be scheduled for routine maintenance and service **122** (which may also include modification, reconfiguration, refurbishment, and so on).

Each of the processes of method **106** may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any number of vendors, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

As shown in FIG. **15**, the aircraft **108** produced by exemplary method **106** may include an airframe **124** with a plurality of systems **126** and an interior **128**. Examples of high-level systems **126** include one or more of a propulsion system **130**, an electrical system **132**, a hydraulic system **134**, and an environmental system **136**. Any number of other systems may be included. Stiffeners and other composite components fabricated by the disclosed method and apparatus may be used in the airframe **124** or in the interior **124**. Although an aerospace example is shown, the principles of the invention may be applied to other industries, such as the automotive industry.

The apparatus embodied herein may be employed during any one or more of the stages of the production and service method **106**. For example, components or subassemblies corresponding to production process **114** may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft **108** is in service. Also, one or more apparatus embodiments may be utilized during the production stages **114** and **116**, for example, by substantially expediting assembly of or reducing the cost of an aircraft **108**. Similarly, one or more apparatus embodiments may be utilized while the aircraft **108** is in service, for example and without limitation, to maintenance and service **122**.

Although the embodiments of this disclosure have been described with respect to certain exemplary embodiments, it is to be understood that the specific embodiments are for purposes of illustration and not limitation, as other variations will occur to those of skill in the art.

What is claimed:

1. A method of fabricating a fiber reinforced composite stiffener that is substantially wrinkle-free, the method comprising:

using a tool, the tool having a sidewall, the sidewall including a first portion along a first length that is less than a total length of the sidewall, the sidewall further including a second portion along a second length that is less than the total length and a third portion along a third length that is less than the total length, the first portion being between the second portion and the third portion, the first portion having an out-of-plane curvature and an in-plane curvature, the second portion having a second curvature different than the in-plane curvature and the out-of-plane curvature, the third portion having the second curvature, the tool further having a bottom tool face along the sidewall and connected to the sidewall at an angle, the bottom tool face also having the out-of-plane curvature along the first length, and the bottom tool face further having the second curvature along the second length and the third length;

using includes forming a lay-up over the tool by laying up a plurality of fiber reinforced composite plies over the tool, including simultaneously conforming the plurality of fiber reinforced composite plies to the first length and the second length along both the sidewall and the bottom tool face; and

compacting the lay-up.

2. The method of claim **1**, wherein reinforcing fibers in each of the plurality of fiber reinforced composite plies have a substantially unidirectional fiber orientation.

3. The method of claim **2**, wherein conforming the plurality of fiber reinforced composite plies to the out-of-plane curvature includes allowing the reinforcing fibers in each of the plurality of fiber reinforced composite plies to deform generally from a nominal linear orientation to a deformed orientation determined by the out-of-plane curvature.

4. The method of claim **3**, wherein conforming the plurality of fiber reinforced composite plies to the in-plane curvature includes allowing the reinforcing fibers in each of the plurality of fiber reinforced composite plies to deform generally from their nominal linear orientation to the deformed orientation as also determined by the in-plane curvature of the tool.

5. The method of claim **3**, wherein compacting the lay-up includes compacting the plurality of fiber reinforced composite plies to substantially eliminate any wrinkles in the plurality of fiber reinforced composite plies and to set deformed fiber orientations into the plurality of fiber reinforced composite plies.

6. The method of claim **1**, wherein fibers in at least certain of the plurality of fiber reinforced composite plies extend substantially continuously through a length of the substantially wrinkle-free fiber reinforced composite stiffener.

7. The method of claim **1** wherein the first portion is lower in height relative to the second portion, in both the sidewall and the bottom tool face.

8. A method of fabricating a substantially wrinkle-free fiber reinforced composite stringer having a hat-shaped cross section, an in-plane curvature along a length of the composite stringer, and an out-of-plane curvature along the length, the method comprising:

assembling a lay-up by laying up fiber reinforced composite plies on a forming tool, the forming tool having a sidewall, the sidewall including a first portion along a first length that is less than a total length of the sidewall, the sidewall further including a second portion along a second length that is less than the total length and a third portion along a third length that is less than the total length, the first portion being between the second portion and the third portion, the first portion having the out-of-plane curvature and the in-plane curvature, the second portion having a second curvature different than the in-plane curvature and the out-of-plane curvature, the third portion having the second curvature, the forming tool further having a bottom tool face along the sidewall and connected to the sidewall at an angle, the bottom tool face also having the out-of-plane curvature along the first length, and the bottom tool face further having the second curvature along the second length and the third length;

forming the out-of-plane curvature in the lay-up along both the sidewall and the bottom tool face using the forming tool; and

while forming the out-of-plane curvature, also forming the in-plane curvature in the lay-up along both the sidewall and the bottom tool face using the forming tool, such that forming the out-of-plane curvature and forming the in-plane curvature also forms the hat-shaped cross section in a manner such that different cross sections along the length change dimensions relative to each other as a result of the out-of-plane curvature.

9. The method of claim **8**, wherein the substantially wrinkle-free fiber reinforced composite stringer includes a cap, sidewalls, and bottom flanges, and wherein the out-of-plane curvature is formed in the bottom flanges of the stringer.

10. The method of claim **8**, wherein the in-plane curvature is formed in the sidewalls of the substantially wrinkle-free fiber reinforced composite stringer.

11. The method of claim **8**, wherein forming the out-of-plane curvature and forming the in-plane curvature includes allowing fibers in each of the fiber reinforced composite plies to deform generally from a nominal linear orientation to a deformed orientation determined by the out-of-plane curvature and the in-plane curvature.

12. The method of claim **8** wherein the first portion is lower in height relative to the second portion, in both the sidewall and the bottom tool face.

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