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ABSTRACT OF THE DISCLOSURE

A composite structure having at least one radially extending part is provided. The composite structure is formed with ply layers. At least one of the ply layers used to form the radially extending part has fibers oriented at 17.5 to 27.5 degrees in relation to an edge of the ply layer.
RADIALLY EXTENDING COMPOSITE STRUCTURES

BACKGROUND
[0001] In aerospace applications there is a need for light weight high strength structures. To meet these requirements fiber reinforced composite materials are often used. Sometimes the structures include radially extending parts. Laying up plies of material in forming radially extending parts leads either to the formation of defects such as wrinkles, which weakens the part, or cannot be achieved since the fiber cannot be stretched radially. Darting can be used to lessen the formation of wrinkles and allow for radial changes, but darting itself weakens the part. This invention provides a method of laying up fiber plies in a radially extending part without darting and without the formation of wrinkles or necessity of darts.

[0002] For the reasons stated above and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art for an improved radially extending composite structures.

SUMMARY OF INVENTION
[0003] The above-mentioned problems of current systems are addressed by embodiments of the present invention and will be understood by reading and studying the following specification. The following summary is made by way of example and not by way of limitation. It is merely provided to aid the reader in understanding some of the aspects of the invention.

[0004] In one embodiment, a composite structure is provided. The composite structure includes a radially extending part that is formed with ply layers. At least one of the ply layers used to form the radially extending part has fibers oriented at 17.5 to 27.5 degrees in relation to an edge of the ply layer.
BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The present invention can be more easily understood and further advantages and uses thereof more readily apparent, when considered in view of the detailed description and the following figures in which:

[0006] Figure 1 is a top view a radially extending part of one embodiment of the present invention;

[0007] Figures 2A and 2B are side perspective views of composite structures having radially extending parts of another embodiment of the present invention;

[0008] Figure 3 is a side perspective view of a tool used to form composite structures of an embodiment of the present invention;

[0009] Figures 4A, 4B, 4C and 4D illustrate possible fiber orientations of embodiments of the present invention;

[0010] Figure 5A is an illustration of patterned flags of one embodiment of the present invention;

[0011] Figure 5B is an illustration of spliced flags of one embodiment of the present invention;

[0012] Figure 5C is a close up view of a spliced area of Figure 5B;

[0013] Figure 5D is a top view of a produced layer of ply having a desired fiber orientation of one embodiment of the present invention;

[0014] Figure 6 illustrates the orientation of fibers in adjacent ply layers of one embodiment of the present invention;

[0015] Figure 7 is an illustration of a forming head of an embodiment used to form ply layers;

[0016] Figure 8 is a forming machine used to form composite structures of one embodiment of the present invention; and
[0017] Figure 9 illustrates a formation flow diagram of one embodiment of the present invention.

[0018] In accordance with common practice, the various described features are not drawn to scale but are drawn to emphasize specific features relevant to the present invention. Reference characters denote like elements throughout Figures and text.

DETAILED DESCRIPTION

[0019] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof, and in which is shown by way of illustration specific embodiments in which the inventions may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that changes may be made without departing from the spirit and scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the claims and equivalents thereof.

[0020] Embodiments of the present invention provide methods and apparatus for forming composite structures with radially extending parts without the need for daring and without the formation of wrinkles that can weaken the structure. In embodiments, plies of fiber having select orientations are laid up one at a time. Materials used to form the composite structures are generally described as ply layers. The ply layers can be made of any materials with fibers (or plies) that exhibit desired characteristics including but not limited to prepreg material and dry fiber material. The prepreg material and the dry fiber material can include, but is not limited to tapes, woven fabrics, non-woven fabrics and non-crimp fabrics. The orientation of the fibers (or plies) within the materials are described further below. Example orientations of fibers in a ply layer are +22.5/-67.5 degrees or -22.5/+67.5 degrees. In fabric embodiments the fibers have at least two fiber orientations per layer. That is, two sets of fibers with orientations that are typically orientated 90 degrees apart from each other are present in fabric embodiments. For example, fiber orientations in a fabric include 22.5 and 112.5 degrees and -22.5 and 67.5 degrees. Due in part to variations in formed ply layers, the above example orientation degrees
can vary. In some cases, the orientation degrees can vary up to 5 degrees or more. In a tape embodiment, the fibers have only one fiber orientation.

[0021] Referring to Figure 1, an example of a radially extending composite structure 100 is provided. In particular, Figure 1 illustrates a top view of a radially extending composite structure 100. The composite structure 100 in this example is annular shaped. As this example illustrates, the part extends radially about a center point from an inner edge 103 to an outer edge 104 of the composite structure 100. Figures 2A and 2B illustrate further full circumference composite structures 200 and 202 that include radially extending parts 204, 206, 208 and 210 respectively. Figure 3 illustrates an example of a tool 300 that can be used to form the full circumference composite structures 200 and 202.

[0022] As discussed above, embodiments use specific fiber orientations in the ply layers. Examples of different orientations used in embodiments are provided in Figures 4A, 4B, 4C and 4D. In particular, Figure 4A illustrates a fiber orientation of 22.5 degrees. The 22.5 degrees is in relation to an edge of a ply layer that is further described below. The 0 degree line represents the edge of the ply layer. Figure 4B illustrates a -22.5 degree orientation. The Fiber orientations illustrated in Figures 4A and 4B would typically be used in ply layers prepreg and dry fiber tapes. Figure 4C illustrates two orientations of fibers, 22.5 degrees and 112.5 degrees. Figure 4D also illustrates two orientations of fibers, -22.5 degrees and 67.5 degrees. In particular, Figures 4C and 4D illustrate fibers in a fabric that have two sets of fibers each 90 degrees apart from each other.

[0023] Typically a stock supply roll of fibers is provided by suppliers in either a 90 degree orientation or a 0 degree orientation. However, the application of the 90 degree ply or 0 degree ply on radially extending parts requires darting (cut out sections) to the radius of the part. In embodiments of the present invention, ply rolls of material are made from the stock rolls to a desired orientation that does not require darting. Referring to Figure 5A, patterned cut flags 502 of material that have been pattern cut out of a supply roll to have a desired fiber orientation is illustrated. The patterned cut flags 502 having the desired fiber orientation are then spliced together as illustrated in Figure 5B. In one embodiment, the flags 502 are lined up with the ends
overlapping as illustrated in the close up view of area 504 which is illustrated in Figure 5C. The amount of the overlap is a function of the design requirements. An example, overlap is 0.5 inches. This overlap in some designs ensures that the load in a given ply can be transferred in shear to an adjacent ply subject to the strength of the resin used. Splice locations are staggered when laying up plies on a tool so they do not overlap. In embodiments, where no overlap is desired, the flags 502 are butt-spliced. In this embodiment, an additional ply can be added to the layup to compensate for the discontinuous material. As long as the splices are staggered, there is always the same number of continuous plies to carry the load. Figure 5D is at top view of a ply layer illustrating a produced ply layer 500 having a fiber orientation of 22.5 degrees. It will be understood, that lines 520 representing fibers are only provided to illustrate the fiber orientation in relation to an edge 522 of the ply layer 500. Fibers in an actual ply layer would be relatively close to each other.

In embodiments, composite structures are created by ply layers formed on a tool one ply at a time. In one embodiment, ply layers having alternating fiber orientations are used to form the composite structure. For example, in one embodiment, alternating ply layers having orientations of +22.5/-67.5 degrees and -22.5/+67.5 degrees are used to form the radially extending composite structures. An example of alternating ply layers 602 and 604 having orientations of +22.5/-67.5 degrees and -22.5/+67.5 degrees is illustrated in Figure 6. One method of applying and forming ply layers on a tool is with a forming head 726 and automatic ply feeder (dispensing device 724). An example of a forming head 724 can be found in commonly assigned US Patent No. 7,513,769 (Benson et al.) filed on July 30, 2004, entitled “Apparatus and Methods for Forming Composite Stiffeners and Reinforcing Structures” which is herein incorporated by reference. In particular, Figure 7 provides an exemplary example of a material dispensing device 724 and the forming head 726. Material 740 (e.g., a ply layer or prepreg cloth) having the desired fiber orientation is fed from a supply and tension roller 742 and over a redirect roller 744 as motivated by a pair of feed rollers 746. The material 740 passes beyond a cutting device 748 which may be used to cut the material to a specified length, width, or both such as described hereinabove with respect to other embodiments of the present invention. The material 740 is then disposed onto a portion of a tool 706A by a tack roller 750.

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[0025] It is noted that the tack roller 750 (and subsequent rollers encountered by the material 740) is shown in a first elevational view with a second, rotated elevational view depicted immediately therebeneath to provide additional understanding of how the material 740 is being shaped by the interaction of various rollers with the material 740 and the underlying tool 706A.

[0026] The forming head 726 includes a plurality of rollers 728A-728D used to shape and debulk material 740 disposed over the tool 706A (or over previously shaped material plies disposed on the tool 706A). Thus, for example, a first roller 728A engages the tool 706A to generally conform the material 740 to the shape of the tool 706A. Second, a set of rollers 728B may be used to press the material against the side walls 754 of the tool 706A. If desired, this may be accomplished with multiple sets of rollers 728B working from the upper portion of the tool 706A to the bottom portion as depicted in the rotated elevational views of the rollers 728B. Another set of rollers 728C may be used to press the material 740 into the interior lower corners 756 of the tool 706A. A squeegee 758 (or shoe) may be used to help pull wrinkles from the material at one or more intermediate locations among the rollers 728A-728D. Finally a set of rollers 728D may be used to press and form the flange members of the composite structure 702.

[0027] It is noted that the process of forming the composite structure 702 includes forming, shaping and debulking the material 740 from the inside out. In other words, the tack roller 750 applies pressure to the tool 706A and material 740 disposed thereon at the center, with subsequent rollers 728A-728D each sequentially applying pressure at a location further towards the outer edges of the material 740. Such a process has been determined to be efficient and effective in removing wrinkles and air gaps between laminar plies of material thereby producing a highly consolidated and debulked composite member.

[0028] A take-up roller 760 may be associated with the forming head 726 (or independently coupled with the carriage assembly 710) to collect carrier material 762 (also referred to as backing) which may be disposed on a surface of, for example, a prepreg material used to form the composite structure 702. The carrier material 762, which may include a suitable polymer material, not only keeps the prepreg material from adhering to itself when in rolled form (i.e., such as when on supply and tension roller 742) but also may remain on the material 740 while
the material 740 is being shaped, formed and debulked so that the various rollers 750 and 728A-728D do not stick to the material 740 or collect and build-up resin of a surface thereof. Additionally, the presence of such carrier material 762 may serve to protect the material 740 used to form a composite structure 702 when the various rollers 728 press and rub against the material 740 during forming of the composite structure 702.

[0029] Another example of a forming head 804 used to form ply layers is illustrated in Figure 8. Forming head 804 is part of a composite forming system disclosed in commonly assigned Patent Application No 12/615,908, entitled “Automated Composite Annular Structure Forming,” filed on November 10, 2009 which is incorporated in its entirety herein. Figure 8 illustrates a tool 800 that is mounted on a tool holding assembly 860 that is in turn rotationally coupled to a tool holding support 861. Ply layers are applied then and formed on the tool 600 in this embodiment. As illustrated, the tool 800 rotates in relation to the tool holding support 661 as the operator 612 applies the material (ply layer) 810 to the tool 800. The forming head 604 that includes forming rollers form the ply layer on the tool 800. Once, the ply layers have been formed, the forming head 804 is pulled back from the tool 800 via track 840. The tool 800 with the formed ply layers 810 can then be removed for curing to form a composite structure. For example, tool 800 forms a composite structure such as composite structures 200 and 202 in Figures 2a and 2b that have radially extending parts 204, 206, 208 and 210 respectfully. Embodiments are not limited to specific cross-sectional geometries of formed composite structures. Any geometry that includes radially extending parts has application.

[0030] Referring to Figure 9, a formation flow diagram 900 of a composite structure of an embodiment is illustrated. As discussed above, the process starts by making a ply layer. This process involves cutting flags from a stock supply having a desired orientation (902). The flags are then lined up end to end (904) and spliced together (906) to form the ply layer. The ply layer is then applied to a forming surface of a tool or mandrel (910). The ply layer on the tool is then formed on the forming surface of the tool (912). It is then determined if more ply layers are required to form the composite structure (914). If more ply layers are required (914), a ply layer having a desired fiber orientation is selected (916). As discussed above, in some embodiments it is desired to alternate the fiber orientations between adjacent ply layers. Once, the ply layer with
the desired orientation has been selected (916) it is applied to the forming surface of the forming tool at (910). Hence, ply layers are formed one at a time over each other until a desired number of layers have been reached at (914). Once, it is determined the ply layering is complete at (914), the formed ply layers on the tool are then cured (918) to form the desired composite structure.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement, which is calculated to achieve the same purpose, may be substituted for the specific embodiment shown. For example, slight variations in orientation of the fibers could be implemented with the same result. Hence, variations of 5 degrees or more may be possible. This application is intended to cover any adaptations or variations of the present invention. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.
CLAIMS:

1. A composite structure comprising:
   at least one radially extending part formed with ply layers, at least
   one of the ply layers used to form the radially extending part having fibers oriented
   at 17.5 to 27.5 degrees in relation to an edge of the ply layer.

2. The composite structure of claim 1, further comprising:
   at least one other ply layer having fibers orientated at -
   17.5 to -27.5 degrees in relation to the edge of the ply layer.

3. The composite structure of claim 1, further comprising:
   at least one other ply layer having fibers orientated at
   62.5 to 72.5 degrees in relation to the edge of the ply layer.

4. The composite structure of claim 1, further comprising:
   at least one other ply layer having fibers orientated at
   -62.5 to -72.5 degrees in relation to the edge of the ply layer.

5. The composite structure of claim 1, wherein the least one ply layer is
   made from a fabric having a first set of fibers and a second set of fibers, the first
   set of fibers and the second set of fibers having different orientations that are
   90 degrees from each other.

6. The composite structure of claim 5, wherein the first set of fibers
   have a fiber orientation of the 17.5 to 27.5 degrees and the second set of fibers
   have a fiber orientation of 107.5 to 117.5 degrees.

7. The composite structure of claim 6, further comprising at least one
   other ply layer being a fabric having a third set of fibers and fourth set of fibers, the
   third set of fibers and the fourth set of fibers having different orientations that are
   90 degrees from each other.
8. The composite structure of claim 7, wherein the third set of fibers have a fiber orientation of the -17.5 to -27.5 degrees and the fourth set of fibers have a fiber orientation of 62.5 to 72.5 degrees.

9. A composite structure comprising:

at least one radially extending part formed with material with fibers in at least one ply layer having first fibers in generally a 22.5 degree fiber orientation in relation to an edge of the ply layer.

10. The composite structure of claim 9, wherein the 22.5 degree orientation is generally a +22.5 degree orientation.

11. The composite structure of claim 9, wherein the 22.5 degree orientation is generally a -22.5 degree orientation.

12. The composite structure of claim 9, wherein the at least one ply layer is a plurality of ply layers having alternating orientations of first fibers generally +22.5 degrees and generally -22.5 degrees.

13. The composite structure of claim 9, wherein the at least one ply layer is a fabric layer also including second fibers in generally a 112.5 degree fiber orientation.

14. The composite structure of claim 9, wherein the at least one ply layer is a plurality of ply layers with adjacent ply layers having alternating fiber orientations.

15. A method of forming a composite structure having a radially extending portion, the method comprising:

applying ply layers one at a time on a forming surface of a tool configured to form a composite structure having at least one radially extending part, wherein fibers in at least one ply layer are oriented 17.5 to 27.5 degrees in relation to an edge of the at least one ply layer;

forming the ply layers on the forming surface of the tool; and
curing the formed ply layers to form the composite structure.

16. The method of claim 15, wherein the fibers in at least one other ply layer are oriented -17.5 to -27.5 degrees in relation to an edge of the at least one other ply layer.

17. The method of claim 15, wherein the fibers in at least one other ply layer are oriented 62.5 to 72.5 degrees in relation to an edge of the at least one other ply layer.

18. The method of claim 15, wherein the fibers in at least one other ply layer are oriented -62.5 to -72.5 degrees in relation to an edge of the at least one other ply layer.

19. The method of claim 15, wherein the fiber orientation of alternating ply layers is 90 degrees apart from each other.

20. The method of claim 15, wherein at least one ply layer is a first fabric layer having a first set of fibers and a second set of fibers, the first set of fibers having the 17.5 to 27.5 degree orientation and the second set of fibers having a 107.5 to 117.5 degree orientation.

21. The method of claim 20, wherein another ply layer is a second fabric layer having a third set of fibers and a fourth set of fibers, the fourth set of fibers having a -17.5 to -27.5 degree orientation and the fourth set of fibers having a 62.5 to 72.5 degree orientation.

22. The method of claim 15, further comprising:

producing material for a ply layer having fibers at a select orientation in relation to an edge of the ply layer.

23. The method of claim 22, wherein producing the material, further comprises:

pattern cutting flags from a stock supply of material to achieve a desired fiber orientation;
placing the flags end to end; and
splicing the flags together to form a ply layer having the select fiber orientation.

24. The method of claim 23, further comprising:

5 overlapping ends of the flags when splicing together.

25. The method of claim 15, wherein applying the ply layers to the tool further comprising:

applying the ply layer to the forming surface of the tool so that the spliced ends of adjacent ply layers do not align.

10 26. A composite structure comprising:

at least one radially extending part formed with ply layers, at least one of the ply layers used to form the radially extending part having fibers oriented at 62.5 to 72.5 degrees in relation to an edge of the ply layer.