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(71) **Applicant** *(for all designated States except US)*: **THE BOEING COMPANY** [US/US]; 100 North Riverside Plaza, Chicago, Illinois 60606-2016 (US).

(72) **Inventors; and**

(75) **Inventors/Applicants** *(for US only)*: **DAN-JUMBO, Eugene A.** [US/US]; 3333 189th Place SE, Bothell, Washington 98012 (US). **KELLER, Russell L** [US/US]; 22213 217th Ave SE, Maple Valley, Washington 98038 (US). **WESTERMAN, Everett A** [US/US]; 11018 SE 326th Street, Auburn, Washington 98092-4769 (US).

(74) **Agents**: **HALPERIN, Brett, L.** et al.; THE BOEING COMPANY, P.O. Box 2515, MC 110-SD54, Seal Beach, California 90740-1515 (US).

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(54) **Title**: PREDICTABLE BONDED REWORK OF COMPOSITE STRUCTURES USING TAILORED PATCHES

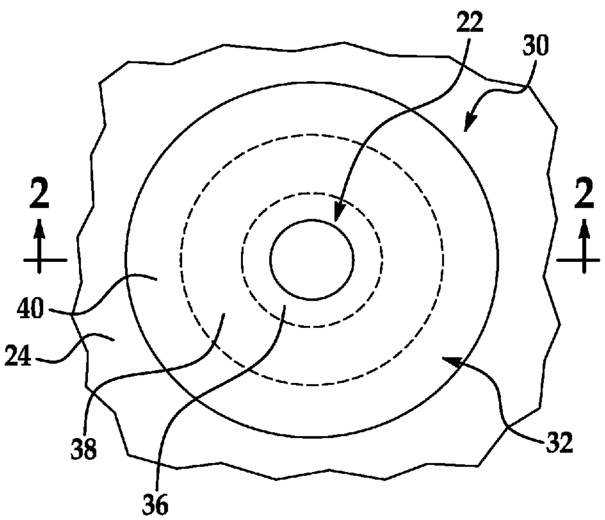

FIG. 1

(57) **Abstract**: A patch for reworking an inconsistent area in a composite structure includes a composite laminate patch and a layer of adhesive for bonding the laminate patch to the composite structure. The laminate patch has at least first and second regions for releasing strain energy around the inconsistent area respectively at different rates.

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PREDICTABLE BONDED REWORK OF COMPOSITE STRUCTURES USING TAILORED PATCHES

TECHNICAL FIELD

This disclosure generally relates to composite structures, and deals more particularly with a method and composite patch for reworking areas of composite structures containing inconsistencies.

BACKGROUND

Composite structures sometimes have localized areas containing one or more inconsistencies that may require rework in order to bring the structure within design tolerances.

In the past, one rework process was performed using a patch that was placed over the inconsistent area and secured to the parent structure using mechanical fasteners. This rework technique was desirable because the condition of the patch could be monitored over time by visually inspecting the fasteners. However, the use of fasteners may increase aircraft weight and/or drag on the aircraft, and may be esthetically undesirable in some applications.

In some applications, rework patches have been secured to a parent structure using a bonded joint, however this technique may also require the use of mechanical fasteners that provide secondary load paths forming an arrestment mechanism to limit the growth of an inconsistency. Furthermore, changes in a bonded joint securing a rework patch on a parent structure may not be easily monitored over time because the attaching mechanism of the joint or joint interface may not be visible.

Accordingly, there is a need for a rework patch and method of reworking inconsistent areas of composite structures, while allowing the condition of the reworked area to be monitored over time using visual or other types of non-destructive inspection techniques.

SUMMARY

The disclosed embodiments provide a rework patch and method of reworking composite structures using a bonded rework patch without the need for mechanical fasteners. The rework patch includes features that allow visual inspection of the condition of the reworked area over time and permit reliable prediction of future bond joint changes. Because the condition of the reworked area may be visually inspected and predictions made about future bond condition, the bonded rework patch and visual inspection technique may allow certification of the rework by aircraft certifying authorities.

According to one disclosed embodiment, a patch for reworking an inconsistent area of a composite structure comprises a composite laminate patch and a layer of adhesive for bonding the laminate patch to the composite structure. The laminate patch is adapted to cover the inconsistent area and has at least first and second regions for releasing strain energy around the inconsistent area respectively at different rates. The laminate patch may include a plurality of fiber reinforced composite laminate plies, wherein the plies in the first region possess characteristics that are different from those of the plies in the second region. The layer of adhesive may include at least first and second sections that respectively underlie and are substantially coextensive with the first and second regions of the laminate patch.

According to another embodiment, a composite rework patch is adapted to be adhesively bonded to a composite structure over an area containing inconsistencies in the structure. The rework patch comprises a plurality of laminated composite plies. The composite plies have multiple regions of differing interlaminar fracture toughness for controlling changes in the condition of the patch. The multiple regions may include first, second and third regions that are substantially concentric around the area of inconsistencies.

According to a further embodiment, a method is provided for reworking an area of a composite structure. The method includes fabricating a composite laminate patch and bonding the laminate patch to the composite structure in the rework area. Fabricating the laminate patch includes forming multiple regions respectively having differing interlaminar fracture toughnesses. Fabricating the patch may be performed by forming a layup of fiber reinforced polymer plies, including forming the multiple regions within the layup, and curing the layup. Forming the multiple regions may include providing the plies in each of the regions with respectively differing characteristics related to interlaminar fracture toughnesses.

The disclosed embodiments satisfy the need for a bonded composite rework patch and method of rework that allow rework of an inconsistent area in a composite structure, in which the condition of the rework can be visually monitored, and any change of the bonded joint may be predicted based on the visual inspection.

10. A composite rework patch adapted to be adhesively bonded to a composite structure over an area containing inconsistencies, comprising:

a plurality of laminated composite plies having multiple regions of differing interlaminar fracture toughness for controlling changes in the condition of the patch.

11. The composite rework patch of claim 10, wherein:

the multiple regions include first, second and third regions,

wherein the second region substantially surrounds the first region, and

the third region substantially surrounds the second region.

12. The composite rework patch of claim 10, wherein:

the multiple regions include first, second and third regions,

the second region has an interlaminar fracture toughness greater than that of the third region, and

the first region has an interlaminar fracture toughness greater than that of the second region.

13. The composite rework patch of claim 12, wherein:

the interlaminar fracture toughness of the third region is between approximately 0.5 and 1 in-lbs/in^2,

the interlaminar fracture toughness of the second region is between approximately 1.5 and 2.0 in-lbs/in^2, and

the interlaminar fracture toughness of the first region is greater than approximately 2.5 in-lbs/in^2,

14. The composite patch of claim 10, wherein:

the multiple regions include first, second and third regions,

the second region has an interlaminar fracture toughness greater than that of the first region, and

the third region has an interlaminar fracture toughness greater than that of the second region.

15. The composite patch of claim 10, wherein:

each of the plies include fiber reinforcement having a fiber orientation, and

the plies within the multiple regions have differing sequences of the fiber orientations.

16. The composite patch of claim 10, wherein at least one of the plies within one of the regions includes at least two sections respectively having fiber reinforcement with differing fiber orientations.

17. The composite patch of claim 10, wherein at one of the plies extends across at least two of the multiple regions.

24. A patch for reworking inconsistent areas in a composite aircraft structure, comprising:

a composite laminate patch including a plurality of plies of fiber reinforced polymer, the laminate patch including first, second and third substantially concentric regions, the second region having an interlaminar fracture toughness greater than that of the first region, and the third region having an interlaminar fracture toughness greater than that of the second region; and,

a layer of adhesive for bonding the laminate patch to the composite structure, the laminate patch including first, second and third sections of a structural adhesive respectively underlying the first, second and third regions of the laminate patch and forming a bonded joint between the laminate patch and the composite aircraft structure, the first, second and third sections of the adhesive layer releasing strain energy surrounding the inconsistent areas respectively at different rates, the first section being separated from the second section by a first gap and the second section being separated from the third section by a second gap.

25. A method of reworking an inconsistent area in a composite aircraft structure, comprising:

laying up multiple plies of fiber reinforced polymer;

dividing the plies into multiple, substantially concentric regions;

providing the multiple regions with differing interlaminar fracture toughnesses;

fabricating first, second and third sections of a structural adhesive;

arranging the first, second and third sections of adhesive in substantially concentric relationship respectively underlying the first, second and third regions of the laminate patch;

forming a first gap between the first and second sections of adhesive;

forming a second gap between the second and third sections of adhesive; and,

using the first, second and third sections of the adhesive to respectively form a bond joint between the first, second and third regions of the laminate patch and the composite aircraft structure, wherein the bond joint is divided into three regions that release strain energy surrounding the inconsistent area respectively at different rates.

BRIEF DESCRIPTION OF THE ILLUSTRATIONS

FIG. 1 is an illustration of a bonded rework patch on a composite structure.

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

FIG. 3 is an illustration of a plan view of the adhesive layer shown in FIG. 2.

FIGS. 3a-3c are illustrations of plan views respectively of sections of the adhesive layer shown in FIG. 3.

FIG. 4 is an illustration of a sectional view taken along the line 4-4 in FIG. 3.

FIG. 5 is an illustration of a plan view of a composite laminate patch forming part of the rework patch shown in FIG. 1.

FIG. 6 is an illustration of a sectional view taken along the line 6-6 in FIG. 5.

Fig. 7 is an illustration of a sectional view similar to FIG. 6, but showing details of a tailored laminate patch divided into regions having differing interlaminar toughness.

FIG. 8 is an illustration of a table showing a ply schedule for the differing regions of the tailored laminate patch shown in FIG. 7.

FIGS. 9-12 are illustrations of plan views respectively illustrating plies 1-4 in the laminate patch shown in FIG. 7.

FIG. 13 is an illustration of a plan view of the rework patch shown in FIG. 1, and illustrating a typical propagation path of a debonding.

FIGS. 14-16 are illustrations of sectional views showing progression of the debonding through regions of the patch.

FIG. 17 is an illustration of a flow diagram for a method for reworking an inconsistent area of a composite structure.

FIG. 18 is an illustration of a flow diagram of aircraft production and service methodology.

FIG. 19 is an illustration of a block diagram of an aircraft.

DETAILED DESCRIPTION

Referring now to FIGS. 1 and 2, according to the disclosed embodiments, a composite rework patch 30 is used to rework an inconsistent area 22 in a composite structure 24. As used herein, “inconsistent area”, “inconsistency” and “inconsistencies” each refer to a localized area in the composite structure 24 that may be outside of designed tolerances. The inconsistency 22 may comprise, for example and without limitation, a void, a dent, or a porosity that may occur at the time that the composite structure 24 is manufactured, or later during the service life of the composite structure 24.

The composite patch 30 comprises a composite laminate patch 32 which overlies the inconsistent area 22 and is bonded to the composite structure 24 by a layer 34 of a structural adhesive forming a bond joint 42. The size of the patch 30 may vary with the application and the dimensions of the inconsistent area 22. The adhesive layer 34 divides the bonded joint 42 and area 22 into first, second and third control regions 36, 38, 40 respectively, that may provide a graceful reduction of transition loads transmitted between the structure 24 and the patch 30. The first control region 36 is centrally located over the inconsistent area 22, and the second and third control regions 46, 48 may respectively comprise a pair of substantially concentric rings surrounding the centrally located first region 36. While the regions 36, 38, 40 are shown as being generally circular in the disclosed embodiment, a variety of other shapes are possible. Also, in other embodiments, the patch 30 may have only two control regions 36, 38, or may have more than three control regions 36, 38, 40.

The first control region 36 may exhibit favorable in-plane adhesive stresses. The second control region 38 may be referred to as a durability region and any disbond within this region between the patch 32 and the parent structure 24 may need to be evaluated and quantified in order to determine whether rework should be performed. The third control region 40, which may be dominated by in-plane shear and peeling moments, may affect the behavior of the entire structural bond between the patch 32 and parent structure 24.

Referring now particularly to FIGS. 2-4, the adhesive layer 34 may comprise a central section 44 surrounded by concentric ring shaped sections 46 and 48. The size and shape of the adhesive sections 44, 46, 48 generally correspond to the first, second and third control regions 36, 38, 40 respectively of the rework patch 30. Each of the adhesive sections 44, 46, 48 may comprise one or more plies of a commercially available structural adhesive which is generally available in film or sheet form that may be cut to the desired shape. The adhesive sections 44, 46, 48 may also be formed from a commercially available structural adhesive paste. As previously noted, multiple plies (not shown) of the adhesive sheet material may be built up to form a desired thickness “t” for each of the adhesive sections 44, 46, 48. The strength of the bond may be tailored using the thickness “t” between patch 32 and structure 24. In some applications only a single ply of adhesive sheet material may be required, while in other applications, more than one ply may be necessary, depending on the application and the thickness of the adhesive sheet.

In one embodiment, circumferential gaps “g” may be formed between adhesive sections 44, 46, 48 to aid in arresting the growth of potential debonding between the laminate patch 32 and the composite structure 24. A filler 50 may be placed in one or both of the gaps “g” to aid in the arrestment.

The properties of each of the adhesive sections 44, 46, 48 may be tailored in a manner that affects the rate at which first, second and third control regions 36, 38, 40 of the bond joint 42 respectively release strain energy. Tailoring of each of the adhesive sections 44, 46, 48 may be achieved by altering the dimensions of the adhesive sections 44, 46, 48, such as thickness “t” or width “w”, or by altering the form of the film, paste, scrim, etc., as well as by altering the structural properties of the adhesive layer, such as fracture toughness, peel or shear properties, or by providing the gap “g” between the adhesive sections 44, 46, 48. Fracture toughness may be described as the general resistance of a material to delaminate. Additionally, a spacer or filler 50 may be interposed between adhesive sections 44, 46, 48 to aid in arresting disbond growth.

The use of the tailored adhesive sections 44, 46, 48 may result in a bonded rework patch 30 that is divided into multiple control regions 36, 38, 40 that respectively release strain energy at different rates. The first, second and third control regions 36, 38, 40 provide for a graceful reduction of transition loads between the patch 32 and the structure 24, which may not only allow prediction of a course of disbond extension, but can allow assessment of the condition of the rework patch 30 through simple visual inspection, or other non-destructive inspection techniques. Although three control regions 36, 38, 40, are shown and discussed, more or less than three control regions may be possible.

The first control region 36 of the patch 30 which overlies the inconsistent area 22 exhibits favorable in-plane stresses that may suppress the stress concentration around the boundary of a disbond of the bonded joint 42. The global adhesive stresses within the first control region 36 may reduce the strain energy release rate necessary for extension of a disbond under maximum load limits applied to the composite structure 24.

The characteristics of the rework patch 30 within the second control region 38 may result in the release of strain energy at a rate greater than that of the first control region 36. Any disbond that may occur in the bond joint 42 within the second control region 38 may be anticipated by a fatigue durability disbond curve (not shown) which defines the work input required to initiate disbond growth. The characteristics of the third control region 40 are selected such that the strain energy release rate within the third control region 40 is greater than that of the second control region 38 to discourage disbond initiation and growth, as well as in-plane shear and peeling moments.

Attention is now directed to FIGS. 5 and 6 which illustrate a laminated patch 32 comprising multiple plies 52 of fiber reinforced polymer in which the plies 52 may be tailored in order to aid in achieving first, second and third control regions 36, 38, 40 respectively, having the desired strain energy release rates. Strain energy release rate within the laminated patch 32 may be tailored within the control regions 36, 38, 40 by selecting and/or arranging the plies such that the plies in each of the regions 36, 38, 40 have different characteristics. In other words, each of the regions 36, 38, 40 may have ply characteristics that are unique to that region. Thus, for example, the plies in region 38 may have characteristics that are different from those in regions 36 or 40, and the plies in region 36 may have characteristics that are different than those in regions 38 and 40. As used herein, “characteristics” and “ply characteristics” refer to, without limitation: the type, size or quantity of fiber reinforcement in a ply; ply thickness; gaps between the plies; materials, elements or structures placed between the plies; the number of plies; the type or density of matrix used in the ply; the layup orientation (angle) of each ply and/or the sequence of ply orientations in a stack of the plies.

The strain energy release rate within one of more of the control regions 36, 38, 40 may be tailored by forming a scarf or tapered joint (not shown) between the patch 32 and the structure 24. The strain energy release rate may also be tailored by providing gaps (not shown) in certain areas between plies 52 in a manner that may alter the mechanical properties of the laminated patch 32 in each of the control regions 36, 38, 40. Also, it may be possible to employ differing orientation sequences of the plies 52 in order to aid in achieving the defined control regions 36, 38, 40. Orientation refers to the layup angle or direction of reinforcing fibers in a ply, for example and without limitation, 0°, 30°, 60°, 90° and/or 0°, +45°, -45°, 90°.

In the example illustrated in FIGS. 5 and 6, the materials used in the plies 52 and/or the orientation sequences within the first control region 36 result in the highest rate of strain relief, while the selection of these materials and/or ply orientation sequences in second and third control regions 38 and 40 respectively result in intermediate and lowest rates of release of strain energy, respectively. In other embodiments, however, depending on the application, the third control region 40 may possess highest rate of strain energy relief, while the first control region 36 posses the lowest rate of strain energy relief.

Attention is now directed to FIG. 7 which illustrates a typical tailored laminate patch 32a comprising eight plies 52 of fiber reinforced polymer, before being compacted and cured into a consolidated laminate. When viewed in plan, the shape of the tailored laminate patch 32a, including regions 36, 38, 40, may be substantially the same as that of the patch 32 illustrated in FIG. 5. The plies 52 forming the tailored laminate patch 32a may be referred to as plies #1-#8. FIG. 8 is a table illustrating the ply orientations for the laminate patch 32a within regions 36, 38, 40 for each of the plies #1-#8, while FIGS. 9-12 show the constituent sections of plies 1-4.

As mentioned above in connection with FIGS. 5 and 6, the characteristics of the plies 52 may be different in each of the regions 36, 38, 40. The rate of release of strain energy in regions 36, 38 and 40 is related to the modulus or stiffness that defines the interlaminar toughness of the patch 32a in the respective region 36, 38, 40. In the disclosed embodiment, the first region 36 has the highest interlaminar fracture toughness, while the third region 40 possesses the lowest interlaminar fracture toughness. In one practical application for example, and without limitation, the interlaminar fracture toughness of the third region 40 has an interlaminar fracture toughness that may be between approximately 0.5 and 1.0 in-#/in^2, and the second region 38 has an interlaminar fracture toughness that may be between approximately 1.5 and 2.0 in-#/in^2. The first region 36 in this example has an interlaminar fracture toughness that may be equal to or greater than approximately 2.5 in-#/in^2. In other embodiments, however, the third region 40 may have the highest interlaminar fracture toughness and the first region 36 may have the lowest interlaminar fracture toughness, with the interlaminar fracture toughness of the second region 38 being between that of the first and third regions 36, 40, respectively.

The particular values of the interlaminar fracture toughness for the regions 36, 38, 40 will depend upon the application and the particular mechanical properties of the plies 52 that are present within the regions 36, 38, 40. Moreover, the values for the interlaminar fracture toughness within the regions 36, 38, 40 may be tailored to the properties of the adhesive layer 34 (see FIG. 3), including the sections 44, 46, 48 of the adhesive layer 34 so that the sections 44, 46, 48 of the adhesive layer 34 and the mechanical properties of the laminate patch 32a within regions 36, 38, 40 are suitably matched to provide maximum performance. Although not shown in FIG. 7, the sections 44, 46, 48 of the adhesive layer 34 respectively underlie, and may be substantially coextensive with the regions 36, 38, 40 of the laminate patch 32a.

As previously discussed, the interlaminar fracture toughness within the regions 36, 38, 40 may be controlled by using differing prepreg materials in the plies 52, and/or by overlapping the plies 52 between adjacent ones of the regions 36, 38, 40, and/or by using different ply orientation sequences within each of the regions 36, 38, 40. For example, FIG. 8 illustrates differing ply orientation sequences for plies #1-#8 within each of the regions 36, 38, 40. It can be seen for example, that in comparing the orientation sequence of the plies 52 for the second and third regions, 38, 40 respectively, ply #4 and ply #5 are oriented at 90° in the third region 40, but have a 0° orientation in the second region 38. As previously mentioned, ply orientation refers to the direction of orientation of unidirectional reinforcing fibers held in a polymer matrix, usually a prepreg, which forms each of the plies 52. The sequence of orientations of the plies #1-#8 for the first region 36 is different from the sequence of orientations for either the second or third regions, 38, 40.

Referring now particularly to FIGS. 7 and 9-12, it can be seen that ply #1 comprises a single, circularly shaped section 51 (FIG. 9) having a 0° degree fiber orientation relative to an orientation reference direction 69, which extends across all three regions 36, 38, 40. Ply #2 includes a circular center section 53 (FIG. 10) having a +45° fiber orientation, and an outer, ring shaped section 55 having a 90° orientation. As a result of the configuration of ply #2, region 36 has combined fiber orientations of 90° and +45° degrees, while regions 38 and 40 both have 90° fiber orientations. Ply #3 comprises a single section 57 (FIG. 11) within region 36 having a -45° fiber orientation, while in regions 38 and 40, gaps 49 (FIG. 7) are present. Finally, ply #4 (FIG. 12) comprises a section 59 having a 0° fiber orientation that extends throughout regions 36 and 38. Section 59 is surrounded by a section 61 having a 90° fiber orientation which is confined to the third region 40. Ply #s 5-8 shown in FIG. 7 are essentially a mirror image of ply #s 1-4 described above.

From the forgoing, it can be appreciated that each of the regions 36, 38, 40 possesses a unique interlaminar fracture toughness in the tailored laminate patch 32a, and/or the bond joint 42 (FIG. 2). The interlaminar fracture toughness within the regions 36, 38, 40 of the patch 32a may be tailored to and compliment the global adhesive stresses in the bond joint 42 so as to contain and resist growth of inconsistencies either in the patch 32a or the bond joint 42.

FIG. 13 illustrates the manner in which a disbond beginning at outer edge 60 of the third control region 40 and growing inwardly, may be arrested. The disbond beginning at edge 60 may be illustrated in this scenario as growing directly inward, as shown at 62 until the boundary 64 is reached between control regions 38 and 40. As a result of the difference in materials in control regions 36, 38, 40, and/or the presence of a gap "g" or filler 50 (FIG. 4), and/or the difference in the adhesive properties of the sections 44, 46, 48 of the adhesive layer 34 (FIG. 2), the disbond is arrested and may move circumferentially around 63 the boundary 64 of the third control region 40. Another scenario may have a disbond progressing from the third region 40 and into the second control region 38, and progressing inwardly toward the first control region 36, as indicated by the numeral 66. When the progression of the disbond reaches the boundary 68 between control regions 36 and 38, it is arrested and may move circumferentially around the boundary 68.

Referring concurrently to FIGS. 13 and 14, as the disbond 72 moves inwardly from the beginning point 60, the outer edge 54 of the rework patch may peel upwardly thereby cracking overlying paint (not shown) which provides a visual indication of disbond initiation and/or growth within the third control region 40. This visual indication of a disbond may terminate at the boundary 64 between control regions 38 and 40.

As shown in FIG. 15, if the disbond 72 continues into the second control region 40 toward the boundary 68, the patch 30 in the area of the control regions 38 and 40 may peel upwardly, thereby further cracking overlying paint to provide a visual indication that the disbond has progressed into or through the second control region 40. FIG. 16 illustrates the disbond having progressed up to the boundary 75 of the inconsistency 22. At this point, the areas of the patch 30 and all three control regions 36, 38, 40 may peel upwardly to further crack overlying paint, thereby providing a still more obvious visual indication that the disbond has advanced to a point where the rework patch 30 may need further attention. From the foregoing, it is apparent that the control regions 36, 38, 40 of the rework patch 30 provide a means of allowing nondestructive visual inspection of the condition of the patch 30, including the bond joint 42 between the patch 30 and the structure 24. As previously noted, other non-destructive inspection techniques may be used to assess the condition of the patch 30, instead of, or as a supplement to, visual inspection.

Attention is now directed to FIG. 17 which illustrates a method for reworking areas of a composite structure containing inconsistencies using the tailored rework patch 32a discussed above. The tailored patch 32a is formed by a series of steps 74 beginning with laying up plies 78 using a ply schedule and orientation sequence that may be similar to those shown in FIGS. 7 and 8. As shown at 80, the plies 52 are divided into multiple regions 36, 38, 40 as part of the ply layup 78. Also, the regions 36, 38, 40 are provided with differing interlaminar fracture toughness as shown at 82, by using differing materials and/or ply orientations as previously discussed.

At 84, a layer 34 of adhesive is formed, and at 86, the adhesive layer 34 is divided into multiple sections 44, 46, 48. The regions 36, 38, 40 of the tailored patch 32a are then aligned, as shown at step 88, with the sections 44, 46, 48 of the adhesive layer 34. The adhesive layer 34 is used to bond the tailored patch 32a to a composite structure, as shown at step 90. At step 92, the patch may be visually inspected over time to determine the condition of the patch in each of the regions 36, 38, 40.

Embodiments of the disclosure may find use in a variety of potential applications, particularly in the transportation industry, including for example, aerospace, marine and automotive applications. Thus, referring now to FIGS. 18 and 19, embodiments of the disclosure may be used in the context of an aircraft manufacturing and service method 100 as shown in Figure 18 and an aircraft 102 as shown in Figure 19. During pre-production, exemplary method 100 may include specification and design 104 of the aircraft 102 and material procurement 106. The rework patches 30 may be specified and designed as part of the specification and design 104 of the aircraft 102, and procured as part of the procurement process 106.

During production, component and subassembly manufacturing 108 and system integration 110 of the aircraft 102 takes place. The patches 30 may be used during production to rework inconsistencies that occur during the manufacturing 108 and/or system integration 110. Thereafter, the aircraft 102 may go through certification and delivery 112 in order to be placed in service 114. The patches 30 may be used to rework inconsistencies in order to achieve certification of the aircraft 102 and/or to satisfy delivery requirements. While in service by a customer, the aircraft 102 is scheduled for routine maintenance and service 116 (which may also include modification, reconfiguration, refurbishment, and so on). The patches 30 may be used while the aircraft 102 is in service to rework areas of the aircraft 102 that may develop inconsistencies while in service, and the condition of the patches 30 may be checked as part of a periodic maintenance routine.

Each of the processes of method 100 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. 19, the aircraft 102 produced by exemplary method 100 may include an airframe 118 with a plurality of systems 120 and an interior 122. The patches 30 may be used to rework inconsistencies in the airframe 118. Examples of high-level systems 120 include one or more of a propulsion system 124, an electrical system 126, a hydraulic system 128, and an environmental system 130. Any number of other systems may be included. Although an aerospace example is shown, the principles of the disclosure may be applied to other industries, such as the marine and automotive industries.

Systems and methods embodied herein may be employed during any one or more of the stages of the production and service method 100. For example, components or subassemblies corresponding to production process 108 may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft 102 is in service. Also, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during the production stages 108 and 110, for example, by substantially expediting assembly of or reducing the cost of an aircraft 102. Similarly, one or more of apparatus embodiments, method embodiments, or a combination thereof may be utilized while the aircraft 102 is in service, for example and without limitation, to maintenance and service 116.

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.

CLAIMS

What is claimed:

1. A patch for reworking an inconsistent area of a composite structure, comprising:

a composite laminate patch adapted to cover the inconsistent area and having at least first and second regions for respectively releasing strain energy around the inconsistent area respectively at different rates; and,

a layer of adhesive for bonding the laminate patch to the composite structure.

2. The patch of claim 1, wherein:

the laminate patch includes a plurality of fiber reinforced composite laminate plies each having a fiber orientation, and

the plies in the first region possess characteristics that are different from the plies in the second region.

3. The patch of claim 2, wherein the characteristic includes at least one of:

a characteristic of the fibers,

the thickness of the plies,

the number of the plies,

a presence of a gap between the plies,

the fiber orientation of the plies, and

the sequence of fiber orientations of the plies in the region.

4. The patch of claim 1, wherein:

the second region of the laminate patch surrounds the first region, and

the second region has an interlaminar fracture toughness greater than the interlaminar fracture toughness of the first region.

5. The patch of claim 1, wherein:

the second region of the laminate patch surrounds the first region, and

the first region has an interlaminar fracture toughness greater than the interlaminar fracture toughness of the second region.

6. The patch of claim 1, wherein composite laminate patch includes a third region for releasing strain energy around the inconsistent area at a rate different than the rate at which strain energy is released from the first and second regions.

7. The patch of claim 6, wherein:

the third region surrounds the second region, and

the second region surrounds the first region.

8. The patch of claim 1, wherein:

the laminate patch includes a plurality of fiber reinforced composite laminate plies, and

at least one of the plies in the first region extends into the second region.

9. The patch of claim 1, wherein the layer of adhesive includes:

at least first and second sections respectively underlying and substantially coextensive with the first and second regions of the laminate patch, the first and second sections of the adhesive layer respectively having characteristics tailored to the first and second regions of the laminate patch.

10. A method of reworking an area of a composite structure, comprising:

fabricating a composite laminate patch including multiple regions respectively having differing interlaminar fracture toughnesses; and

bonding the laminate patch to the composite structure in the rework area.

11. The method of claim 10, wherein fabricating the patch includes:

forming a layup of fiber reinforced polymer plies, including forming the multiple regions within the layup; and

curing the layup.

12. The method of claim 11, wherein forming the multiple regions includes providing the plies in each of the regions with respectively differing characteristics related to interlaminar fracture toughnesses.

13. The method of claim 10, further comprising:

periodically determining the condition of the bonded laminate patch by visually inspecting each of the regions of the patch.

14. The method of claim 12, wherein the bonding includes:

forming a layer of adhesive having multiple sections respectively associated with the multiple regions of the laminate patch, and

placing the adhesive layer between the laminate patch and the composite structure.

15. A patch fabricated by the method of claim 10.

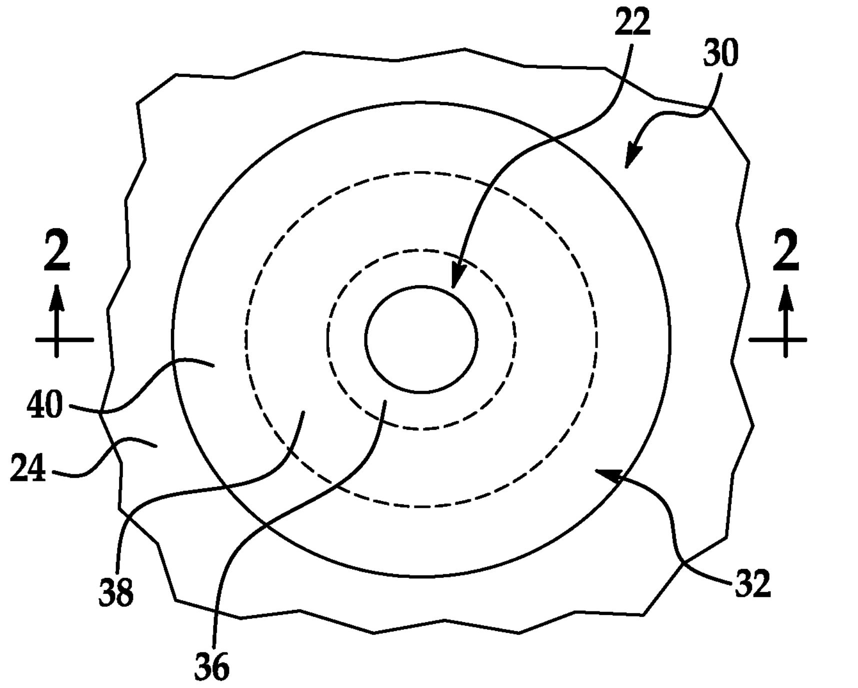

FIG. 1

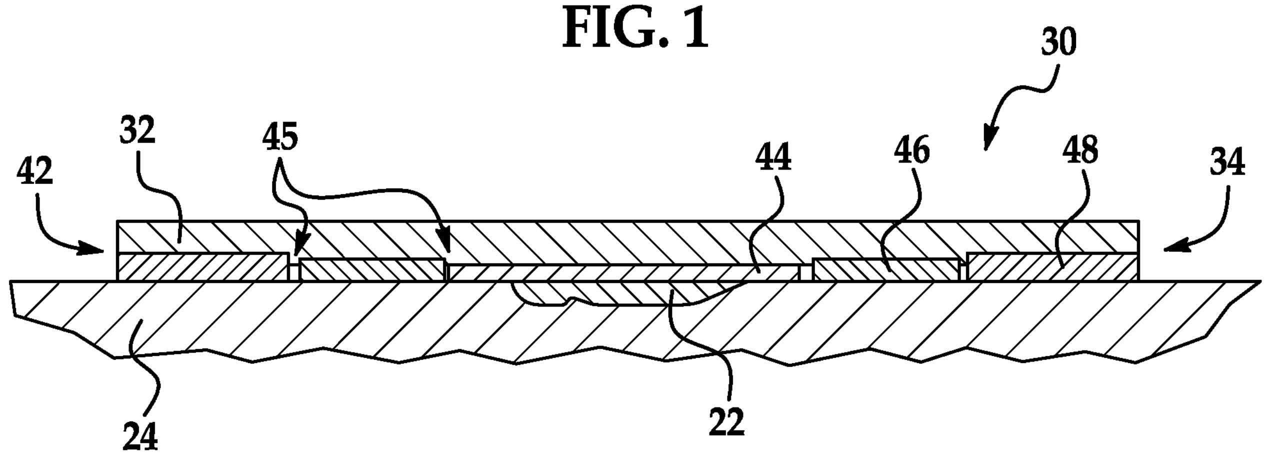

FIG. 2

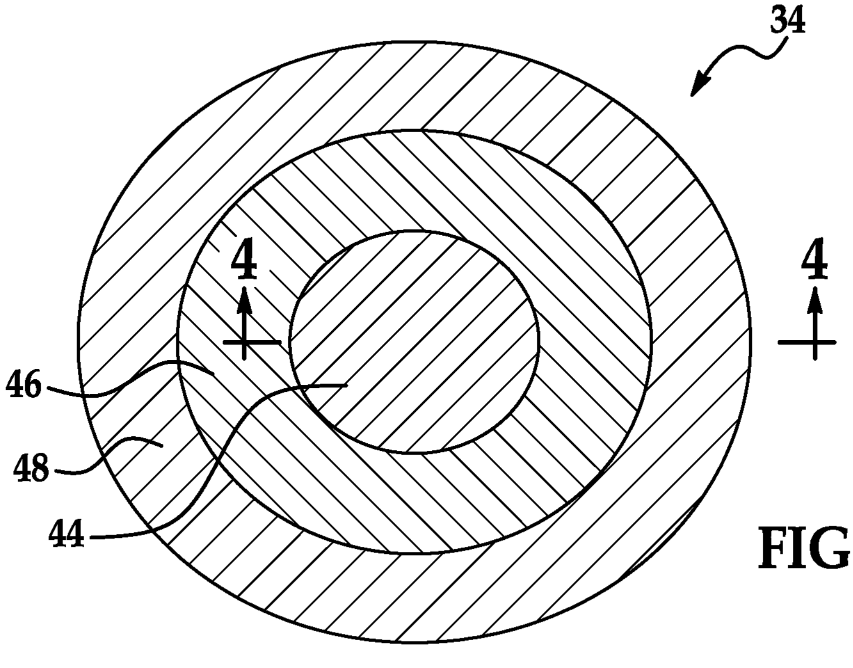

FIG. 3

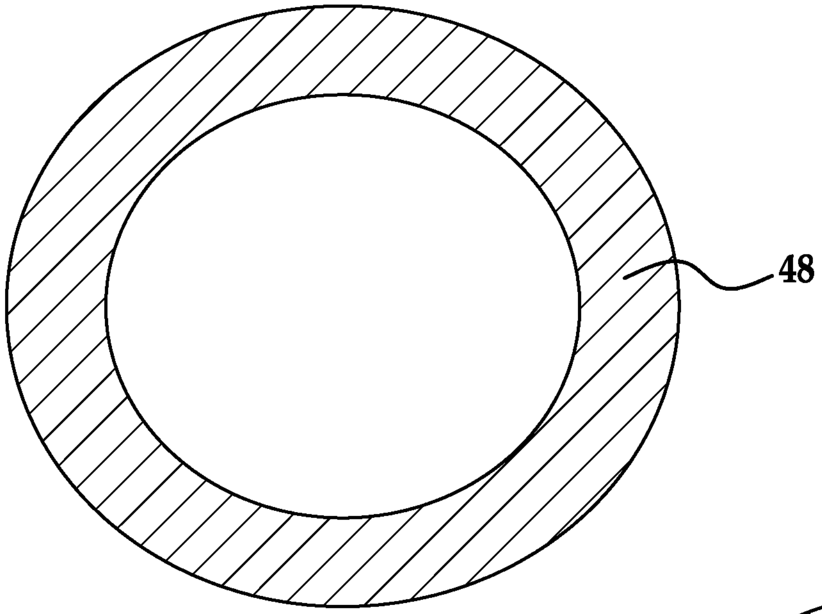

FIG. 3A

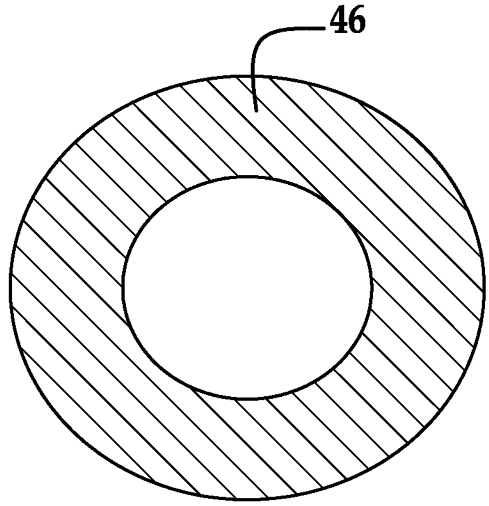

FIG. 3B

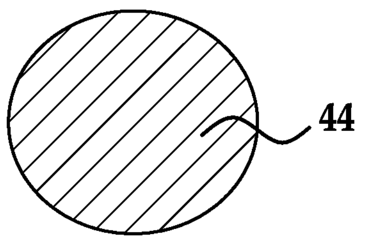

FIG. 3C

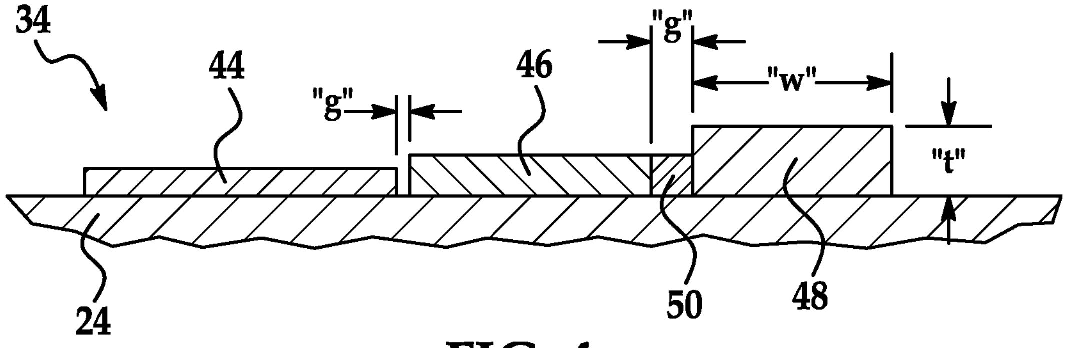

FIG. 4

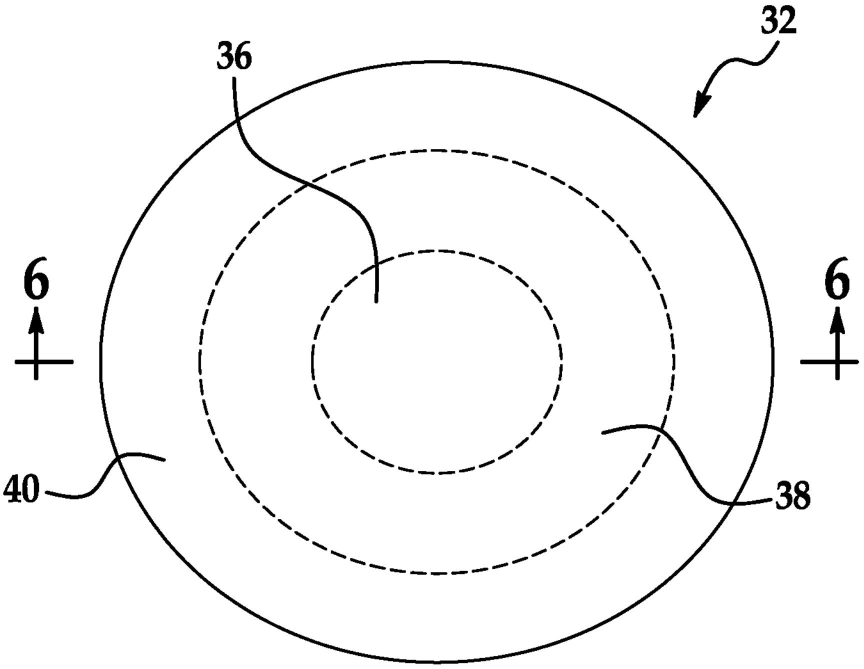

FIG. 5

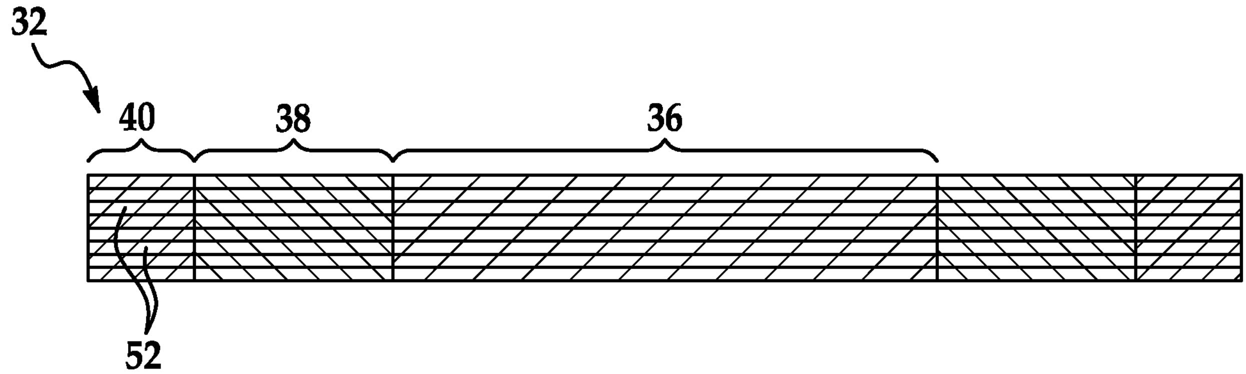

FIG. 6

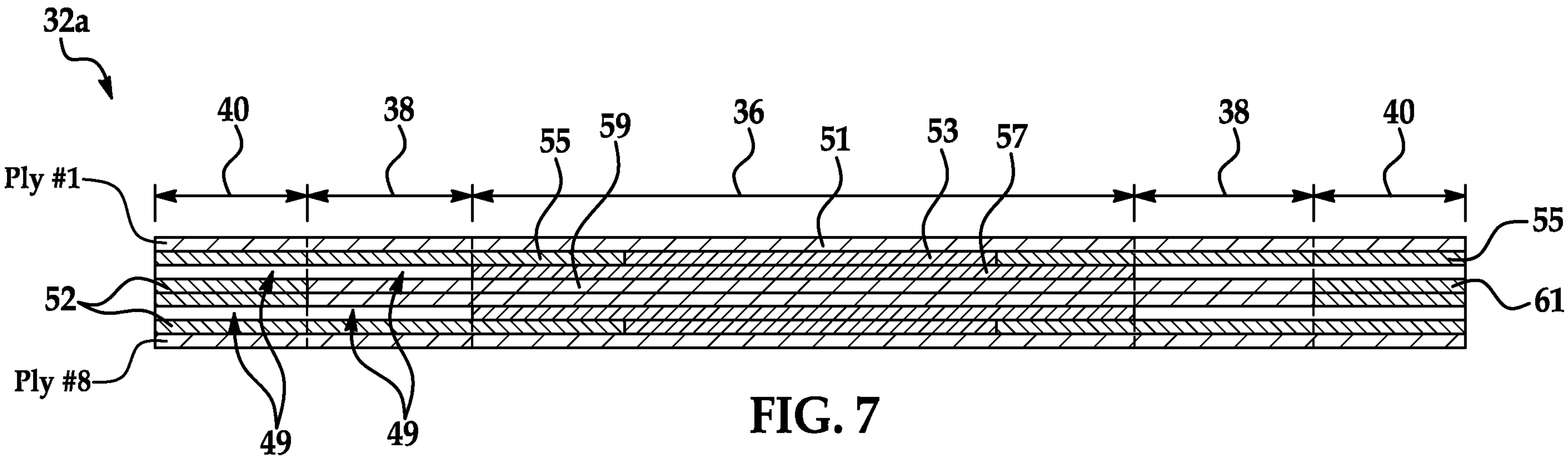

FIG. 7

Ply # (47)	Third Region (40)	Second Region (38)	First Region (36)
1	0	0	0
2	90	90	90/+45
3	none	none	-45
4	90	0	0
5	90	0	0
6	none	none	-45
7	90	90	90/+45
8	0	0	0

FIG. 8

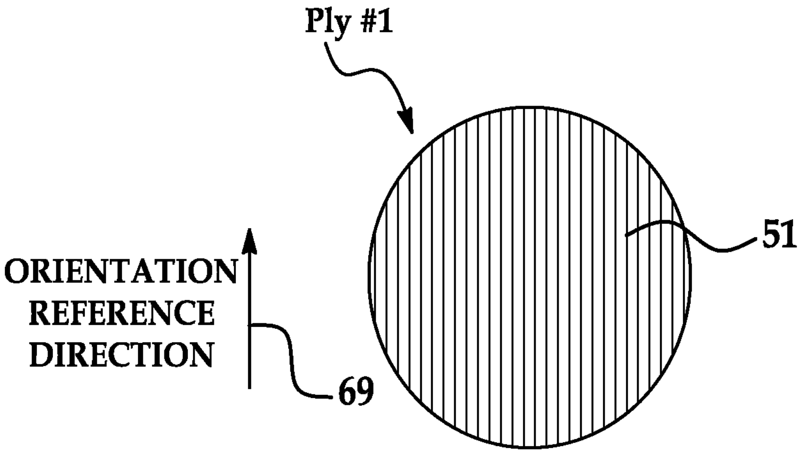

FIG. 9

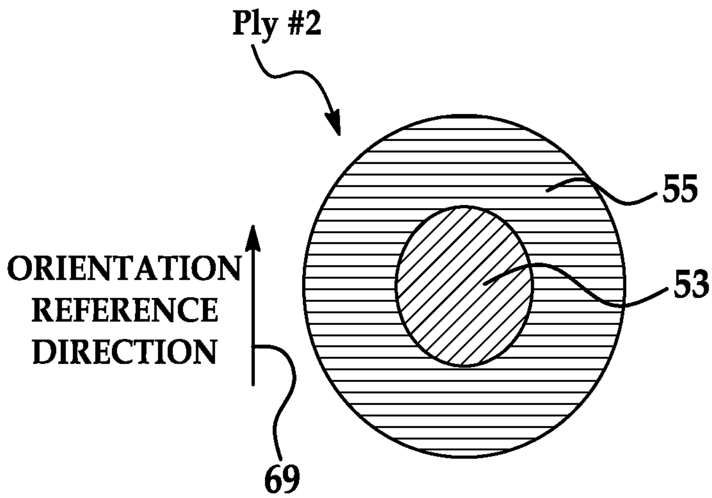

FIG. 10

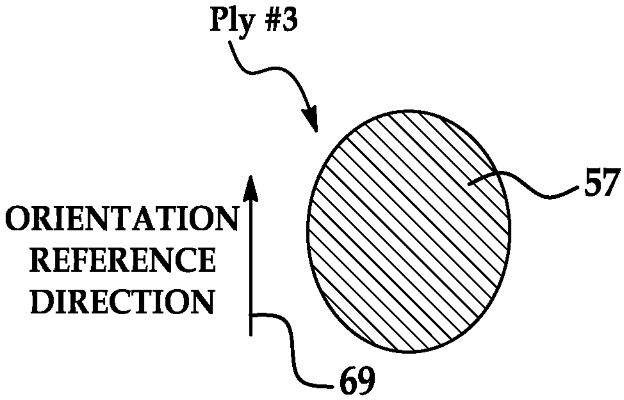

FIG. 11

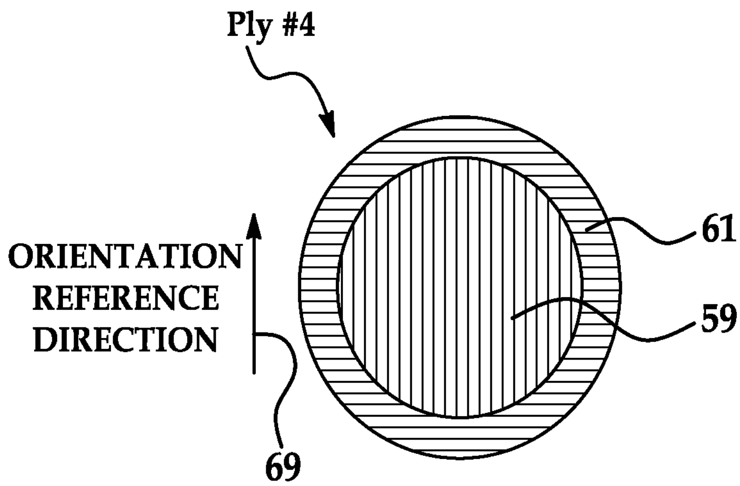

FIG. 12

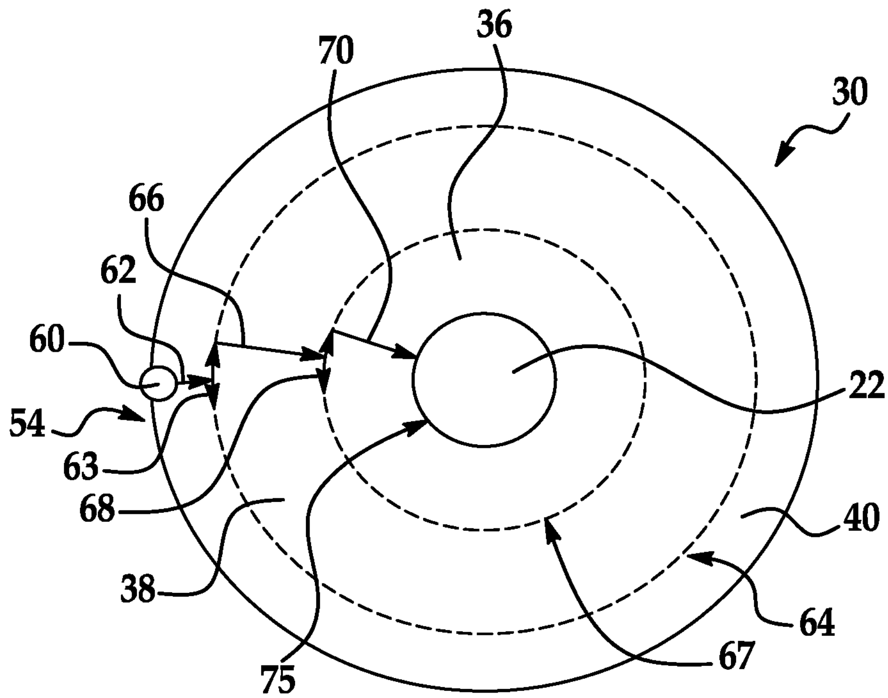

FIG. 13

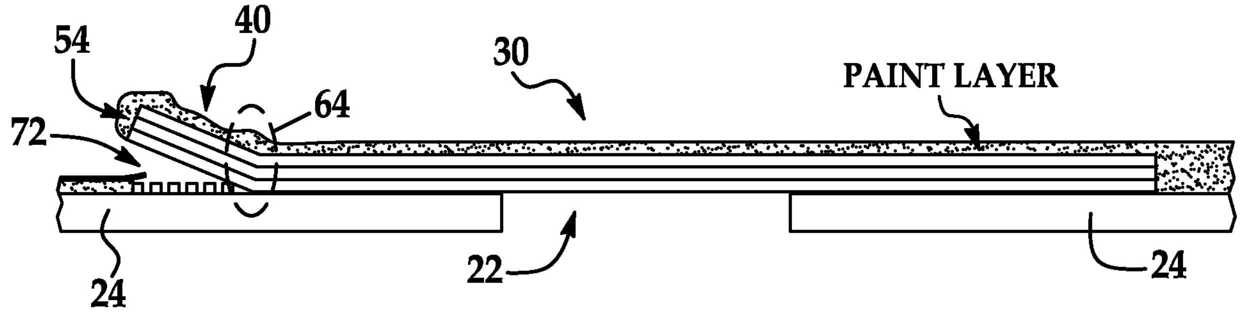

FIG. 14

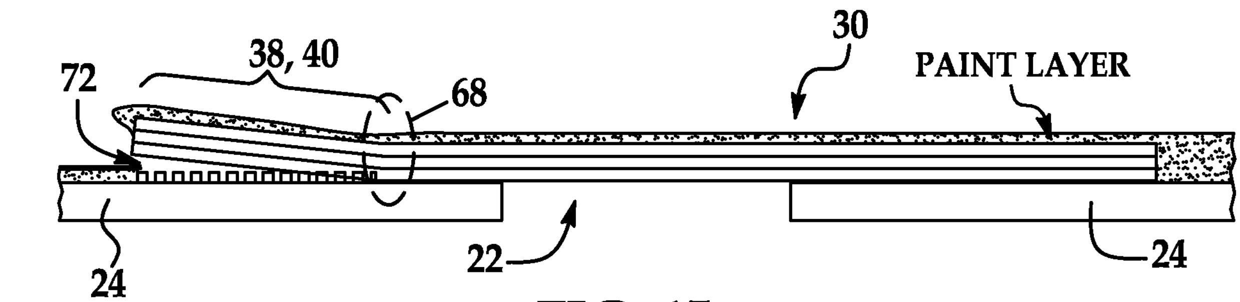

FIG. 15

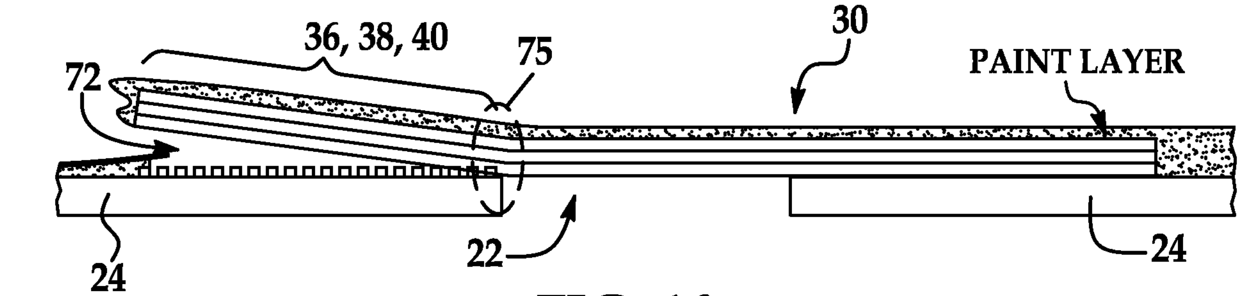

FIG. 16

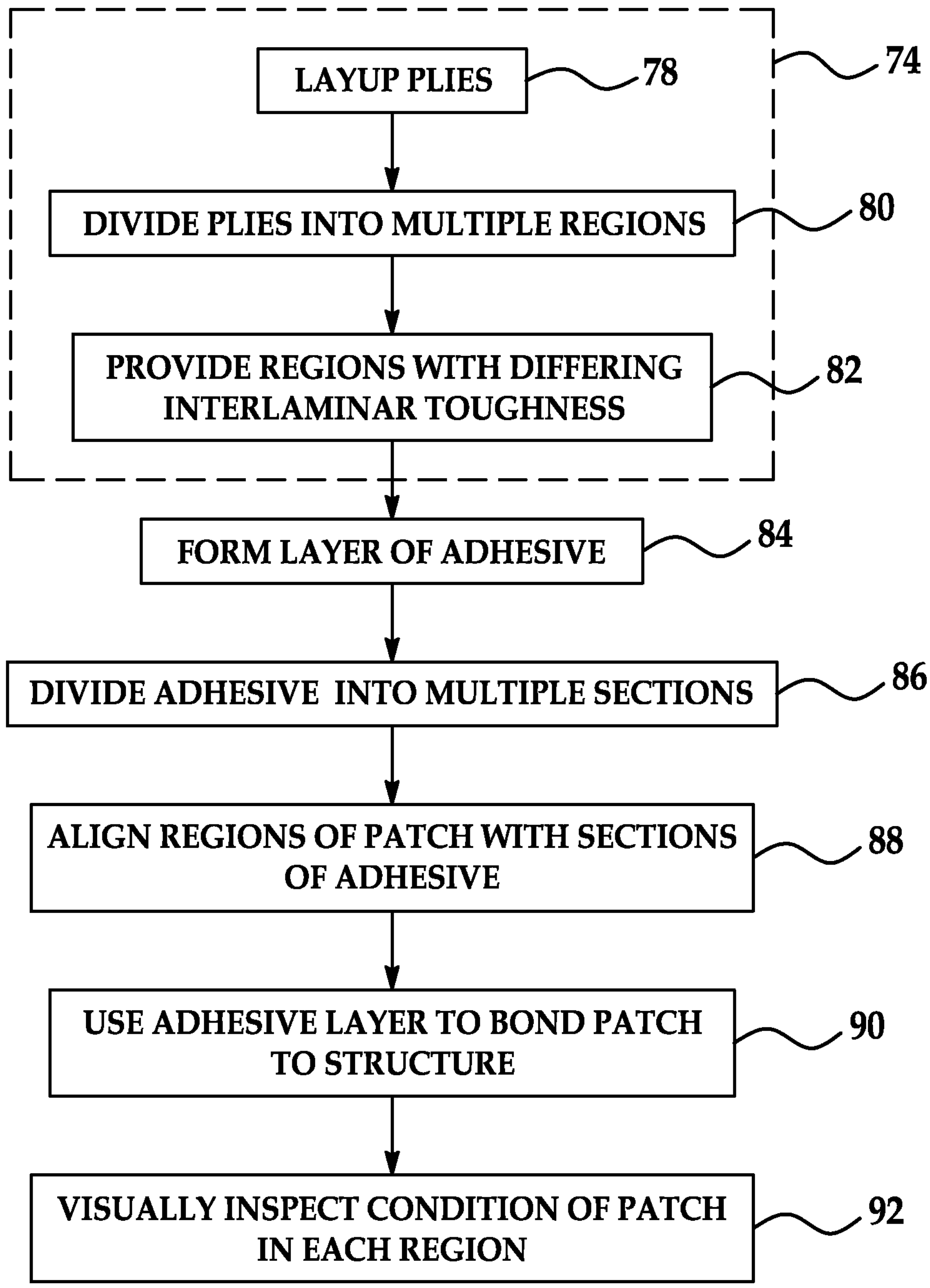
LAYUP PLIES
78
74
DIVIDE PLIES INTO MULTIPLE REGIONS
80
PROVIDE REGIONS WITH DIFFERING INTERLAMINAR TOUGHNESS
82
FORM LAYER OF ADHESIVE
84
DIVIDE ADHESIVE INTO MULTIPLE SECTIONS
86
ALIGN REGIONS OF PATCH WITH SECTIONS OF ADHESIVE
88
USE ADHESIVE LAYER TO BOND PATCH TO STRUCTURE
90
VISUALLY INSPECT CONDITION OF PATCH IN EACH REGION
92

FIG. 17

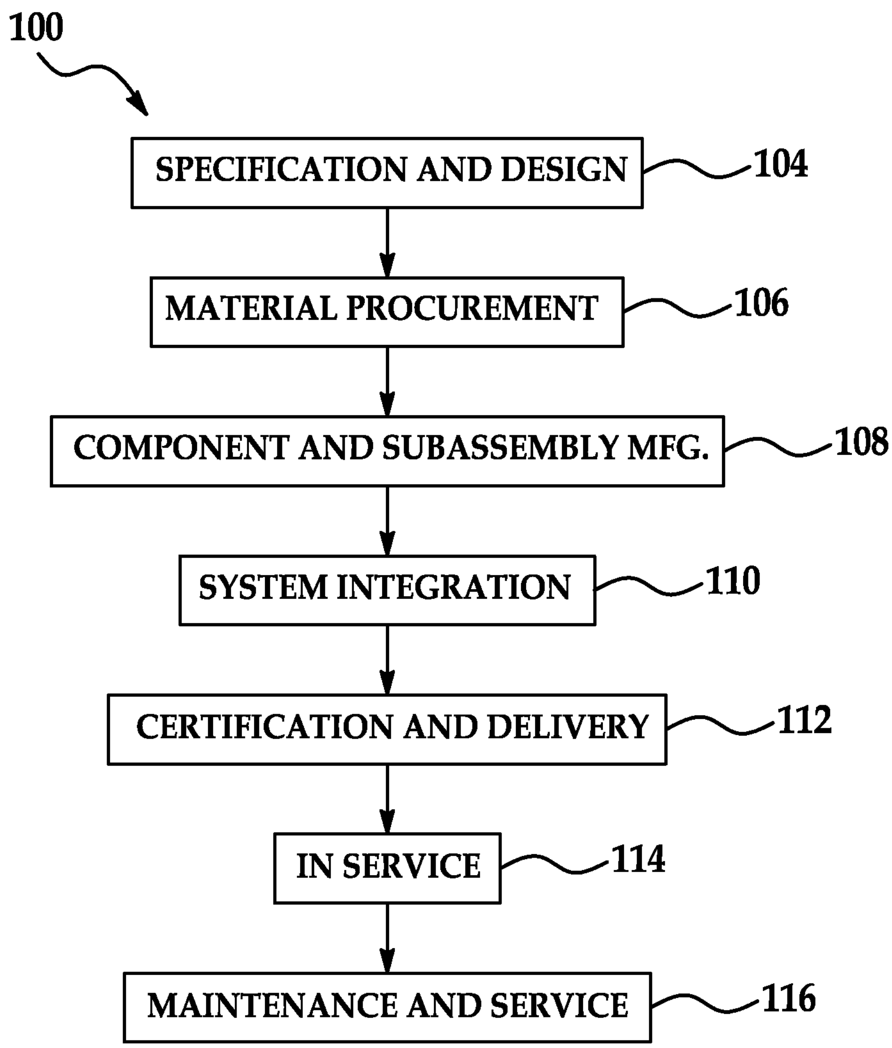
100
SPECIFICATION AND DESIGN
104
MATERIAL PROCUREMENT
106
COMPONENT AND SUBASSEMBLY MFG.
108
SYSTEM INTEGRATION
110
CERTIFICATION AND DELIVERY
112
IN SERVICE
114
MAINTENANCE AND SERVICE
116

FIG. 18

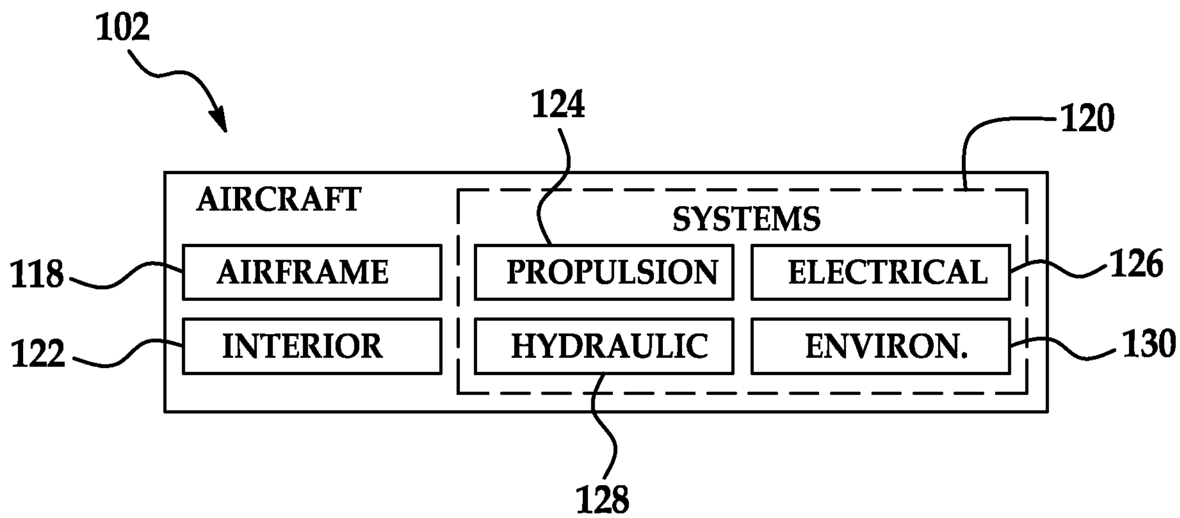
102
124
120
AIRCRAFT
SYSTEMS
118
AIRFRAME
PROPULSION
ELECTRICAL
126
122
INTERIOR
HYDRAULIC
ENVIRON.
130
128

FIG. 19

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/026252

A. CLASSIFICATION OF SUBJECT MATTER
INV. B29C73/10
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B29C B64F B64C B23P

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, 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	EP 1 972 429 A2 (UNITED TECHNOLOGIES CORP [US]) 24 September 2008 (2008-09-24) paragraphs [0001], [0010], [0026] - [0031] figures 8,9	1-3, 8-12,14, 15
A	BAKER A A ED - MIDDLETON DONALD H: "Repair Techniques for Composite Structures" 1 January 1990 (1990-01-01), COMPOSITE MATERIALS IN AIRCRAFT STRUCTURES, LONGMAN, NEW YORK, PAGE(S) 207 - 227 , XP008103764 ISBN: 978-0-582-01712-2 the whole document	1-15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 June 2010	29/06/2010

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, Fax: (+31-70) 340-3016	Ullrich, Klaus

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2010/026252

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 1972429 A2	24-09-2008	US 2008233346 A1	25-09-2008