An aircraft window frame includes a laminated outer rim and inner sash having a central aperture for receiving a window pane. The sash is transversely offset from the rim and they include different layers between the opposite inboard and outboard sides of the frame.
FIG. 7
COMPOSITE AIRCRAFT WINDOW FRAME

[0001] This application claims the benefit of U.S. Provisional Application No. 60/880,100; filed Jan. 12, 2007.

BACKGROUND OF THE INVENTION

[0002] The present invention relates generally to aircraft, and, more specifically, to windows therein.

[0003] In the typical commercial aircraft, numerous windows are distributed along both sides of the fuselage from the cockpit aft to just before the tail. The fuselage is tubular and varies in diameter or radius between the forward and aft ends of the aircraft, and correspondingly the size and curvature of the windows also vary along the length of the aircraft.

[0004] Each window includes a frame suitably mounted in a corresponding aperture in the external skin of the aircraft, and each frame securely mounts therein a corresponding window pane.

[0005] Typical aircraft skins are made of high strength metal, such as aluminum, and the typical window frame is also made of high strength metal. Various metal fabrication methods are therefore used to fabricate the individual window assemblies for the different size and strength requirements for each depending upon the specific location of the window along the length of the aircraft.

[0006] Aircraft weight directly affects aircraft efficiency during flight, and aircraft are therefore being continually developed for reducing weight while providing sufficient strength of the various aircraft components for enjoying long service life during commercial operation.

[0007] Furthermore, the cost of commercial aircraft operation is a paramount design objective especially with the ever increasing price of engine fuel. The initial manufacturing cost of the aircraft itself is also an important design objective, with both the cost of the initial aircraft purchase and subsequent cost of operation being significant criteria in the competitive evaluation of aircraft and their expected low cost operation during the service life.

[0008] Accordingly, it is desired to provide an improved aircraft window frame, and method of its manufacture.

BRIEF DESCRIPTION OF THE INVENTION

[0009] An aircraft window frame includes a laminated outer rim and inner sash having a central aperture for receiving a window pane. The sash is transversely offset from the rim and they include different layers between the opposite inboard and outboard sides of the frame.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The invention, in accordance with preferred and exemplary embodiments, together with further objects and advantages thereof, is more particularly described in the following detailed description taken in conjunction with the accompanying drawings in which:

[0011] FIG. 1 illustrates an exemplary commercial aircraft in flight, with an enlarged elevational sectional view of the one of the numerous windows found therein.

[0012] FIG. 2 is an elevation view of the outboard side of the exemplary window illustrated in FIG. 1 mounted in a portion of the fuselage and taken along line 2-2.

[0013] FIG. 3 is a partly sectional, isometric view of the exemplary window illustrated in FIG. 2 taken in isolation from the aircraft.

[0014] FIG. 4 is an enlarged cross sectional view of a portion of the window illustrated in FIG. 3 and taken along line 4-4.

[0015] FIG. 5 is a flowchart representation of the various layers forming the laminated window frame illustrated in FIGS. 3 and 4.

[0016] FIG. 6 is a flowchart of the layup sequence for the various layers illustrated in FIG. 5 in fabricating the window frame.

[0017] FIG. 7 is a flowchart of the staging and assembly of the layers illustrated in FIG. 6.

[0018] FIG. 8 is a flowchart for press molding the stacked press charge illustrated in FIG. 7 in the manufacture of the composite window frame.

DETAILED DESCRIPTION OF THE INVENTION

[0019] FIG. 1 illustrates an exemplary airplane or aircraft powered by gas turbine engines in flight. The aircraft includes numerous windows arranged in rows along both sides of the fuselage or outer skin from the forward cockpit end of the aircraft to just before the aft tail.

[0020] The windows maintain the pressure integrity of the cabin and protect the passengers therein from the external environment, including the fast stream of external air flowing aft over the outer skin during aircraft flight.

[0021] Each window is suitably mounted through a corresponding aperture in the aircraft skin, and the windows vary in size and configuration along the length of the aircraft. Since the fuselage is generally cylindrical or tubular it has an internal diameter, or radius A, which varies along the length of the aircraft from the sharp nose, through the wide passenger body, and to the sharp tail.

[0022] Each window is specifically sized and configured to match the local curvature, or radius A, of the aircraft skin, and therefore many different sized windows are required for each aircraft, and must be manufactured during production with corresponding differences.

[0023] The numerous windows in the aircraft may be identical in design but may suitably vary in configuration, including size and curvature thereof. An exemplary window is illustrated in transverse section in FIG. 1 and in plan view in FIG. 2. Each window includes a unitary composite window frame in which is suitably mounted a conventional, transparent window pane. The frame is suitably mounted through the corresponding aperture in the aircraft skin and supports the pane therein.

[0024] The composite frame is illustrated in more detail in an exemplary embodiment in FIGS. 3 and 4. The frame includes a radially outer annular flange or rim and a concentric, radially inner annular flange or sash surrounding a central aperture which is sealingly closed by the window pane mounted therein.

[0025] The sash is transversely offset from the rim across the thickness thereof in common laminations across that thickness. The laminated rim and sash include a plurality of lamina or layers, for example, which extend laterally or radially therethrough along the radial axis R of the frame.

[0026] The laminae or layers are preferably different from each other by transversely between the opposite inboard and outboard sides of the frame which correspond with the
inboard or internal side of the aircraft cabin and the outboard or external side of the aircraft skin.

[0027] The sash 24 illustrated in FIG. 4 is elevated above and transversely bridged to the lower rim 22 by an annular rib 32 around the full circumference of the central aperture 26. The inboard side of the sash 24 and rib 32 define a central pocket 34 in which the window pane 20 may be mounted. The sash 24, or sash bar, defines an annular muntin in which the window pane 20 may be mounted and trapped, and withstands the differential pressure exerted across the window from the pressurized aircraft cabin.

[0028] The rim 22, sash 24, and rib 32 are integral with each other in a single or unitary component, and are continuous in circumference around the central aperture 26 illustrated in FIGS. 2 and 3.

[0029] The integral rim, sash, and rib therefore collectively define forward and aft vertical columns or posts 36,38, and upper and lower horizontal rails 40, 42 integrally joined to the opposite ends thereof.

[0030] The posts 36,38 are spaced apart laterally or horizontally along a minor axis 44 of the frame 18, and define the horizontal width W of the frame.

[0031] The two rails 40,42 are spaced apart longitudinally or vertically along a longer major axis 46 of the frame and define the height or length L thereof.

[0032] The two side posts 36,38 laterally bound the central aperture 26, and the two rails 40,42 provide an upper header and lower sill which vertically bound the central aperture 26, and collectively, the posts and rails completely surround the central aperture 26 laterally or circumferentially.

[0033] The rim 22 illustrated in FIGS. 3 and 4 has apreferably uniform thickness T from the outer perimeter of the frame to its junction with the perpendicular rib 32 and provides sufficient surface area for structurally attaching the window frame to the aircraft skin typically using bolts or other suitable fasteners.

[0034] Correspondingly, the sash 24 tapers or decreases in thickness radially inwardly from its junction with the rib 32 to the radially inner perimeter of the sash which defines a relatively thin arcuate lip 48 that circumferentially surrounds or bounds the central aperture 26.

[0035] In the preferred embodiment, the outboard side 30 along the sash 24 is generally parallel to the inboard side 28 along the rim 22 in two different generally flat planes spaced transversely apart by the bridging rib 32.

[0036] Correspondingly, the inboard side 28 of the sash 24 slopes radially outwardly toward the offset lower rim 22 to its junction with the transition rib 32 to form a sloped annular seat 50 completely surrounding the window pane 20 which has a corresponding beveled perimeter conforming with the seat bevel.

[0037] In this way, differential pressure loads acting on the window pane during flight are carried through the beveled joint to the tapered sash 24, which sash 24 has a relatively thick arcuate fillet or junction with the transition rib 32 for in turn carrying the pressure loads to the surrounding rim with reduced stress.

[0038] The rim 22, rib 32, and sash 24 illustrated in FIG. 4 provide a continuous structural loadpath between the concentric outer and inner perimeters of the frame, and the common layers 1-7 extend radially therethrough and comprise high-strength fibrous laminae fixedly bound in a rigid resin matrix 52 illustrated schematically in FIG. 4.

[0039] The different layers illustrated in FIG. 4 preferably include an externally exposed outboard layer 1 facing outwardly from the aircraft to the environment, a transversely opposite, internally exposed inboard layer 7 facing inwardly in the aircraft cabin, and a plurality of different inside or middle layers 2-6, for example, laminated and hidden between the opposite outboard and inboard layers.

[0040] The exposed common outboard layer 1 completely covers the outboard or external face of the window frame to provide tailored protection thereof, including lightning protection.

[0041] Additional protection for the window frame may be provided by bonding an annular erosion shield 54 to the outboard side of the sash 24 as shown in FIGS. 2-4. The erosion shield is preferably thin sheet metal, such as titanium, and provides a continuous annular annulus along the posts 36,38 and rails 40,42 completely surrounding the central aperture 26 to protect against wind and rain erosion.

[0042] The height or depth of the offset between the sash 24 and rim 22 illustrated in FIG. 4 is selected to match the thickness of the surrounding aircraft skin 14, shown in phantom, so that the outboard surface of the sash will be substantially flush with the outboard surface of the aircraft skin.

[0043] Correspondingly, the thin erosion shield 54 is recessed in the sash and projects slightly proud or outboard of the aircraft skin by about 1-3 mils (0.02-0.08 mm) to provide a slightly elevated relief for ensuring that the erosion shield takes the wind and rain erosion instead of the window pane and edge of the skin. The slight protrusion of the erosion shield nevertheless provides smooth aerodynamic flow of the ambient air 16 as it flows past the window during aircraft operation at speed.

[0044] Furthermore, the erosion shield 54 illustrated in FIG. 4 conforms with the flat outboard surface of the sash and has arcuate opposite edges blending inwardly into the aircraft. For example, the erosion shield 54 preferably wraps in part around the sash lip 48 to minimize or eliminate direct exposure of the underlying composite laminate to the external free stream air 16 which can contain rain or debris particles that would otherwise erode the relatively softer composite sash.

[0045] The composite laminated window frame 18 illustrated in FIG. 3 enjoys specific advantages in design, strength, and manufacture, as well as in the cost of manufacture and durability in service life. The window frame 18 is defined by its common rim 22, sash 24, and transition rib 32 which may be suitably varied in size, thickness, and configuration, with corresponding differences in length L, width W, and curvature in different planes represented by the annular radius R of the window frame itself, as well as the vertical curvature A of the window frame conforming with the local curvature of the tubular aircraft cabin.

[0046] Since the window frame 18 is specifically configured for use in an aircraft that can fly at substantial speed and elevation in a potentially hostile flight environment, it can be readily tailored in strength and attributes for enhancing its durability and structural performance. The laminated design of the window frame permits practically unlimited variations in material properties and configurations in the various layers introduced into the final frame design.

[0047] More specifically, the fibrous layers 1-7 illustrated in cured state in FIG. 4 preferably include different annular patterns, designated by the prefixes 56a-h, as shown sche-
matically in FIG. 5, with the specific pattern for a specific layer being dependent upon the final window design.

[0048] For example, for the exemplary aircraft illustrated in FIG. 1, seventeen different window configurations may be used for the substantially larger number of windows found in the aircraft, ninety-two for example, recognizing the symmetry on opposite sides of the aircraft cabin. And, the seventeen configurations may further be differentiated by five basic weight classes for ultimate strength. These five weight classes include extra light, light, medium, heavy, and extra heavy in which the rib 32 varies in height or length.

[0049] Accordingly, the basic patterns 56a-h illustrated in FIG. 5 are exemplary of various patterns that may be used in fabricating aircraft window frames depending upon the specific aircraft application and need for windows therein. Since the basic window frame itself is annular in general, its configuration may range from a round or circular porthole to the exemplary oval or oblong configuration illustrated in FIG. 2, and may also extend to other configurations such as more rectangular or trapezoidal as desired for the specific aircraft application.

[0050] A particular advantage of the laminated window frame disclosed above is the initially flat laminae that may be readily cut to the common annular pattern illustrated in FIG. 5 and assembled together to complete the requisite frame configuration.

[0051] Although the layer patterns could be a continuous annulus, certain advantages accrue by segmenting each layer around its circumference. Accordingly, each pattern 56a-h may include differently shaped ribbon shapes or segments, designated by the suffix 1-4, with the segments being complementary with each other to collectively form the corresponding annular pattern 56a-h with suitable overlapping or splicing of the segments around the posts 36,38 and ribs 40,42 shown in FIG. 3 which surround the central aperture 26.

[0052] Since the basic configuration of the window frame illustrated in FIG. 3 is oblong in this embodiment, the corresponding patterns 56a-h shown schematically in FIG. 5 are correspondingly oblong and provide a full rib annulus of fibrous material with small overlaps or splices between the adjoining segments in each layer.

[0053] As initially illustrated in FIG. 4, the outboard layer 1 preferably has a different fibrous pattern than the inboard layer 7. And, the middle layers 2-6, for example, preferably have different fibrous patterns than both the outboard layer 1 and the inboard layer 7.

[0054] The various fibrous materials used in the window frame illustrated in FIG. 4 may themselves be conventional and commercially available, and are preferentially chosen for their different attributes. Representative fibrous materials are shown magnified in FIGS. 4 and 5.

[0055] For example, the outboard layer 1 preferably comprises a plain weave high strength carbon fiber woven fabric having interwoven therein metal fibers or filaments, such as phosphor bronze or aluminum, to provide lightning strike protection for the window frame in its use in the aircraft subject to lightning storms. The filaments are schematically represented by the grid lines in FIG. 4, and the white squares represent the fine fiber ribbons or fiber bundle taws interwoven therewith.

[0056] Suitable lightning strike fabric material is preimpregnated (prepreg) with resin, such as epoxy resin, for subsequent curing, and is commercially available from Hexcel Corporation, Salt Lake City, Utah.

[0057] The middle layers 2-6 preferably comprise corresponding mats of randomly oriented carbon fiber slivers or chips for providing quasi-isotropic strength, or equal strength in all lateral directions in 360 degrees around the mats.

[0058] This high-strength, random fiber material is available under the trademark HexMC, or Hexcel Molding Compound, and is commercially available from the Hexcel Corporation, Lyon, France. The chips are short fiber ribbons or fiber bundle taws preimpregnated with epoxy or polymer resin, and are about 2 inches long and 1/2 inch wide, with a variable thickness of 4-8 mils (50.8 by 8.4 by 0.1-0.2 mm).

[0059] The inboard layer 7 preferably comprises very lightweight fiberglass, or E-glass, fibers woven in fine fabric to prevent excessive carbon fiber breakout from the underlying carbon middle layers when the rim is drilled for receiving the fasteners for attachment to the aircraft.

[0060] This fiberglass layer is commercially available in Style 108 from the Hexcel Corporation, Salt Lake City, Utah.

[0061] All of the fibrous materials used in the numerous layers 1-7 of the window frame are provided in woven fabrics or random mats in corresponding epoxy resin matrices, which upon final curing collectively form the unitary hard resin matrix 52 illustrated in FIG. 4 integrally bonding together all layers and all fibers in a one-piece unitary window frame.

[0062] The outboard lightning strike layer 1 and the inboard drill mat layer 7 sandwich transversely therebetween the numerous high strength carbon middle layers 2-6 as required for corresponding window configuration and strength.

[0063] The middle layers 2-6 may be as few or as numerous as desired, with all layers sharing the common quasi-isotropic carbon fiber material found therein, but which layers are inherently different from each other due to the random orientation of the carbon fiber chips. Nevertheless, the individual middle layers provide similar high strength in all directions, and numerous middle layers are used to correspondingly increase strength and rigidity in the resulting window frame.

[0064] Since all layers 1-7 share the common oblong configuration of the resulting window frame, the various exemplary patterns 56a-h illustrated in FIG. 5 may be used as desired for the different fibrous layers.

[0065] For example, the lightning strike outboard layer 1 illustrated in FIG. 4 preferably uses the 4-segment pattern 56g-1-4 illustrated in FIG. 5 in order to maximize material usage and minimize waste, and permit the woven fiber bundle taws to be oriented plus and minus 45 degrees from the major and minor axes to avoid distortion during molding.

[0066] Correspondingly, the drill mat inboard layer 7 illustrated in FIG. 4 preferably uses the two-segment pattern 56f-1,2 illustrated in FIG. 5 in order to maximize material usage and minimize waste.

[0067] And, the various middle layers 2-6 may use the various patterns 56a-f illustrated in FIG. 5. These various middle patterns include two or four segments around the perimeter of the window frame, with corresponding small overlaps (shown as dashed lines) therebetween as required.

[0068] The different patterns permit circumferential offset of the corresponding segment overlaps, and may be used to control the final thickness of the window frame and maintain its uniformity within suitable tolerances.

[0069] In one exemplary embodiment, the five high-strength middle layers 2-6 shown in FIG. 4 correspond with
the five different patterns 56a-e, respectively, shown in FIG. 5 to displace or stagger as far as practical the corresponding splice joints.

[0070] Since the cross sectional profile of the window frame illustrated in FIG. 4 varies from the uniform thickness outer rim 22 to the tapering thickness inner sash 24, the various patterns and material compositions illustrated in FIG. 5 may be used to precisely control both this thickness profile and the offset configuration of the rim and sash.

[0071] In the seventeen different configurations of window frames for the one aircraft, the various dimensions of the rim and the sash illustrated in FIG. 4 vary, and may be readily accommodated by varying the different patterns 56a-h illustrated in FIG. 5 as required to best form the specific frame design in uniformity of composition and relatively free of irregularities and defects.

[0072] The thickness, length, local width B, and profile of each flat pattern may be selected so that when the multiple layers are combined in a stack they will collectively form the required three-dimensional (3D) profile shown in FIG. 4. This includes the flat rim 22, perpendicular rib 32, and offset tapered sash 24.

[0073] For example, since the window frame is formed of numerous layers of fibrous materials initially in flat form, those flat layers must be suitably molded to the 3D configuration illustrated in FIG. 4, which includes the relatively sharp bend between the flat rim 22 and the perpendicular rib 32, with the sash 24 again bending in turn generally perpendicular to the upright rib 32.

[0074] The initial flexibility inherent in the raw prepreg middle layers 2-6 and the outboard and inboard layers 1,7 permits staging and premolding, and then molding of the previously flat layers with flexible shearing or lateral shifting between the layers to meet the final 3D window frame profile without undesirable wrinkling of the layers or undesirable voids or spaces therein.

[0075] In particular, the unwoven, random mat form of the fibers in the middle layers 2-6 provides additional advantages in achieving complex 3D shapes. The individual fiber chips in the mat layers may shift and flow in their resin matrices both laterally in each layer and transversely between adjacent layers during the staging and molding process to achieve the varying thickness and 3D sectional profiles in the final composite frame without undesirable defects.

[0076] As indicated above, the various patterns 56a-h illustrated in FIG. 5 share common attributes since they use substantially full width ribbon segments collectively assembled in each layer to match the oblong pattern of the final window frame.

[0077] For example, patterns 56a,c,e,g,h include corresponding single vertical segments in the corresponding forward and aft posts 36,38. Correspondingly, patterns 56b,d,e,g include single segments in the corresponding upper and lower rails 40,42. In this way, the corresponding splices may be located in the transition corners between the posts and rails.

[0078] The first two patterns 56a,b and pattern 56h illustrated in FIG. 5 include double, or two only, segments which collectively form both the posts 36,38 and rails 40,42 with two splices only. The double segments 56a,b are continuous in the posts 36,38 and overlap together in the side rails 40,42. Correspondingly, the double segments 56a,b are continuous in the rails 40,42 and overlap together in the posts 36,38.

[0079] In this way, the overlapping splices may be confined to either the posts or the rails near the neutral bending axes corresponding with the major and minor axes 44,46, and depends upon the specific configuration of the window frame.

[0080] Patterns 56c,d,e,g are each four segments only which collectively form the posts 36,38 and rails 40,42 in each layer. In these configurations, the posts and rails may have substantially continuous fibrous material, with the overlapping splices being located near the four corners that bridge the posts and rails. In these patterns, two segments form the two posts 36,38 and two segments form the two rails 40,42.

[0081] In the two patterns 56e,g the four segments overlap in the rails 40,42. And in the two patterns 56c,d, the four segments overlap in the two posts 36,38.

[0082] Since the window frame illustrated in FIG. 2 is oblong along the major axis 46, the central aperture 26 illustrated in FIGS. 2 and 5 is similarly oblong, with the window approaching a generally rectangular configuration with four arcuate corners.

[0083] Correspondingly, the pattern 56/i includes two pairs of rectangular segments 56/1,2 and 56/3,4 which may be arranged symmetrically about either the minor or major axis 44,46 or both, and as described hereinafter may be used to advantage for controlling the final weight of the window frame while symmetrically adding to the desired frame strength about the two bending axes 44,46.

[0084] In view of the oblong configuration of the exemplary window, the two patterns 56a,b each include a pair of semi-oblong segments which may also be disposed symmetrically about the minor and major axes 44,46 for structural advantage. In these configurations, the splices are located at the corresponding neutral bending axes 44,46 of which bending stress is minimal.

[0085] The composite laminate configuration of the window frame illustrated in FIG. 5 includes the differently configured outboard layer 1 and inboard layer 7, and one or more middle layers 2-6.

[0086] In practice, the individual layers are relatively thin and therefore multiple middle layers 2-6 will be utilized to increase thickness and strength. And, the multiple exemplary patterns illustrated in FIG. 5 permit various permutations of layer configuration for specifically tailoring each window frame for its intended location in the aircraft, as well as specifically configuring the sectional profile illustrated in FIG. 4 for mounting the window pane 20 therein, and in turn mounting the window frame to the aircraft.

[0087] This composite design of the window frame therefore enjoys efficiencies of design, tailored strength, and ease of manufacture which complements the laminated configuration itself.

[0088] FIGS. 5-8 illustrate schematically a method of manufacturing or making the composite laminated window frame 18 in a preferred embodiment.

[0089] As indicated above, the initial fibrous materials may be commercially procured in typical roll or flat form. In particular, the fibrous material is provided in resin prepreged fibrous prepreg sheets, designated 1-7p to correspond with the layered form thereof. The uncured prepreg sheets are suitably cut flat to shape or profile in the various desired patterns 56a-h illustrated in FIG. 5 to form corresponding ones of the outboard, inboard, and middle layers 1-7 shown cured in FIG. 4.
In FIG. 6, the various prepreg layers 1-7 are still soft in their uncured, raw state and may be readily assembled in a common stack thereof in a preferred layup sequence. Depending on the total number of layers required, one or two stacks of the layup prepregs may be assembled, with two stacks 1-4 and 5-6 being illustrated schematically.

In FIG. 7, the prepreg stack or stacks 1-4 and 5-6 are suitably staged, or B-staged, under heat in an oven 58 to partially pre-cure the resin matrix. This staging controls the viscosity of the resin and the relative flexibility of the stack, and permits the stacked layers to initially conform with each other.

The so-staged stack is then cooled to form a press-ready charge 60.

In FIG. 8, the press charge 60 undergoes molding in a two part mold 62,64 under suitable heat and pressure to form the cured laminated window frame 18 in 3D contour.

Due to the random configuration of the carbon fiber middle layers 2-6, the weight tolerance on the corresponding prepreg material thereof is relatively high, and about plus or minus twenty percent (±20%) for example. This means for a unit area of the middle layers, the weight thereof may vary as much as plus 20 percent or minus 20 percent which is particularly problematic since the specification or reference weight for the final window frame must be closely held to small tolerances of plus or minus one percent for example.

However, the large weight variation of the middle prepreg layers corresponds with the substantial flexibility of these raw layers and the variable thickness thereof. These attributes are used to advantage in precisely forming the final frame without undesirable wrinkling and voids.

Accordingly, each prepreg layer 1-7 is suitably weighed prior to layup, and for layers 1-6 this weighing is preferably accomplished without the conventionally provided backing paper on the prepregs, while the weighing of the inboard layer 7 may be conducted with its backing paper in view of its extremely flexible form. The weight of the backing paper may be separately accounted for and removed (by trimming) from the final weight.

After the layers are weighed, their collective weight may then be compared with the corresponding design or reference specification weight for the final frame. If the design weight is not met, the collective weight of the stacked prepreg layers 1-7 may be adjusted by adding additional prepreg layers to the stack or removing prepreg layers therefrom in order to match the specification weight within the desired small tolerance.

Adjustment weight should be added or removed from the prepreg stack symmetrically relative to either the minor or major axes 44,46, or both. For example, a full layer (8th), such as the two-segment pattern 56b illustrated in FIG. 5 may be added to the stack where large weight increase is required.

Or, the rectangular strip pattern 56b illustrated in FIG. 5 may be added in pairs in the post or rail positions, or both as required in a different (9th) layer.

Correspondingly, excess weight may be removed by removing an entire layer, or by symmetrically removing portions from a single layer.

In this way, the final weight of the window frame may be precisely controlled within small weight tolerances by controlling the number of middle layers and patterns thereof for the high strength random fiber mats which are sandwiched between the differently configured outboard and inbound layers 1,7.

In order to control the efficacy of the staging process, the number of middle layers 2-6 in an individual stack along with the outboard lightning strike layer 1 is limited, to a maximum of five for example. If more than five middle layers are required, then the layers should be divided substantially equally into two corresponding stacks for staging.

For example, for six middle layers, three layers each would be provided in two stacks, with one stack including the lightning strike layer 1.

For seven middle layers, three middle layers would be stacked with the lightning strike layer in one stack, and four middle layers would be assembled in another stack.

In FIG. 6, five middle layers 2-6 are illustrated, with three middle layers 2-4 being assembled in one stack with the lightning strike layer 1, and the other stack including the two middle layers 5,6.

For the two stack staging of the fibrous layers illustrated in FIG. 6, the collective weight of the two stacks is preferably adjusted by adding or removing the prepreg layers at the top of one or both of the two stacks.

As shown in FIG. 7, the two prepreg stacks 1-4 and 5-6 are separately staged side by side for example in the oven 58 and partially heat cured. Following suitable cooling of the staged stacks, the two stacks may be stacked together in one complete stack 1-6 to form the common press charge 60 which then undergoes molding as described above.

As shown schematically in FIGS. 6 and 7, the prepreg layers are preferably stacked in numerical or positional sequence in one stack 1-4 starting first with the outboard prepreg layer 1 and followed by corresponding ones of the middle layers 2-4, for example. And in the other stack, the remaining middle layers 5-6 are stacked in reverse numerical or positional sequence. The stacking sequence is determined by the requisite layer position in the specific frame design.

In this way, the two prepreg stacks 1-4 and 5-6 may then be stacked top-to-top as illustrated in FIG. 7 to provide a continuous numerical or positional sequence between the inboard and outboard sides 28,30 for the resulting window frame 18.

This reverse sequence of the structural middle layers 2-6 in the two stacks illustrated in FIGS. 6 and 7 permits adjustment of the collective weight of the layers near the middle of the stack. This adjustment maintains structural integrity of the layers which bound the center layer of the frame near the neutral bending axis, and maximizes the resultant structural strength of the frame.

Furthermore, since the preferred sequence and patterns of the middle layers are used to control the different sizes and configurations of the numerous windows, weight adjustment of the frames along the center layer will not adversely affect the final configuration of the frame.

Since the initial prepreg layers 1-7 illustrated in FIG. 6 are formed from initially flat prepreg material, and the final configuration of the molded window frame 18 illustrated in FIG. 8 varies in 3D configuration, a further improvement in the manufacturing method may be obtained by introducing special shop aids or trays 66,68 illustrated schematically in FIGS. 6 and 7.

The prepreg layers 1-4 are preferably stacked atop a first staging tray 66, with the remaining middle prepreg layers 5,6 being correspondingly stacked atop a second staging tray.
68. The two trays 66, 68 conform in size and 3D configuration with the corresponding outboard and inboard sides 28, 30 of the resulting window frame 18.

[0115] For example, FIG. 3 illustrates the outboard side 30 of the window frame 18 in which the annular sash 24 is elevated on a plate atop the surrounding lower rim 22. Accordingly, the first staging tray 66 illustrated in FIG. 6 will conform in mirror-image configuration with the outboard side 30 illustrated in FIG. 3, and include a central molding recess or land corresponding with the elevated sash, and an elevated molding rim or land corresponding with the window rim.

[0116] Since the window frame illustrated in FIG. 3 has the slight curvature A along its longitudinal axis, the inboard side 28 is slightly concave in the vertical direction around the aircraft, and the opposite outboard side 30 is slightly convex. Correspondingly, the top of the first tray 66 illustrated in FIG. 6 will be slightly concave to conform with the slightly convex outboard side 30 of the window frame.

[0117] Similarly, the second tray 68 illustrated in FIG. 6 conforms with the inboard side 28 of the window frame illustrated in FIG. 3. The top side of the second tray 68 will therefore be slightly convex to conform with the slightly concave inboard side 28 of the window frame. The second tray 68 has an elevated molding sash or inner land conforming with the recessed seat 50 of the sash 54 illustrated in FIG. 4, with a surrounding molding rim or lower land conforming with the inboard surface of the frame rim 22.

[0118] Accordingly, the corresponding prepreg stacks 1-4 and 5-6 may then be staged atop their corresponding trays 66, 68 as shown schematically in FIG. 7 which will conform the initially flat prepregs 1-6 to the 3D configuration of the corresponding frame sides 28, 30. The preformed staged layers 1-6 will no longer be flat and will initially conform better with the desired final configuration of the window frame 18 illustrated in FIG. 8, and thusly improve press molding of the so-preformed press charge 60.

[0119] The initial prepreg material includes flexible fibers and uncured resin matrix which maintain the flexibility of the cut prepregs layers. The stacked prepreg layers remain flexible, but nevertheless have increased rigidity due to the relatively thick assembly thereof.

[0120] During heat staging, the elevated temperature of the oven 58 affects the viscosity of the resin which may become lower or more liquid due to heating, but with continued heating the staged layers become stiffer due to partial curing. Accordingly, the staging is preferentially conducted for obtaining a press charge 60 with suitable resin viscosity and layer flexibility so that the subsequent press molding thereof the press charge stack of layers will more readily conform with the desired 3D configuration of the window frame.

[0121] In the preferred embodiment illustrated in FIG. 7, only the outboard layer 1 and the middle layers 2-6 are staged under heat and then suitably cooled. The two stacks are assembled together in a common stack after which the inboard prepreg layer 7 is then added to the staged stack to form the final press charge 60 prior to pressure molding thereof. The two shop trays 66, 68 are suitably removed from both stacks to form the press charge 60 which has sufficient rigidity for manual handling and for seating inside the lower press mold 62 for the subsequent press molding operation.

[0122] As indicated above, press molding may be effected using the pair of molds 62, 64 shown in FIG. 8 which are specifically configured for the corresponding inboard and outboard sides 28, 30 of the resulting window frame 18. The lower mold 62 includes a complementary annular recess therein which conforms with the inboard side 28 of the frame 18. And, the upper mold 64 has a complementary anvil conforming with the outboard side 30 of the frame.

[0123] The preformed press charge 60 is placed in the lower mold 62 and then covered with the upper mold 64, and then substantial pressure is applied thereto for molding the press charge under heat to cure the resin matrix therein and form the rigid window frame 18.

[0124] In one fabrication process actually conducted, the prepreg stacks 1-4 and 5-6 illustrated in FIG. 7 were staged at several hundred degrees for a portion of an hour for suitable staging thereof and premolding to the supporting trays 66, 68. The resulting, premolded press charge 60 was then pressure molded in the mold pair 62, 64 illustrated in FIG. 8 at a suitably higher curing temperature for less than an hour under a high molding pressure exceeding 1000 psi. Actual pressures, temperatures, and times for staging and molding will be determined for the specific material compositions and resins desired in accordance with conventional practice.

[0125] In this way, the initially flat prepreg layers 1-6 were staged to a complementary intermediate preform and then press molded to final configuration in which the several layers were able to smoothly and evenly slide relative to each other to achieve the final 3D stepped configuration of the window frame without objectionable wrinkling of the layers or undesirable voids or other defects therein.

[0126] Such defects may be suitably detected in the final window frame 18 using various forms of nondestructive testing, such as ultrasonic detection, for improving the quality control of the resulting window frames 18.

[0127] Following the press molding operation illustrated in FIG. 8, the window frame 18 may undergo suitable post-processing. For example, the window frame may be deflashed using suitable sanders to remove sharp edges and extraneous material. The window frame may also undergo post curing at elevated temperature for sufficient time to complete curing and hardening of the specific resin matrix, such as typical heat cured epoxy resins.

[0128] And, a row of holes may be suitably drilled around the perimeter of the frame rim 22 for receiving fasteners to later attach the frame to the aircraft fuselage. The inboard drill mat layer 7 prevents excessive carbon breakout from the middle layers when the rim is drilled from its outboard side.

[0129] As part of the post processing of the window frame 18, the metal erosion shield 54 may be suitably bonded to the outboard side of the sash 24 for protecting the sash and its inner lip from rain and particle erosion when used in the aircraft application.

[0130] In final form, the composite laminated window frame 18 is a one piece or unitary member being relatively simple in configuration with the wide supporting outer rim 22 and the narrow offset inner sash 24. The window frame enjoys the substantial strength of its laminated construction with high strength carbon fibers and is substantially rigid due to its simple 3D configuration.

[0131] The preferred manufacturing process described above allows the initially flat prepreg layers to conform with each other and slide as required as the flat layers are staged and molded to the final 3D configuration of the frame. Undesirable wrinkling and voids or defects in the layers and their
integral resin matrix are avoided or reduced for maximizing yield of acceptable window frames being manufactured.

[0132] While there have been described herein what are considered to be preferred and exemplary embodiments of the present invention, other modifications of the invention shall be apparent to those skilled in the art from the teachings herein, and it is, therefore, desired to be secured in the appended claims all such modifications as fall within the true spirit and scope of the invention.

Accordingly, what is desired to be secured by Letters Patent of the United States is the invention as defined and differentiated in the following claims in which we claim:

1. An aircraft window frame comprising:
   a. laminated outer rim and transversely offset inner sash
   b. having a central aperture for receiving a window pane;
   and
   said laminated rim and sash including common layers extending radially therethrough, and said layers being different transversely between opposite inboard and outboard sides of said frame.
2. A frame according to claim 1 further comprising an annular rib transversely bridging in common layers said rim and sash to provide a central pocket on said inboard side for mounting said pane therein.
3. A frame according to claim 2 wherein:
   a. said rim, sash, and rib collectively form forward and aft posts spaced apart laterally along a minor axis of said frame, and upper and lower rails spaced apart longitudinally along a major axis of said frame to surround said central aperture;
   and
   said sash is offset from said outboard side of said rim with an exposed common outboard layer thereover.
4. A frame according to claim 3 wherein said rim, rib, and sash comprise a plurality of fibrous common layers fixed in a rigid resin matrix.
5. A frame according to claim 4 wherein said layers comprise said exposed outboard layer, a transversely opposite exposed inboard layer, and a plurality of different middle layers laminated therebetween.
6. A frame according to claim 5 wherein said rim has a uniform thickness, and said sash decreases in thickness from said rib to a thin lip circumferentially bounding said central aperture.
7. A frame according to claim 6 wherein said outboard side along said sash is generally parallel to said inboard side along said rim.
8. A frame according to claim 7 wherein said inboard side of said sash slopes toward said offset rim to form a seat for receiving said pane.
9. A frame according to claim 6 further comprising a metal erosion shield bonded to the outboard side of said sash and wrapping around said lip in a continuous annulus along said posts and rails surrounding said central aperture.
10. A frame according to claim 5 wherein said fibrous layers comprise different patterns each including a plurality of differently shaped segments overlapping along said posts and rails around said central aperture.
11. A frame according to claim 10 wherein said outboard layer has a different fibrous pattern than said inboard layer, and said middle layers have different fibrous patterns than said outboard layer.
12. A frame according to claim 11 wherein:
   a. said outboard layer comprises carbon fiber woven fabric having interwoven metal filaments therein;
   b. said inboard layer comprises fiberglass woven fabric; and
   c. said middle layers comprise corresponding mats of randomly oriented carbon fiber chips.
13. A frame according to claim 10 wherein said patterns include single segments in said posts.
14. A frame according to claim 10 wherein said patterns include single segments in said rails.
15. A frame according to claim 10 wherein said patterns include double segments collectively forming said posts and rails.
16. A frame according to claim 15 wherein said double segments are continuous in said posts and overlap in said rails.
17. A frame according to claim 15 wherein said double segments are continuous in said rails and overlap in said posts.
18. A frame according to claim 10 wherein said patterns include four segments collectively forming said posts and rails.
19. A frame according to claim 18 wherein said patterns include two segments forming said posts, and two segments forming said rails.
20. A frame according to claim 18 wherein said four segments overlap in said rails.
21. A frame according to claim 18 wherein said four segments overlap in said posts.
22. A frame according to claim 10 wherein said central aperture is oblong along said major axis.
23. A frame according to claim 10 wherein said patterns include a pair of rectangular segments arranged symmetrically about said minor or major axis.
24. A frame according to claim 10 wherein said patterns include a pair of semi-obleng segments arranged symmetrically about said minor or major axis.
25. A method of manufacturing said window frame according to claim 5 comprising:
   a. cutting to pattern resin impregnated fibrous flat prepregs to form said outboard, inboard, and middle layers;
   b. laying a plurality of said prepreg layers in a common stack;
   c. staging said prepreg stack under heat;
   d. cooling said staged stack to form a press charge; and
   e. molding said press charge under heat and pressure to form said frame in three-dimensional contour.
26. A method according to claim 25 wherein said prepreg layers comprise different patterns each including a plurality of differently shaped segments overlapping along said posts and rails around said central aperture.
27. A method according to claim 26 wherein said outboard layer has a different fibrous pattern than said inboard layer, and said middle layers have different fibrous patterns than said outboard layer.
28. A method according to claim 25 further comprising:
   a. weighing each prepreg layer;
   b. comparing the collective weight of said prepreg layers with a corresponding specification weight for said frame; and
   c. adjusting said collective weight to match said specification weight by adding or removing prepreg layers in said prepreg stack.
29. A method according to claim 25 further comprising:
   a. laying said prepreg layers in two stacks;
   b. adjusting collective weight of said two stacks to match a corresponding specification weight for said frame by adding or removing prepreg layers at the top of one of said stacks;
staging said two prepreg stacks; and
stacking together said two staged prepreg stacks to form a
common press charge for molding thereof.

30. A method according to claim 29 wherein:
said prepreg layers are stacked in sequence in one stack
starting first with said outboard prepreg layer and fol-
lowed by corresponding ones of said middle layers, and
in reverse sequence in the other stack; and
said two prepreg stacks are stacked together top-to-top to
provide a continuous sequence between said inboard
and outboard sides of said frame.

31. A method according to claim 25 wherein:
said prepreg layers are stacked atop a staging tray conform-
ing in three dimensional configuration with a corre-
sponding side of said frame; and
said prepreg stack is staged atop said tray to conform said
initially flat prepregs to said three dimensional configu-
ration of said corresponding frame side.

32. A method according to claim 25 further comprising:
staging said outboard and middle layers; and
adding said inboard prepreg layer to said press charge prior
to molding.

33. A method according to claim 25 wherein said press
charge is molded in a pair of molds conforming with said
opposite inboard and outboard sides of said frame.

34. An aircraft window frame comprising:
a laminated outer rim and transversely offset inner sash
having a central aperture for receiving a window pane;
said laminated rim and sash including common layers
extending radially therethrough, and said layers being
different transversely between opposite inboard and out-
board sides of said frame; and
a metal erosion shield bonded to the outboard side of said
sash and wrapping around a lip thereof in a continuous
annulus along said sash and surrounding said central
aperture.

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