

(19) World Intellectual Property  
Organization  
International Bureau



(43) International Publication Date  
24 February 2005 (24.02.2005)

PCT

(10) International Publication Number  
**WO 2005/016643 A1**

(51) International Patent Classification<sup>7</sup>: **B32B 03/12**

(21) International Application Number:  
PCT/US2003/022827

(22) International Filing Date: 19 July 2003 (19.07.2003)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant: **AEROSPACE COMPOSITE STRUCTURES, LLC** [US/US]; 4321-B Fulcrum Way, NE, Rio Rancho, NM 87144 (US).

(72) Inventors: **DONNELLY, Matthew, William**; 55 McCall Loop, Edgewood, NM 87015 (US). **KASOFF, William, Andrew**; 726-21 Tramway Vista Drive NE, Albuquerque, NM 87122 (US). **MCCULLOCH, Patrick, Carl**; 6 Remington, Irvine, CA 92620 (US). **WILLIAMS, Frederick, Truman**; 6005 Truchas Drive NE, Albuquerque, NM 87109 (US).

(74) Agent: **BAILEY, Vincent, P.**; 30100 Town Center Drive, Suite O-157, Laguna Niguel, CA 92677 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW.

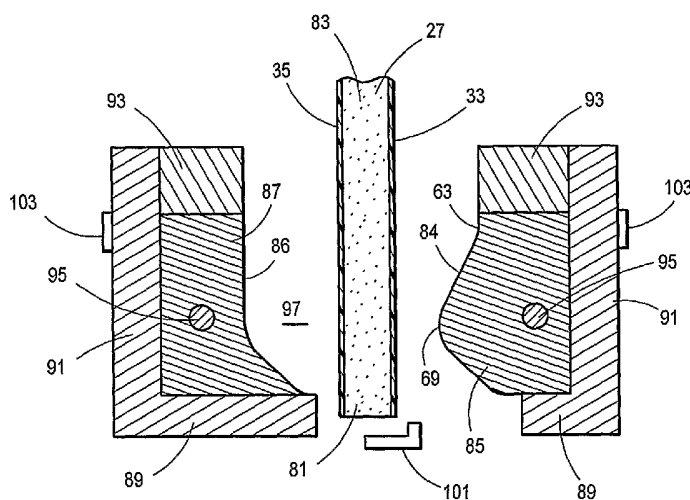
(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**Declaration under Rule 4.17:**

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE,*

[Continued on next page]

(54) Title: METHOD OF THERMOFORMING FRTP SANDWICH PANELS, THERMOFORMED ARTICLES, MODULAR CONTAINER



(57) Abstract: A method is disclosed utilizing off the shelf constant cross section thickness sandwich panels comprised of Fiber Reinforced Thermoplastic (FRTP) resin skins (23, 33) and low density thermoplastic (TP) resin core (27) wherein the steps of selectively and controllably exposing the panels to heat and incrementally thermoforming the core-skin into an integral consolidated composite edge or intra-panel area in consideration of subsequent mating and attachment of the FRTP sandwich panel to other structures is achieved. The exact configuration of articles so thermoformed is design optimized for an application for ease of manufacture, assembly, weight savings, and in-service structural performance. Further disclosed is a load bearing modular designed cargo container (1) assembled from such thermoformed FRTP sandwich panels (1, 5, 7) in which the integral core-skin consolidated composite edge configuration accounts for applied load transfer, useful container load volume, impact and damage tolerance, and repair and replace issues.



WO 2005/016643 A1



KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)

**Published:**

— with international search report

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

TITLE:

Method of Thermoforming FRTP Sandwich Panels, Thermoformed Articles, Modular Container .

5    TECHNICAL FIELD:

The present invention relates generally to thermoforming of sandwich panels comprised of fiber reinforced thermoplastic (FRTP) skins and low-density core of a thermoplastic material, thermoformed panel articles made therefrom, and more particularly an assembled container structure comprised of the thermoformed FRTP sandwich panels and attachment hardware.

10BACKGROUND ART:

Container structures such as those used for land, sea and air transport of goods having multi-piece metallic constructions are known. These structures make use of monocoque designs wherein relatively thin gage sheets forming a shell are mechanically fastened to angle, hat-section, doublers or similar stiffening elements. The monocoque shell structure formed is thus load bearing through the stiffening elements. Such structures are heavy due to their basic metallic construction, the use of robust stiffening elements, and the presence of mechanical fasteners required to assemble the shell and stiffeners. As the stiffening elements of a monocoque design are typically located on the interior of the shell structure, the stiffening elements of the design limit the useful volume of the container and interfere with internal loading of such containers as do the mechanical fasteners which protrude into the container volume.

15  
20

25       These metallic structures are also susceptible to short lifecycles due to physical damage from mis-handling and their inherent lack of damage tolerance. Additionally, corrosion damage from their exposure to a harsh environment including fluctuating

temperature extremes, water, ice, oils, solvents, and salt shortens their useful life cycle. Often an entire container is replaced where only stiffening elements or shell elements are damaged rather than performing a limited repair on the damaged element due to the load-bearing capacity of the individual elements.

5

Fiber Reinforced Plastics (FRP) are a non-metallic, composite material of a first, reinforcing element such as fiberglass, carbon, aramid fiber or woven form thereof which is encapsulated and bound within a second, matrix element such as a cured or hardened plastic of polyester, epoxy or other resin. Structures made from FRP's benefit from the composite synergy of the two, or more, constituent elements namely higher specific strength to weight ratios of FRP over conventional metallic structures such as aluminum or steel and are thus lighter in weight. Generally, when compared to their conventional metal counterparts, FRP's show better corrosion resistance, improved impact and damage tolerance, and lower piece/part count due to the increased complexity of designs possible with FRP's. For these and other benefits, FRP's have been integrated into aerospace, automotive, recreational, and industrial applications as direct replacement for metal structures. One such example is the use of polyester-fiberglass FRP in the marine industry for ship hulls, bulkheads, and decks. A second example is the use of carbon-epoxy FRP in aerospace applications such as aircraft fuselage and flight control structures.

10  
15  
20

A first type of FRP materials incorporates a single or multiple layer of FRP material consolidated or pressed into a sheet or panel often referred to as a laminate. While exhibiting increased strength to weight performance over metallic structures, replacing metallic structures with FRP laminates has met with mixed results. The nature of their multi-constituent fiber and matrix-binder form invites separation of the constituents at the interface of fiber and matrix-binder under concentrated, high stress conditions, particularly at attachment points and impact damage from handling or adverse

25

environment conditions. Although generally more damage tolerant than metallic structures, FRP structures do not have well defined, time-proven means of repairing local damage to insure structural integrity of the whole. The FRP laminate construction often incorporates monocoque design utilizing shell, stiffening elements, and fasteners. Thus  
5 weight and damage repair/ replace issues minimize the benefits of 100% FRP.

A second type of FRP materials incorporates a sandwich construction wherein a low density core material of foam or cellular construction is sealed at its surfaces by thin layers of FRP laminate material or skins. One such core material is honeycomb, a nodal  
10 arrangement of thin paneled, parallel cells comprised of aluminum, coated paper, polymeric or other material. Sandwich structure FRP's exhibit superior stiffness and high strength to weight ratios compared even to solid panels of FRP. However, like FRP laminate materials, repair of localized damage to sandwich structure to insure structural integrity of the whole is more art than science. Also, honeycomb core of aluminum or  
15 coated paper is susceptible to moisture ingress, which causes corrosion, weight increase and / or sacrifices structural integrity and performance.

The low density foam or honeycomb core also presents serious issues in mechanically attaching the FRP sandwich panel to another structure. Such core materials  
20 do not resist bearing or pull-out load well and fail under such conditions if un-reinforced. Thus, local reinforcement of the attachment area or special fastener inserts adding weight, special manufacturing steps and interposing dissimilar materials is necessitated. The dissimilar materials raises CTE and bond integrity issues of concern to the structure. Hence, manufacturing the FRP sandwich structure often requires design specific sculpting or  
25 forming of the core in consideration of panel edge core-crush as well as appropriate configuration for mechanical attachment to the sandwich panel.

The integration of FRP laminate panels and FRP sandwich panels into applications where metallic structures are replaced has met with mixed success. While light weight, stiff structures with reduced part count can be achieved, these FRP structures have their own shortcomings including: limited design configurations and reduced weight savings, particularly on (mechanical) attachment to other components; design specific, low rate manufacturing techniques for a given configuration and desired performance requirements; damage tolerance issues from stress, physical impact and environmental exposures. As with monocoque design metallic structures, the use of FRP panel and FRP sandwich panel materials in monocoque container structures often results in replacing an entire structure where only a component has been damaged or its structural integrity suspect.

#### SUMMARY OF THE INVENTION:

In the present invention, standard off-the-shelf constant cross section thickness sandwich panel structure (83) is comprised of Fiber Reinforced Thermoplastic (FRTP) resin inner skin made of a fiber reinforcing a thermoplastic resin in a fixed proportion, an outer skin made of a fiber reinforcing a thermoplastic resin in a fixed proportion, and a low density thermoplastic core material sandwiched between and integrally fixed to the inner and outer skins. The sandwich panel structure is selectively and controllably exposed to heat and incrementally thermoformed with the core-skin thermoplastic consolidated into a decreased thickness integral edge or intra-panel area in consideration of subsequent mating and attachment of the FRTP sandwich panel to similarly formed FRTP sandwich panels or other structures. The exact configuration of the integral thermoformed area is design optimized to overcome manufacturing, assembly and in-service and structural performance shortcomings of prior art and FRP sandwich panel structures rather than simply substituting the FRTP panel for a metallic, FRP, or other non-FRTP structure.

Specifically, a localized area of the FRTP skin and core sandwich panel is thermoformed and consolidated into an article having an integral localized region of homogeneous thermoplastic melt. In the preferred embodiment, the localized area of panel is configured into at least three optimized designs including: an angled core skin sandwich thickness thermoform consolidated to a reduced thickness radiused and angled skin-core edge; an angled core-skin sandwich thickness thermoform consolidated to a reduced thickness flat, or non-radiused nor angled skin-core edge; a radiused and angled core-skin sandwich thickness thermoform consolidated to a reduced thickness radiused and angled skin-core corner. The core-skin edge and corner areas so thermoform consolidated are comprised of the reinforcing fibers of the FRTP skins and the TP resin of both the FRTP skins and TP core. Thus, as a localized and thermoform consolidated region of the sandwich panel, the homogenous melt region advantageously benefits from the increased weight ratio of TP resin to fiber due to the contribution of TP resin of the core as opposed to the TP resin of the FRTP skins alone. This is accomplished without removal of the original raw stock panel material and without the addition of reinforcing materials to the localized areas, rather by transforming the thermoplastic into an optimized structural form and configuration.

Further, in the present invention, an improved load-bearing container is assembled from such thermoformed FRTP sandwich panel article (components) comprised of FRTP laminate skins and low-density core of thermoplastic material. A modular sandwich panel design is utilized rather than a monocoque shell-stiffener design. The use of modular sandwich panel construction requires consideration of the design for the panel's edge closure and intra-panel area assembly points to account for fastening and assembly integration to mating components. With the inventive modular, non-monocoque design, a load applied to the container is distributed by the integrally thermoformed and consolidated edges through-out the entire container assembly without the use of

independent container stiffening members rather than the load being transferred and concentrated in container (stiffening) members. This improvement further results in individual repair and replacement of damaged modular container components rather than replacement of the entire container structure.

5

These optimized, local area skin-core designs of the thermoformed FRTP skin and core panel result in the following improvements over the prior art:

Provide an improved load bearing point for attachment of a sandwich panel to another structure with minimal waste or removal of skin-core material and eliminates steps of removing and replacing skin and core material from the raw stock panels at attachment points;

Eliminate multiple, dedicated, configuration specific tooling for variations in final panel size and shape;

Avoid the added weight, cost, and introduction of local reinforcing materials or means to provide load bearing attachment points on an FRP sandwich panel edge or intra-panel point;

Facilitates a load bearing attachment without introduction of dissimilar CTE materials at the site of reinforcement providing structural continuity and integrity of the panel.

20

It is an object of the present invention to provide a method of processing standard constant cross section thickness FRTP skin and TP core sandwich panel structures such that:

An article results having localized areas which are comprised of a consolidated melt of TP matrix-binder and reinforcing fiber exhibiting improved structural and performance properties over the un-formed sandwich panel, namely improved load bearing

points for attachment to the panel, improved impact and damage tolerance at edge areas, improved core crush resistance and stabilization in core thickness transition areas;

Flexible tooling is utilized to minimize cost of duplicative, specialized tooling dies and fixtures for component configuration details and to form articles in an incremental  
5 fashion;

A standard, constant cross section thickness FRTP sandwich panel structure is efficiently utilized such that removal, scrap and inventory is minimized.

It is an object of the present invention to produce an improved container structure  
10 assembly from FRTP skin and TP core sandwich panel articles processed by a thermoform and consolidation method, the container structure exhibiting:

Minimized weight due to the use of modular, FRTP sandwich panel design benefiting from minimized part-piece count, minimized quantity of (fastener) attachment means, elimination of need for localized attachment point reinforcement by addition of  
15 stabilizing potting materials or specialized fastener inserts;

Distribution of container loading to bear upon the entire modular structure rather than concentrating loads in container stiffening, monocoque components by utilizing the inventive integrally thermoformed edge close-out and corner configurations for modular components resulting in improved load bearing performance at component termination  
20 points and assembled container joints;

Improved impact resistance and damage tolerance from in service loads and environmental conditions by use of skin-core sandwich panel of TP matrix-binder composite including localized areas design optimized for load and in-service structural performance;

25 Facilitating repair/replacement of individual, modular components of the container assembly by eliminating load bearing "stiffening" elements via use of high stiffness to

weight ratio sandwich panels versus replacement of entire container assemblies upon load-bearing component damage;

Maximized useful container volume loading due to elimination of fastener protrusion into the load volume and elimination of internal stiffening members required  
5 with monocoque structures.

#### BRIEF DESCRIPTION OF THE DRAWINGS:

Figure 1 is a schematic perspective view of a load bearing container assembly constructed of modular FRTP sandwich panels.

10 Figure 2 is a rearward looking cross-sectional view of the container assembly and elemental detail of opposing FRTP panel elements and container hardware.

Figure 3 is a forward-looking cross-sectional view of the container assembly and elemental detail of opposing FRTP panel elements and container hardware.

15 Figure 4A is an enlarged cross-sectional view illustrative of the construction of thermoformed container FRTP side panel detail elements.

Figure 4B is an enlarged cross-sectional view illustrative of the construction of thermoformed container FRTP top panel detail elements.

Figure 5A is an illustration of thermoforming a radiused edge configuration in a FRTP sandwich panel.

20 Figure 5B is an illustration of the further forming and cooling of the radiused edge configuration in an FRTP sandwich panel.

Figure 6A is an inner plan view of a container FRTP panel illustrating the formed; radiused corner at the juncture of perpendicular radiused edged FRTP sandwich panels.

25 Figure 6B is an outer plan view of a container FRTP panel illustrating the formed; radiused corner at the juncture of perpendicular radiused edged FRTP sandwich panels.

Figure 6C is a perspective view of the juncture of two radiused edge FRTP side panel panels and a top panel FRTP panel forming a closed corner joint of the container.

BEST MODE FOR CARRYING OUT THE INVENTION:

**Figure 1** illustrates a schematic perspective view of a container as may be used by example for air cargo applications. The general shape, geometry and scale of the figure is not limiting of the invention's scope or application to air cargo applications; in contrast to sea, land and intermodal containers; rather is shown to aid in the invention's disclosure. Container 1 has a forward end 2 and rearward end 4.

Container 1 further has two side panels 3 and 5, rear panel 7, top panel 9, base 11 and with opening 6 at forward end 2 which is framed by: base 11 and the forward termination of side panels 3 and 5, and top panel 9, opening 6 framed by base 11 and panels 3, 5 and 9 serving as an access to the interior of the container. In a preferred embodiment, a closure means 22, not shown, for closing opening 6, may include any enclosure mechanism, known to the art including a simple fabric covering device to an intricate mechanical closure device.

Panels 3, 5, and 7 of container 1 are generally single vertical planar sandwich panels whereas panel 9 is a single horizontal planar sandwich panel, all constructed of FRTP sandwich panel structure of Fiber Reinforced Thermoplastic (FRTP) skins and low-density core of thermoplastic material. In an alternate embodiment, container 1 is comprised of four side panels 3, 5, 7, and 8 wherein side panel 8 is at forward end 2 and is fitted with opening 6 and closure means 22 rather than opening 6 being framed by adjacent elements 3, 5, 9 and 11 as described previously. In the preferred embodiment, rear panel 7 has two planes, one vertical plane extending from its upper edge partially toward its lower edge and a second plane angled from the vertical plane at an angle of 20 to 70 degrees and extending toward and terminating at base 11.

**Figure 2** shows a rearward looking cross section view of container 1 wherein the details of sandwich panel constructed side panels 3 and 5 and top 9 can be seen as well as subcomponents of the base 11. **Figure 3** shows a forward looking cross section view of container 1 wherein details of sandwich panel constructed side panel 3 and 5 and top panel 9 can be seen as well as subcomponents of base 11 forward framing members 10, 12, 14.

In the preferred embodiment, base 11 is further comprised plate 13 and an edge rail 15 located along the opposite sides and the rear periphery of base 11 thereby framing it on three sides except at forward end 2. Edge rail 15 is further comprised of inner horizontal leg 17, outer horizontal leg 19 and vertical leg 21. Three right angled forward framing members 10, 12, and 14 are located at the forward end 2 and frame opening 6 and serve as forward end close-out hardware for panels 3, 5 and 9. Plate 13 and edge rails 15, and forward framing members 10, 12, 14 can be comprised of any suitable material which will perform and function in the necessary structural manner. In the preferred embodiment, plate 13 is an aluminum sheet, edge rails 15 are aluminum extrusions, and forward framing members 10, 12, and 14 are aluminum angles.

In the foregoing embodiment, plate 13 is fixedly attached at its periphery to edge rail 15's inner horizontal leg 17 by attachment means 16. Similarly, forward framing members 10, 12 and 14 are fixedly attached at their point of contact with base 11 and forward edges of panels 3, 5 and 9 by attachment means 18. Attachment means 16 and 18 may be any appropriate means known to the industry including but not limited to interference fit, slip fit, nut-bolt, riveting, adhesive bond or equivalent means. In the preferred embodiment, attachment means 16 and 18 are mechanical fastening means.

25

In an alternative embodiment of base 11, rather than being comprised of separate elements, plate 13 attached to edge rail 15 and its sub-elements, base 11 comprises a single

structure having the features of outer horizontal leg 19, vertical leg 21 and plate 13 thereby reducing or eliminating inner horizontal leg 17 and means 16 as appropriate.

Side panels 3, 5 and 7 and top panel 9 are fabricated from an FRTP sandwich panel structure (83) which is a standard off the shelf constant cross section thickness FRTP sandwich panel comprised of an inner composite skin made of a fiber reinforcing a thermoplastic resin in a fixed proportion, an outer composite skin made of a fiber reinforcing a thermoplastic resin in a fixed proportion, and a low density thermoplastic resin core sandwiched between and integrally fixed to the inner and outer skins. FRTP sandwich panel structure 83 is thermoformed into the specific sub-elements specific to each of side panels 3, 5 and 7 and top panel 9.

**Figure 4A** is drawn to side panel 3 and is also illustrative of the structure of panels 5 and 7. As can be seen, each of side panels 3 and 5, and rear panel 7 are further comprised of inner skin 23, outer skin 25, core 27, lower edge 29, radiused upper edge 31, a radiused side edge 32. Radiused side edge 32 is perpendicular at the forward and rearward planar terminus of panels 3 and 5 and perpendicular at opposing planar terminus of panel 7. Inner skin 23 is made from a fiber reinforcing a thermoplastic resin in a fixed proportion, outer skin 25 is made from a fiber reinforcing a thermoplastic resin in a fixed proportion, and core 27 is made from a low density thermoplastic resin sandwiched between and integrally fixed to inner skin 23 and outer skin 25.

Referring to **Figure 4B**, top panel 9 is further comprised of inner skin 33, outer skin 35, core 27 and four radiused periphery edges 37 at the terminus of panel 9's planar edges. Inner skin 33 is made from a fiber reinforcing a thermoplastic resin in a fixed proportion, outer skin 35 is made from a fiber reinforcing a thermoplastic resin in a fixed

proportion, and core (27) is made from a low density thermoplastic resin sandwiched between and integrally fixed to inner skin 33 and outer skin 35.

Referring again to **Figures 2 and 3**, it can be seen that panels 3, 5, and 7 are joined to respective edge rails 15 by attachment means 39 through the respective mated portions of the side panel's lower edges 29 and edge rail 15's vertical leg 21. A plurality of attachment means 39 is dispensed along the length of leg 21 and edge 29. A plurality of attachment means 20 joins periphery edge 37 of top panel 9 to upper edge 31 of panels 3, 5, and 7 and joins panels 3, 5, 7 at the juncture of each respective panel's side edge 32. Means 39 and 20 may be any appropriate means known to the industry including but not limited to nut-bolt, rivet, adhesive bond or equivalent means. In the preferred embodiment, a mechanical fastening means is used.

Attention is drawn to **Figures 2 and 3** to illustrate that the assembly by attachment means 20 of thermoformed radiused edges 31 and 37 results in a compact, nested joint and insures that where means 20 is a mechanical fastener it does not extend beyond the central panel thickness of panels 3, 5, 7, or 9 and does not protrude into the inner loading volume of container 1 thereby maximizing the useful container volume. Similarly, the assembly by attachment means 20 of adjacent thermoformed edges 32 results in a compact nested joint and insures that a mechanical fastener means 20 does not protrude into the container volume thereby maximizing the useful container volume. The assembly of two such adjacent edges into a compact nested joint results from these integrally thermoformed edges being design optimized to transfer load such that applied loads are distributed throughout the container without the use of independent container stiffening members.

The use of sandwich panel construction, particularly with FRTP, for panels 3, 5, 7, 9 in a load bearing structure requires consideration of the panel's edge close out and intra-

panel area attachment points to accommodate attachment means 18, 39 and 20. The compressive strength of a sandwich panel through its thickness will vary with the density of the core material and is typically too low to accommodate attachment means such as fasteners without local reinforcement at the attachment point.

5

In a first prior art scenario, in an attempt to address edge and intra-panel area attachment issues, the FRP industry practice has been to locally increase compressive strength of the sandwich panel at its edge or within the panel's area by adding foam or paste type potting materials which become rigid or to add local fastener inserts. These and  
10 other methods of increasing compressive strength adds weight and cost to the sandwich panel and structure.

In a second prior art scenario, the FRP industry extensively machines, sculpts or otherwise modifies the core material at the panel's edge or at its intra-panel area before  
15 fixing the skins such that the core material is beveled at an angle through its thickness to a termination point and the upper and lower skins are subsequently fixed to the core. Upon fixing the lower skin to the core, the upper skin is conformed to the core bevel geometry and the upper and lower skins are extended beyond the core's termination point such that a suitably thick attachment flange is formed at the edge of the panel by the extended upper  
20 and lower skins. This approach does not allow cost efficient, high rate manufacturing as the beveled edge is not amenable to manufacturing processes such as flat platen press or molding and requires considerable hand labor.

The preceding scenario requires component and configuration specific tooling  
25 since core material is manufactured to constant thickness cross-section. Such configuration specific, custom tooling is expensive to manufacture and inventory. Additionally, the now beveled core still requires stabilizing with a reinforcing foam or

paste along its bevel length. This is required to prevent the core from crushing (core-crush) as the outer skin is applied, consolidated and processed to completion. Such core stabilizing adds weight and cost.

5           In yet another prior art scenario, the core is beveled after the upper and lower skins are fixed to the constant cross-section core necessitating removing one skin and detail machining the core's edge to a transition bevel. A replacement skin is fixed to the core bevel geometry to replace the removed skin and a robust attachment flange is formed at the edge of the panel by the extended upper and lower skins. While configuration specific  
10 tooling is avoided, costly custom manufacturing techniques are needed to remove skin and core, to replace and consolidate skin.

Prior art attempts at addressing sandwich panel attachment issues has required removal and waste of skin/core material; necessitated adding dissimilar reinforcing  
15 materials to the site; increased manufacturing time, cost and weight to the sandwich panel and thus assembled structures. Additionally, the modified panel structure and dissimilar materials now presented at the modification or fastener point invite cracking and separation or de-bonding of (plastic) matrix-binder materials due to differing material's coefficients of thermal expansion (CTE) and surface seal integrity (migration path into  
20 structure for moisture, oils, solvents, dirt) which both reduce aesthetics and structural integrity and which in turn increase maintenance and repair costs of the component and assembly.

In the present invention, the improved and distributed load bearing container  
25 addresses panel edge and intra-panel attachment issues of sandwich panel construction without the need for potting, fastener inserts, component specific tooling, or custom

modification techniques, minimal material removal and waste; nor the introduction of dissimilar materials into the panel.

The invention utilizes Fiber Reinforced Thermoplastic (FRTP) skins and low density thermoplastic (TP) core to construct the sandwich panel. The sandwich panel edge, or an intra-panel area, is selectively and controllably exposed to heat and forming pressure (thermoformed) to soften and angularly collapse the panel's cross-section thickness including the core material, deform the FRTP skins, and form a consolidated, homogenous melt of core-skin of integral robust design configuration desired for the panel's subsequent attachment to a mating component. The core-skin so thermoformed and consolidated is now comprised of the reinforcing fibers of the skins and the TP matrix-binder of both the FRTP skins and the TP core. Therefore the weight ratio of the matrix-binder to reinforcing fibers in this consolidated area is greater as opposed to the ratio in the FRTP skins alone. Thus, the thermoformed area is optimized for fastener attachment and load-bearing performance utilizing a melt of homogeneous materials or materials closely matched for CTE and related properties.

The thermoforming of the skins and core into a consolidated, homogenous melt is possible because the thermoplastic resin of the FRTP matrix material and TP core material softens as it is exposed to its molecular specific melt temperature. The thermoplastic is advantageously deformable under pressure (thermoformed) within a range of temperatures at the thermoplastic's specific melt temperature. This temperature range is referred to as the processing window of the specific thermoplastic. When cooled below the lower limit of the processing window, the thermoplastic becomes rigid and will hold the deformed shape.

Any of a wide variety of thermoplastic resins can be used as the matrix of the FRTP and as the core material as seen in Table I below. The fiber reinforcing the thermoplastic resin of the skins may be continuous or discontinuous fibers or a textile fabric form thereof including fiberglass, aramid, carbon, nylon, polyester, polyolefin or similar materials.

**Table 1**

|    | Thermoplastic   | Processing Temperature Window |                |
|----|-----------------|-------------------------------|----------------|
|    | <u>Material</u> | <u>(DEG C)</u>                | <u>(DEG F)</u> |
| 10 | ABS             | 180-240                       | 356-464        |
|    | Acetyl          | 185-225                       | 365-437        |
|    | Acrylic         | 180-250                       | 356-482        |
|    | Nylon           | 260-290                       | 500-554        |
|    | Polycarbonate   | 280-310                       | 536-590        |
| 15 | LDPE            | 160-240                       | 320-464        |
|    | HDPE            | 200-280                       | 392-536        |
|    | Polypropylene   | 200-300                       | 392-572        |
|    | Polystyrene     | 180-260                       | 356-500        |
|    | PVC, rigid      | 160-180                       | 320-365        |

20

In the preferred embodiment, the FRTP skins are comprised of fiberglass fibers coated with polypropylene or commingled with polypropylene fibers in fixed proportions and woven into a textile fabric form. A commercially available form of this product is TWINTEX<sup>®</sup> available from Vetrotex America. When heated to the melt processing range and formed between platens and subsequently cooled, Twintex forms a sheet material which is marked by thermoplastic resin matrix encapsulating the fiberglass woven form in a fully consolidated medium containing from 40 to 80% by weight fiberglass

reinforcement to thermoplastic resin ratio as desired. The skin panel may be a single layer or a multiple layer, consolidated laminate. Once formed, it can be re-heated and cooled to form a secondary shape or further thermoformed to other thermoplastic materials.

5           The invention's thermoplastic material of the core may take the form of low density foam, expanded foam or a parallel cellular node pattern or honeycomb structure and may itself be reinforced with any of the enumerated fibers. While the thermoplastic of the core is preferably the same thermoplastic matrix of the FRTP skin, dissimilar yet compatibly processed thermoplastics may be used for skin and core. The FRTP skins may  
10 be fixed to the core utilizing a wet bonding adhesive or melt film adhesive between the components or may be directly thermally fused.

          In the preferred embodiment, the thermoplastic core material is made from unreinforced polypropylene thermoplastic resin in a parallel cellular node pattern or  
15 honeycomb structure. The polypropylene core is fixed to the polypropylene fiberglass FRTP skin panels by a thermal fusing process. The thickness of the FRTP skins may be in the range of .005 inches (0.0127 cm) to 2 inches (5.08 cm), the TP core thickness in the range of .050 inches (0.127 cm) to 10 inches (25.4 cm), and hence the overall thickness of the sandwich panel can vary in the range of 0.625 of an inch (0.1588cm) to upwards of 14  
20 inches (35.56 cm).

          In the preferred embodiment, the sandwich panels of the invention are: in the overall thickness range of 0.25 inches (0.635 cm) and 1 inch (2.54 cm) with the FRTP skins being comprised of a single or multiple layers in the range of 0.010 inch (0.0254 cm)  
25 to 0.080 inch (0.2032 cm) thick each. Additionally, cured and consolidated FRTP skins contain by weight a glass fiber to thermoplastic resin ratio of 50-75% and a honeycomb core density of 3 pounds per cubic foot (48 kg/cubic meter) to 8 pounds per cubic foot

(128 kg per cubic meter). The FRTP skin-TP core sandwich panel is made into a panel of constant cross-section thickness wherein initial tooling requirements and costs are minimized.

5           Three thermoformed sandwich panel article configurations will be illustrated herein in detail. There is considerable design freedom in forming of the FRTP sandwich panel which results in many design configurations suitable for general or specific attachment and load bearing conditions. For instance, the thickness, length, width, and area formed and intended to be the fastener attach point can be varied depending upon load  
10   conditions, thickness of FRTP skins, weight ratio of fiber to resin, thickness and density of core, attachment means geometry, etc. Thus, the inventive process is capable of, and applicable to, a wide range of thermoformed design and configurations beyond these three illustrated article configurations. In all instances, a standard constant cross section FRTP sandwich panel structure (83) having an inner skin made of a fiber reinforcing a  
15   thermoplastic resin in a fixed proportion, an outer skin made of a fiber reinforcing a thermoplastic resin in a fixed proportion, and a low density thermoplastic resin core sandwiched between and integrally fixed to the inner skin and outer skin is thermoformed into the specific core-skin configuration of integral panel edge or corner.

20           These three configurations are illustrated in **Figures 4A** and **4B** and further in **Figures 6A, 6B**, and are discussed below. These thermoformed design configurations are namely: (1) common configured radiused upper edge 31, radiused side edge 32, and radiused periphery edge 37; (2) lower edge 29; (3) and radiused corner 38. Each configuration is carefully designed for optimal component and system performance and  
25   the configuration achieved through the inventive thermoforming process. Each configuration's detailed elements will be reviewed prior to discussing the forming process.

Figure 4A is an enlarged view of panel 3 although it is also illustrative of the construction of panels 3, 5 and 7 and showing lower edge 29 and radiused upper edge 31. Radiused side edge 32 is perpendicular at the forward and rearward planar terminus of panels 3 and 5 and perpendicular at opposing planar terminus of wall 7. Radiused edge 32 has common sub elemental details as comprising radiused upper edge 31 as illustrated. These edges are representative of the desired configurations for the sandwich panel's thermoformed edges and are shown in further detail. Inner skin 23, outer skin 25, core 27; lower edge 29 and upper edge 31 are shown as in **Figure 2**.

At lower edge 29, each of panels 3, 5 and 7 are further comprised of a lower trim end 45, bevel end 47, bevel transition length 49, bevel start 51, inner attachment length 54, outer attachment length 53. Transition length 49 is a sub-length of outer skin 25 and spans from bevel start 51 to bevel end 47. Inner attachment length 54 is a sub-length of inner skin 23 and spans from bevel start 51 to trim end 45. Outer attachment length 53 is a sub-length of outer skin 25 and spans from bevel start 51 to trim end 45. In a preferred embodiment, said lower edge 29 is flat and parallel with the plane of inner skin 23 along the sandwich panel area.

At upper edge 31, each of panels 3, 5 and 7 are further comprised of upper trim end 55, bevel end 57, bevel transition length 56, forty-five degree bevel start 59, inner attachment length 58, outer attachment length 60. Transition length 56 is a sub-length of inner skin 23 and spans from bevel end 57 to bevel start 59. Inner attachment length 58 is a sub-length of inner skin 23 and spans from bevel start 59 to trim end 55. Outer attachment length 60 is a sub-length of outer skin 25 and spans from bevel start 59 to trim end 55. In the preferred embodiment, inner and outer attachment lengths 58 and 60 are radiused at forty five degrees from bevel start point 59 to trim end 55 and concave towards

inner skin 23 the radius being on size with the cross section thickness of core 27 and skins 23 and 25.

The design details of upper edge 31 are identical for radiused side edge 32 of panel 3, 5 and 7, namely bevel end 57, transition length 56, and bevel start 59, inner attachment length 58, outer attachment length 60. Side edge 32, not shown, is off-set at ninety degrees and perpendicular to upper edge 31 at both the forward and rearward terminus end of panels 3 and 5, and at the opposing terminus ends of panel 7 which are adjacent to panels 3 and 5 in **Figures 1, 2, 3**.

**Figure 4B** is an enlarged view illustrative of top panel 9 and showing radiused periphery edges 37 which is present at all four planar terminus ends of panel 9, two of which are illustrated here. The sandwich panel's thermoformed edges are shown in further detail. Inner skin 33, outer skin 35, core 27, and radiused periphery edges 37 are shown as in **Figure 3**.

At periphery edge 37, top panel 9 is further comprised of trim ends 61, bevel end 63, transition length 65, bevel start 67, inner attachment length 69, and outer attachment length 71. Transition length 65 is a sub-length of inner skin 33 and spans from bevel end 63 to bevel start 67. Inner attachment length 69 is a sub-length of inner skin 33 and spans from bevel start 67 to trim end 61. Outer attachment length 71 is a sub-length of outer skin 35 and spans from bevel start 67 to trim end 61. This periphery edge 37 and its detailed elements comprise the periphery of panel 9, i.e. all four sides of panel 9.

**Figures 6A, 6B and 6C** are plan views of radiused corner 38, which is common to panels 3, 5, 7 and 9. Radiused corner 38 is formed at: the perpendicular juncture of upper edge 31 and side edges 32 of panels 3 and 7; the perpendicular juncture of upper edge 31

and side edge 32 of panels 5 and 7; and at the juncture of perpendicular periphery edges 37 of panel 9. Also, in the preferred embodiment wherein panel 7 is comprised of two planes, radiused corner 38 sweeps through a smaller angle than ninety degrees at the rear to middle length of the vertical height of panels 3 and 5 along their radiused edge 32 and  
5 coincident with their mating point with panel 7's planar juncture. The angular sweep of this length is on the order of 20 to 70 degrees from the vertical plane of panel 7 versus the sweep of corner 38 through the ninety degrees of two panels at right angles.

The present invention utilizes an inventive thermoforming process to configure a  
10 standard FRTP sandwich panel structure 83 of constant cross section thickness into the detailed sandwich panel with integral core-skin edge closeouts 29, 31, 32, 37 illustrated in Figures 4A and 4B and to form radiused corner 38 illustrated in Figures 6A and 6B. This is accomplished with minimal tooling and manufacturing cost, minimal raw material waste, and utilizes non-dissimilar, thermally compatible materials throughout the  
15 component's cross section.

The resulting thermoplastic sandwich panel exhibits: superior impact resistance and damage tolerance, reform-ability of edge details, offers modular remove and replace repair strategies and flat stacking/shipping of finish-formed components. Further, the  
20 sandwich panels with core-skin edge close outs so formed and depicted may be assembled in a modular fashion into a container structure such as described and illustrated in the preceding disclosure. Integration of such panels in a modular fashion result in assembled container structure benefits including: reduced piecepart/fastener count; structural load distribution across the structure without independent container stiffening or concentrated  
25 load bearing by components; improved sealing of the assembly from the environment; maximizing container volume for cargo by eliminating inner stiffening members and recessing fasteners from protrusion into cargo volume.

Thermoforming of a planar constant cross section panel of FRTP sandwich structure 83 to melt and collapse the TP core material and reform the melt with that of the fixed FRTP skins is achieved by heating the sandwich panel material to the heat processing temperature range of the respective TP and forming the final desired shape under compression followed by cooling and hardening of the melt while retaining the shape. In this process, the FRPT sandwich panel is selectively and controllably exposed to heat and forming pressure thereby allowing deformation of both the FRTP skin and underlying core material in a precise and incremental fashion.

The application of heat energy to the sandwich panel structure can be accomplished through radiant, conductive or other heating means. In the preferred embodiment, conductive heating provides a selectively, controlled melt process. The greatest amount of heat is applied to locations requiring the most deformation.

Attention is drawn to **Figure 5A** illustrating forming of the integral core-skin edge configuration of top panel 9 at radiused periphery edge 37 wherein the core 27 and skins 33, 35 will be thermoformed from bevel start 67 to bevel end 63 and along attachment lengths 69 and 71 to trim end 61. In the preferred embodiment, attachment lengths 69 and 71 will be formed at forty five degrees to the plane of outer skin 35 and radiused concave towards inner skin 33 with a radius sized to the cross section thickness of core 27 and skins 33 and 35. This illustration is identical for forming the corresponding sub details of radiused edge 31 and 32 of panels 3, 5, and 7 and is illustrative of forming the respective corresponding sub details of edge 29 of panels 3, 5 and 7. While the illustrated thermoforming of sandwich panel structure 83 into top panel 9 having inner skin 33, outer skin 35, and core 27, panel structure 83 may be similarly thermoformed into side panel 3, 5 or 7 having inner skin 23, outer skin 25, and core 27.

Conductive heating at end 81 of a standard constant cross section panel of FRTP sandwich structure 83 into the configuration of integral radiused side edge 37 is accomplished by contact-melting with a heated set of matched male die 85 and matched female die 87 of the desired configuration. The dies 85 and 87 are exposed on those surfaces 84 and 86 which are intended to come into contact with the panel structure 83. The dies have insulated elements 89, 91 and 93 in areas that are not intended to come in contact with or to form the thermoplastic. Insulation element 93 at the upper end of the dies serves as a forming stop, which prevents melting under heat and pressure past the core bevel end 63. The insulated elements and heated elements of the dies, coupled with drive means 103 for driving dies 85 and 87 such as pneumatic piston or screw mechanism to force them into the panel, allows for selective and controllably exposing the FRTP panel structure to the thermoplastic's optimal process temperature.

The thermoforming process illustrated here proceeds as follows:

Heating means 95 in dies 85 and 87 brings each die half to the desired temperature for the thermoplastic, namely to within 5 to 20 % of the lower end temperature value of the thermoplastic's melt processing temperature window. Dies 85 and 87 are opened, panel structure 83 is inserted into the die cavity space 97 and positioned to the desired depth and transverse location and held by registration means 101, a mechanical, electro-optical or combination device thereof to register panel structure 83 into its position appropriate for the edge to be thermoformed.

Modest, controlled and gradient contact (gage) pressure in the range of less than 1 Psi (689.5 MPa) to less than 100 Psi (68950 MPa) is applied by means 103 forcing heated dies

85 and 87 into space 97 and compressing FRTP skins 33 and 35 toward the mid-plane of panel structure 83.

Increased, controlled gradient heat, in the range of 10 to 90 % of the lower to upper range of the thermoplastic's melt processing temperature; and pressure, in the range of 10 to 200 % greater than the initial contact pressure, is applied along the area of contact with the thermoplastic matrix skins wherein the thermoplastic material begins to soften as it is exposed to its melt temperature. This further, controlled and gradient heat and compression (pressure) on the skins and core causes the core to melt, give way and collapse within the two FRTP skins. This melt of FRTP skin and TP core is further consolidated under increased pressure by means 103 and forming the final core-skin edge configuration. Once the melt and consolidation of skin and core of panel structure 83 is complete, die 85 and 87 are retracted away from space 97 and panel structure 83.

Dies 85 and 87 may be of any length, width and travel as appropriate for the desired formed configuration and panel size or area. Die halves may be heated by any suitable means 95 including but not limited to resistive heating mechanisms or a circulated heated medium. A mold release, not shown, may be used on the die halves or a release film, not shown, on the outer skin surfaces of panel structure 83 to prevent sticking of the molten thermoplastic onto the tooling. Controlled melting and cooling can be achieved by processing below and at the lower end of the processing windows of Table 1 for a given thermoplastic material.

Referring now to **Figure 5B**, once the heated dies 85 and 87 are fully retracted, a cold set of matched dies 105 and 107 are moved into position and forced into the melt zone of thermoformed panel structure 83 by drive means 103 to cool the part below the lower end of the specific thermoplastic's process temperature window. Dies 105 and 107

may be at ambient temperature or cooled by cooling means 109, including a static or circulated cooling medium, depending upon the temperature required to bring the thermoplastic below its softening temperature to retain its formed shape.

5 Thermal melt and collapse of the core in conjunction with compression of the melt zone during forming can easily result in bunching up of the FRTP skin fiber on one side of the radiused periphery edge 37 unless proper attention is paid in the formed joint design. Two factors must be controlled in minimizing FRTP skin fiber bunching of panel 9: (1) maintaining an exterior path length which is approximately equal for inner attachment  
10 length 69 and outer attachment length 71, and (2) use of radii from bevel start 67 to trim end 61 which are large relative to the thickness of the joint and on size with the combined skin-core-skin thickness of the FRTP sandwich panel being formed. In this manner, the total average slip of the skins 33 and 35 being formed, as measured by the off-set of each skin relative to each other at trim end 61, is negligible as opposed to having one skin slide  
15 during forming past the other a dis-proportionate length.

Heated die sets and cold die sets may be sized to form the entire final edge length of any component such as edge 37 of panel 9. In the preferred embodiment, the die sets are sized to form only a partial length of the final edge length of a component. In this way,  
20 thermoforming and cooling of a component's edge is achieved incrementally rather than in one step. This incremental approach is desirable particularly at the juncture of any perpendicular edges of a component. Whether a component's edge length is formed in one step or incrementally, the remaining periphery of a component is formed by re-positioning and indexing the panel into the (desired) heated and cold forming dies. For instance, a  
25 square shaped component will have one of it's side edges formed as illustrated, be re-positioned and indexed at 90 degrees for a second side, and re-positioned so forth until the panel's entire periphery has been formed as desired.

The thermoforming process; described for the periphery edge 37 of panel 9 resulting in the preferred forty-five degree edge configuration and illustrated in Figures 5A and 5B; is similarly applied to a constant cross section, planar FRTP sandwich panel structure 83 to thermoform the preferred forty-five degree core-skin edge configuration for radiused upper edge 31 and radiused side edge 32 of panels 3, 5 and 7 as illustrated in Fig. 4A.

The core-skin edge configuration of lower edge 29 of panels 3, 5 and 7 is similarly formed by thermoforming a constant cross-section, planar FRTP sandwich panel structure as described in the preceding paragraphs. The flat ended, or duck billed edge details of lower edge 29 are shown in Figure 4A. To thermoform a sandwich panel core-skin edge of this configuration, a heated matched male-female tool set and cooled male-female tool set designed to this flat or duck billed configuration, rather than the radiused forty-five degree configuration, are required. Similarly, these dies for the duck bill configuration require insulated sections where heat (forming) is not intended to come into contact with the finished part. Here again, intended exposure of the un-formed FRTP panel to heat and forming pressure is selective and controlled as described above.

The specifics of the tooling and processing required for the duck bill or flat edged panel thermoforming is comparable to that required for the radiussed edge thermoforming. However, it should be noted that the lengths of inner attachment length 54 and outer attachment length 53 will be more closely matched during and after thermoforming than those of elements 69 and 71. Thus bunching up of FRTP skin at the forming point is less an issue than in forming the forty five-degree radiused edge. Here, similar to the forty-five degree configuration, skin 25 is formed along its length from bevel start 51 to bevel end 47, referred to as transition length 49, and formed along skin 25's length from bevel start

51 to trim end 45, referred to as outer attachment 53. Also, skin 23 is formed along its length from bevel start 51 to trim end 45, referred to as inner edge skin 54.

As shown in **Figures 6A and 6B**, a radiused corner 38 is formed within panels 3, 5 and 7 where radiused upper edge 31 meets perpendicular, radiused side edge 32. Radiused corner 38 is formed at both the forward and rearward points of upper edge 31 meeting side edge 32 for both panels 3 and 5. Radiused corner 38 is formed in panel 7 where top edge 31 meets side edge 32 at the planar terminus of edge 31. Radius corner 38 is concave toward the surface of inner skin 23 and convex at the surface of outer skin 25. Tracing the perimeter of panel 3, 5 or 7, as edge 31 terminates, radiused corner 38 begins and sweeps a radius about an angle of ninety degrees until radiused corner 38 meets the termination point of perpendicular edge 32. As with flat lower edge 29, inner attachment length 54 and outer attachment length 53 which result from the thermoforming and consolidation of inner skin 23, core 27 and outer skin 25 comprise a consolidated melt which comprises corner 38 as it sweeps from one perpendicular radiused upper edges 31 to the other. In the preferred embodiment, the radius of corner 38 is sized to the cross section thickness of core 27 and skins 23 and 25 and maintains a forty five degree angle to the plane of outer skin 25.

In the embodiment in which panel 7 has a vertical plane and an angular, offset plane configuration, radiused corner 38 sweeps through an angle less than ninety degrees at panel 7's planar adjustment and in the range of 20 to 70 degrees from the vertical of panel 7 and along each opposite radiused edge 32 of panel 7. Similarly, corner 38 will sweep through a like angle of 20 to 70 degrees from the vertical on panels 3 and 5 along their rearward radiused edge 32 to coincide with their mating points with panel 7.

Similarly, radiused corner 38 is formed where each of the four periphery edges 37 of top panel 9 meet an adjacent, perpendicular edge 37. Here, radiused corner 38 is concave toward the inner skin 33 of panel 9 and convex on the outer skin 35 of panel 9. As one edge 37 of panel 9 terminates, radiused corner 38 begins and sweeps an angle of twenty to ninety degrees until it meets the termination point of an adjacent, perpendicular edge 37. Thus, four radiused corners 38 comprise panel 9.

Thermoforming of FRTP skin and TP core sandwich panel structure 83 into configuration of radiused corner 38 is achieved in at least two ways. First, a heated die set corresponding to 85 and 87 and cold die set corresponding to 105 and 107 are configured to the specific design details of radiused corner 38. The die set is designed to the final desired concave (inner) and convex (outer) surface dimensions of radiused corner 38 and take into account all skin and core forming in the 20 to 90 degree arc of any radiused corner 38. The heated dies are employed to selectively and controllably expose the FRTP skins and TP core of sandwich panel structure 83 to heat and pressure to soften and collapse the core within the skins and thereby thermoform the raw FRTP skin-core stock in a single step to the desired final configuration.

Second, and the preferred embodiment, a heated die set and cold die set are sized to a sub-length of the inner and outer dimensions desired for corner 38 along its sweep angle of twenty to ninety degrees from edge termination to edge termination thus forming the corner incrementally. The radiused corner 38 may be formed into the sandwich panel structure 83 either before or after forming the adjacent panel edges 29, 31, 32 or 37 described previously. The inventive process for thermoforming the FRTP skin TP core sandwich panel is employed wherein the panel's corner location is positioned and held in the desired position by index 101 between heated die halves. The skin and core in the area to be formed are selectively and controllably exposed to heat and pressure to soften and

collapse the TP core between the FRTP skins along the incremental radial length of corner 38. Upon cooling the thermoformed length, the panel is re-positioned to index 101 between die halves to form the next incremental length of corner 38. This process is repeated until the entire radial length of corner 38 is formed along its twenty to ninety  
5 degree sweep.

Referring to **Figures 5A and 4B**, it can be seen that skin 33 is formed along its length by die 85 from bevel start 67 to bevel end 63, this length of skin 33 referred to as transition length 65. Skin 33 is also formed along its length by die 85 at bevel start 67 to  
10 its termination at trim end 61, this length of skin 33 referred to as inner attachment length 69. Similarly, outer skin 35 is formed from bevel start 67 to trim end 61, this length of skin 35 referred to as outer attachment length 71.

The consolidated melt of thermoplastic in the FRTP skin 33 along its attachment  
15 lengths 65 and 69 and the melt of thermoplastic in skin 35 along its attachment length 71 interacts with the melt of thermoplastic in the core 27 along their respective, common surfaces or interfaces forming a consolidated FRTP composite cross section. Given the compatibility of the thermoplastic (TP) material of the skins and core and the thermoforming temperatures and pressures, this interaction will vary from a consolidated  
20 first melt 91 region of enhanced core thermoplastic -to- skin thermoplastic melt adhesion or bond at this interface to a second consolidated melt 92 region of indiscernible interface or commingling between thermoplastic melt of skin and core in the consolidated FRTP composite regions.

25 It is found that the first melt 91, an enhanced melt-to-melt adhesion interface, is dominant from the point of bevel end 63 to bevel start 67 along transition length 65 of skin 33 and core 27 whereas an indiscernible interface or commingling of core-skin

thermoplastics is dominant from the point of bevel end 67 to trim end 61 along the inner attachment length 69 and outer attachment length 71. It is found that in the second melt 92, the indiscernible interface region, that the commingled melt of core thermoplastic with skin thermoplastic raises the weight ratio of thermoplastic resin to reinforcing fiber  
5 (oppositely, the weight ratio of fiber to resin decreases) as compared to the weight ratio of resin to fiber in each of skins 33 and 35 alone as in the un-thermoformed areas of panel 83.

The increased weight of resin contributes to this consolidated FRTP composite core-skin edge being less stiff and more flexible than the un-formed panel area due to the  
10 nature of thermoplastic laminates versus sandwich structures which in-turn improves impact and damage tolerance of the edge. The contribution of thermoplastic resin from the core to this consolidated edge area also improves interlaminar shear of the consolidated skins 33 and 35 by providing additional resin to maintain adherence of the separate skins and their fiber reinforcements under loading which concentrates stress between the  
15 interface of fiber to matrix and inner attachment length to outer attachment length. Additionally, the first melt 91 region, the enhanced melt-to-melt adhesion at the interface between transition length 65 and core 27, improves resistance to loading and core-crush along the thermoformed core bevel transition without the addition of stabilizing materials.

20 The characteristics of the melt interfaces and the associated benefits illustrated for edge 37 will be identical for core-skin edge configurations other than radiused periphery edge 37 including edges 29, 31, 32 and radiused corner 38 as well as intra-panel core-skin configurations and other configurations that are possible with the inventive thermoform process for FRTP skin – TP core sandwich panels.

25

The improvements over the prior art which the configuration of radiused edge elements 31, 32 and 37 and radiused corner 38 present include the following:

4. a compact nested joint results from the assembly by means 20 at the two panel  
juncture of the 3 and 5 panel to panel 7 along their respective mating thermoformed edges  
32 wherein load transfer is distributed throughout the entire container without the use of  
5 independent container stiffening members by virtue of the integral consolidated core-skin  
edge and core-bevel transition regions resulting from the inventive thermoforming of  
FRTP skin-TP core panel edges;
5. the three panel juncture of panels 3, 7 and 9 and 5, 7 and 9 form a compact  
10 nested corner assembly 132 as seen in Fig 6C which is self-sealing from environmental  
effects and eliminates or minimizes the use, cost and weight of sealant materials as well as  
improved load transfer and load distribution throughout the entire container without the  
use of independent stiffening members as described for two panel junctures of such edges  
and further minimizing tooling and inventory cost;
- 15 6. Elimination of unique right and left half modular components for assembly of  
The Container structure of side panels 3, 5, or 7 thus minimizing tooling, assembly and  
inventory of left-right configurations required for fabricating the panels;
- 20 7. the resulting recess approximate to the thickness of the core and skins at the  
two panel Juncture of panels 3 and 5 to 7 and at the three panel juncture of panels 3 and 7  
to 9 and 5 and 7 to 9 prevents fasteners from protruding into the load volume of space 6  
thereby maximizing the container's load volume;
- 25 8. Improved impact and damage tolerance and interlaminar shear of the core-skin  
edge resulting from the thermoplastic contributed by the core to the consolidated,  
thermoformed region;

9. Where edge thermoformed component panels are to be stored or transported prior to integration into an assembly, the configuration of edges 29, 31, 32, 37 and corner 38 allows for nested, flat stacking of multiple formed panels minimizing storage and transportation space.

While the disclosure herein of the thermoforming process, articles made from the process, and structures assembled therefrom is illustrative of the general principles and preferred embodiments of the invention, it is understood that the descriptions and embodiments herein are not intended to limit the claimed scope of the invention where modification of size, degree, steps, arrangement of parts, details of function or other features are variable but fall within the spirit and scope of the invention.

#### INDUSTRIAL APPLICABILITY:

15 The method of thermoforming composite sandwich panels made of fiber reinforced thermoplastic skins and thermoplastic core may be exploited to convert such panels to finished articles having thermoformed edges as described herein creating a finished article with improved functional performance including damage tolerance and load bearing strength through the thermoformed edges as opposed to the un-formed sandwich panel area. The resulting thermoformed articles may be assembled into structures benefiting from the article's improved functional performance such as a modular cargo container structure as described herein.

25

CLAIMS:

What is claimed is:

1. An FRTP composite sandwich panel (3, 5, 7, 9) where damage tolerance and load  
5 bearing performance is improved by an integrally thermoformed edge decreasing in cross section thickness to a consolidated composite, said composite sandwich panel comprising:

a sandwich panel structure (83) having an inner FRTP composite skin (23, 33)  
being made of a fiber reinforcing a thermoplastic resin in a fixed proportion, an outer  
10 FRTP composite skin (25, 35) being made of a fiber reinforcing a thermoplastic resin in a fixed proportion, a low density thermoplastic resin core (27) sandwiched between and integrally fixed to said inner skin and outer skin,

an integrally thermoformed edge (29, 31, 32, 37) having a bevel start (51,59,67)  
15 and a bevel end (47, 57, 63) defining a decrease in the cross section thickness of said sandwich panel structure area (83), a transition length (49, 56, 65) of said inner skin between said bevel start and bevel end, a trim end (45, 55, 61), an inner attachment length (54, 58, 69) of said inner skin between said bevel start and said trim end, an outer attachment length (53, 60, 71) of said outer skin between said bevel start and said trim end,  
20 with said edge being thermoformed such that said sandwich structure's cross section thickness decreases from bevel end to bevel start along said transition length wherein said core's thermoplastic resin forms a first consolidated melt (91) with said inner skin's thermoplastic resin along said transition length and wherein said core's thermoplastic resin forms a second consolidated melt (92) with both said inner skin's thermoplastic resin and  
25 with said outer skin's thermoplastic resin along said inner and outer attachment lengths whereby the resulting integral edge transitions from the full sandwich panel structure's

thickness to a consolidated FRTP composite more damage tolerant and load bearing than said sandwich structure area.

2. The FRTP composite sandwich panel according to claim 1, wherein said first  
5 consolidated melt (91) has an enhanced core thermoplastic to skin thermoplastic melt adhesion such that resistance to loading and core crush are improved along transition length (49, 56, 65) without the addition of localized stabilizing material.

3. The FRTP composite sandwich panel according to claim 2, wherein said second  
10 consolidated melt (92) has a co-mingled melt of said core thermoplastic to said inner skin thermoplastic and to said outer skin thermoplastic such that the weight ratio of thermoplastic to fiber increases along said inner attachment length (54, 58, 69) and said outer attachment length (53, 60, 71) whereby interlaminar shear, impact resistance, and damage tolerance of the consolidated FRTP composite is improved over the FRTP  
15 composite sandwich panel structure.

4. The FRTP composite sandwich panel according to claim 3, wherein said low density thermoplastic resin core (27) is further comprised of polypropylene thermoplastic of a cellular honeycomb structure.

20

5. The FRTP composite sandwich panel according to claim 4, wherein the fiber reinforcing a thermoplastic resin in a fixed proportion of said inner FRTP composite skin (23, 33) and outer FRTP composite skin (25, 35) is in a ratio of 50 to 75 percent of fiber to thermoplastic resin by weight.

25

6. The FRTP composite sandwich panel according to claim 5, wherein the fiber

reinforcing a thermoplastic resin of said inner FRTP composite skin (23, 33) is fiberglass and wherein the fiber reinforcing a thermoplastic resin of said outer FRTP composite skin (25, 35) is fiberglass.

5 7. The FRTP composite sandwich panel according to claim 6, wherein the thermoplastic resin of said inner FRTP composite skin (23, 33) is polypropylene and wherein the thermoplastic resin of said outer FRTP composite skin (25, 35) is polypropylene thermoplastic.

10 8. The FRTP composite sandwich panel according to claim 1 or 7, wherein said sandwich panel structure is planar and said thermoformed edge is further comprised of a plurality of radiused edges (31, 32, 37) having a radius at forty five degrees from the plane of said outer skin (25, 35) and concave toward said inner skin (23, 33) from said bevel start (59, 67) to said trim end (55, 61) along said inner attachment length (58, 69) and  
15 outer attachment length (60, 71), said radius being equal to the cross section thickness of said sandwich panel structure (83) at said bevel end (57, 63).

9. The FRTP composite sandwich panel according to claim 8, wherein said radiused edges are further comprised of a plurality of radiused corners (38) at the juncture of  
20 adjacent terminus of two of said radiused edges said corner being concave toward said inner skin (23, 33), convex toward said outer skin (25, 35), angled at forty five degrees from the plane of said outer skin (25, 35), the radius of said corner being equal to the cross section thickness of said sandwich panel (83) at said bevel end (57, 63), and having a sweep of between twenty and ninety degrees as said corner sweeps from adjacent radiused  
25 edge to adjacent radiused edge along the perimeter of said panel.

10. The FRTP composite sandwich panel according to claim 9, wherein said thermoformed edge is further comprised of at least one lower edge (29) parallel with the plane of said inner skin (23) of said sandwich panel structure (83) from said bevel start (51) to said trim end (45) along said inner attachment length (54) and outer attachment length (53).

11. A modular cargo container (1) assembled with FRTP composite sandwich panels where container loads are distributed throughout the assembled panels by integrally thermoformed panel edges and edge assemblies, said cargo container comprising:

10 a base (11) having a forward end (2) and a rearward end (4), and an edge rail (15) along said base's opposite sides and rear periphery said edge rail having an outer horizontal leg (19) and a vertical leg (21),

15 three vertically planar panels (3, 5, 7), two opposite each other and the third located between the two, having an inner FRTP composite skin (23) being made of a fiber reinforcing a thermoplastic resin in a fixed proportion, an outer FRTP composite skin (25) being made of a fiber reinforcing a thermoplastic resin in a fixed proportion, a low density thermoplastic resin core (27) sandwiched between and integrally fixed to said inner skin and outer skin, a forward and rearward integrally thermoformed side edge (32), an integrally thermoformed upper edge (31), a plurality of integrally thermoformed radiused corners (38), an integrally thermoformed lower edge (29) which is attached to said base (11) along the length of lower edge (29) by a plurality of attachment means (39) attaching said lower edge to the vertical leg of said edge rail,

25 a horizontally planar top panel (9) having an inner FRTP composite skin (33) being made of a fiber reinforcing a thermoplastic resin in a fixed proportion, an outer FRTP

composite skin (35) being made of a fiber reinforcing a thermoplastic resin in a fixed proportion, said low density thermoplastic core (27) sandwiched between and integrally fixed to said inner skin (33) and outer skin (35), an integrally thermoformed periphery edge (37), a plurality of said integrally thermoformed radius corners (38),

5

three right angled forward framing members (10, 12, 14) fixedly attached to forward end of said base (11), fixedly attached to forward ends of said side edges (32) of said opposite side panels and fixedly attached to periphery edge (37) of said top panel's forward end by a plurality of attachment means (18),

10

a plurality of attachment means 20 to attach and assemble said vertical panels to each other along the length of their adjacent thermoformed side edges (32) and to attach thermoformed upper edges (31) of said vertical panels along their common length with thermoformed periphery edges (37) of said horizontal panel whereby the assembly of two side edges and the assembly of the upper edge to the periphery edge results into a compact nested joint which distributes applied loads throughout the entire container assembly without the use of independent container stiffening members,

15

a plurality of compact nested corner assemblies (132) resulting from the assembly of the radiused corners (38) of two adjacent vertical side panels and the radiused corner (38) of one horizontal top panel whereby said corner assembly is self sealing without the use of independent sealing means and said corner assembly distributes applied loads throughout the entire container assembly without the use of independent container stiffening members,

20

25

an opening (6) serving as an access to the interior of container (1) and framed by said forward framing members (10, 12, 14) and forward end of said base,

12. The cargo container according to claim 11, wherein said low density thermoplastic resin core (27) is further comprised of polypropylene thermoplastic of a cellular honeycomb structure.

5

13. The cargo container according to claim 12, wherein the fiber reinforcing a thermoplastic resin in a fixed proportion of said inner skin (23) and outer skin (25) of said vertically planar panels is in a ratio of 50 to 75 percent of fiber to thermoplastic resin by weight and wherein the fiber reinforcing a thermoplastic resin in a fixed proportion of said  
10 inner skin (33) and outer skin (35) of said horizontally planar top panel is in a ratio of 50 to 75 percent of fiber to thermoplastic resin by weight.

14. The cargo container according to claim 13, wherein the fiber reinforcing a thermoplastic resin of said inner skin (23) and outer skin (25) of said vertically planar  
15 panels is fiberglass and wherein the fiber reinforcing a thermoplastic resin of said inner skin (33) and outer skin (35) of said horizontally planar top panel is fiberglass.

15. The cargo container according to claim 14, wherein the thermoplastic resin of said inner skin (23) and outer skin (25) of said vertically planar panels is polypropylene  
20 thermoplastic and wherein said inner skin (33) and outer skin (35) of said horizontally planar top panel is polypropylene thermoplastic.

16. The cargo container according to claim 11 or 15, wherein the vertical panel located between the vertical panels opposite each other is further comprised of two planes, one  
25 vertical plane extending from its upper edge partially toward its lower edge, and a second plane angled from the terminus of the vertical plane at an angle of 20 to 70 degrees from the vertical plane and extending toward and terminating at said base.

17. The cargo container according to claim 16, wherein said base is further comprised of a plate (13), three edge rails (15) each at the opposite sides and rear periphery of said base and each edge rail having an inner horizontal leg (17), an outer horizontal leg (19), a  
5 vertical leg (21), and a plurality of attachment means (16) attaching said plate to said inner horizontal leg.

18. The cargo container according to claim 17, wherein said edge rails (15) are made of structural aluminum extrusions and said plate (13) is aluminum.

10

19. The cargo container according to claim 11, further comprising a closure means whereby said opening is enclosed.

20. A method of thermoforming a constant cross section FRTP composite sandwich  
15 panel comprising the steps:

selecting a constant cross section FRTP composite sandwich panel structure (83) having an inner FRTP composite skin (23, 33) being made of a fiber reinforcing a thermoplastic resin in a fixed proportion, an outer FRTP composite skin (25, 35) being  
20 made of a fiber reinforcing a thermoplastic resin in a fixed proportion, a low density thermoplastic resin core (27) sandwiched between and integrally fixed to said inner and outer skins,

positioning end (81) of said FRTP composite sandwich structure over a matched set of dies (85, 87) comprising a male die half (85) and a female die half (87) said dies  
25 having heating means (95), a plurality of insulating elements (89, 91, 93), a drive means (103) for driving said dies, a registration means (101) to register said panel structure in position,

heating said dies by heating means (95) to a temperature within 5 to 20 percent of the lower end temperature value in said FRTP sandwich panel's thermoplastic's melt processing window,

opening said dies by said drive means to form a die cavity space (97) between said  
5 male and female die halves,

inserting said end of said sandwich panel structure into said cavity,

positioning said panel end to desired depth and transverse position and holding with said registration means,

applying modest, controlled and gradient contact gage pressure in the range of  
10 689.5 MPa to less than 68950 MPa to said sandwich panel structure by said drive means such that said heated dies are forced into said cavity space compressing the FRTP composite sandwich panel's inner skin and outer skin into the midplane of said panel structure and said core whereby the thermoplastic of said skins and said core begins to soften,

15 applying simultaneous and further heating of said dies to a temperature in the range of 10 to 90 percent of the lower to upper temperature values of said FRTP sandwich panel's thermoplastic melt processing window by said heating means and increasing pressure applied to said sandwich panel structure skin and core by said drive means in the range of 10 to 200 percent greater than the contact gage pressure whereby said  
20 thermoplastic core begins to melt, give way, collapse within said inner skin and said outer skin forming the thermoplastic of said core and thermoplastic of said skins into a an integral consolidated FRTP composite edge (29, 31, 32, 37) in said sandwich panel structure ,

retracting said dies away from the formed core and skin edge of said sandwich  
25 panel structure by said drive means,

forcing a cold set of matched dies (105,107) by said drive means into said cavity and in contact with said consolidated composite edge said cold set of matched dies

comprising a male die half (105) and a female die half (107) having a cooling means (109) for cooling said dies,

cooling said FRTP composite edge to a temperature below the melt process temperature window of said FRTP sandwich panel so that the FRTP composite edge  
5 maintains its formed shape.

21. The method of thermoforming a constant cross section FRTP sandwich panel according to claim 20, wherein the consolidated FRTP composite edge is further comprised of a bevel start (51,59,67) and a bevel end (47, 57, 63) defining a decrease in  
10 the cross section thickness of said sandwich panel structure area (83), a transition length (49, 56, 65) of said inner skin between said bevel start and bevel end, a trim end (45, 55, 61), an inner attachment length (54, 58, 69) of said inner skin between said bevel start and said trim end, an outer attachment length (53, 60, 71) of said outer skin between said bevel start and said trim end, with said edge being thermoformed such that said sandwich  
15 structure's cross section thickness decreases from bevel end to bevel start along said transition length wherein said core's thermoplastic resin forms a first consolidated melt (91) with said inner skin's thermoplastic resin along said transition length and wherein said core's thermoplastic resin forms a second consolidated melt (92) with both said inner skin's thermoplastic resin and with said outer skin's thermoplastic resin along said inner  
20 and outer attachment lengths whereby the resulting integral edge transitions from the full sandwich panel structure's thickness to a consolidated FRTP composite more damage tolerant and load bearing than said sandwich structure area.

22. The method of thermoforming a constant cross section FRTP sandwich panel  
25 according to claim 21, wherein said sandwich panel structure is planar and said thermoformed edge is further comprised of a plurality of radiused edges (31, 32, 37) having a radius at forty five degrees from the plane of said outer skin (25, 35) and concave

toward said inner skin (23, 33) from said bevel start (59, 67) to said trim end (55, 61) along said inner attachment length (58, 69) and outer attachment length (60, 71), said radius being equal to the cross section thickness of said sandwich panel structure (83) at said bevel end (57, 63).

5

22. The method of thermoforming a constant cross section FRTP sandwich panel according to claim 22, wherein said radiused edges are further comprised of a plurality of radiused corners (38) at the juncture of adjacent terminus of two of said radiused edges said corner being concave toward said inner skin (23, 33), convex toward said outer skin (25, 35), angled at forty five degrees from the plane of said outer skin (25, 35), the radius of said corner being equal to the cross section thickness of said sandwich panel (83) at said bevel end (57, 63), and having a sweep of between twenty and ninety degrees as said corner sweeps from adjacent radiused edge to adjacent radiused edge along the perimeter of said panel.

15

23. The method of thermoforming a constant cross section FRTP sandwich panel according to claim 22, wherein said thermoformed edge is further comprised of at least one lower edge (29) parallel with the plane of said inner skin (23) of said sandwich panel structure (83) from said bevel start (51) to said trim end (45) along said inner attachment length (54) and outer attachment length (53).

20

25

1/6

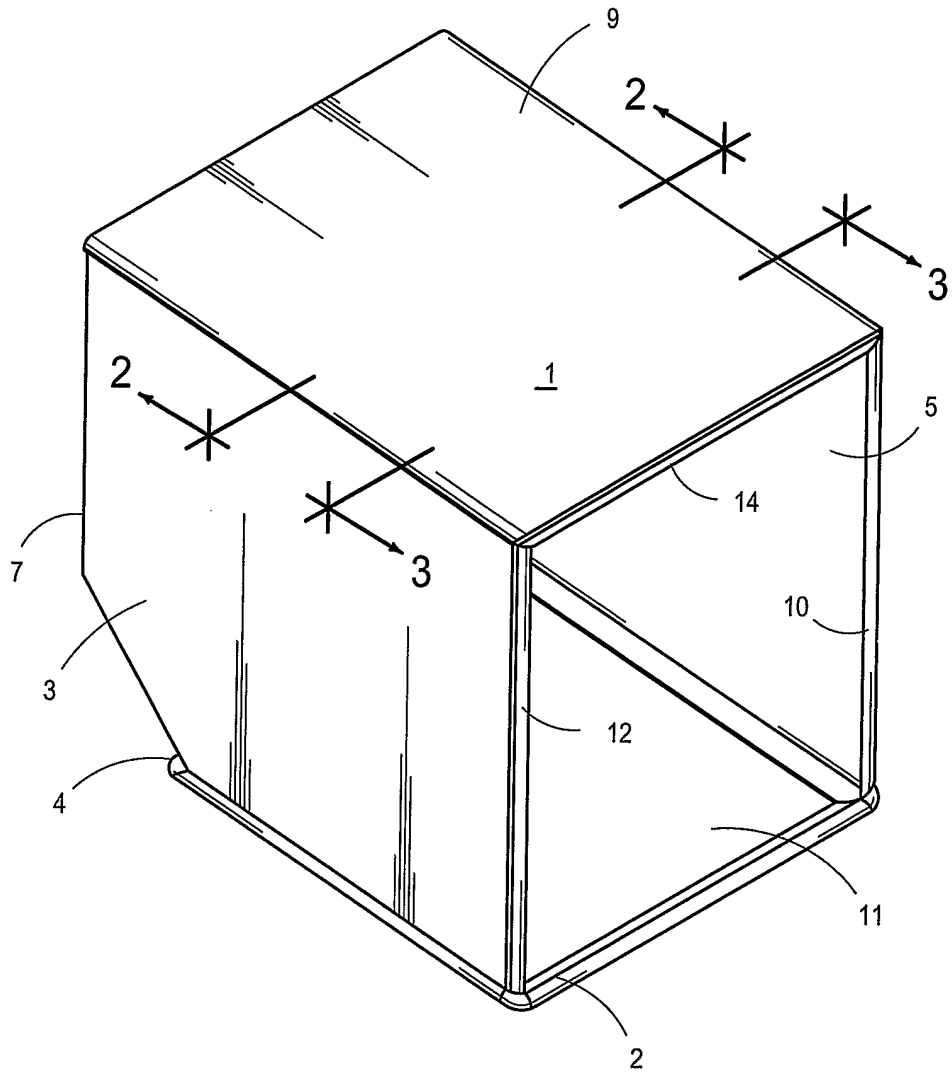


FIG. 1

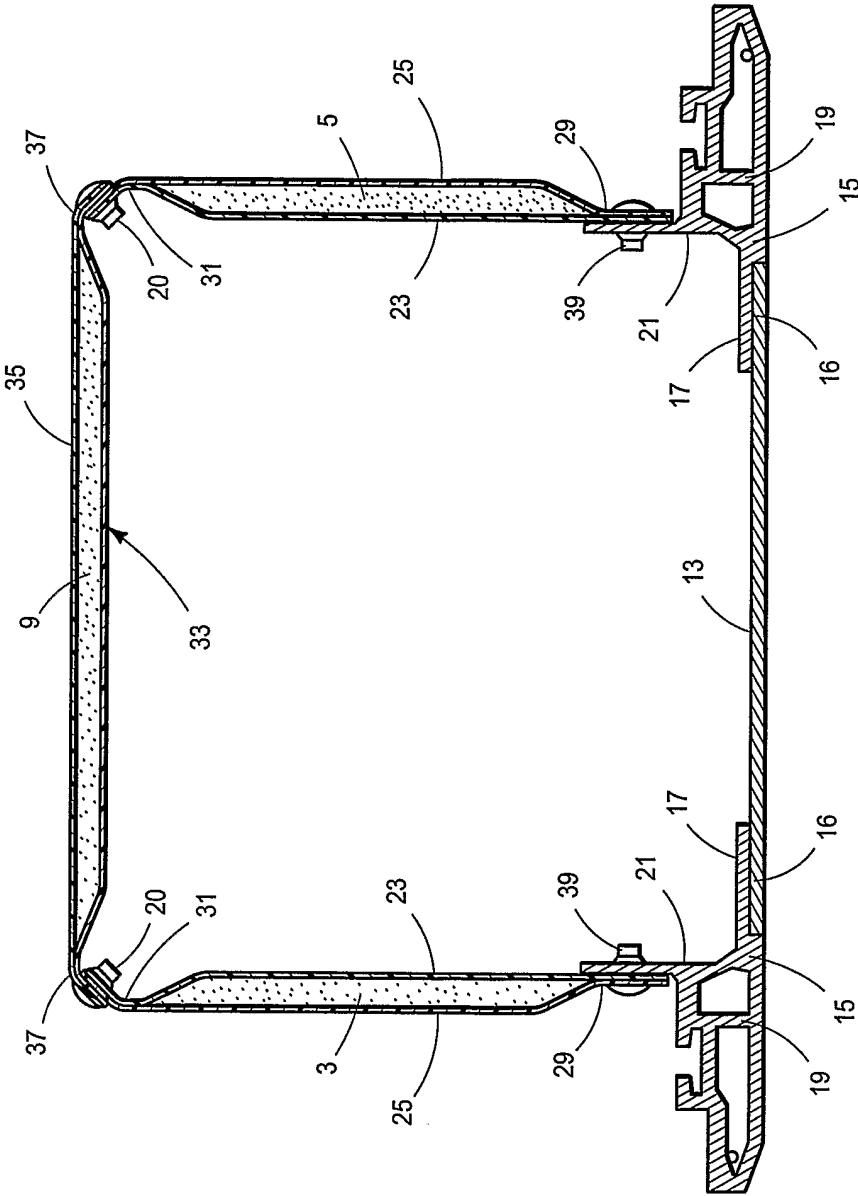
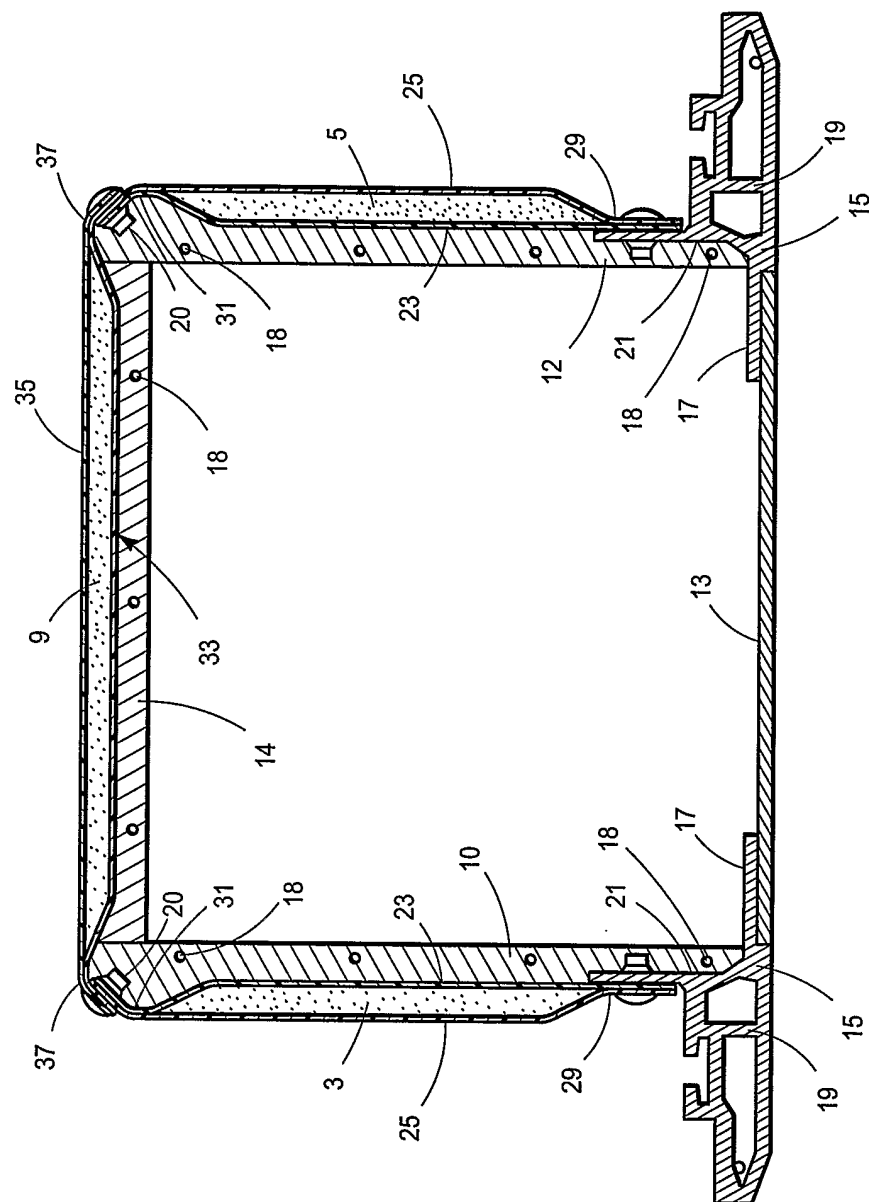


FIG. 2



**FIG. 3**

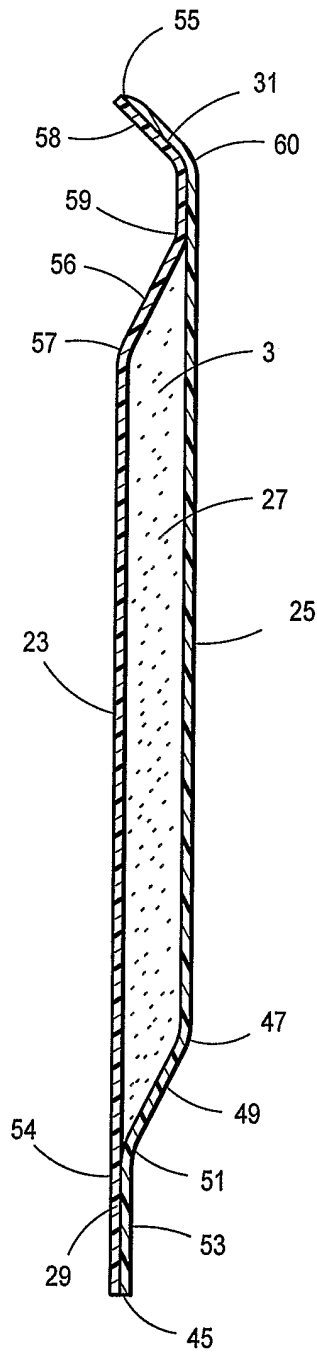


FIG. 4A

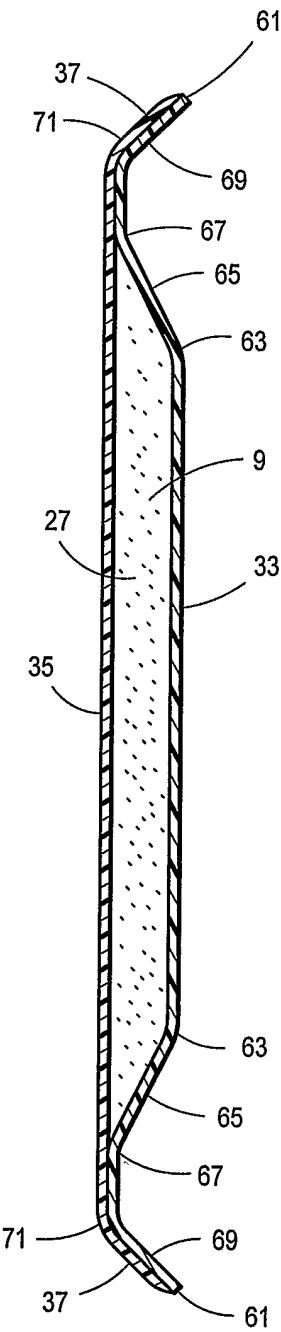


FIG. 4B

5/6

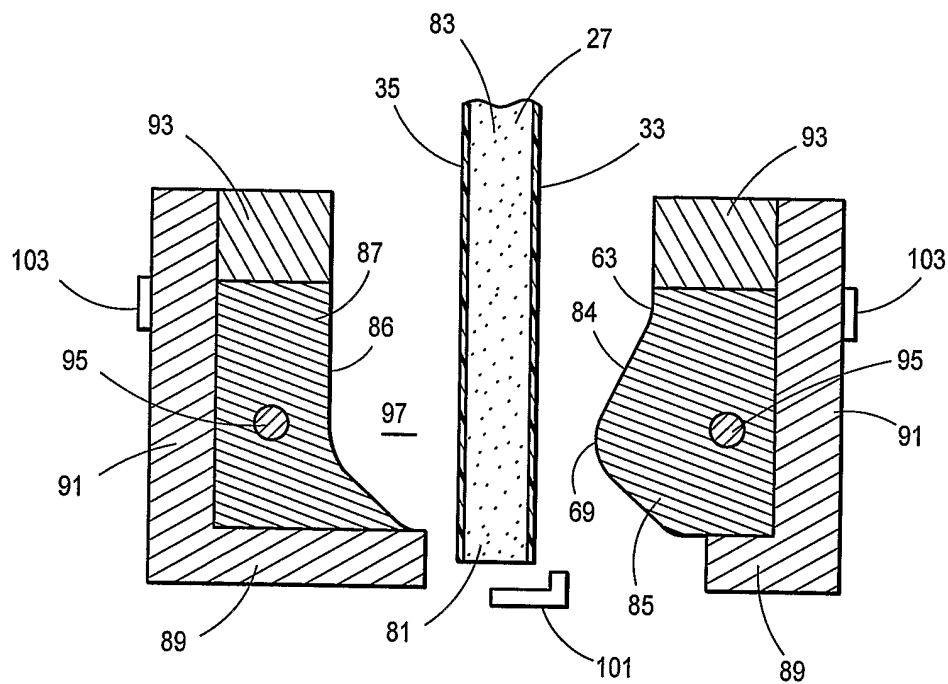


FIG. 5A

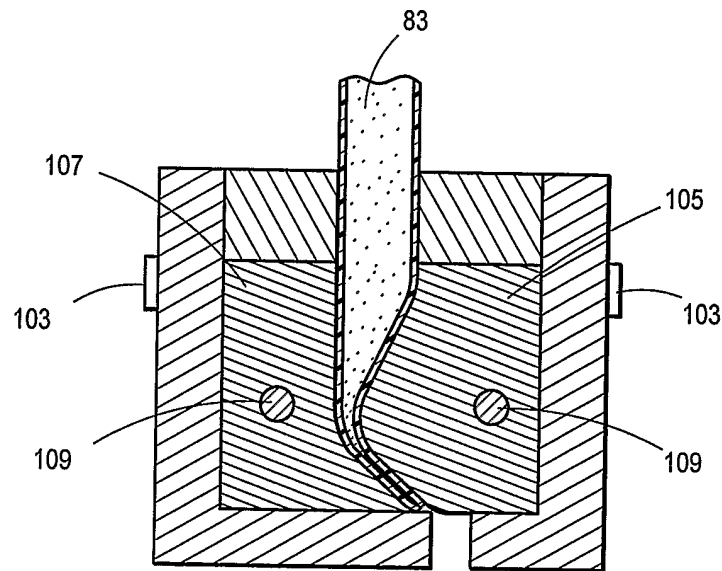


FIG. 5B

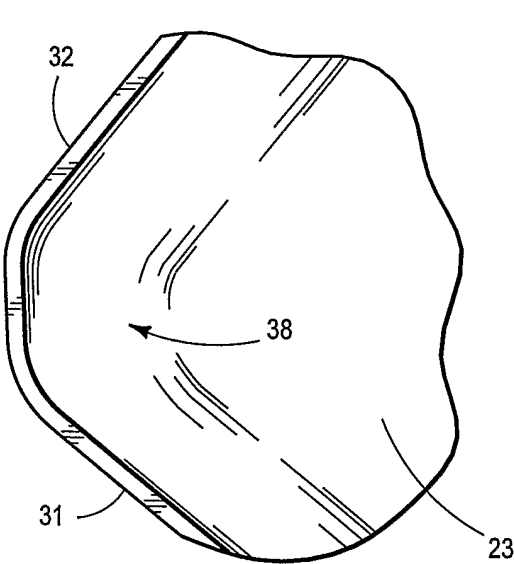


FIG. 6A

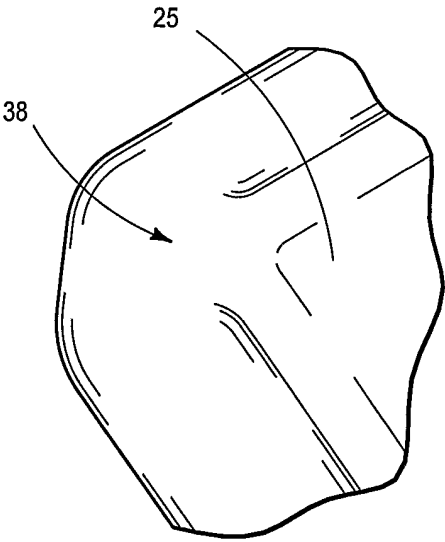


FIG. 6B

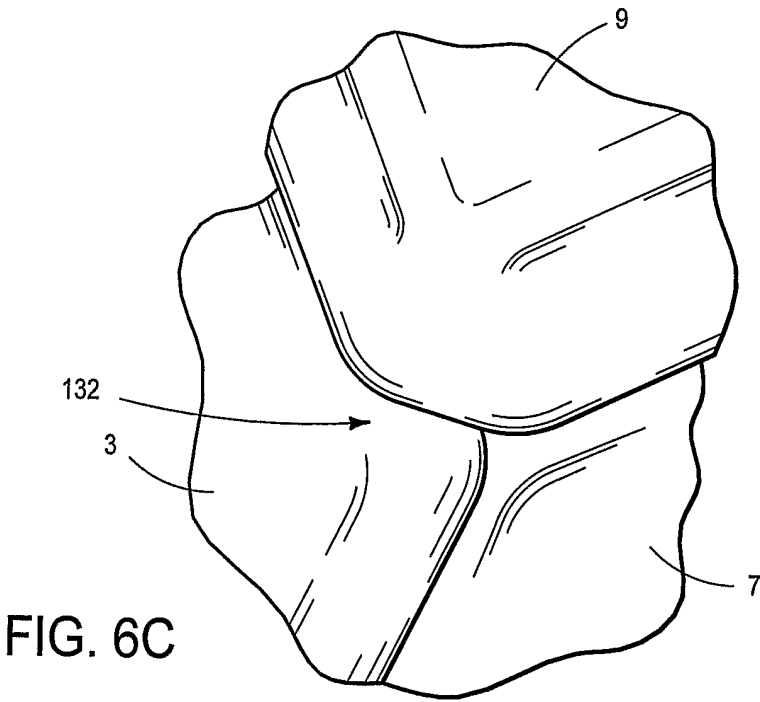


FIG. 6C

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US03/22827

| <b>A. CLASSIFICATION OF SUBJECT MATTER</b>                                                                                                                                           |                                                                                                                                                                     |                                                                                                                                                                                                                                                  |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| IPC(7) : B32B 03/12                                                                                                                                                                  |                                                                                                                                                                     |                                                                                                                                                                                                                                                  |
| US CL : 220/1.5; 264/331.11; 428/158                                                                                                                                                 |                                                                                                                                                                     |                                                                                                                                                                                                                                                  |
| According to International Patent Classification (IPC) or to both national classification and IPC                                                                                    |                                                                                                                                                                     |                                                                                                                                                                                                                                                  |
| <b>B. FIELDS SEARCHED</b>                                                                                                                                                            |                                                                                                                                                                     |                                                                                                                                                                                                                                                  |
| Minimum documentation searched (classification system followed by classification symbols)<br>U.S. : Please See Continuation Sheet                                                    |                                                                                                                                                                     |                                                                                                                                                                                                                                                  |
| 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 practicable, search terms used)<br>EAST                                                 |                                                                                                                                                                     |                                                                                                                                                                                                                                                  |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                        |                                                                                                                                                                     |                                                                                                                                                                                                                                                  |
| Category *                                                                                                                                                                           | Citation of document, with indication, where appropriate, of the relevant passages                                                                                  | Relevant to claim No.                                                                                                                                                                                                                            |
| A,E                                                                                                                                                                                  | US 2003/0190452 A1 (LUCAS et al) 09 October 2003 (09.10.2003).                                                                                                      |                                                                                                                                                                                                                                                  |
| A,E                                                                                                                                                                                  | US 6,615,741 B2 (FECKO et al) 09 September 2003 (09.09.2003).                                                                                                       |                                                                                                                                                                                                                                                  |
| A                                                                                                                                                                                    | US 6,551,441 B1 (SATO et al) 22 April 2003 (22.04.2003).                                                                                                            |                                                                                                                                                                                                                                                  |
| A                                                                                                                                                                                    | US 6,114,000 A (MUROI et al) 05 September 2000 (05.09.2000).                                                                                                        |                                                                                                                                                                                                                                                  |
| A                                                                                                                                                                                    | US 5,688,353 A (DUBLINSKI et al) 18 November 1997 (18.11.1997).                                                                                                     |                                                                                                                                                                                                                                                  |
| A                                                                                                                                                                                    | US 5,227,113 A (HAMABE et al) 13 July 1993 (13.07.1993).                                                                                                            |                                                                                                                                                                                                                                                  |
| A                                                                                                                                                                                    | US 5,043,127 A (BRAMBACH) 27 August 1991 (27.08.1991).                                                                                                              |                                                                                                                                                                                                                                                  |
| <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.                                     |                                                                                                                                                                     |                                                                                                                                                                                                                                                  |
| * Special categories of cited documents:                                                                                                                                             |                                                                                                                                                                     |                                                                                                                                                                                                                                                  |
| "A"                                                                                                                                                                                  | document defining the general state of the art which is not considered to be of particular relevance                                                                | "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                                              |
| "E"                                                                                                                                                                                  | earlier application or patent published on or after the international filing date                                                                                   | "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                                                                     |
| "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) | "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 |
| "O"                                                                                                                                                                                  | document referring to an oral disclosure, use, exhibition or other means                                                                                            | "&" document member of the same patent family                                                                                                                                                                                                    |
| "P"                                                                                                                                                                                  | document published prior to the international filing date but later than the priority date claimed                                                                  |                                                                                                                                                                                                                                                  |
| Date of the actual completion of the international search<br>08 December 2003 (08.12.2003)                                                                                           |                                                                                                                                                                     | Date of mailing of the international search report<br><b>29 DEC 2003</b>                                                                                                                                                                         |
| Name and mailing address of the ISA/US<br>Mail Stop PCT, Attn: ISA/US<br>Commissioner for Patents<br>P.O. Box 1450<br>Alexandria, Virginia 22313-1450<br>Facsimile No. (703)305-3230 |                                                                                                                                                                     | Authorized officer<br>Wendy Boss <i>Wendy Boss</i><br>Telephone No. 703-308-0661                                                                                                                                                                 |

# INTERNATIONAL SEARCH REPORT

PCT/US03/22827

## Continuation of B. FIELDS SEARCHED Item 1:

220/1.5, 4.01, 660; 264/239, 241, 248, 257, 258, 280, 299, 319-322, 325, 330, 331.11, 345; 428/71, 73, 116, 117, 156-158, 192, 304.4, 309.9, 313.3, 313.5, 364, 365