Title: METHOD FOR BONDING A FACING SKIN TO A FREEFORM-FABRICATED COMPOSITE CORE

Abstract: A method for bonding a facing skin to a freeform-fab π cated core of a composite article generally comprises the steps of fabricating a core using a free-form fabrication machine, said core including an internal reinforcing structure with a plurality of integral structural elements formed at or near a surface of the core, applying an adhesive to the surface of the core, placing a facing skin against the adhesive to form a composite lay-up, and curing the composite lay-up to form the composite article, with the adhesive passing through or around the integral structural elements, thus enhancing the bond between the facing skin and the freeform-fab π cated core.
METHOD FOR BONDING A FACING SKIN TO A FREEFORM-FABRICATED COMPOSITE CORE

BACKGROUND OF THE INVENTION

The present invention relates to the manufacture of freeform-fabricated core composite articles, and, more specifically, to a method for bonding one or more facing skins to the freeform-fabricated core of such an article.

As more fully described in U.S. Patent No. 6,630,093, which is incorporated herein in its entirety by reference, composite articles are used to produce items that must be lightweight, but very strong and very durable. For example, composite articles have been embraced by the aerospace industry, and advanced composites have been used to build airframe structures, such as wing skins, fuselage sections, and many other internal structures and components. In fact, many general aviation aircraft and almost all military aircraft are comprised primarily of composites, which allows the aircraft to be lighter, stronger, and more durable as compared to metal-framed aircrafts. Advanced composites are also used to produce a wide-range of other products, including sporting goods and racing bikes, but use in such products is normally limited
to applications where the superior properties of the composite (e.g., high strength to a weight ratio, resistance to corrosion, and ease of reparability) is of greater importance than the higher cost of manufacturing and using composites. Unfortunately, the higher cost of product development and manufacturing inherent in using composites, as compared to traditional manufacturing methods and materials, is often not sufficiently offset by the superior properties of composites to be a practical alternative for mass production of goods.

Therefore, in order to facilitate the manufacture of composite articles and allow for more ready mass production of goods incorporating composite articles, U.S. Patent No. 6,630,093 describes a method for making freeform-fabricated core composite articles using any one of several classes and types of freeform-fabrication machines. The result is a strong, but lightweight, core to which facing skins made from fiber-reinforced polymer materials are bonded. Specifically, a tool path computer program is created from a three-dimensional computer-aided-design (3D-CAD) file specifying the geometry and dimensions of a composite core. This tool path program controls a freeform-fabrication machine that forms a solid part through the formation of successive layers of polymer, metal, or ceramic materials that are fused together. Several types of freeform-fabrication machines can be used for fabricating the composite core. For example, Fused Deposition Modeling employs a combination heater/extrusion head operating under computer control to extrude beads or tows of viscous thermoplastic to produce a series of stacked and fused sectional planes. In stereo lithography, a computer-controlled cold laser is used to cure photocurable epoxy held in a vat, one thin sectional layer at a time. By fabricating the core in this manner, there is no need to first construct bond tools, molds, mandrels, or other part-specific tooling.
As mentioned above, once the composite core has been fabricated, facing skins made from fiber-reinforced polymer materials can be bonded to the core. The composite core provides rigid separation between the facing skins and contributes shear strength to the resulting composite article. The quality or degree of adhesive strength that is possible between the core and facing skins is governed by the unique characteristics of the materials being used and the surface characteristics of the fabricated core. For example, a Selective Layer Sintering (SLL) freeform fabrication machine is capable of fabricating parts in sintered steel, and a composite core made from such a metal is somewhat porous. Of course, porous materials offer more surface area to bond to, thereby increasing the adhesive strength. By contrast, composite cores fabricated using stereo lithography machines are generally non-porous and very smooth, which makes adhesive bonding of the facing skins more difficult. Similarly, while Fused Deposition Modeling (FDM) is capable of fabricating strong parts in engineering-grade thermoplastics like acrylonitrile butadiene styrene (ABS), polycarbonate, and polyphenylsulfone, these materials are recognized for their poor adhesive qualities.

Poor adhesion between the core and facing skins becomes particularly problematic in sandwich structures, a common type of composite article in which two thin, stiff, and strong facing skins are separated by a thick, light, and weaker core. The design principle of a sandwich structure is based on a common I-beam, which is an efficient structural shape because as much of the material as possible is placed in the flanges and away from the center of bending or neutral axis. The remaining material in the connecting web causes the flanges act in concert and to resist shear and buckling loads. In a sandwich structure, the facing skins are analogous to the flanges of an I-beam, while the core is analogous to the web. However, in a sandwich structure, the core is usually of a different material that that of the facing skins, and it is spread out as a continuous
support for the facing skins rather than concentrated in a narrow web. In any event, the facing skins act together to form an efficient stress couple or resisting moment counteracting the external bending moment. The core resists in shear load and stabilizes the facing skins against buckling or wrinkling. Therefore, the bond between the facing skins and the core must be strong enough to resist the shear and tensile stresses set up between them, making the adhesive that bonds the facing skins to the core critically important. If the bond between the facing skins and core fails, the result is a significant loss of overall strength of the structure, especially in shear load. The failure of the bond between the facing skins and core occurs is commonly referred to as "delamination."

In a sandwich structure, the facing skins are typically bonded to the core using excess matrix resin, adhesive film, or spray-on adhesive to obtain a load transfer between the component. For example, a typical and conventionally fabricated sandwich structure may be formed by using an adhesive film to bond the facing skins to a Nomex®-treated paper core with an open honeycomb cell structure. (Nomex® is a registered trademark of the E. I. Du Pont de Nemours and Company of Wilmington, Delaware.) In forming such a sandwich structure, the adhesive may be dripped over the edge of the open cell structure of the core to form fillets, which serves to increase the surface area for adhesive bonding. If the facing skins were not compressed fully against the core or cured properly, gaps or air bubbles may be formed between the facing skins and core, thus adversely impacting the structure's ability at these locations to resist shear loads and bending moments. Furthermore, over time, the reliability of adhesive bonds decreases. For example, small particles, such as sand or water impacting the forward surface of an aircraft radome at high speeds, can cause tiny fissures or cracks in the facing skins. Cracks or fissures in the facing skins can also be caused through overstressing, through exposure
to adverse vibrations, or through sustained exposure to corrosive chemicals. Regardless of the specific cause, water vapor can then infiltrate between layers of the facing skins or between the facing skins and core. When the water vapor condenses, small amounts of liquid water are trapped inside. In the case of an aircraft or other product incorporating composite articles that is routinely exposed to freezing temperatures, the expansion force generated when liquid forms into ice can cause delamination. This is especially problematic when the core is constructed from paper, aluminum, or other material that susceptible to water damage.

Since reliance solely on adhesives in manufacturing sandwich structures does not ensure good bond strength, nor does it preclude the possibility of future delamination, a variety of methods have been developed to prevent delamination and to spot it early once it occurs. For instance, considerable research by government and private industry has been undertaken to invent better adhesives. Strict procedures have also been mandated by the Federal Aviation Administration and the Department of Defense to ensure good bond strength between facing skins and cores. Unlike monocoque airframing structures made from aluminum, ribs, spars, and skins, where fatigue or degradation of the structure can be visually observed, structural degradation in sandwich structures can rarely be identified by visual inspection. Inspecting sandwich structures requires more elaborate, expensive techniques such as X-ray examination or computed tomography. However, all of these measures do not adequately address the real root cause of sandwich structures delamination and failure - insufficient strength between the facing skins and the core.

**SUMMARY OF THE INVENTION**

The present invention is a method for bonding one or more facing skins to the freeform-
fabricated core of a composite article. Specifically, to enhance the bond between the facing skins and the freeform-fabricated core, mechanical bonds are formed simultaneous with the lay-up and curing of the composite article by allowing adhesive (in a viscous state) to pass through or around and adhere to channels, receivers, openings, or other integral structural elements engineered into and formed in the core of the composite article as part of the fabrication of the core.

In one exemplary composite article manufactured in accordance with the method of the present invention, the composite article is comprised of a freeform-fabricated core to which a pair of facing skins are bonded through use of an adhesive film. The core includes upper and lower (exterior) surface members integral with and bounding an internal reinforcing structure which is comprised of an arrangement of hex cells. To enhance the bond between the facing skins and the freeform-fabricated core, as part of the fabrication of the core, a network of adhesive flow channels is formed in the upper and lower surface members of the core. During the curing process, the adhesive is drawn into and fills these interconnected adhesive flow channels.

In another exemplary composite article manufactured in accordance with the method of the present invention, the composite article is again comprised of a freeform-fabricated core to which a pair of facing skins are bonded through use of an adhesive film. The core includes upper and lower (exterior) surface members bounding an internal reinforcing structure. To enhance the bond between the facing skins and the freeform-fabricated core, as part of the fabrication of the core, an interconnected network of adhesive flow channels is again formed in the upper and lower surface members. Furthermore, in this embodiment, generally rectangular openings are also defined through the upper and lower surface members of the core, each such
opening being bounded on four sides by the adhesive flow channels. In any event, during the curing process, the adhesive is drawn into and fills these interconnected adhesive flow channels.

In another exemplary composite article manufactured in accordance with the method of the present invention, the composite article is again comprised of a freeform-fabricated core to which a pair of facing skins are bonded through use of an adhesive film. The core includes upper and lower (exterior) surface members bounding an internal reinforcing structure. To enhance the bond between the facing skins and the freeform-fabricated core, as part of the fabrication of the core, multiple receivers (e.g., in the shape of a truncated cone) are formed in the upper and lower surface members of the core. During the curing process, the adhesive is drawn into and fills the receivers formed in the upper and lower surface members of the core.

In another exemplary composite article manufactured in accordance with the method of the present invention, the composite article is again comprised of a freeform-fabricated core to which a pair of facing skins are bonded through use of an adhesive film. In this embodiment, the core includes an internal reinforcing structure which is comprised of an arrangement of hex cells without any solid upper and lower surface members, i.e., an open cell structure. Therefore, to enhance the bond between the facing skins and the freeform-fabricated core, as part of the fabrication of the core, multiple openings are defined through the walls of the cells of the internal reinforcing structure and are positioned near the upper and lower portions of the internal reinforcing structure where the facing skins are bonded to the core. During the curing process, the adhesive flows along the walls of the cells of the internal reinforcing structure, away from the facing skins, and through the openings defined through the walls of the cells.

In another exemplary composite article manufactured in accordance with the method of the present invention, the composite article is again comprised of a freeform-fabricated core to
which a pair of facing skins are bonded through use of an adhesive film. In this embodiment, the core includes an internal reinforcing structure which is comprised of an arrangement of hex cells without any solid upper and lower surface members, i.e., an open cell structure. Therefore, to enhance the bond between the facing skins and the freeform-fabricated core, as part of the fabrication of the core, each of the walls of the cells of internal reinforcing structure is designed with an enlarged edge portion at the top and bottom thereof. During the curing process, the adhesive flows along the walls of the cells of the internal reinforcing structure, away from the facing skins, flowing around and encapsulating the enlarged edge portions.

The method of the present invention thus provides an enhanced bond between facing skins and the freeform-fabricated core of a composite article. Because of this enhanced bond between the facing skins and core, the composite article had improved overall strength and durability.

DESCRIPTION OF THE DRAWINGS

Figures 1A-1D are various views of an exemplary composite article manufactured in accordance with the method of the present invention;

Figures 2A-2D are various views of another exemplary composite article manufactured in accordance with the method of the present invention;

Figures 3A-3D are various views of another exemplary composite article manufactured in accordance with the method of the present invention;

Figures 4A-4D are various views of another exemplary composite article manufactured in accordance with the method of the present invention; and
Figures 5A-5D are various views of another exemplary composite article manufactured in accordance with the method of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is a method for bonding one or more facing skins to the freeform-fabricated core of a composite article. Specifically, to enhance the bond between the facing skins and the freeform-fabricated core, mechanical bonds are formed simultaneous with the lay-up and curing of the composite article by allowing adhesive (in a viscous state) to pass through or around and adhere to channels, receivers, openings, or other integral structural elements engineered into and formed in the core of the composite article as part of the fabrication of the core.

An exemplary composite article manufactured in accordance with the method of the present invention is generally comprised of a freeform-fabricated core to which multiple facing skins are bonded. As described above, a tool path computer program is created from a three-dimensional computer-aided-design (3D-CAD) file specifying the geometry and dimensions of a composite core. This tool path program controls a freeform-fabrication machine that forms a solid part through the formation of successive layers of polymer, metal, or ceramic materials that are fused together. By fabricating the core in this manner, there is no need to first construct bond tools, molds, mandrels, or other part-specific tooling. In any event, in accordance with the method of the present invention, the 3D-CAD file specifies not only the outer shape of the core, but also specifies the geometry and dimensions of the internal reinforcing structure, which may include hex cells, box cells, trusses, tetrahedral trusses, spheres, and/or arches. Furthermore, and more importantly, the 3D-CAD file specifies channels, receivers, openings, or other integral
structural elements that are formed in the core to provide enhanced bonding between the facing skins and the freeform-fabricated core.

Once the core has been fabricated and assembled (if multiple core sections are independently fabricated), the core is ready for lay-up and curing. During this process, in accordance with the teachings of the present invention, adhesive passes through or around the channels, receivers, openings, or other integral structural elements engineered into and formed in the core, thus enhancing the bond between the facing skins and the freeform-fabricated core.

Figures 1A-1D are various views of an exemplary composite article 10 manufactured in accordance with the method of the present invention. Referring first to Figure 1A, the composite article 10 is comprised of a freeform-fabricated core 12 to which a pair of facing skins 20, 22 are bonded. In this regard, the core 12 includes upper and lower (exterior) surface members 12a, 12b integral with and bounding an internal reinforcing structure 12c, which in this example, is comprised of an arrangement of hex cells, i.e., a honeycomb structure. In any event, the upper and lower surface members 12a, 12b facilitate bonding of the facing skins 20, 22 to the core 12, as further described below. In this example, the facing skins 20, 22 are made from a fiber-reinforced polymer material, and the bonding of the facing skins 20, 22 to the freeform-fabricated core 12 makes use of an adhesive film 30. To enhance the bond between the facing skins 20, 22 and the freeform-fabricated core 12 of the composite article 10, as part of the fabrication of the core 12, and irrespective of what class or type of freeform-fabrication machine is used, a network of adhesive flow channels 14 is formed in the upper and lower surface members 12a, 12b of the core 12. Figure 1B is a partial plan view of the core 12, illustrating the interconnected adhesive flow channels 14 in a grid pattern along the upper surface member 12a
of the core 12. Figure 1C is a partial side view of the core 12, illustrating the generally
trapezoidal cross-section of the adhesive flow channels 14 in this example.

Once the adhesive film 30 is applied to the upper and lower surface members 12a, 12b of the
freeform-fabricated core 12, the facing skins 20, 22 are placed against the adhesive film 30
and the core 12. Then, the facing skins 20, 22 are cured to form a strong bond between the
facing skins 20, 22 and the core 12. In this regard, the combination of the facing skins 20, 22
and the freeform-fabricated core 12 is referred to as a "composite lay-up," and the procedure for
applying the facing skins 20, 22 to the exterior surface of the core 12 is referred to as the "lay-
up." A vacuum is applied to the composite lay-up, effectively compressing the facing skins 20,
22 against the exterior surfaces of the freeform-fabricated core 12, and then the composite lay-up
is cured. This is generally accomplished by subjecting the composite lay-up to a predetermined
(higher than ambient) temperature for prescribed period of time while under vacuum pressure;
however, some materials are able to cure at ambient atmospheric temperature and pressure.

Referring now to Figure 1D, during such a curing process, the adhesive is drawn into and
fills the interconnected adhesive flow channels 14 formed in the upper and lower surface
members 12a, 12b of the core 12. Accordingly, there is an enhanced bond between the facing
skins 20, 22 and the freeform-fabricated core 12.

Figures 2A-2D are various views of another exemplary composite article 110
manufactured in accordance with the method of the present invention. Referring first to Figure
2A, the composite article 110 is again comprised of a freeform-fabricated core 112 to which a
pair of facing skins 120, 122 are bonded through use of an adhesive film 130. The core 112
again includes upper and lower (exterior) surface members 112a, 112b bounding an internal
reinforcing structure 112c. To enhance the bond between the facing skins 120, 122 and the
freeform-fabricated core 112 of the composite article 110, as part of the fabrication of the core 112, an interconnected network of adhesive flow channels 114 is again formed in the upper and lower surface members 112a, 112b of the core 112, similar to those channels described above with reference to Figures IA-ID. However, in this embodiment, generally rectangular openings 115 are also defined through the upper and lower surface members 112a, 112b of the core 112, each such opening 115 being bounded on four sides by the adhesive flow channels 114. In other words, each of the upper and lower surface members 112a, 112b are best described as lattices. Figure 2B is a partial plan view of the core 112, illustrating the interconnected adhesive flow channels 114 in a grid pattern along the upper surface member 112a of the core 112. Figure 2C is a partial side view of the core 112, illustrating the generally trapezoidal cross-section of the adhesive flow channels 114 in this example.

As with the embodiment described above with reference to Figures IA-ID, once the adhesive film 130 is applied to the upper and lower surface members 112a, 112b of the freeform-fabricated core 112, the facing skins 120, 122 are placed against the adhesive film 130 and the core 112. Then, the facing skins 120, 122 are cured to form a strong bond between the facing skins 120, 122 and the core 112. Referring now to Figure 2D, during such a curing process, the adhesive is drawn into and fills the interconnected adhesive flow channels 114 formed in the upper and lower surface members 112a, 112b of the core 112. Accordingly, there again is an enhanced bond between the facing skins 120, 122 and the freeform-fabricated core 112.

Figures 3A-3D are various views of another exemplary composite article 210 manufactured in accordance with the method of the present invention. Referring first to Figure 3A, the composite article 210 is again comprised of a freeform-fabricated core 212 to which a pair of facing skins 220, 222 are bonded through use of an adhesive film 230. The core 212
again includes upper and lower (exterior) surface members 212a, 212b bounding an internal reinforcing structure 212c. To enhance the bond between the facing skins 220, 222 and the freeform-fabricated core 212 of the composite article 210, as part of the fabrication of the core 212, multiple receivers 214 are formed in the upper and lower surface members 212a, 212b of the core 212. Figure 3B is a partial plan view of the core 212, illustrating such receivers 214 along the upper surface member 212a of the core 212, and having generally circular upper and lower edges. Figure 3C is a partial side view of the core 212, illustrating that the receivers 214 have a generally trapezoidal cross-section. In other words, in this example, each receiver 214 can be characterized as being in the shape of a truncated cone.

As with the embodiments described above, once the adhesive film 230 is applied to the upper and lower surface members 212a, 212b of the freeform-fabricated core 212, the facing skins 220, 222 are placed against the adhesive film 230 and the core 212. Then, the facing skins 220, 222 are cured to form a strong bond between the facing skins 220, 222 and the core 212. Referring now to Figure 3D, during such a curing process, the adhesive is drawn into and fills the receivers 214 formed in the upper and lower surface members 212a, 212b of the core 212. Accordingly, there again is an enhanced bond between the facing skins 220, 222 and the freeform-fabricated core 212.

Figures 4A-4D are various views of another exemplary composite article 310 manufactured in accordance with the method of the present invention. Referring first to Figure 4A, the composite article 310 is again comprised of a freeform-fabricated core 312 to which a pair of facing skins 320, 322 are bonded through use of an adhesive film 330. In this embodiment, the core 312 includes an internal reinforcing structure 312c which, in this example, is comprised of an arrangement of hex cells without any solid upper and lower surface members,
i.e., an open cell structure. Therefore, to enhance the bond between the facing skins 320, 322 and the freeform-fabricated core 312 of the composite article 310, as part of the fabrication of the core 312, multiple openings 314 are defined through the walls of the cells of the internal reinforcing structure 312c. Figure 4C is a partial side view of the core 312, illustrating that the openings 314 are generally circular or ovular, and more importantly, are positioned near the upper portion of the internal reinforcing structure where the facing skins 320 is bonded to the core 312. Of course, although not illustrated in Figure 4C, similar openings may also be positioned near the lower portion of the internal reinforcing structure where the facing skins 322 isbonded to the core 312.

Accordingly, once the adhesive film 330 is applied to the freeform-fabricated core 312, the facing skins 320 is placed against the adhesive film 330 and the core 312. Then, the facing skins 320 is cured to form a strong bond between the facing skins 320 and the core 312. Referring now to Figure 4D, during such a curing process, the adhesive flows along the walls of the cells of the internal reinforcing structure 312c, away from the facing skin 320, and through the openings 314 defined through the walls of the cells. Accordingly, there again is an enhanced bond between the facing skin 320 and the freeform-fabricated core 312.

Figures 5A-5D are various views of another exemplary composite article 410 manufactured in accordance with the method of the present invention. Referring first to Figure 5A, the composite article 410 is again comprised of a freeform-fabricated core 412 to which a pair of facing skins 420, 422 are bonded through use of an adhesive film 430. In this embodiment, and similar to the embodiment described above with reference to Figures 4A-4D, the core 412 includes an internal reinforcing structure 412c which, in this example, is comprised of an arrangement of hex cells without any solid upper and lower surface members, i.e., an open
cell structure. Therefore, to enhance the bond between the facing skins 420, 422 and the freeform-fabricated core 412 of the composite article 410, as part of the fabrication of the core 412, each of the walls of the cells of internal reinforcing structure 412c is designed with an enlarged edge portion 414 at the top and bottom thereof. Figure 5B is a partial plan view of the core 412, illustrating such enlarged edge portions 414 along the upper surface of the cells of internal reinforcing structure 412c, which in this example, have a somewhat diamond-shaped cross-section. Figure 5C is a partial side view of the core 412, again illustrating such enlarged edge portions 414. Of course, although not illustrated in Figure 5C, similar enlarged edge portions may also be provided along the lower surface of the cells of internal reinforcing structure 412c.

Accordingly, once the adhesive film 430 is applied to the internal reinforcing structure 412c of the freeform-fabricated core 412, the facing skin 420 is placed against the adhesive film 430 and the core 412. Then, the facing skin 420 is are cured to form a strong bond between the facing skin 420 and the core 412. Referring now to Figure 5D, during such a curing process, the adhesive flows along the walls of the cells of the internal reinforcing structure 412c, away from the facing skin 420, flowing around and encapsulating the enlarged edge portions 414. Accordingly, there again is an enhanced bond between the facing skin 420 and the freeform-fabricated core 412.

The method of the present invention thus provides an enhanced bond between facing skins and the freeform-fabricated core of a composite article. Because of this enhanced bond between the facing skins and core, the composite article had improved overall strength and durability.
One of ordinary skill in the art will recognize that additional embodiments are possible without departing from the teachings of the present invention or the scope of the claims which follow. This detailed description, and particularly the specific details of the exemplary embodiments disclosed herein, is given primarily for clarity of understanding, and no unnecessary limitations are to be understood therefrom, for modifications will become obvious to those skilled in the art upon reading this disclosure and may be made without departing from the spirit or scope of the claimed invention.
What is claimed is:

1. A method for bonding a facing skin to a freeform-fabricated core of a composite article, comprising the steps of:
   - fabricating a core using a free-form fabrication machine, said core including an internal reinforcing structure with a plurality of integral structural elements formed at or near a surface of the core;
   - applying an adhesive to the surface of the core;
   - placing a facing skin against the adhesive to form a composite lay-up; and
   - curing the composite lay-up to form the composite article, with the adhesive passing through or around the integral structural elements.

2. The method as recited in claim 1, wherein said curing step includes applying a vacuum to the composite lay-up, effectively compressing the facing skin against the freeform-fabricated core.

3. The method as recited in claim 1, wherein said curing step includes subjecting the composite lay-up to a predetermined and higher than ambient temperature for a prescribed period of time.
4. The method as recited in claim 2, wherein said curing step includes subjecting the composite lay-up to a predetermined and higher than ambient temperature for a prescribed period of time during application of the vacuum.

5. The method as recited in claim 1, wherein the adhesive is the form of a film applied to the surface of the core.

6. The method as recited in claim 1, wherein the freeform-fabricated core further includes at least one exterior surface member integral with the internal reinforcing structure to facilitate bonding of the facing skin to the freeform-fabricated core.

7. The method as recited in claim 6, wherein the integral structural elements are multiple adhesive flow channels formed in the exterior surface member of the freeform-fabricated core, such that, during curing the composite lay-up to form the composite article, the adhesive is drawn into and fills the adhesive flow channels.

8. The method as recited in claim 7, wherein the multiple adhesive flow channels are interconnected in a grid pattern.

9. The method as recited in claim 7, wherein each adhesive flow channel has a generally trapezoidal cross-section.
10. The method as recited in claim 8, wherein the exterior surface member of the freeform-fabricated core defines multiple generally rectangular openings therethrough, with each such opening being bounded within the grid pattern of adhesive flow channels.

11. The method as recited in claim 6, wherein the integral structural elements are multiple receivers formed in the exterior surface member of the freeform-fabricated core, such that, during curing the composite lay-up to form the composite article, the adhesive is drawn into and fills the receivers.

12. The method as recited in claim 11, wherein each receiver is a truncated cone.

13. The method as recited in claim 1, wherein the internal reinforcing structure of the freeform-fabricated core is an open cell structure comprised of an arrangement of cells.

14. The method as recited in claim 13, wherein multiple openings are defined through one or more walls of the cells of the internal reinforcing structure near the facing skin, such that, during curing of the composite lay-up to form the composite article, the adhesive flows along the walls of the cells of the internal reinforcing structure, away from the facing skin, and through the openings defined through the walls of the cells.

15. The method as recited in claim 13, wherein one or more walls of each cell of the internal reinforcing structure is provided with an enlarged edge portion, such that, during curing of the composite lay-up to form the composite article, the adhesive flows along the walls of the...
cells of the internal reinforcing structure, away from the facing skin, flowing around and encapsulating the enlarged edge portions.

16. A method for bonding at least two facing skins and a freeform-fabricated core of a composite article, comprising the steps of:
   
   fabricating a core using a freeform fabrication machine, said core including an internal reinforcing structure with a plurality of integral structural elements formed at or near respective upper and lower surfaces of the core;

   applying an adhesive to the respective upper and lower surfaces of the core;

   placing one facing skin against the adhesive along the upper surface of the core and a second facing skin against the adhesive along the lower surface of the core to form a composite lay-up; and

   curing the composite lay-up to form the composite article, with the adhesive passing through or around the integral structural elements.

17. The method as recited in claim 16, wherein said curing step includes applying a vacuum to the composite lay-up, effectively compressing the facing skins against the freeform-fabricated core.

18. The method as recited in claim 16, wherein said curing step includes subjecting the composite lay-up to a predetermined and higher than ambient temperature for a prescribed period of time.
19. The method as recited in claim 17, wherein said curing step includes subjecting the composite lay-up to a predetermined and higher than ambient temperature for a prescribed period of time during application of the vacuum.

20. The method as recited in claim 16, wherein the adhesive is the form of a film applied to the respective upper and lower surfaces of the core.

21. The method as recited in claim 16, wherein the freeform-fabricated core further includes upper and lower surface members adjacent to and integral with the internal reinforcing structure to facilitate bonding of the facing skin to the freeform-fabricated core.

22. The method as recited in claim 21, wherein the integral structural elements are multiple adhesive flow channels formed in the upper and lower surface members of the freeform-fabricated core, such that, during curing the composite lay-up to form the composite article, the adhesive is drawn into and fills the adhesive flow channels.

23. The method as recited in claim 22, wherein the multiple adhesive flow channels in each of the upper and lower surface members are interconnected in a grid pattern.

24. The method as recited in claim 22, wherein each adhesive flow channel has a generally trapezoidal cross-section.
25. The method as recited in claim 23, wherein the upper and lower surface members of the freeform-fabricated core each define multiple generally rectangular openings therethrough, with each such opening being bounded within the grid pattern of adhesive flow channels.

26. The method as recited in claim 21, wherein the integral structural elements are multiple receivers formed in the upper and lower surface members of the freeform-fabricated core, such that, during curing the composite lay-up to form the composite article, the adhesive is drawn into and fills the receivers.

27. The method as recited in claim 26, wherein each receiver is a truncated cone.

28. The method as recited in claim 16, wherein the internal reinforcing structure of the freeform-fabricated core is an open cell structure comprised of an arrangement of cells.

29. The method as recited in claim 28, wherein multiple openings are defined through one or more walls of the cells of the internal reinforcing structure near the facing skins, such that, during curing of the composite lay-up to form the composite article, the adhesive flows along the walls of the cells of the internal reinforcing structure, away from the facing skins, and through the openings defined through the walls of the cells.

30. The method as recited in claim 28, wherein one or more walls of each cell of the internal reinforcing structure is provided with an enlarged edge portion, such that, during curing of the composite lay-up to form the composite article, the adhesive flows along the walls of the
cells of the internal reinforcing structure, away from the facing skins, flowing around and encapsulating the enlarged edge portions.

31. A composite article, comprising:
   a freeform-fabricated core, including an internal reinforcing structure with a plurality of integral structural elements formed at or near a surface of the core;
   a facing skin bonded to the core by an adhesive, with said adhesive passing through or around the integral structural elements to enhance the bond between the facing skin and the freeform-fabricated core.

32. The composite article as recited in claim 31, in which the adhesive is first applied to the surface of the core, and the facing skin is then placed against the adhesive to form a composite lay-up, with the adhesive passing through or around the integral structural elements during curing of the composite lay-up.

33. The composite article as recited in claim 31, wherein the freeform-fabricated core further includes at least one exterior surface member integral with the internal reinforcing structure to facilitate bonding of the facing skin to the freeform-fabricated core.

34. The composite article as recited in claim 33, wherein the integral structural elements are multiple adhesive flow channels formed in the exterior surface member of the freeform-fabricated core.
35. The composite article as recited in claim 33, wherein the integral structural elements are multiple receivers formed in the exterior surface member of the freeform-fabricated core.

36. The composite article as recited in claim 31, wherein the internal reinforcing structure of the freeform-fabricated core is an open cell structure comprised of an arrangement of cells.

37. The composite article as recited in claim 36, wherein multiple openings are defined through one or more walls of the cells of the internal reinforcing structure near the facing skin, such that, during curing of the composite lay-up to form the composite article, the adhesive flows along the walls of the cells of the internal reinforcing structure, away from the facing skin, and through the openings defined through the walls of the cells.

38. The composite article as recited in claim 36, wherein one or more walls of each cell of the internal reinforcing structure is provided with an enlarged edge portion, such that, during curing of the composite lay-up to form the composite article, the adhesive flows along the walls of the cells of the internal reinforcing structure, away from the facing skin, flowing around and encapsulating the enlarged edge portions.
**INTERNATIONAL SEARCH REPORT**

**International application No**
PCT/US 08/56840

**A CLASSIFICATION OF SUBJECT MATTER**

IPC(8) - B32B 9/04, E04C 2/54 (2008.04)

USPC - 428/411, 52/783.1

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

**B FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

USPC - 428/411, 52/783.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 428/411, 593, 52/783.1, 633, 264/46 7, 156/100

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PUBWEST(U.S.PTO,PDB,JPAB,JPAB.USOCR), Google Patent, Google Search Terms Used freeform composite core fabrication machine film facing skin flow channel trapezoid vacuum curing internal reinforcing structure receiver adhesive

**C DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>US 6,630,093 B1 (JONES) 7 October 2003 (07 10 2003) entire document especially Fig 1, 5, 6 and 9-12, col 2, ln 25-35, col 4, ln 54-68, col 5, ln 27-35, col 6, ln 4-21, col 7, ln 10-16, col 9, in 1-31, col 10, ln 20-45 and col 11, ln 11-23</td>
<td>1-6, 13, 16-21, 28, 31-33, 35 and 36</td>
</tr>
<tr>
<td>Y</td>
<td>US 6,030,483 A (WILSON) 29 February 2000 (29 02 2000), col 6, ln 27-33 and col 6, in 50-65</td>
<td>7-12, 14, 15, 22-27, 29, 30, 34, 37 and 38</td>
</tr>
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**I** Further documents are listed in the continuation of Box C

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- "A" document defining the general state of the art which is not considered to be of particular relevance
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**Date of the actual completion of the international search**
3 June 2008 (03 06 2008)

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**Name and mailing address of the ISA/US**
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