

GEL COATED REINFORCED COMPOSITE

BACKGROUND

Market economics for aesthetic composite structures comprising a substrate and an aesthetic surface layer often favor use of thermosetting resin systems for the substrate. Low raw material and tooling costs are frequently cited as factors supporting selection of thermosetting materials. However, use of thermosetting materials can produce volatile organic compound (VOC) emissions, and generally results in long cycle times.

For example, one commonly used approach for creating aesthetic parts involves a two step procedure, wherein a thermoplastic surface layer is formed using a traditional thermoforming method, a thermosetting material is injected or sprayed behind this surface layer and is cured in-place to create a bi-layered structure having a reinforced sub-layer and a thermoplastic surface layer. Many thermosetting systems and methods are employed to create the reinforced sub-layer. These include, for example, spray-up fiberglass reinforced plastic (FRP), resin transfer molding, vacuum-infusion, and various reinforced foam in-place technologies.

US patent 4,356,230 to Emanuel et al describes a process for transferring a coating from the mold surface to the substrate during the molding operation and during solidification of the molded part. US patent 4,742,121 to Toman describes gel coat formulations, which are typically applied by spaying.

It is desired to produce a composite gel coated composite material having rigidity and low CTE required for many structural applications. It is desired to make an adherent gel coated article by a process that produces low VOC emissions with a short cycle time. Other desirable qualities are a gel coat as an aesthetic layer with a high surface quality, excellent mechanical adhesion and minimization of wrinkles and part imperfections.

SUMMARY

An embodiment of a method of forming a gel-coated article comprises thermoforming a reinforced thermoplastic substrate sheet into a desired shape having. In one embodiment, the shape has an initial porosity extending inwardly from a surface area. It is desirable that porosity be at least acquired by the article prior to curing the thermosetting gel coat material to achieve mechanical bonding of the gel coat with the article. The surface area is contacted with a gel coating material. The porosity is desirable sufficient to permit penetration of said gel coating material into at least a surface region. The desired shape is molded together with the gel coating material to form an adherent bond between the gel coating material and the desired shape. The gel coating material permeates into the desired shape and is cured to form a mechanical bond therewith. According to one embodiment, the fiber-reinforced material may be a lightweight fiber-reinforced plastic material having a void content sufficient to allow a vacuum to be applied through the shaped substrate. According to another embodiment, the fiber-reinforced material may be a densified material, which may initially have low, or no surface porosity but will acquire surface porosity during the forming or molding process. Typically, such surface porosity or surface roughness may be acquired through a lofting of fibers contained in the substrate material. The shaped substrate with an adjacent gel coat material is molded together to form an adherent bond between the gel coat material and the shaped substrate. According to an embodiment, the reinforced thermoplastic substrate sheet has a void content sufficient to allow a vacuum to be applied there through. According to an embodiment, a differential gaseous pressure is utilized to form the shaped substrate.

Another embodiment of a method of forming a layered article comprises heating a substrate sheet to a temperature sufficient to allow lofting of fibers of the substrate sheet; disposing the substrate sheet against a membrane assisted pressure box; pushing the substrate sheet onto a mold to form a shaped substrate; disposing the gel coat material adjacent to shaped substrate, and molding the gel coat material with the shaped substrate to form an adherent bond. Another embodiment includes the utilization of matched tooling for forming.

The above-described and other features will be appreciated and understood by those skilled in the art from the following detailed description, drawings, and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Refer now to the figures, which are exemplary embodiments, and wherein the like elements are numbered alike.

Figure 1 is cross sectional view of an exemplary gel coated plastic reinforced article.

Figure 2 is a cross-sectional side view of a cross-sectional side view of a matched tool with an exemplary substrate to be thermoformed.

Figure 2A, right portion, is a cross-sectional side view of membrane assisted vacuum/pressure equipment with an exemplary substrate to be thermoformed.

Figure 3 is a molding system with a gel coat material for molding to the shaped substrate.

DETAILED DESCRIPTION

Disclosed herein are methods for making gel coated layered articles having a substrate with an open-celled structure. It should be noted that, as used herein, the term “open-celled” has its ordinary meaning, and describes cells in fluid communication with adjacent cells such that fluid communication is established from one surface through to an opposite surface. The term “thermoforming” and its various derivatives have their ordinary meaning, and are used herein to generically describe a method of heating and forming a sheet into a desired shape. Thermoforming methods and tools are described in detail in DuBois and Pribble’s “Plastics Mold Engineering Handbook”, Fifth Edition, 1995, pages 468 to 498.

The term “layer” is used herein for convenience, and includes materials having an irregular shape as well as sheets and films. It should further be noted that the terms “first,” “second,” and the like herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another, and the terms “a” and “an” herein do not denote a limitation of quantity, but rather denote the presence of at

least one of the referenced item. Furthermore, all ranges disclosed herein are inclusive and combinable (e.g., ranges of “up to about 25 weight percent (wt.%), with about 5 wt.% to about 20 wt.% desired, and about 10 wt.% to about 15 wt.% more desired,” is inclusive of the endpoints and all intermediate values of the ranges, e.g., “about 5 wt.% to about 25 wt.%, about 5 wt.% to about 15 wt.%,” etc.).

The methods disclosed herein are of particular utility in the manufacture articles comprising a gel coat material disposed on an open-celled, fiber-reinforced thermoformable substrate. The gel coat desirably functions as a surface layer for the substrate, and is selected to be compatible with the substrate.

The substrate material comprises thermoplastic materials. Exemplary thermoplastic materials include polypropylene, polycarbonate (PC), polyester, polyetherimide (PEI), polyarylene ethers, and the like, as well as combinations comprising at least one of the foregoing thermoplastic materials, for example PC/PET blends. Linear or branched aromatic polycarbonates may be used. In one embodiment, polycarbonates comprising units derived from one or more of 2,2-bis(4-hydroxyphenyl) propane (“Bisphenol A”), bis(2-hydroxyphenyl) methane, 1,1-bis(4-hydroxyphenyl)-3,3,5-trimethylcyclohexane, fluorenone bisphenol, 1,1-bis(4-hydroxyphenyl) ethane, 2,6-dihydroxynaphthalene, bis(3,5-diethyl-4-hydroxyphenyl) sulfone, 2,2-bis(3,5-dibromo-4-hydroxyphenyl) propane, 4,4'-dihydroxydiphenyl ether, spiro biindane bisphenol, and the like, may be used. Suitable thermoplastic polyesters include, for example, poly(alkylene dicarboxylates) such as poly(ethylene terephthalate) (PET), poly(1,4-butylene terephthalate) (PBT), poly(trimethylene terephthalate) (PTT), poly(ethylene naphthalate) (PEN), poly(butylene naphthalate) (PBN), poly(cyclohexanedimethanol terephthalate), poly(cyclohexanedimethanol-co-ethylene terephthalate) (PETA), and poly(1,4-cyclohexanedimethyl-1,4-cyclohexanedicarboxylate) (PCCD); poly(alkylene arenedioates); and combinations comprising at least one of the foregoing polyesters.

In an exemplary embodiment, the gel coat 10 comprises a pigmented prepromoted resin, which is typically sprayable. The use of unsaturated polyesters in admixture with unsaturated aromatic monomers such as styrene may be used for the production of cross linked polymers initiated peroxide. Unsaturated polyesters may be prepared

from the condensation of unsaturated acids or acid anhydrides with polyols. The most common unsaturated acid used is either maleic anhydride or fumaric acid. For improved hydrolysis resistance, vinyl esters, formed from the reaction of an aromatic polyepoxide with an unsaturated monocarboxylic acid may be used. Other systems described in US patent 4,742,121 to Toman, include urethane polyesters having various pendant unsaturation, isocyanate-functional acrylic systems, graft copolymer systems having an acrylic backbone and alkyd resin chains, and vinyl esters based on aromatic polyepoxide resin. The patent describes acrylate resins having multiple carbon-to-carbon bond unsaturation attached to the polymer chain. The description of the gel coat resins set forth in the US patent 4,742,121 in columns 1 to 10 is incorporated into the present specification by reference. Other gel coat systems may be based on epoxy polymers.

The plastic materials of the substrate comprise sufficient bonding capability to provide sufficient structural integrity to the substrate to enable thermoforming thereof. For example, the substrate can comprise fibers and thermoplastic material(s) such that the substrate can be disposed in a thermoforming system and thermoformed. In another exemplary embodiment, the substrate can comprise fibers, thermosetting material(s), and an agent wherein the agent retains the structure of the substrate in the desired form (e.g., a sheet) such that the substrate can be disposed in a thermoforming system and thermoformed.

The fibers employed in the substrate are selected such that a fiber-reinforced plastic is formed, and optionally an open-celled fiber-reinforced plastic material. Fiber type, size, amount, and the like may vary with the plastic material employed in making the substrate. In an exemplary embodiment, the fibers are selected to impart the desired void volume to the substrate. In order to attain the desired mold replication and a desired void volume, the fibers can be capable of lofting (e.g., of expanding in the z-direction when heated). Exemplary fiber types include, but are limited to, glass fibers (e.g., E-glass ("electrical glass", e.g., borosilicate glass), S-glass ("structural glass", e.g., magnesia/alumina/silicate glass), and the like), mineral fibers, polymer fibers, natural fibers, and the like, as well as combinations comprising at least one of the foregoing fibers. Optionally, the fiber diameter (width) may be about 6 micrometers

to about 25 micrometers. Optionally, the fiber length may be about 2 millimeters (mm) to about 75 mm.

The fiber-reinforced plastic material of the substrate comprises a sufficient amount of plastic material and fibers to provide the desired structural integrity and void volume to the substrate. For example, the fiber-reinforced plastic substrate can comprise about 25 weight percent (wt.%) to about 75 wt.% plastic material, specifically about 35 wt.% to about 65 wt.%, and more specifically about 40 wt.% to about 60 wt.% plastic material may be employed. About 25 wt.% to 75 wt.% fibers with the plastic material, specifically about 35 wt.% to about 65 wt.% and more specifically about 40 wt.% to about 60 wt.% fibers may be used. The weight percents are based on the total weight of the fiber-reinforced plastic substrate.

Examples of suitable commercially available substrate materials include, but are not limited to, AZDEL® SuperLite® and AZDEL® Glass Mat Thermoplastics (GMT), which are available from AZDEL, Inc., Shelby, NC, having various matrices including, but not limited to, polypropylene, polycarbonate (e.g., LEXAN® from General Electric Company), polyester (e.g., VALOX® from General Electric Company), polyetherimide (e.g., ULTEM® from General Electric Company), polyarylene ether (e.g., polyphenylene ether; PPO® Resin from General Electric Company), polystyrene, polyamide and/or combinations comprising at least one of the foregoing.

For example, the substrate may be produced according to the Wiggins Teape method (e.g., as discussed in U.S. Patent Nos. 3,938,782; 3,947,315; 4,166,090; 4,257,754; and 5,215,627). For example, to produce a mat according to the Wiggins Teape or similar method, fibers, thermoplastic material(s), and any additives are metered and dispersed into a mixing tank fitted with an impeller to form a mixture. The mixture is pumped to a head-box via a distribution manifold. The head box is located above a wire section of a machine of the type utilized for papermaking. The dispersed mixture passes through a moving wire screen using a vacuum, producing a uniform, fibrous wet web. The wet web is passed through a dryer to reduce moisture content and, if a thermoplastic is used, to melt the thermoplastic material(s). A non-woven scrim layer may also be attached to one side or to both sides of the web to facilitate

ease of handling the substrate (e.g., to provide structural integrity to a substrate with a thermoset material). The substrate can then be passed through tension rolls and cut (guillotined) into the desired size.

In accordance with the present method, the substrate is thermoformed into a shape substantially corresponding to the shape of the desired final article. Generally, thermoforming comprises the sequential or simultaneous heating and forming of a material onto a mold, wherein the material is originally in the form of a sheet and is formed into a desired shape. Once the desired shape has been obtained, the formed article is cooled below its solidification or glass transition temperature. Generally, any thermoforming method capable of producing a formed substrate having a void content sufficient to enable a vacuum to be pulled therethrough, e.g., a void content of greater than or equal to about 5 vol.% may be employed. For example, suitable thermoforming methods include, but are not limited to, mechanical forming (e.g., matched tool forming), membrane assisted pressure/vacuum forming, membrane assisted pressure/vacuum forming with a plug assist, and the like.

In a matched tool forming method of forming the substrate, a substrate is heated at a sufficient temperature and for a sufficient time to allow the substrate to reach a softening temperature (which may also be referred to as a forming temperature) such that the substrate may be physically worked (i.e., work-formed) into a desired shape. It is noted that the substrate may be heated in various fashions, such as in radiant thermoforming ovens (which may include a top and/or bottom heater). The substrate is then disposed between a male forming tool and a female forming tool. The male and female forming tools are brought in physical contact with each other via stops (disposed at a peripheral edge of each tool) under a pressure sufficient to form the substrate into the desired shape, while maintaining void contents in the ranges previously mentioned. Suitable pressures will depend on the particular substrate composition, and are readily determined by one of ordinary skill in the art without undue experimentation. However, it is noted that use of excessive pressure is to be avoided, as it may close some or all of the cells thereof to below a desired void content, rendering the substrate insufficiently porous.

Referring now to Figure 2, a cross-sectional view of a matched tool forming is provided. A heated substrate sheet 50 is held in position relative to a male forming tool 52 and female forming tool 54 typically using clamps. It is noted that the male forming tool and the female forming tool are configured to "match", i.e., complement, each other. The male forming tool and the female forming tool may optionally comprise a plurality of holes and respectively. Disposed at a periphery of male forming tool and female forming tool are stops (spacers), which are used to determine the thickness of the shaped substrate. The stops are positioned outside of the forming area. The male tool and female tool are constructed of materials that are compatible with the substrate materials. For example, the tool may be constructed of, but not limited to, the following materials: aluminum, steel, epoxy, silicone rubber, filled tooling resin, and the like.

During forming, the substrate is heated to a temperature sufficient to allow thermoforming and desirably sufficient to allow lofting of the fibers in the substrate. For example, a temperature of about 450°F (about 232°C) to about 700°F (about 371°C), more specifically, about 550°F (about 288°C) to about 650°F (about 343°C), is suitable for thermoforming a glass fiber-reinforced polycarbonate substrate sheet. The heated substrate is then formed by creating relative motion between the male tool and female tool such that stops are contacted. Bringing the male tool together with the female tool with the substrate sheet there between causing the substrate sheet to conform to the shapes of the male and female tools. The substrate can then be cooled to form a shaped substrate. A pressure of about 5 atmosphere (about 101 kPa) to about 10 atmosphere (about 1013 kPa), more particularly about 1 atmosphere (about 101 kPa) to about 5 atmosphere (507 kPa) is employed to form the AZDEL® SuperLite® substrate.

In a membrane-assisted vacuum/pressure forming method, a heated substrate is disposed against a pressure box 58. Vacuum and pressure are simultaneously applied to the substrate. More particularly, a vacuum is pulled through a forming tool and positive pressure is applied to the side of the membrane 56 opposite the side closest to the forming tool. The direction of the vacuum and pressure are indicated schematically in the Figure 3 by arrows. The vacuum applied through the mold causes the sheet to be pulled into/onto (hereinafter onto) the mold. Suitable pressures

(positive and negative) will depend on the particular substrate and are readily determined by one of ordinary skill in the art without undue experimentation. Further, as noted above, excessive pressure is to be avoided, as it may close some or all of the cells, rendering the substrate insufficiently porous.

Figure 3 schematically illustrates a membrane assisted vacuum/pressure thermoforming method. A heated substrate 24 is disposed between a pressure box 22 and a forming tool 20. While forming tool may be a male forming tool or a female forming tool, the forming tool is illustrated as a male forming tool. Forming tool comprises holes such that a vacuum may be applied through the forming tool. Clamps may be used to hold the substrate sheet in position relative to the pressure box and the forming tool. A membrane, more specifically, a non-permeable membrane 26, is stretched across the opening of the pressure box. As discussed above, a first surface of the substrate is brought in physical contact with forming tool via a vacuum being pulled through the forming tool, while a second surface is brought in physical contact with membrane. A pressure is applied to the membrane from membrane side. Since substrate is an open-celled, fiber-reinforced thermoplastic material having a void content greater than or equal to about 5 vol.% as discussed above, a vacuum is pulled directly through the substrate. As such, the membrane is employed to push the substrate onto the forming tool (i.e., a vacuum is pulled through the substrate and pulls membrane and therefore substrate toward tool as the positive pressure from pressure box pushes the membrane toward to tool). In other words, a vacuum cannot be pulled through the membrane. Rather, the vacuum pulls the membrane toward the forming tool as pressure applied to the membrane pushes the membrane toward the forming tool. Once the substrate is on the forming tool, it is cooled to form the shaped substrate.

For example, if AZDEL® SuperLite® is the substrate, a pressure of about 0.5 atmosphere to about 8 atmospheres may be applied to the membrane to push the substrate toward forming tool 20, while a vacuum is being pulled through forming tool 30. More particularly, about 1 (about 101 kPa) atmosphere to about 3 atmospheres (about 304 kPa) of pressure may be applied to the membrane.

The above described thermoforming methods are provided merely for exemplary purposes. It is to be understood that the substrate may be formed by any thermoforming method, wherein the resulting molded substrate has a void content such that a vacuum may be applied through the substrate.

After thermoforming the substrate to produce a shaped substrate, the shaped substrate may optionally be trimmed to substantially the final shape of the desired article. The trimming may occur prior to or subsequent to disposing of the gel coat on the shaped substrate. The trimming method may include, for example, laser trimming, water jet trimming, trim press trimming, and the like, as well as combinations comprising at least one of the foregoing methods.

The molding of the thermoformed reinforced resin material is carried out to form a structural bond between the reinforced resin material and the gel coat. Preferably, an adherent bond between the reinforced resin and the gel coat is formed with the gel coat permeating into the open cell structure of the reinforced resin material to form an integral laminate. The thermoformed laminate is trimmed into at least the rough shape of the final article. The trimmed shape is then registered with or placed into a cavity of the molding tool. The gel coat material, either in uncured or slightly cured form, is introduced into or onto the other portion of the mold cavity. The mold is closed to the point where gel coat material flows into the reinforced resin material and the gel coat material is cured to bond with the reinforced resin material. It is desirable that the Class A surface be retained to minimize glass read through and other surface imperfections. The interface includes gel coat material and reinforced resin material. The mold is opened and the structural part is removed. Molds are typically made from a metal having high thermal conductivity such as aluminum. Molds for gel coating applications may be polyester based since high temperatures are not needed for the curing process.

Structural articles formed using the materials and methods disclosed herein may include any use where a layered plastic article may be advantageous. For example, articles include but are not limited to, exterior and interior components for aircraft, automotive (e.g., cars, trucks, motorcycles, and the like). For example, various

components include, but are not limited to panels, quarter panels, rocker panels, vertical panels, horizontal panels, fenders, head liners, doors, and the like.

Advantageously, the methods disclosed herein simplify the production of cosmetic, structural parts and panels compared to methods employing thermosetting materials. In various embodiments, the production of these parts can proceed on a single forming station with greater efficiency than is currently possible. Methods that use thermoforming have required a separate, non-thermoforming step to dispose the substrate or sub-layer onto a shaped layer (e.g., a shaped gel coat), e.g., by spraying, injecting, or the like. However, by employing a substrate with a sufficient void volume to enable a vacuum to be pulled through the shaped substrate to pull another layer onto that substrate, the gel coat can also be applied using thermoforming. Since the shaped substrate can be formed on a male or female mold, the subsequent layer (e.g., gel coat) can be an aesthetic layer applied to an outer surface of the shaped substrate.

This method reduces the types of equipment used to produce these layered products and can decrease formation time and simplify the layered article manufacturing process. In addition, when this thermoforming method does not employ a thermosetting material, VOC emissions are greatly reduced, if not eliminated, compared to other method using a thermosetting material. The relatively low pressures that are employed in the methods disclosed herein also allows for relatively low tooling costs. Finally, the porous nature of the underlying substrate structure helps reduce thermo-elastic stresses that arise during the attachment of the surface layer.

Example though not limited to this method, a process for making final structural aesthetic parts includes forming SuperLite® sheets from Azdel Inc. via pressure, matched tool, vacuum or vacuum bag process. By controlling the pressure, a degree of porosity remains in the substrate. The composite perform is then placed into a matched tool where a thermosetting gel coat has been applied to one or both halves of the tool. The tool is then closed and a pressure of 1 to 500 psi is applied as the gel coat cures. Because of the porous nature of the substrate, there is appreciable gel coat

percolation through the substrate enabling significant mechanical bonding between the layers.

SuperLite® sheet may be manufactured with various thermoplastic matrices such as polypropylene, Nylon, LEXAN® POLYCARBONATE, VALOX® polyester, ULTEM® polyetherimide, NORYL® polyphenylene ether resin, or blends may be used to form the composite sheet. Fully dispersed wet laid chopped mat is typically used to create the porous open cell reinforcement for the thermoplastic composite. Proper selection of fiber type and geometry is desired for achieving the desired porosity in the composite. These parameters are dependent on the particular system utilized. In addition, processing conditions and tooling must be tuned during forming to balance substrate detail and mechanical integrity with part porosity. Typical fiber types include, but are not limited to E-glass, S-glass, and basalt. Fiber diameters range from 6um to 25 um. Fiber lengths vary from 2 mm to 50 mm in commonly used wet laid reinforcement constructions. Resin content ranges from 30% to 70% by weight depending on the combination of resins and reinforcements that are used. Molding or forming pressures vary from 1 to 10 atmospheres for these materials with lower pressures being most useful for semi-crystalline systems. Higher pressures may be required for amorphous structures. Vacuum assist is often employed to improve molded part detail and to prevent air entrapment during forming.

In more detail, the article consists of a gel coat 10 over a reinforced, porous thermoplastic substrate 14, 16. Because of the porous nature of the thermoplastic substrate and method for creating the article, significant intermingling of the gel coat and the substrate create a strong mechanical bond. The system may or may not be “balanced” with a film or gel coat 12 on the backside of the structure.

Figure 1 shows a cross section of the multi-layer material system. A typical thickness for the top 10, and, if necessary, the bottom 12, gel coat is between 0.025 and 2.5 mm, more specifically 0.25 mm to 1 mm. A typical thickness for the porous reinforced thermoplastic substrate 14, 16 is between 1 and 10 mm, more specifically 2 to 5 mm. Depending on the amount of gel coat applied, the tooling dimensions and processing conditions, the gel coat may infuse through between 1 and 100% of the thickness of the porous thermoplastic composite 14.

A SuperLite® sheet comprising glass fibers and a ULTEM® resin and LEXAN® polycarbonate resin blend is heated in a thermoforming oven to between 450 and 700 °F and transferred to a molding station where the material is formed using either a matched tool or pressure forming technique. Positive pressure of between 1 and 500 psi is applied, and vacuum between 0 and 14.7 psi is pulled. Figure 2 shows the matched tool technique and the pressure forming technique.

The SuperLite® resin preform is then removed from the tool and allowed to cool before the gel coating stage. Due to the material and processing conditions, the preform maintains some porosity. A gel coat is sprayed into one or both halves of a matched tool sized to the preform. The preform is transferred to the tool and the tool is closed and pressure of between 1 and 250 psi is applied. The gel coat is allowed to cure under pressure until the final part is ready to be removed. Figure 3 shows the gel coating process.

While the invention has been described with reference to an exemplary embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A method of forming a gel coated article, the method comprising:

forming a fiber enforced thermoplastic substrate sheet into a desired shape;

contacting a surface area of the desired shape with a thermosetting gel coating material;

molding together said desired shape and a gel coating material to form a adherent bond between said gel coating material and said desired shape wherein said gel coating material permeates into a porous region adjacent the surface area of said desired shape to form a mechanical bond therewith, said porous region comprising residual porosity or porosity resulting from lofting of fibers.
2. The method of Claim 1, wherein said molding by closing mold sections and one of said mold sections comprise said gel coating material.
3. The method of Claim 1, wherein the fibers have a fiber diameter of about 6 micrometers to about 25 micrometers, and a fiber length of about 2 millimeters to about 75 millimeters.
4. The method of Claim 1, wherein the gel coat material is a thermosetting resin material and said gel coating material is cured during molding.
5. The method of Claim 1, wherein the shaped substrate is an open-celled, fiber-reinforced plastic material.
6. The method of Claim 1, wherein the substrate sheet comprises:

about 25 wt.% to about 75 wt.% plastic material;

about 25 wt.% to about 75 wt.% fibers; and

wherein weight percents are based on a total weight of the substrate sheet.
7. The method of Claim 6, wherein the substrate sheet comprises:

about 35 wt.% to about 65 wt.% plastic material; and

about 35 wt.% to about 65 wt.% fibers.

8. The method of Claim 6, wherein the plastic material is selected from the group consisting of polycarbonate, polypropylene, polyester, polyetherimide, polyphenylene ether, polystyrene, polyamide, and combinations comprising at least one of the foregoing.
9. The method of Claim 1, wherein the substrate sheet is thermoformed with a membrane assisted vacuum pressure forming method with a plug-assist.
10. The method of Claim 1, wherein the substrate sheet is thermoformed with a membrane assisted vacuum pressure forming method with a plug-assist.
11. The method of Claim 1, wherein thermoforming the substrate sheet further comprises heating the substrate to a temperature sufficient to allow lofting of the fibers.
12. The method of Claim 11, wherein the temperature is about 450°F (about 232°C) to about 700°F (about 371°C).
13. The method of Claim 1, wherein the substrate sheet further comprises a non-woven scrim disposed on a surface of the substrate sheet.