Reprinted From:
Engineering & Manufacturing Solutions for Industry
COMPOSITES TECHNOLOGY

THERMOPLASTIC COMPOSITES LIGHTEN TRANSIT BUS

Low-pressure forming processes and low-density, long fiber-reinforced thermoplastic come together to cut weight of aluminum transit bus roof air conditioning door by 40 percent.

Composites material suppliers and molders have spent many years developing and producing lightweight components for automobiles and heavy trucks, aimed at improving fuel efficiency and cost. During this period, much less attention has been devoted to mass transit applications for composites. But that is changing, as transit equipment manufacturers and governments recognize the opportunities to reduce fuel consumption and road wear, particularly for buses. Transit authorities in New Jersey, for example, have requested bids for new buses that weigh 5,000 lb/2,270 kg less than current models in use, says Uday Vaidya, director of the Engineering Plastics and Composites Laboratory at the University of Alabama at Birmingham (UAB). Vaidya and his colleagues Sellvum Pillay and Haibin Ning, in collaboration with the National Composite Center (NCC, Kettering, Ohio) and other partners, have recently completed a five-year effort, funded by the U.S. Department of Transportation, to demonstrate how buses can be made lighter using composites.

Source: North American Bus Industries

North American Bus Industries' (NABI) 60-BRT is a common articulated bus for public transport in major cities. A number of the auxiliary systems, including the air conditioning, are housed on the roof of the bus under access doors similar to that trialed in the UAB/NCC project.

A key entity in the contracted effort was North American Bus Industries Inc. (NABI, Anniston, Ala.), a major producer of heavy-duty diesel, compressed natural gas (CNG), liquefied natural gas (LNG) and hybrid electrically powered buses. NABI offers standard-floor and low-floor transit buses, including 60-ft/18.2m articulated versions. In 2001, NABI also offered the first bus with an all-composite body (see "Learn More," p. 47).

For this program, NABI provided the platforms from which the UAB/NCC team selected components for its series of demonstrations. In the program's first four years, composite bus seats, floor and frame sections, body panels and a battery box door were produced. For the culminating project, an aluminum door/cover for the roof-mounted air conditioning system was selected for conversion. The net result is an innovative hybrid: an unreinforced thermoplastic outer skin, made using low-cost thermoforming technology, backed with a structural, low-density thermoplastic composite inner panel produced by low-pressure compression molding. The finished product meets or exceeds all requirements for fit, form and function, exhibiting greater stiffness, improved vibration damping and a mass reduction of nearly 40 percent compared to the aluminum production part.

INITIAL TRIAL WITH UNREINFORCED TPO

The air conditioning cover doors on the NABI 60-BRT (see "Learn More") are part of a series of rooftop doors that give access to the heating, ventilation and air conditioning (HVAC) equipment. Other doors provide access to natural gas tanks and other systems. The existing production door is approximately 4 ft wide and 6 ft long (1.22m by 1.83m). Weighing 46.2 lb/21 kg, the door is assembled from a curved 0.125-inch/3-mm thick sheet of aluminum with a metallic stiffener rib. During service and maintenance of the bus, technicians prop the cover open, using an extender arm on one end of the door. Under its own weight, the unsupported end deflects approximately 1.9 inches/48 mm, a target for improvement by switching to a lighter weight composite door. Other goals of the project included providing a ready-to-paint or molded-in color surface, better sound absorption/damping characteristics, and the use of simple, low-cost manufacturing technologies.

Initial finite element analysis conducted at UAB looked at a smooth outer skin with a ribbed inner panel, both produced via thermoforming, using an extruded unreinforced thermoplastic polyolefin (TPO) sheet material for both panels. The selected material was Sequel E3000, a modified polypropylene from Solvay Engineered Polymers Inc. (Auburn Hills, Mich.). With inner and outer panels each measuring 0.125 inch/3mm thick, this design offered a reduction in deflection but a weight savings of only 18.5 percent compared to the baseline. It was concluded that this design failed to offer enough weight savings to justify conversion; the parts would have to be significantly thinner or they would have to be thermoformed from material of lower density. This latter possibility would appear difficult to achieve given that the specific gravity of the TPO is already a low 1.07.

LOFTED THERMOPLASTIC HITS DEFLECTION/WEIGHT TARGET

The solution was found by replacing the unreinforced, ribbed inner panel with a lightweight, glass-reinforced thermoplastic composite material, SuperLite SL551400.109, supplied by Azdel Inc. (Lynchburg, Va.). The SuperLite material is a form of glass mat thermoplastic (GMT), but unlike traditional GMT, which requires compression molding at 1,500 psi to 2,000 psi (10 MPa to 13 MPa), it can be consolidated via low-cost methods such as vacuum thermoforming or low-pressure compression molding (less than 50 psi/0.3 MPa). This permitted part forming with low-cost tooling on the same equipment used for the outer panel.

The SuperLite material is manufactured using a slurry process, similar to that used in papermaking. Chopped glass and polypropylene are combined in an aqueous slurry and captured by a moving belt that transports the material through a drying process. The material contains fibers oriented not only in the x/y plane but also a percentage oriented vertically or at angles in the z direction. During manufacture, the sheet is consolidated, causing fibers with z orientation to bend and remain so as the material solidifies. When the finished sheet is subsequently heated during part production, these fibers straighten and have a "springing" effect, causing the material to increase in thickness or "loft." Although by weight the composite contains 55 percent glass and 45 percent resin, lofting introduces a substantial amount of air through the panel thickness, resulting in much lower densities than fully consolidated GMT of the same thickness. For example, the material used on the bus program, at 1,400 g/m² areal weight, has a specific gravity of only 0.56 when heated to melting point and compressed to 0.125-inch/3-mm thickness.

The finished composite AC door, shown in open position for access to the air conditioning unit. Freestanding deflection is significantly reduced compared to the much heavier standard production aluminum door.

Source: NCC

Although not required by specifications, the composite door is able to withstand the weight of two people when closed. The exterior TPO skin can be painted to match specific customer color schemes or may be formed using precolored, multilayer, high gloss sheets.

Analyses run on combinations of an unreinforced TPO outer sheet (still required to meet the surface appearance requirements) with the SuperLite inner predicted deflection of less than 1.2 inches/30 mm in the fully open position and a total weight of less than 33 lb/15 kg — a mass savings of more than 30 percent. This was considered sufficient to move forward with prototype manufacture.

MANUFACTURING PROCESSES OFFER HIGH-RATE POTENTIAL

Although earlier projects in the program had involved fully consolidated long fiber thermoplastic components, most of which could be manufactured

Source: Univ. of Alabama – Birmingham

Step 1

Detailed aluminum forming tool for the lofted glass-reinforced polypropylene structural inner panel. Cooling lines are cast into the mold to remove heat from the preheated sheet.

Step 2

Preheated, lofted sheet is placed between the aluminum upper forming tool and the mating lower tool. The mold is closed under low pressure and the sheet is cooled.

Step 3

After cooling, the formed composite inner panel is removed from the clamping frame. The part will be trimmed prior to bonding to the outer skin.

Step 4

The aluminum vacuum forming mold for the Class A thermoplastic olefin (TPO) outer skin. As with the inner panel, cooling lines are cast into the mold to remove heat from the preheated sheet.

Step 5

The formed outer TPO skin has been indexed to the removal station and is ready to be unloaded from the clamping frame and trimmed.

Step 6

A technician applies adhesion-promoting liquid primer to the bonding surfaces of the composite inner panel. The primer also is applied to the inside of the outer skin panel.

Step 7

Foam tape adhesive is applied to the bonding surfaces of the inner panel. The outer and inner panel are mated at low pressure to insure full contact.

Step 8

Two finished doors, after robotic trimming (the one at left is viewed form the inside, the one at right, shows the outside surface.

at the National Composite Center, the team selected thermoforming to manufacture the composite AC door. Because the Center does not have thermoforming equipment, NCC helped UAB find a site for the manufacture of the components in the prototype production phase, notes Pritam Das, program manager for advanced composites at NCC. The work was done at Portage Casting & Mold Inc. (Portage, Wis.).

Thermoforming is a common technology for high-rate production of commodity items, such as plastic cups and packaging. Such parts are made by simple vacuum forming of a heated thermoplastic sheet over a male or female tool. A variant called *pressure forming* introduces a pressure box on the nonvacuum side of the part to force the plastic material into more detailed shapes and improve surface appearance, with quality similar to injection molded parts. A more complex process, called *twin-sheet thermoforming*, applies vacuum to one side of each of two plastic sheets and presses them together, creating parts seamed at key joints with hollow inner sections.

The first choice of the team for the AC door was twin-sheet thermoforming of the smooth TPO outer sheet with the SuperLite ribbed inner panel. However, this produced parts with uneven shrinkage and also resulted in significant print-through of the ribs due to differences in thermal expansion between the two materials. This necessitated manufacture of the components individually, followed by a secondary bonding process.

The tooling was fabricated by Portage Casting & Mold and consists of a curved, smooth mold for the outer TPO skin and a ribbed mold for the inner panel. Both were fabricated by casting 356 aluminum to near-net shape, with heating and cooling lines cast in place. The molds were finish machined and polished to a 100-grit sandpaper finish. It was decided to compression mold the inner panel to a thickness of 0.125 inch/3 mm, so Portage also fabricated a mating tool out of laminated tooling mahogany for this step.

The molding was done on a four-station rotary thermoforming machine supplied by Brown Machine LLC (Beaverton, Mich.). Capable of accommodating parts as large as 10 ft by 12 ft (3m by 3.65m), the machine also can generate forming pressures of up to 60 psi/0.4 MPa. Thermoforming of the outer skin involved loading the flat sheet of TPO onto a clamping frame and moving it through heating ovens until forming temperature was reached (360ºF to 400ºF/182ºC to 204ºC). The sheet then was transferred to the preheated vacuum forming tool, maintained at 150ºF to 160ºF (65ºC to 71ºC). After forming and cooling, the part was moved to the machine's loading/unloading station and removed. Due to the number of manual steps involved in prototype fabrication, total cycle time was 300 seconds, but Vaidya expects that in an automated situation parts could be produced every 100 seconds. While most of the outer panels produced used the paintable Sequel E3000, several trials were done using a multilayer co-extruded sheet of roughly the same thickness as the paintable sheet, which combined E3000 and a thin, weatherable, pigmented cap layer of Indure E1500 HG (high gloss), also from Solvay. Use of the E1500 HG part enabled successful production of parts with molded-in color and a Class A finish, eliminating the painting step. Although NABI prefers to paint the parts to match specific bus colors, Das emphasizes that both materials process identically in the thermoforming step and, thus, the program validated the no-paint option for other applications of the technology.

For the inner panel, the machine was set up for compression molding, using the aluminum male tool and the mahogany female tool. The low-density composite sheet, which has a delivered thickness of 0.25 inch/6 mm, was loaded into the clamping frame and heated to 400ºF/204ºC, which caused the material to loft to a thickness of approximately 0.35 inch/9 mm. The lofted sheet was transferred to the molding cell, where it was compressed to a thickness of 0.125 inch/3 mm under 40 psi to 50 psi (0.3 MPa to 0.35 MPa). The aluminum male tool was maintained at 125ºF/52ºC while the mahogany female tool was heated to less than 100ºF/38ºC. After cooling, the panel was transferred to the unloading station and removed. Total cycle time was about 240 seconds per inner panel. In production, the lower tool also would be aluminum and the cycle times with automation reportedly could be reduced to 80 to 100 seconds.

TECHNOLOGY BENEFITS FAR-REACHING

The two molded components were trimmed by hand and then assembled via adhesive bonding. First, 3M Tape Primer 94, a liquid, was rolled onto the mating surface of each part and allowed to dry. The primer provides additional bonding strength to the low-surface-energy polypropylene and TPO. Next, the mating surface of the SuperLite inner panel was covered with 3M VHB Tape 5952, an adhesive tape in a foam carrier. Both materials were supplied by 3M Industrial Adhesives and Tapes Div. (St. Paul, Minn.). The parts were assembled, placed in a press fitted with the upper tool used on the outer panel and the lower tool used to form the inner panel and compressed at 13 psi/0.9 MPa for several seconds to ensure contact before removal. The assembly then was placed in a fixture and trimmed to finished dimensions on a 5-axis CNC machine supplied by Parpas America Corp. (Bloomfield Hills, Mich.). After mounting hardware was attached, the part was ready for installation on the bus.

Validation of the design objectives included deflection testing, vibration testing, mass verification and installation on the test bus at NABI. The composite door showed significant improvement in freestanding deflection at 1.1 inch/27 mm — almost half that of the aluminum production door. In vibration testing of the materials used in the door, the TPO/SuperLite combination showed the highest damping ratio of any individual material and more than ten-fold the ratio of the aluminum it replaced. The high damping capacity of the thermoplastic door is expected to result in excellent noise abatement.

The actual weight of the composite door is 27.1 lb/12.3 kg, 39 percent lighter than the aluminum door. Vaidya estimates that if all rooftop doors on the bus were replaced with composites, total weight savings per vehicle would be 500 lb/227 kg. In the weight-reduction scheme for an entire bus, using this method and these materials for the rooftop doors could, for example, satisfy 10 percent of the New Jersey Transit authority's weight reduction request and would do so without sacrificing part durability: Although the AC doors are designed with a "no step" requirement, when mounted on the bus, they demonstrated the ability to support the weight of two people, notes Das (see photo p. 44).

The doors are currently undergoing field trials and durability testing at NABI. Vaidya does not know if this particular design will enter full production for NABI, but he says it is being considered for use as a replacement door. He points out, however, that when lifecycle costs are considered (up to 500,000 miles/800,000 km or 12 years), the composite door offers significant economic benefits. He also notes that the UAB/NCC team is already in discussions with manufacturers in other transit categories, such as light and heavy rail, about possible applications of the material. NCC's Das also sees widespread opportunities outside mass transit, including golf carts, agriculture equipment, heavy truck and medium-volume automotive parts as well as the home appliance industry.

—Dale Brosius, Contributing Writer