Innovative Structural Thermoplastic Air Conditioning Roof Cover Door for Mass Transit Bus

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Abstract
This paper deals with the design and analysis of an air conditioning (AC) cover roof door of an articulated mass transit bus using advanced thermoplastic composites. Innovative thermoplastic composites materials and thermoforming processing technologies have been demonstrated to form an AC door that has an outer skin on thermoplastic polyolefin (TPO) and an inner rib-stiffened liner made of AZDEL SuperLite, a glass mat polypropylene (PP) material. The thermoplastic AC door is approximately 40% lighter than the metal counterpart and can be readily molded in a mass-produce able cost-effective manner.

Introduction

Thermoplastic composites are finding increasing use in a variety of applications such as mass-transit, automotive and military structures. Thermoplastics are attractive compared to traditional materials, such as steel, aluminum and thermoset composites, in these applications due to their high specific strength, good damping capacity, corrosion resistance, superior impact resistance, high toughness and ease of shaping and recycling [1]. The matrix in thermoplastic composites is generally comprised of polypropylene (PP), polyethylene (PE), polyamide (PA) or other polymers. E-glass fiber is a commonly used reinforcing material [2]. By introducing them into mass transit applications, composites help ton increase fuel efficiency and decrease maintenance costs due to their low weight. Various composite components have been designed and manufactured for ground transportation including structural roof panels in high-speed railway coaches, bus structures, front cabins of high-speed locomotives, and non-structural interior panels [3, 4]. Thermoplastic composites have been successfully introduced into a wide range of applications previously using thermoset composites [1-4]. This work deals with design and manufacturing of thermoplastic composites for mass transit applications.

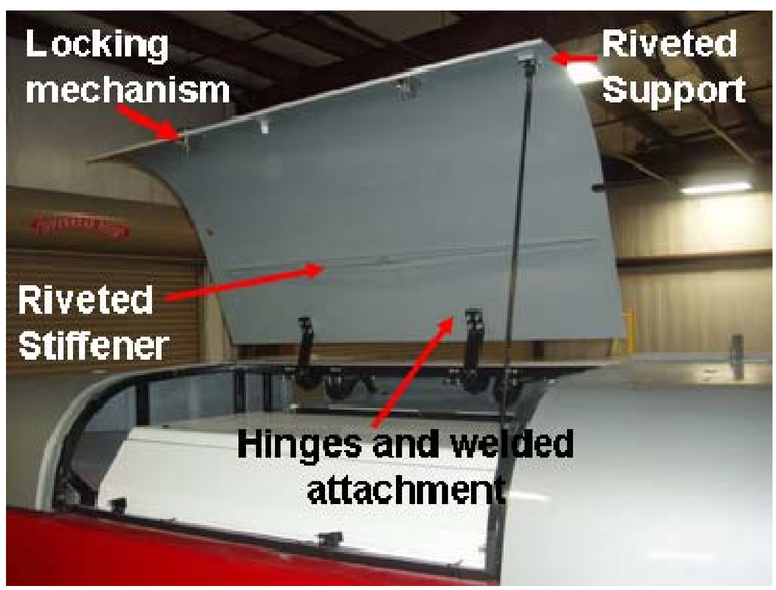


Figure 1. AC roof cover door on a mass transit bus

Design Requirements of Air Conditioning (AC) Roof Door

The AC door/cover is a curved geometry component located on the roof of the bus (Figure 1). Its main function is to protect, cover and house the heating and ventilation conditioning (HVAC) equipment. During service and maintenance of the bus, technicians open this cover and prop it open using an extender arm. Under these conditions, the cover needs to be stiff enough to avoid excessive deformation caused by its own weight in the area that is free to deflect by the action of gravity. The AC door/cover is hinged at the center rib to allow ease of service of the HVAC system.

In its current version, the AC door is manufactured by forming a sheet of aluminum into the curved shape. Due to the size of this component (1.8 m (6ft) long, 1.2 m (4ft) wide each) and its mass ~21kg, weight reduction was desirable. The existing AC door is assembled to a welded stiffener which stabilizes the sheet metal and improves its bending performance.

The design constraints for the thermoplastic composite AC door were as follows:

- Exhibit substantially less free standing deformation than the current aluminum design, when propped open with the extender arm
- Provide weight savings in comparison to the existing aluminum design.
- Feature a ready to paint surface or a color matched paint film to eliminate costly and painting processes.
- Provide better sound absorption and damping characteristics than the aluminum baseline.
- Allow for less labor intensive manufacturing cycle.

Thermoplastic Composite AC Door

The thermoplastic material was considered in comparison with the aluminum baseline. The redesigned component preserved the external appearance of the existing AC cover to ensure fit with the hardware presently used. The thermoplastic composite AC door incorporates multilayered thermo formable sheets [5] which comprise structural and aesthetical aspects of the doors. Two thermoplastic material types were used. The external layer made of thermoplastic polyolefin (TPO) provided the aesthetical finish requirements (painted or ready to paint); ultraviolet (UV) and environmental protection. The internal sheet made of glass mat thermoplastic was corrugated to provide structural stiffness. The conceptual solid model of the thermoplastic composite AC door is shown in Figure 2. The thermoplastic AC cover door was designed to be reinforced along its length via three (3) deep formed corrugations and also in the radial direction by multiple slimmer ribs which increase its buckling performance in the open position. All corner radii were maximized to minimize the probability of wrinkles during the molding of the prototypes.

For the structural analysis the initial thickness of each sheet is considered to be 3 mm. The resulting stresses and strains and apparent stiffness of this configuration were the starting point in determining the final thicknesses of the sheets in order to match the stiffness of the aluminum AC door. The structural layer incorporated sinusoidal grooves in the hoop direction to increase the moment of inertia and therefore the stiffness of the section. The incorporation of a longitudinal groove or a series of these increases the stiffness of the door in the longitudinal direction and serves as a replacement of the structural truss of the baseline.

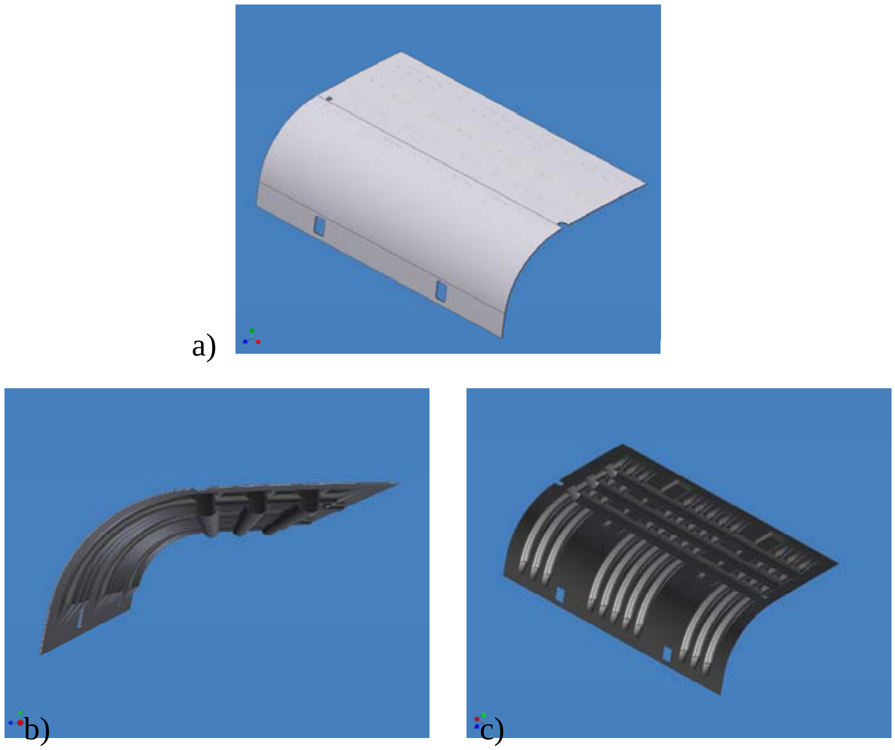


Figure 2. Thermoplastic Composite AC Door Concept; (a) TPO outer shell; (b, c) Inner glass mat PP rib-stiffened liner

The bending stiffness of different common reinforcing geometries was calculated and compared with the baseline truss stiffened design. This enabled selection of the geometry and size of the stiffening members. The results obtained from the structural analysis indicates that (3”/70 mm-deep) sine hat beams made of glass mat PP 3 mm thick provides equivalent flexural rigidity to

Table 1. Thermoplastic AC Cover parameters

	Items	Thickness (mm)	Material	Density (g/cm³)	Mass (kg)	Total Mass (kg)	Weight savings
Baseline design	Shell	3	Al	2.7	19.6	21	
	stiffener truss	--	Al	2.7	1.4		
UAB design	Top Shell	3	TPO	1.07	7.8	12.9 (12.3*)	39%
	Bottom Shell	3	SuperLite	0.56	5.1		

*data based on conceptual model generated by UAB

that offered by the 20 mm metallic truss structure that is featured in the baseline. An important consideration in the selection of the rib geometry was that the stiffening approach had to be “moldable” during the forming process. The internal sheet enhances the flexural stiffness of the overall AC cover and compensates for the low elastic modulus of the exterior TPO sheet. The elastic modulus of the aluminum is 70 GPa, while the elastic moduli of the TPO and glass mat PP are 1600 MPa and 2100 MPa respectively.

In order to determine the thickness of the two sheets and the deformations for a variety of load cases, several finite element models were built to compare the thermoplastic composite designs to the baseline. The loading scenario used for these analyses simulates the free-standing deflection observed on the AC cover in its open position as shown in Figure 1. This loading scenario includes; inertial loading (a function of the density of the cover's constituents and the action and direction of gravity), and displacement/rotation constraints (at the hinged connections and at the point of attachment of the extender arm). All the finite element models developed were carefully checked for element shape, aspect ratio and Jacobian calculations.

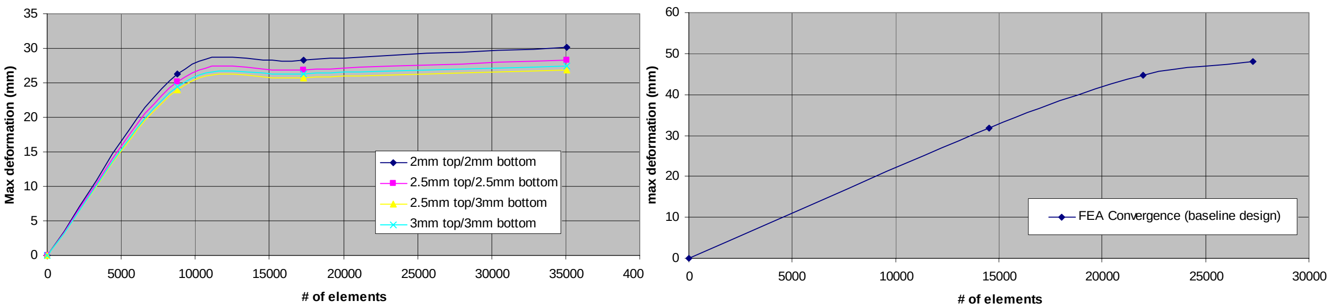
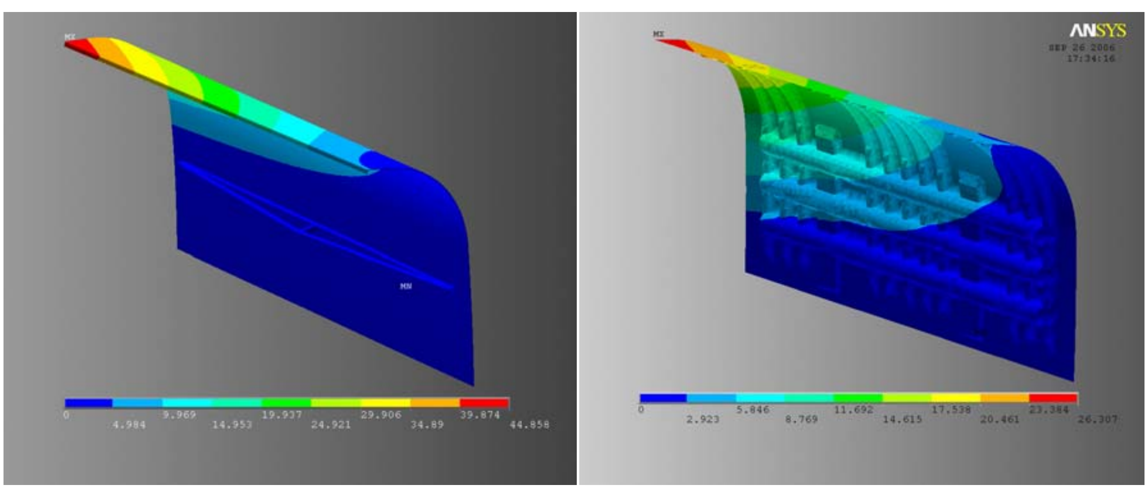


Figure 3. (a) Deformation convergence for (a) thermoplastic door with different thicknesses, (b) baseline aluminum/steel door.

Both the baseline design simulations and the new UAB concept simulations were run and analyzed for convergence. The solid design models were generated in Pro/E wildfire. An IGES file of the solid design was inputed to Hypermesh® for meshing. Three different mesh sizes were considered in all cases obtaining solutions to coarse size meshes (~8000 elements) intermediate meshes (~15000) and fine meshes (~35000) elements until deformation convergence was reached as shown in Figure 3a and 3b. To determine the optimum thickness of the individual



(a) (b)

Figure 4 (a) Baseline Aluminum/Steel Design; (b) Thermoplastic Composite Design. Deflection scale is in mm. Note 48 mm free standing deflection of baseline, and 27 mm for composite.

sheets, three different thicknesses were evaluated (2 mm, 2.5 mm, and 3 mm). The 3 mm external sheet/3 mm internal sheet combination was found to provide a combination of adequate weight savings versus low freestanding deflection with a total weight of 12.3 kg (39% weight savings in comparison with baseline design) and a total deformation of 27 mm almost half of the baseline freestanding deflection of 48 mm. The deformation contours for the baseline design and the UAB concept are shown in Figs 4 and 4b respectively. The resulting deformation as a function of total mass of the different concepts are shown in Figure 5. It can be seen that the composite solution is not only lighter but provides for much lower free standing deformation.

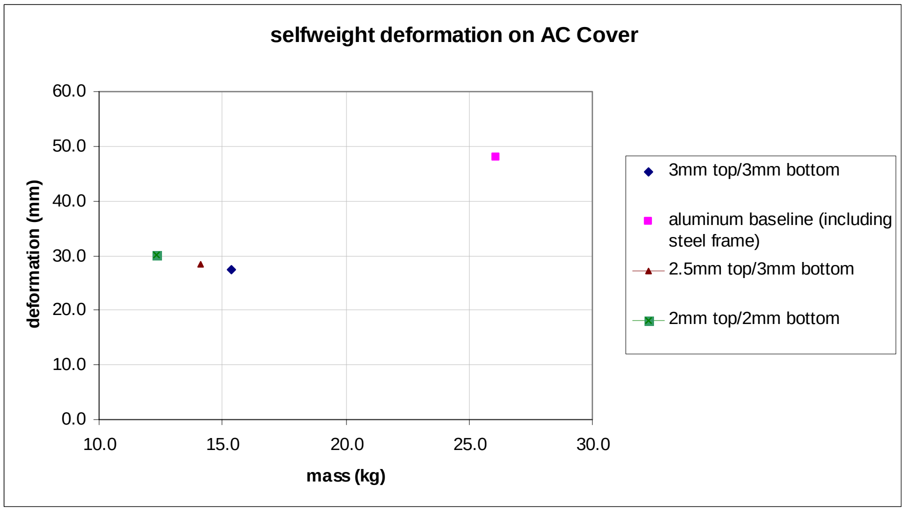


Figure 5. Deformation versus mass for baseline and thermoplastic composite door

Summary:

A large roof cover door for an air conditioning unit of a mass transit bus made from thermoplastic composite materials was designed and analyzed. The comparison was with respect to a baseline aluminum version. The design concept featured incorporating lightweight thermoplastic polyolefin and glass mat PP materials in a thermoforming processing operation. The detailed design demonstrated; (a) 77% less free standing deformation than the current aluminum design, when propped open with the extender arm; (b) weight savings in the order of 40% were demonstrated compared to the existing aluminum design; (c) thermoplastic materials that enabled painting as required for mass transit applications; and (d) sound absorption and damping characteristics of the thermoplastic materials were an order of magnitude higher than the aluminum baseline. A separate paper will deal with manufacturing details of the thermoplastic AC cover roof door.

References:

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