C118

Process Selection for a Composite Transit Vehicle Door

Case study

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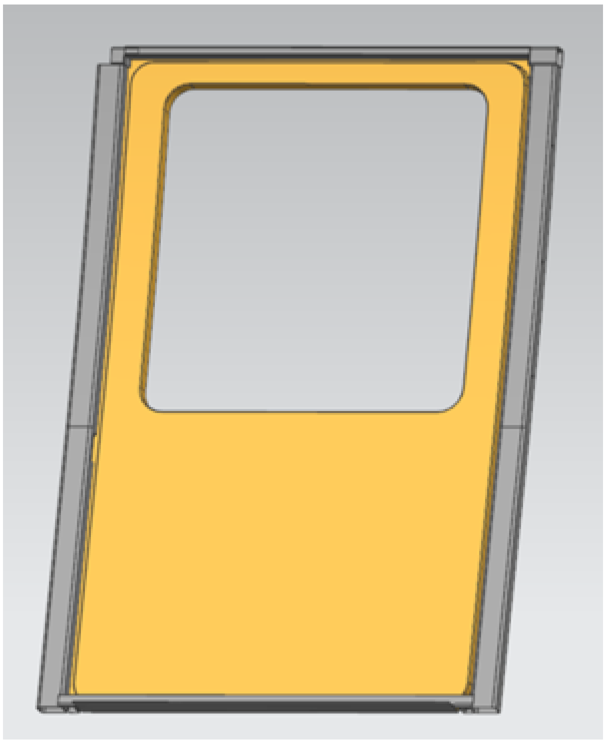
Objective functions	**Cost**	Maintain
	Rate	Maintain
	Quality	Maintain
MSTE workflow	Development	
Prerequisites	• Development	

Summary[edit | edit source]

Hand layup, Light RTM, and RTM (A293) manufacturing processes were assessed to determine the most appropriate process to manufacture an external door on a mass transit vehicle as shown in the figure below. A preliminary analysis was performed to determine the required materials and layups for each of the processes. The weights and costs were estimated based on the preliminary designs. Although each manufacturing method had its own advantages, light RTM was selected as it could meet all the design requirements, while being the least expensive for the predicted production volume.



Transit vehicle external door

Challenge[edit | edit source]

The design and manufacturing of the exterior door needed to meet key requirements to be approved for service. These functional requirements included:

1. Aesthetics – Class A surface finish that is free from material print-through .
2. Structural – Meet minimum safety factor and maximum deflection limits when undergoing:
    1. Door slamming
    2. Door opening
    3. High g-force collision load cases
3. Thermal – Meet maximum deflection limits while experiencing:
    1. Cold exterior and interior surfaces (winter)
    2. Hot exterior and interior surfaces (summer)
    3. Cold exterior and warm interior (heating inside)
    4. Hot exterior and cool interior (cooling inside)
4. Weight – Maximum allowable weight specified.
5. Production Volume – Up to 1000 parts required annually.
6. Cost – Lowest cost option that could meet the other requirements.

The design and final properties of the door changed depending on the manufacturing method selected. The ability of hand layup, light RTM, and RTM processing to meet the targets listed above needed to be assessed before moving into the detailed design phase.

Approach[edit | edit source]

A preliminary design was required for each manufacturing method to assess which was most appropriate for the door. Material properties research was combined with analysis using classical laminate theory to determine a suitable layup for each manufacturing method.

Hand Layup[edit | edit source]

The materials used for the hand layup design included chopped strand mat, stitched unidirectional mat, polyester bulker mat, and low-density polyurethane foam core. The laminate schedule is shown in the list below. The chopped strand mat was required against the exterior surface to reduce print-through of the directional fibres and the edges of the core. The unidirectional mat was required to provide the necessary stiffness and strength for the door to survive the structural and thermal load cases. The polyester bulker mat was included to increase the thickness of the door for improved flexural stiffness, while reducing the cost and weight compared to using additional fibreglass plies. The polyester bulker mat also helped to reduce print-through from the edges of the core. The low-density polyurethane core increased the flexural stiffness of the part while reducing the weight and cost of the part.

Click here for more on fibre architecture and here for more on core materials

Hand Layup Design

- Chopped strand mat
- Unidirectional mat
- Polyester bulker mat
- Low density polyurethane foam core
- Polyester bulker mat
- Unidirectional mat
- Chopped strand mat

Only A-side tooling is used for hand layup manufacturing so the B-side (interior) of the part has a rough surface finish. This results in part thickness variability along the interior surface of the door and between each door. Thickness variability can lead to challenges for part fit-up with other components. It also makes achieving a good seal more difficult which can lead to the need to increase the door closing force.

The expected fibre mass fraction is between 25% and 30% for hand layup processing. This means additional plies of glass fibre were required to achieve a strength and stiffness equivalent to the RTM design. The lower fibre content also meant the coefficient of thermal expansion of the hand layup design was higher resulting in increased deformation during the thermal load cases. This was compensated for by including the unidirectional reinforcement ply to provide additional stiffness along the length of the door.

Light RTM[edit | edit source]

The materials used for the Light RTM design included a stitched infusion sandwich mat consisting of a non-woven synthetic core sandwiched between two layers of chopped strand mat, stitched unidirectional mat, and low-density polyurethane foam core. The laminate schedule is shown in the list below. The stitched sandwich mat was included in the design to allow for resin flow during the infusion process. The resin could travel easily through the non-woven synthetic core, while the chopped strand mat provided strength and stiffness. The sandwich mat was included on the exterior of the layup so the chopped strand mat plies could help block print through from the other materials. The unidirectional mat was required to provide the necessary stiffness and strength for the door to survive the structural and thermal load cases. The low-density polyurethane core increased the flexural stiffness of the part while reducing the cost of the part. A polyester bulker mat was not required for the light RTM design because the stitched mat with its nonwoven synthetic core provided the required thickness to the part.

Light RTM Design

- Infusion sandwich mat
- Unidirectional mat
- Low density polyurethane foam core
- Unidirectional mat
- Infusion sandwich mat

Light RTM processing uses A-side tooling that is similar to the hand layup tooling with a few additional features along the flange to aid in vacuum and resin flow. However, light RTM processing also requires a semi-rigid B-side tool. This created an additional expense that had to be amortized over the production run. The B-side tool resulted in a smoother surface finish on the interior surface of the door than for hand layup processing. The thickness control along the interior surface of the door, and consistency between doors, was much better with light RTM processing. This reduced the likelihood of part fit-up issues with other door components, including the frame, latches, and hinges.

The expected fibre mass fraction is approximately 30% for light RTM processing. This is a similar fibre content achievable from hand layup processing, but significantly lower than for RTM processing. Similar to hand layup, the lower fibre content meant the coefficient of thermal expansion was higher compared to the RTM design and resulted in increased deformation during the thermal load cases.

The use of resin infusion processing improved the repeatability of the process and resulted in more consistent parts compared to hand layup. One disadvantage compared to hand layup was the increased challenge of making changes to the design thickness after the B-side tool was built because the B-side tool sets the part cavity thickness. This became an issue during early production runs when a change in layup increased the thickness of the part and made it more difficult to close the B-side tool and reduced the flow of resin during the infusion process. If the change in thickness had been greater it would have necessitated the replacement of the B-side tool.

RTM[edit | edit source]

The materials used for the RTM design included chopped strand mat, stitched unidirectional mat, and medium-density polyurethane foam core. The laminate schedule is shown in the list below. Similar to the hand layup design, the chopped strand mat was required against the exterior surface to reduce print-through from the other materials. The unidirectional mat provided the necessary stiffness and strength to meet the structural and thermal requirements. The low-density polyurethane foam core used for the hand layup and light RTM design was replaced by a medium-density core. This was due to the higher pressure used during RTM processing that necessitated a core with greater compression strength.

RTM Design

- Chopped strand mat
- Unidirectional mat
- Medium density polyurethane foam core
- Unidirectional mat
- Chopped strand mat

RTM processing uses rigid A-side and B-side tooling that can withstand the higher pressures of the RTM process. The tooling is significantly more expensive than the tooling for hand layup or light RTM processing and needed to be amortized over the production run. The use of a rigid B-side tool resulted in a smooth surface finish on the interior surface of the door. RTM processing resulted in the most consistent part thickness due to the rigid tooling. This reduced the likelihood of part fit-up problems and increased the probability of achieving a good seal with minimal applied force.

The expected fibre mass fraction for RTM processing is upwards of 50%. This is significantly higher than hand layup and light RTM. The higher fibre content allowed for the removal of the polyester bulker mat as the additional thickness was not required to achieve the required stiffness values. The higher fibre content also decreased the coefficient of thermal expansion compared to the hand layup and RTM lite designs, resulting in less thermal deflections.

Similar to light RTM, the use of RTM processing improved the repeatability and consistency of the parts compared to hand layup. However, also like the light RTM design, changes to the layup after the tooling is built is not possible without costly part A and part B tool re-machining.

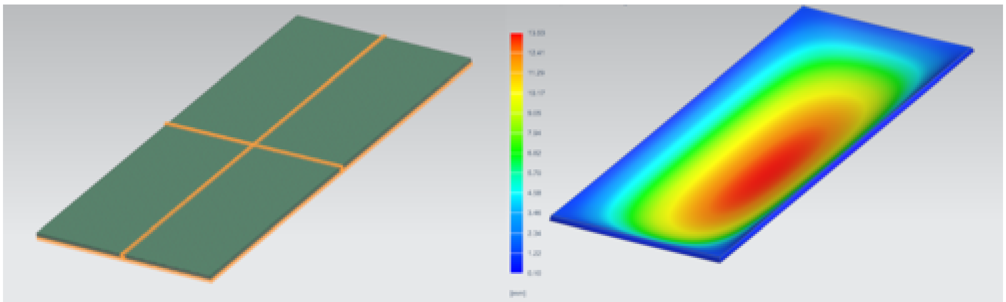
Structural Assessment[edit | edit source]

Performing a detailed finite element analysis of the door during the preliminary assessment of the manufacturing options was too time consuming and expensive. Instead, a stiffness requirement was defined based upon allowable deflection values for the structural load cases. The mechanical properties of each material were then used with classical laminate theory to calculate the longitudinal, transverse, and flexural stiffness of each design. The flexural stiffness of each design is provided in the table below. The required longitudinal flexural stiffness was 4.3 GPa based on the specified load cases.

Design	**Flexural Stiffness (GPa)**	
	Longitudinal	Transverse
Hand layup	5.28	3.87
RTM lite	5.42	4.29
RTM	6.05	3.98

Thermal Assessment[edit | edit source]

The thermal deflection of the door was estimated using a simple finite element model of a sandwich panel as shown in the figure below. The panel was simply supported around its outer edges to simulate the door resting on the seal. The four thermal load cases outlined above were applied. The load case with the greatest deflection was the cold exterior combined with heating inside the vehicle. The deflections for the hand layup and the light RTM designs were almost identical to each other at approximately 23 mm. This was within the requirement for a maximum deflection of 25mm. The deflection for the RTM design was approximately 40% less with a value of 13.5mm as shown in the figure below.



Thermal Sandwich Panel FEA Model and Deflection Results

Weight Estimate[edit | edit source]

With the structural and thermal suitability of each design confirmed, the weight of the three designs was estimated and is shown in the table below. The weights of the hand layup and light RTM designs were close to each other. The hand layup design was a little heavier due to the polyester bulker mat absorbing slightly more resin than the infusion sandwich mat used in the light RTM design. The RTM design was approximately 20% lighter than the other two designs. This was due to the higher fibre content achievable by the RTM process. The higher fibre content led to greater mechanical properties that allowed for the removal of the polyester bulker mat. Some of the weight saved from the removal of the bulker mat was offset by the need to include a higher density core to withstand the pressures of the RTM process.

Design	Estimated Weight (kg)
Hand layup	15.9
Light RTM	15.3
RTM	12.1

Cost Estimate[edit | edit source]

The production costs for each design were estimated by using the Ashby cost model which takes into consideration material, tooling, capital equipment, and labour costs. The estimated per unit costs for production of 1000 units annually are shown in the table below. The RTM design was the most expensive at this production volume. Although the material and labour costs were less expensive for the RTM design, the tooling costs, and capital equipment costs to setup a new production cell, were much higher. Even though these costs were amortized over the entire production run, the production volumes weren’t high enough to offset these costs. The RTM lite design was the least expensive option because of the labour savings compared to the hand layup design.

Design	Estimated Cost per Unit ($)
Hand layup	1,150
RTM lite	1,000
RTM	1,350

Outcome[edit | edit source]

Light RTM was selected as the manufacturing method for this door based on the design criteria. The design was able to meet the aesthetic requirements by using the infusion sandwich mat to block print through from the unidirectional glass fibre mat and core. The light RTM layup also met the structural deflection and strength requirements. The light RTM design exhibited more thermal deflection than the RTM design but met the requirements. The light RTM design was 20% heavier than the RTM design due to its lower fibre content, but the light RTM design was 25% less expensive and this was the deciding factor when making the manufacturing process selection. The light RTM also had the advantage of not requiring a large capital investment in equipment and tooling at the start of the project since the customer’s manufacturing division was already setup for light RTM manufacturing, but did not have an appropriately sized RTM manufacturing cell in place.

About **Help**

Resin transfer moulding (RTM) involves loading a preform into a two (or more) piece, matched tool, closing it, and injecting resin under pressure (~15-100 psi, or ~1-7 bar).

Well suited to small to medium sized parts, limited to large sizes due to injection pressure loads and tool cost.

For polymer matrix composites (PMCs), resin refers to the matrix; the continuous material phase that binds the reinforcement together, maintains shape, and transfers load. Resins are divided into two main groups: thermosets and thermoplastics.