HIGH-VOLUME MANUFACTURE OF A COMPOSITE DOOR MODULE BY A NOVEL 3D-PREFORM TECHNOLOGY

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Abstract

The environmental targets facing the automotive industry have led to an accelerated search for materials and processes with maximum weight-saving potential. Target applications range from semi-structural to fully structural parts, where safety is of paramount importance. New light weighting solutions must also provide opportunities for cost saving and be potentially suitable for recycling. Inherent to the cost-saving requirement is a need for reasonable material costs, short cycle-times and complex shape forming capabilities. Thermoplastic-based composites have been shown to offer significant advantages in these respects. However, the high viscosity of thermoplastic resins places severe demands on impregnation methods, and subsequent forming operations rise important issues with regard to both preform integrity and tooling.

A novel composite 3D-preform technology and the associated manufacturing equipment have been developed. This technology enables complex 3D shaping of preforms, which considerably reduces cost/time for the high-rate processing of thermoplastic-based composites. Both the manufacturing approach and the design freedom offered by our 3D-preform technology will be described in what follows, and its full 3D design and molding capabilities will be demonstrated for a car door module currently under development with major supply-chain partners.

1. Background

Composite materials are used extensively for semi-structural applications in the automotive industry. However, because of the higher materials costs of continuous fiber based materials, limited progress has been made in fulfilling the economic demands of structural applications. There is rapidly increasing interest in cost-effective and lightweight alternatives that are able to meet the stringent requirements of large volume automotive production. Our composite preform technology has proven to be one of the main contenders in the race to meet these requirements (Figure 1). We have demonstrated 20-30 % weight reduction (in exceptional cases up to 50 %) and 10-20 % cost reduction in a range of applications.

Parts with complex shapes, multiple functions and tailored structural properties can be manufactured in a single step operation using the 3D preform cell process. The 3D-preform combines the design freedom and net-shape processing of injection and compression-flow molding with structural inserts consisting of robotically placed unidirectional (UD) thermoplastic composite tape-pregs (tows) and also stamped fabrics. Hence, loads may be introduced and distributed efficiently within the component, and at the same time, the creep resistance, stiffness and strength may be increased while working with the same or a reduced cross-sectional area.
2. Composite 3D-Preform Technology

Our fully automated 3D-preforming cell converts a composite raw material (e.g. tape-preg, commingled yarn) by melting and shaping it into any 3-dimensional shaped preform. The 3-D preform is subsequently used as the basic reinforcement structure (skeleton) in molded, e.g. injection molding, compression molding parts. The preform may be seen as a composite "skeleton" tailored according to the loading requirements of the final component. The main manufacturing steps when integrated with injection molding are illustrated in Figure 2.
Currently, typical raw materials used for the 3D-preforming process are tapepregs based on continuous carbon fiber (CF) or glass fibers (GF) in a PP or PA matrix. Glass fiber has shown to be a preferred alternative when strength is the main requirement, while carbon fiber may be preferred if high stiffness is a priority. During the 3D-preform manufacturing process, the tape-pregs are melted, mixed and consolidated into one homogeneous tow. Subsequently, the tow is laid out in the automated robot cell to the desired 3D-shape. On cooling, this results in a finished solid composite preform, with a complete cycle-time in the order of 60 seconds.

For the subsequent over-molding operation, conventional neat or short fiber reinforced polymers (PA, PP, PET, ABS etc.) can be used. To achieve a desired bonding between the over-molded material and the 3D-preform, it requires compatibility between the constituents. In some cases, additional geometrical interlocking may provide additional bond strength. Levels and rates of processing temperature and pressure are crucial parameters for reliable bond strength between the constituents.

The mechanical properties for a structural beam produced with and without a 3D-preform insert is shown in Figure 3.

As summarized in Figures 4, the 3D-preform technology leverages the design freedom of injection molding, a wide variety of surface feel (soft or hard, smooth or textured, etc.) and the robustness of composites (Figure 3). In brief, it enables the production of extremely robust and tough composites with the cost effectiveness and design freedom of conventionally molded plastics.
Cost

Figure 5 gives an example of a cost breakdown associated with a typical structural application produced in high serial production. Typically, raw materials represent some 40-50% of the overall costs.

![Figure 5](image)

**Figure 5.** Cost breakdown for a typical structural composite part using our technology

3. The 3D-Preform Manufacturing Cell

The 3D-preform-manufacturing cell comprises 6 basic system elements as shown in Figure 6. Each of these elements can be tailored in order to suit the specific demands of the application, materials and production set-up. The system is fully automated and production synchronized, providing high-layup rate at temperature up to 400 °C.

![Figure 6](image)

**Figure 6.** The basic system elements of the 3D-Preform-line
The principle operation steps:

- selected composite tape-pregs are fed through a, placement rate controlled, preheating oven, with integrated consolidation device
- the hot consolidated composite tow or strand pass through a temperature controlled and fully 3D-flexible conveyor arm
- prior to placement, the hot composite tow passes through the attached deposition head of the first robot,
- the molten tow is then deposited on a jig fixed to a rotating, sliding or tilting table robot which is the second robot,
- consolidation roller applies pressure to the tow during deposition
- placed material is cooled with an air-jet system,
- several turns of material are applied at high deposition rates,
- at the end of the cycle the ready 3D-preform is automatically cut and moved by the 3rd robot to the subsequent over-molding operation.

Overall manufacturing conditions are exemplified in the Figure 7.

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*Figure 7. Example of typical Manufacturing conditions*

Additional support systems may be attached to the 3D-preform manufacturing cell, such as automatic insert loading and unloading equipment (bushings, fabrics, hinges, etc.) as well as Quality Control systems such as automatic vision control. As the cycle time of the preform production is of the same order of magnitude as those in conventional injection or compression molding operations (approximately 1 min.), the 3D-preform manufacturing cell is well suited to direct integration and inline process. The 3D-prefrom cell may also be integrated to other composite manufacturing techniques such as RTM and thermoforming.
4. Composite Door Module Concept

This concept forms part of an effort to investigate the possibility of using tailored 3D-preform for high-volume production. The value of this concept lies primarily in the weight, cost and sub-part reduction and it offers with respect to a metal door module in the same price range. A weight reduction of up to 20% is achieved by local reinforcement of a thermoplastic door structure with continuous fiber preforms. One of the key benefits of the 3D-preform technology is the positioning of the various 3D-preforms for dedicated load introduction and load distribution. Another key benefit is the reduction of the number of sub-parts (Figure 8). Fabric inserts may be used locally in combination with preforms, especially near latches and hinges. Hence the composite door module consists of only 6 parts as compared with 17 parts for the steel door module.

Figure 8. The part geometries of a steel door module (left) and a composite door module (right).

5. Design Overview

The overall design and development cycle includes some essential steps:

- Adaptation of the engineering simulation methodology to 3-D preform containing structures
- Structural analysis and specification of technical details for the parts
- Validation of CAE/FEM simulation
- Testing for representative physical properties related to the load case
- Performance characterization of the part

In developing the part, the whole value chain needs to be considered: manufacturing process and tool design, assembly and end-of-life. The introduction of local inserts can improve performance but they entail an increase in complexity. It is very important to define which aspects of performance should be prioritized in order to keep complexity to a minimum. To do this, we follow the guidelines given below.
Design engineering development: priority is given to a few designs with relatively simple geometries and load requirements. Concept development is supported by CAE in order to define the number and form of the inserts.

Process development: It is vital that tool design be discussed and developed in parallel with part design to ensure safe and efficient development and manufacture. Various adaptations to the tooling may be needed in order to position the insert and maintain it in place during mold closure and injection.

6. Overview of the 3D-preform Manufacturing Concept

The developed tailored 3D-preform manufacturing line adapted to the composite door module is shown in Figure 9.

Because the component in question is required to pass the crash test, it is necessary to focus not only on weight-reduction but also on the engineering strength under a wide range of operating conditions. Therefore, extensive testing with various preforms (different materials combinations and shape configurations) is carried out in order to verify process reliability and product performance.

7. Summary and Next Steps

The fast-growing and dynamic field of composite manufacturing for the high-volume market provides unique opportunities but also unique challenges in a complex value-chain environment. To maintain an important position, it is important to strengthen this position continually through technological advancement and the improved price competitiveness.
8. Acknowledgements

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9. References

