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Process analysis for structural optimisation of thermoplastic composite component using the building block approach

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ABSTRACT

The paper aim is to establish and optimise the prediction model of a thermoplastic fibre reinforced component designed and manufactured through an integrated injection moulding process (Hybrid Moulding). This is done by the Finite Element Analysis (FEA) and then the process simulations, considering the composite material as an elastic anisotropic woven fabric to study the deformations undergone during the manufacturing process. The proposed methodology for creating the predictive model is fairly accurate, and it is a novel method which can be easily integrated and adapted into a components initial design phase. This optimisation technique can replace the expensive and traditional trial and error procedures during the design and prototyping phase, and it significantly decreases the time to build the final component.

The final scope of the research is to simplify the product development phase of general lightweight automotive thermoplastic components by creating an innovative methodology for predictive modelling.

1. Introduction

The inherent ability of advanced fibre reinforced/prepreg polymers (composite materials) to allow complex designs to be tailor made for its design flexibility to meet high specific strength and stiffness.

Thermoplastic composite material usage has been growing steadily in the lightweight automotive sector where a high specific strength, low density and corrosion resistance is crucial [1–3]. Although composite materials have been widely considered in the automotive sector [4–5], it is still not widely implemented due to uncertainty and complexity involved in the prediction of durability in the design phase. Contrary to the aerospace industry [6] where the final efficiency and robustness of the component is a priority with more product development cycle time with much more resources. Another limiting factor is as the design complexity increases the modelling gets more complicated and requires sophisticated finite element analysis techniques and dependable standards [7].

On a theoretical level various approaches are proposed in analytical and semi-analytic approaches [8–9] but creating a prediction model on a commercial level is still uncertain. The main issue is the lack of a common standard methodology or knowledge sharing of methodology for material characterisation, FEA (Finite Element Analysis) and validation.

A building block approach has been set as a guideline and implemented for this research, developed by NASA for their Advanced Composite Technology (ACT) and High-Speed Research Program [10] to efficiently substantiate the durability and performance of the component design sequentially as illustrated in Fig. 1.

Both cost and performance objectives are met with the building block approach by characterising the material by testing on some less expensive specimen as a first step; evaluating technology risk early and progressively building a knowledge database at various structural complexity levels of the specimen [11]. The building block approach involves (Level 1) characterising the material experimentally and validating by FEA; (Level 2) progressing on to component validation experimentally and by FEA; (Level 3) moving on to component optimisation to examine the change in the component behaviour during the manufacturing process; (Level 4) and integrating the model into complicated full-scale components.

A state-of-the-art overmolded composite component was chosen for this research as the component, as in the fast-evolving thermoplastic composite technology, the latest trend in the automotive sector is the use of hybrid composites structures where the mechanical properties of multiple composite materials give the

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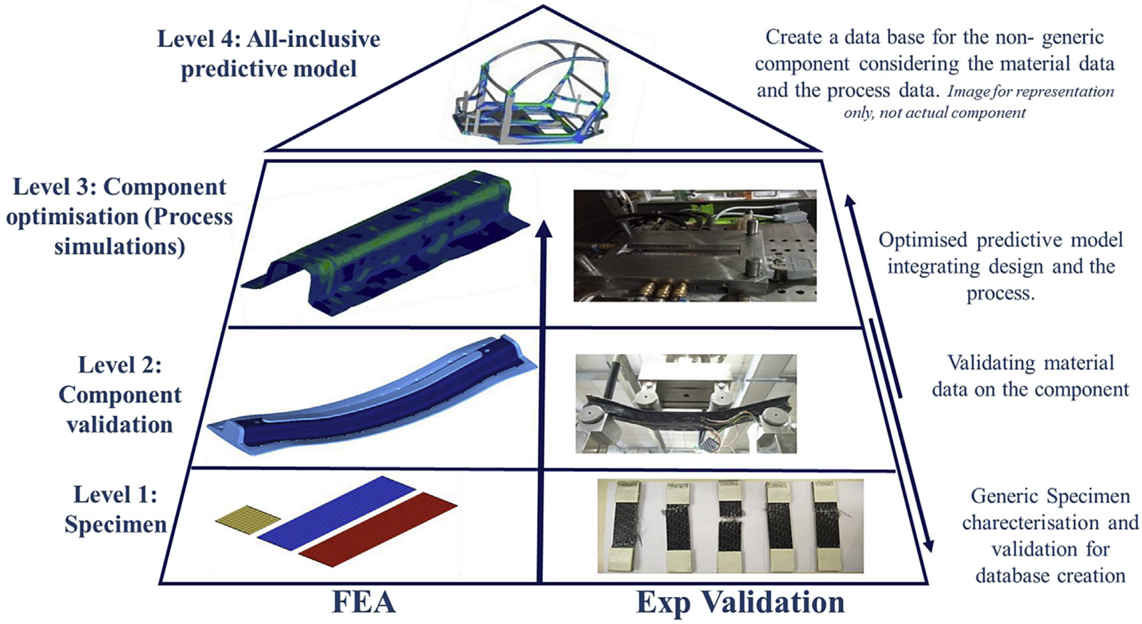

Fig. 1. Building block approach.

structural property to a single component [10,12,13]. The design flexibility combining the ease of tailoring high-strength and stiffness components with elevated functional integration including crack propagation resistance [14], better acoustic and damping properties, enhanced protection against collapse in a crash [15] and cost savings with its hybrid process [16], makes this an enabling technology [17].

The hybrid moulding process is regarded as a massive innovation combining the traditional method of aligning individual layers continuous fibre prepreg oriented in different directions to match the required stress profile as reinforcement followed by injecting the short fibre resin around the prepreg to obtain the required shape of the final part in a single mould. The obvious major benefits are the decreased cycle time and the ability to realise complex profiles and to contrive the reinforcements with a continuous fibre prepreg. This combination of the moldability of short fibre composite materials with the high strength of continuous fibre composites to a single component opens up a lot of new possibilities for thermoplastic composites. The only drawback for a hybrid overmolding process is its difficulty in anticipating the combined strength and bond quality of the component [18] which is the intent of the research.

The desired shape of the reinforcement for the composite laminates is obtained by using a punch and die setup to deform the continuous fibre prepreg (e.g., compression moulding) or composite fabrics to its required shape [19]. The stage in which the fabric or the laminate is deformed is known as the forming stage. The focus of recent academic and industrial researchers is to completely recognise the process parameters associated with composite materials during manufactures such as in-plane fabric deformations, fibre direction change, thickness variations and the tendency to develop internal stresses and strains during production. [20], [43–45].

Fig. 2 shows the overmolded component considered for this study. An accurate prediction model of a novel over-molded composite component has been done and presented, which combines short fibre thermoplastic composite moulded to the required

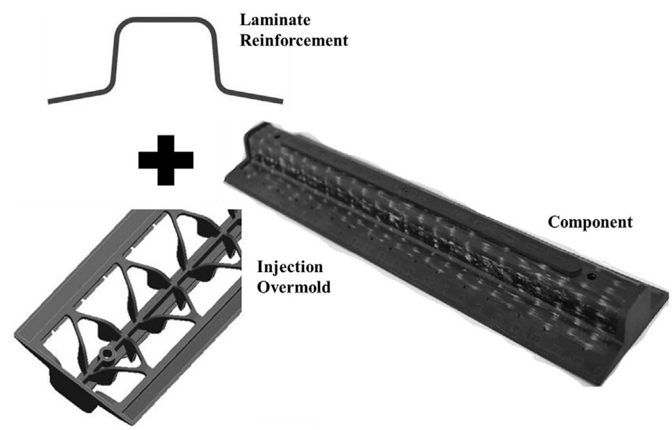

Fig. 2. The overmolded component.

geometry reinforced with continuous fibre reinforced thermoplastic laminate [21]. The hybrid moulding process employed for this research constitutes a continuous glass fiber reinforcement consolidated with a polymer layer as substrate which is thermoformed to the required geometry and is further over molded with short fibre reinforced polymer compound in a single step process; the substrate being TEPEX® Dynalite 104-RG600(2)/47% [22] (Bond-Laminates), a continuous fiber twill 2/2 E-glass impregnated with polypropylene and the over-mold is Xmod™ GD301FE [23] (Borealis), a 30% glass fiber polypropylene compound intended for injection moulding. An extensive characterisation study has been done with finite element material cards developed by matching FEA stress/strain curves to the experimental stress-strain curves for tensile compressive and shear properties of the materials. The further detailed study has been done on the substrate used by characterising the continuous fibre twill 2/2 E-glass fabric separately as a part of the process characterisation. (WVR 600 T supplied by Crystex composite materials) [24].