DIGITAL TWIN METHODOLOGY FOR COMPRESSION MOULDED THERMOPLASTIC COMPOSITE OPTIMISATION

D.J. Hughes[1*], S.Keir[1], C.Meggs[1]

[1] *Teesside University, TS1 3BA, Middlesbrough, UK*
*Corresponding author (d.j.hughes@tees.ac.uk)

Keywords: *digital twin; compression; thermoplastic; manufacture; simulation*

Introduction

There has been significant uptake of compression moulded continuous fibre reinforced thermoplastic composite (CFRTP) parts, particularly within emerging composite sectors in recent years. Further growth has been limited however by difficulties in material substitute product optimisation.

One of the fastest growing sectors for CFRTP's is in automotive structures, largely driven by regulations to reduce CO2 emissions [1]. Due to these regulations car manufacturers have been developing of new technologies for CO2 emission reduction with significant interest in weight reduction of automotive structures. Consequently, composites have begun to feature heavily within the structural and semi-structural components of automotive systems. There is particular interest in thermoplastic composites (TPC's) that offer fast production rates, low specific gravity and in many cases are recyclable [2]. The majority of TPC's utilised in the automotive industry are based on short or long fibres, however there is a focus on utilising the improved mechanical properties possible with continuous fibre [3]. In order to form structural composites using CFRTP suitable for material substitution in automotive production, parts must be optimised to reduce weight, cost and production times. In this work we assess the use of digital twin methodology to perform this optimisation.

Digital Twin Methodology

The digital twin methodology refers to a holistic approach to the description of a component, product or system. A "Digital Twin" is ultrarealistic in geometric detail, including manufacturing, and material detail [5]. There are still limitations in achieving these comprehensive simulations and fully validating them as accurate structural life predictions. Two of the key variables which needs to be included in any digital twin model is material and manufacturing data. This is particularly challenging in composite laminates given the inherent product flexibility and laminar nature of the materials. To accurately define these properties a digital representation of the materials and ply layup is required.

Digital manufacturing simulation software for composites, like Fibresim (Siemens PLM) used in this work, take a component-based approach to the fabrication of a laminate. Digital manufacture simulation allows for laminate optimisation to be defined and controlled in the simulation environment before being released to the production floor. These iterations can included stress analysis, manufacturability assessment and waste reduction. The computer aided manufacturing (CAM) outputs of digital manufacturing can also be used to control the layup process increasing the correlation of the digital twin to the manufactured component.

Materials and Manufacture

A commercial truck (HGV) flue cowl is used as a benchmarking problem (shown in figure 1a). The cowl is a XENOY alloy (semi-crystalline polyester (PBT) and polycarbonate (PC)) uni-directional (UD) glass pre-preg (59% fibre by volume). Consolidated ply thickness average is 0.21 mm.

Table 1: *Mechanical Properties XENOY alloy Glass UD tape.*

Tensile strength (0°) (MPa)	2020
Tensile modulus (0°) (GPa)	134
Density (g/cm³)	1.6

XENOY alloy is ideally suited to the automotive industry due to its heat resistance and impact resistance. XENOY also exhibits ideal flow characteristics for the manufacture of thermoplastic pre-preg tapes.

Tapes on the original part are laid at -15,15,-45,45,0,-15,15 with the three inner plies providing the majority of the structural support. Loading is predominantly along the flat fixing surfaces, the curved body is designed to protect against compressive impact loadings.

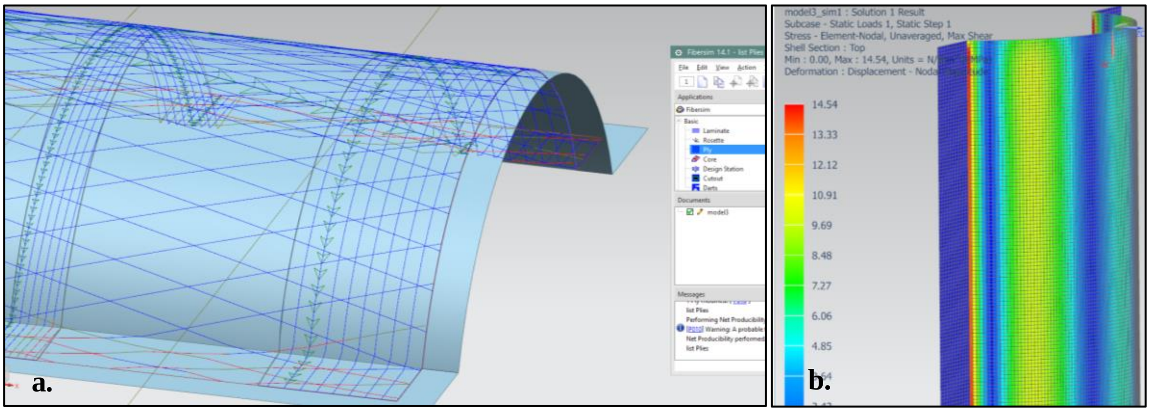

Figure 1: a. *Net producability assessment of the HGV cowl component generated in Fibresim. Full body surface plies and selective hoop reinforcements shown.* **b**. *Max shear laminate simulation output.*

Results and Discussion

A digital twin surface is generated within Siemens NX10 and a multi-physics simulation defined to represent the in-use conditions using the Nastran laminate solver. Thermal variation, static and dynamic fatigue loads are simulated (figure 1b). The original ply layup was designed in Fibresim and imported into the NX laminate modeller. This data includes fibre warping and wrinkling which more closely represents the actual part properties. Information on the matrix flow during hot-pressing can also be simulated and input to the digital twin. The laminate is then iteratively modified and optimised within the simulation environment with all design criteria considered including manufacturability. It is shown that material usage can be reduced using selective hoop reinforcements as shown in figure 1a. The hoop reinforcement plies function as bonded stiffeners to prevent shear buckling. Overlay regions are optimised and represented in the digital twin. This laminate modification lead to a 13% reduction in material use.

The digital twin methodology provides huge potential for reduction in testing, approval and optimisation of structures. The optimisation of CFRTP parts is shown to be supported by the use of the digital twin method. Design optimisation can be made in the light of complex loading criteria and life-cycle representations to assess comprehensively the impact of composite ply layup. Selective reinforcement is used to provide material use reduction without compromising mechanical performance. Integrated digital manufacturing is a valuable tool in developing digital twin models in order to reach a minimum weight or cost under multi-physics constraints.

Acknowledgements

The authors would like to thank Siemens PLM for provision of the Fibresim software.

References

[1] Ishikawa T, Amaoka K, Masubuchi Y, Yamamoto T, Yamanaka A, Arai M, Takahashi J. Overview of automotive structural composites technology developments in Japan, Composites Science and Technology, Volume 155, Pages 221-246, 2018,.

[2] Friedrich, K. & Almajid, A.A. Manufacturing Aspects of Advanced Polymer Composites for Automotive Applications. Applied Composite Materials 20: 107, 2013.

[3] Komornicki, J., Bax, L., Vasiliadis, H., & Ong, K. Polymer composites for automotive sustainability. Innovation Manager and SusChem Secretary, 2015.

[4] Kulkarni H, Beardmore P. Design methodology for automotive components using continuous fibre-reinforced composite materials. Composites, Volume 11, Issue 4, 1980.

[5] Tuegel E, Ingraffea A, Eason T, Spottswood S. Reengineering Aircraft Structural Life Prediction Using a Digital Twin. International Journal of Aerospace Engineering, 2011.