Bonding between thermostable polymers processed by FFF and PEEK/carbon fiber laminate

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1. Introduction

Additive manufacturing techniques such as Fused Filament Fabrication (FFF) has the potential to realize complex geometry parts without the need of expensive tooling. Production of more complex geometry composite structures with flexibility and customizability could be achieved through the combination of Automated Fiber Placement (AFP) with FFF. Thus, the challenge is to add functions or reinforcements (stiffeners, brackets, etc.) to composite parts manufactured by AFP, with additive manufacturing by FFF (Fig. 1).

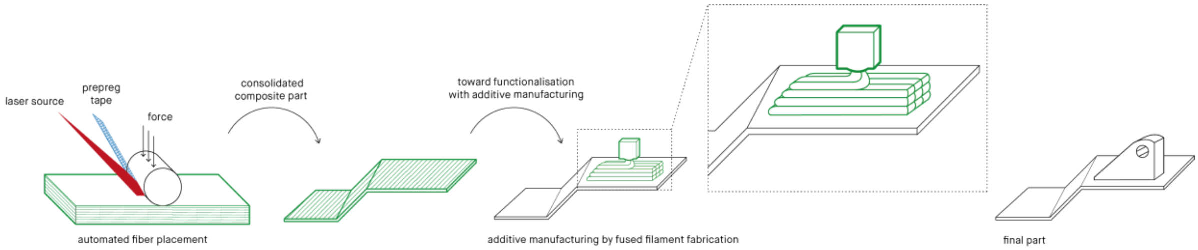

Fig. 1 - Illustration of the combined automated fiber placement and FFF processes.

The main issue concerns the bonding quality at the interfaces between printed layers, and between the composite part and the 3D printed function. The bonding quality among polymer filaments in the FFF process determines the integrity and final mechanical properties of the printed part. The quality and strength of the bonding depends on different parameters: chemical affinity between the added material and the substrate, and thermal history of the materials. Thermal energy available at the interface and the cooling rate of the materials are key parameters that will determine the final bonding strength [1] [2]. Composite laminates involved in this study are obtained using a poly ether ether ketone (PEEK) matrix reinforced with carbon fibers. Materials studied for the additive manufacturing process are thermostable polymers. These are very challenging to process with FFF because they require high processing temperatures. High thermal gradient cause partial and weak interlayer bonding that leads to apparition of defects in the printed parts and lower mechanical strength [3] [4]. This study focuses on the impact of process parameters on the cohesion and adhesion of 3d-printed thermostable polymers with a composite laminate.

2. Materials and experimental

2.1. Materials

Two materials are used for the FFF part: Victrex AM 200 provided by *Victrex* and Ultem 9085 provided by *Rescoll*. AM 200 is a fully aromatic PEEK based poly aryl ether ketone (PAEK) copolymer. Ultem 9085 is a PEI based material.

2.2. Experimental

A full description of the methodology used for the experimental study is available [5]. Influence of printing speed (varies from 16 to 26 mm/s), printing temperature (varies from 360 to 400°C) and printing chamber temperature (varies from 150 °C to 200°C) on the inter-layer adhesion and neck development inside AM 200 and Ultem parts is first investigated. The analyzed response is the porosity rate, which is a good indicator of the partial bonding between printed beads. Factors are analyzed in a full factorial design 3^3, as 27 total runs per material. The analysis of significance is performed by means of the analysis of variance (ANOVA) method. Parameter sets leading to the best bonding strength are finally identified with 3-point bending tests and tensile tests.

The second study focuses on the adhesion between Ultem and AM 200 with the composite laminate. A robotized 3d printing machine developed by *Coriolis Composites* is used to print the thermostable polymer part on the substrate. A air heater is added to the print head to bring sufficient thermal energy to ensure bonding. Assemblies are manufactured with different temperatures around the nozzle (from 300°C to 600°C). The interface between the printed part and the composite substrate is observed with an optical microscope. Fracture resistance at the is measured with an asymmetrical wedge test.

3. Conclusion

Results of the first study show that, for both materials, effects of printing chamber temperature and extrusion temperature on the porosity rate are significant. The printing speed has no significant effect on porosity. The average porosity rate inside AM 200 printed parts is less than 2% and around 17% inside the Ultem 9085 parts. Concerning the second study, images of the interface indicate that increasing the temperature around the nozzle increases the degree of contact between the printed part and the composite laminate (Fig. 2).

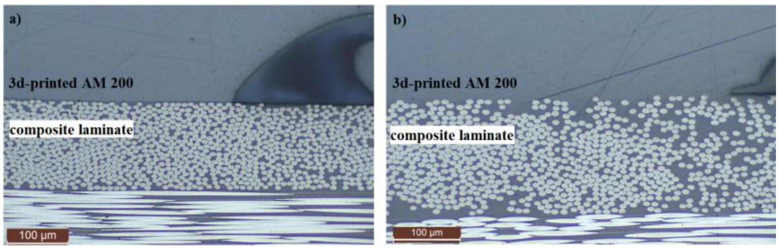

Fig. 2 – Microscopic observations of AM 200/composite assemblies printed with a temperature around the nozzle of a) 400°C, b) >400°C.

Acknowledgements

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