3D PRINTED CONTINUOUS CF/PA6 COMPOSITES: INTERFACIAL BONDING ANALYSIS

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Introduction

Continuous fibre reinforced polymer (FRP) composites are widely used in aerospace, marine and automotive industries owing to their high performance to weight ratio. They are traditionally manufactured by manual lay-up, resin transfer moulding, pultrusion or filament winding. However these methods imply long production time, elevated costs and frequently the need for moulds [1]. Therefore, there is a growing interest in the new processes based on additive manufacturing, as the fused deposition modelling (FDM) technology [2]. The aim of this study is to evaluate the interface quality of a 3D printed continuous carbon/PA6 composite. Although interface quality is a key-parameter for mechanical performance of 3D printed continuous fibre composites, there is little data available on these aspects [3-5]. In this work, interfacial properties were investigated at two different scales: at the filament/matrix scale and at the interlaminar one.

Materials and methods

All specimens used in this study were fabricated using a desktop 3D printer: the MarkTwo® developed by Markforged®. Samples were printed with a nylon filament and a carbon filament (CF) supplied by Markforged®. The interface quality between the reinforcement and the matrix was investigated by performing fragmentation tests on monofilament composites. For these tests, 3D printed carbon/nylon samples with only one filament of carbon aligned in the loading direction and centered in the specimens were manufactured [6]. The Mode I interlaminar behaviour of the 3D printed CF/nylon composites has been investigated by testing DCB specimens. Two different stacking sequences have been studied in order to analyse two interfaces: the 0°//0° interface and the +45°//-45° interface. DCB samples were made of 24 layers. Four layers with carbon filament were deposited in each specimen, i.e. two composite layers on each side of the delamination plane. The other twenty layers were made with pure nylon filament. The additive manufacturing process was interrupted in order to place the 45µm thick nonadhesive insert at the midplane of the coupon [6].

Results

Fragmentation tests were realised on monofilament composites and micro-CT observations were made after failure. Thanks to the measurement of fragment lengths, the interfacial shear strength value (*IFSS*) was determined (Table 1).
DCB tests were made using an incremental test method in order to determine the interlaminar fracture toughness values (G_{Ic}). For the 0°//0° interface, the G_{Ic} value was determined equal to 1228±114 J/m^2, and for the +45°//-45° interface, the G_{Ic} value was measured at 2150±525 J/m^2. Experimental results were then compared with numerical simulations made by finite element method (Figure 1).

Critical fragment length (mm)	**σ_f (l_c) (MPa)**	**IFSS (MPa)**
4.75 ± 0.25	485 ± 70	19.9 ± 5.2

Table 1 - Critical fragment length, strength value of the filament for critical length, and IFSS value for single filament carbon/PA6 samples.

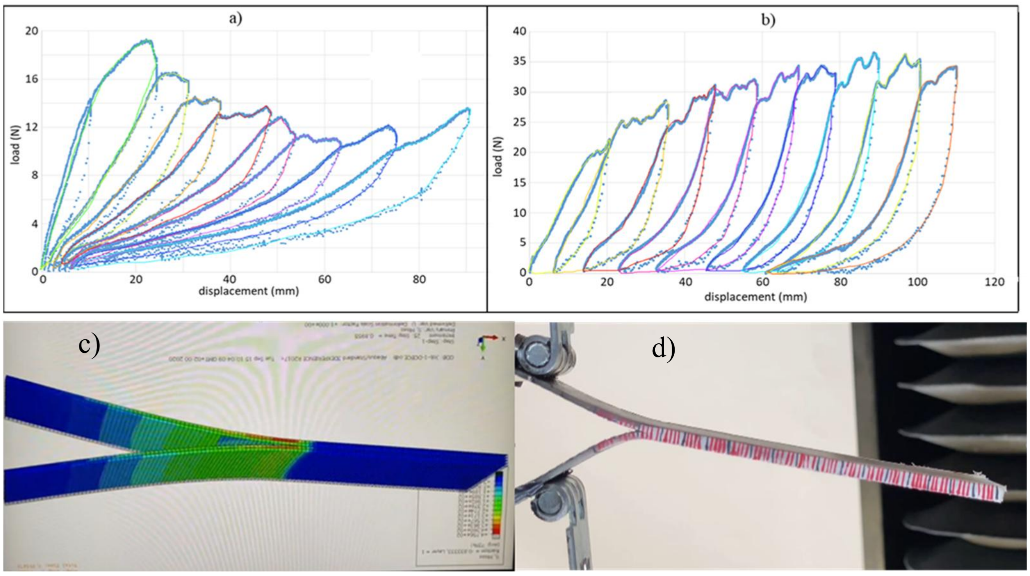

Fig. 1 - Load-displacement curves of DCB specimens: a) for 0°//0° interface, and b) for +45°//-45° interface. Numerical (c) and experimental (d) DCB tests.

Conclusions

Fragmentation tests show that the obtained IFSS value is quite similar to that of classical molded carbon/PA6 composites. The obtained results from DCB tests are also quite promising. These results give a database that can be useful for further industrial developments of 3D printed continuous composites, in particular to enrich finite element models for designing optimised structures.

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References

[1] Goh GD et al. Characterization of mechanical properties and fracture mode of additively manufactured carbon fiber and glass fiber reinforced thermoplastics. Mat. & Des. 2018;137:79-89.

[2] Wickramasinghe S. et al. FDM-Based 3D Printing of Polymer and Associated Composite: A Review on Mechanical Properties, Defects and Treatments, Polymers 2020 ; 12(7):1529.

[3] He Q, Wang H, Fu K, Ye L. 3D printed continuous CF/PA6 composites: Effect of microscopic voids on mechanical performance. Composites Science and Technology 2020 ; 191:108077.

[4] Barile C, Casavola C, Cazzato A. Acoustic emissions in 3D printed parts under mode I delamination test. Materials 2018 ; 11(9):1760.

[5] Garcia-Guzman L et al. Fracture resistance of 3D printed adhesively bonded DCB composite specimens using structured interfaces: Experimental and theoretical study. Composite Structures 2018 ; 188:173-184.

[6] F. Touchard, L. Chocinski-Arnault, T. Fournier, C. Magro, A. Lafitte, A. Caradec, Interfacial adhesion quality in 3D printed continuous CF/PA6 composites at filament/matrix and interlaminar scales. Composites Part B, 218 (2021) 108891.