MODE-I FRACTURE TOUGHNESS OF THIN CF/PA6 UD COMPOSITES IDENTIFIED IN A DCB TEST WITH STIFFENING AL BEAMS IN THE PRESENCE OF DEBONDING

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ABSTRACT

Compression molding of unidirectional (UD) carbon fiber-reinforced polyamide6 (CF/PA6) prepreg tapes is conducted to manufacture thin 4-ply UD laminates. Two cooling rates of 43 °C/min and 760 °C/min are obtained using different press machines. Isothermal cooling through the thickness of the laminates is ensured by the small laminate thickness and validated by thermal cycle recording at different locations. Different cooling rates result in different degrees of crystallinity [1], and their effects on mode-I fracture toughness are studied in the current work. To prevent excessive bending and yielding when testing thin specimens in DCB mode, stiffening beams should be bonded to the specimens [2], [3]. Hence, aluminum (Al) stiffening beams are bonded to both sides of the thin laminates. The surfaces of the CF/PA6 and Al adherends are ground and degreased before bonding. Various types of adhesives are tried, including epoxy-based and methacrylate adhesives. Combinations of different mechanical treatments of the surface, such as sandblasting (SB) or sandpaper grinding (SP) with different grit sizes, are tried to promote CF/PA6-Al adhesion. A double cantilever beam (DCB) experiment is performed on specimens following the ASTM D5528 standard. The results for all cases showed premature failure at CF/PA6-Al interfaces and test failure at small displacements (Fig. 1a) even before mid-plane crack initiation. In the load-displacement curves, several drops are visible, caused by the defects in the adhesive layer. In other words, defects in the adhesive layers could result in local drops of the force followed by lower specimen stiffness. The post-mortem surface of the CF/PA6 in Fig. 1b shows no adhesive on the composite surface. Instead, the adhesive is attached to the Al beam. This observation indicates adhesive failure during the DCB test due to the poor wettability of the composite substrate.

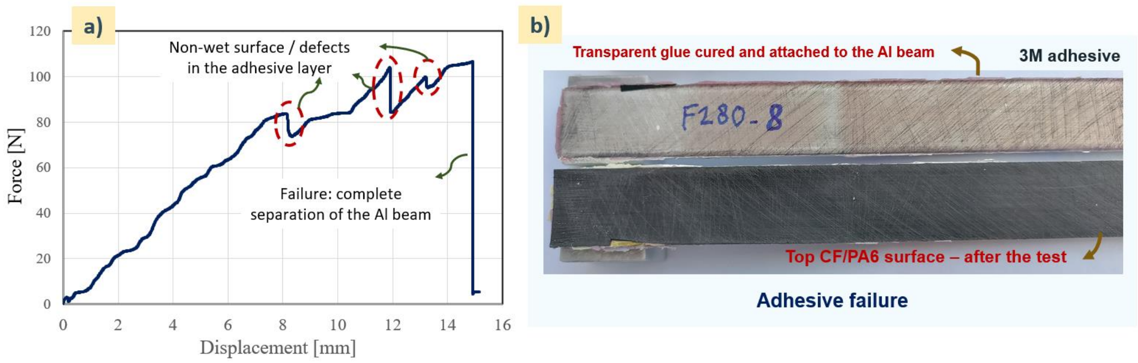

Figure 1: Result from DCB test on CF/PA6-Al specimens, a) force-displacement curve; b) post-mortem surfaces showing Al surface and the top (dry) surface of the composite.

The wettability of the CF/PA6 samples is examined using a sessile drop technique, and a water contact angle (WCA) of 73° with the polar component of surface energy (γ_p) equal to 7 mN/m is found. SP or SB treatment of the laminate surface led to higher surface hydrophobicity and lower γ_p. To improve wettability and surface energy, plasma jet activation with argon gas is implemented, which could drop the WCA to 10.8° ± 2° and increase the γ_p to 29.7 mN/m for the CF/PA6-SB. DCB specimens prepared after plasma treatment are tested, and results are shown in Fig. 2. As illustrated (Fig. 2a), premature failure at CF/PA6-Al interface is still occurring. Nevertheless, the test could continue up to higher displacements, and a stick-slip behavior is obtained (Fig. 2b). While the adhesive-covered surface of the composite confirms the improved wettability and a cohesive failure (Fig. 2c) of the adhesive, the failure prefers the lower fracture toughness of the adhesive (thermoset-based) compared to the much tougher thermoplastic composite interface. The authors propose a finite element approach to model the current behavior and measure the energy release rates (ERRs) of such specimens for different modes [4].

Further experiments with different plasma jet parameters are still ongoing. Alternatively, instead of Al, other materials with high stiffness, such as composites, could be tried that might promote adhesion and mitigate the challenges available in joining stiffening beams to CF/PA6 composites for the mode-I type of loading. In the case of perfect bonding between the beams, mode-I ERR of the specimens prepared at different processing conditions (i.e., cooling rates) can be measured and compared.

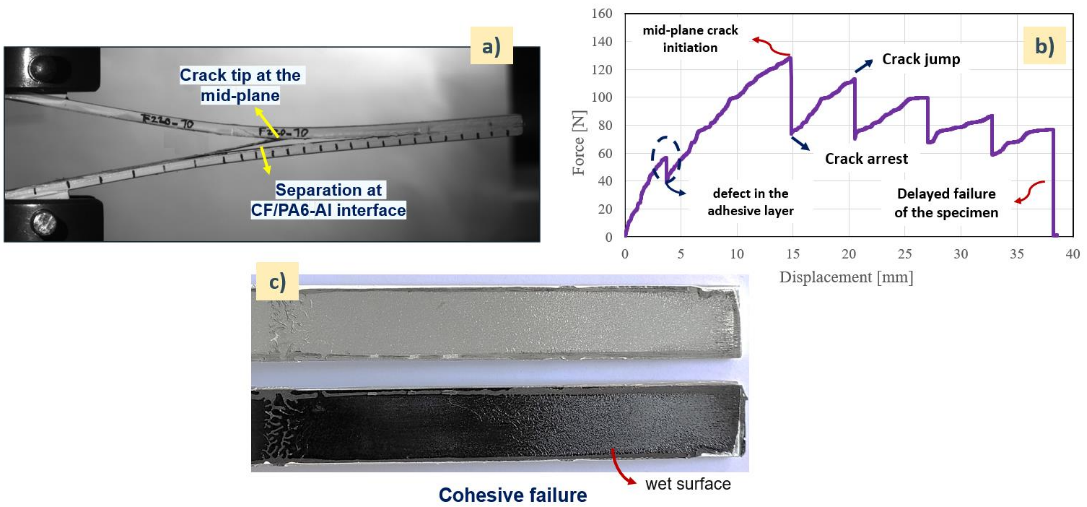

Figure 2: Result from DCB test after plasma treatment, a) premature failure of the adhesive; b) stick-slip behavior (crack jumps and arrests); c) top surface of the laminate showing cohesive failure.

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REFERENCES

[1] S. Simaafrookhteh, S. V. Lomov, and J. Ivens, “Cooling rate effects on consolidation quality of carbon fiber reinforced polyamide6 (CF/PA6) laminated composites,” in *European Conference on Composite Materials (ECCM20)*, Lausanne, Switzerland, vol. 4, pp. 283–290, 2022.

[2] J. R. Reeder, K. Demarco, and K. S. Whitley, “The use of doubler reinforcement in delamination toughness testing,” *Composites Part A: Applied Science and Manufacturing*, vol. 35, no. 11, pp. 1337–1344, 2004.

[3] P. Tsokanas, T. Loutas, G. Kotsinis, V. Kostopoulos, W. M. van den Brink, and F. Martin de la Escalera, “On the fracture toughness of metal-composite adhesive joints with bending-extension coupling and residual thermal stresses effect,” *Composites Part B: Engineering*, vol. 185, p. 107694, 2020.

[4] S. Simaafrookhteh, P. Tsokanas, S. V. Lomov, and J. Ivens, “Finite element modeling of interlaminar fracture of thin carbon fiber/polyamide6 laminates with stiffening beams,” in *EuroNorth SIMULIA Regional User Meeting*, Manchester, UK, 2022.