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Interlaminar Fractographic of Carbon Fiber/Epoxy Composites

K. Silva[1], G. Marinucci, and D. Andrade

[1] *kletson@usp.br, Correspondence Address*

1. Introduction

Composite materials utilizing Carbon Fiber (CF) have been extensive applications in engineering. The strength-to-weight ratio and excellent fatigue resistance make composite material attractive for various fields, like as nuclear industry. Carbon-fiber-reinforced polymers is being composed of the combination of at least two distinct materials (reinforcement and matrix), with a well-defined interface between them (1; 2). The good interface is important because with a great interfacial or interlaminar adhesion the load-transfer between the fibers and matrix is done (3). An good interfacial bonding ensures efficient load transfer from matrix to the fibers and internal crack propagation, which helps reduce stress concentrations and improve the ultimate performance of composites (4; 5). Then, to correct analysis is important to identify the interlaminar failures and identify the kinds fracture's mode (Figure 1) and to comprehensive and clear understanding of fracture modes of loading (Figure 2).

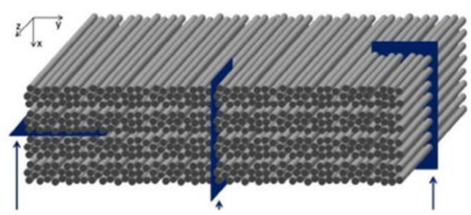

Figure 1: Illustration with basic fracture modes - adapted **(6)**

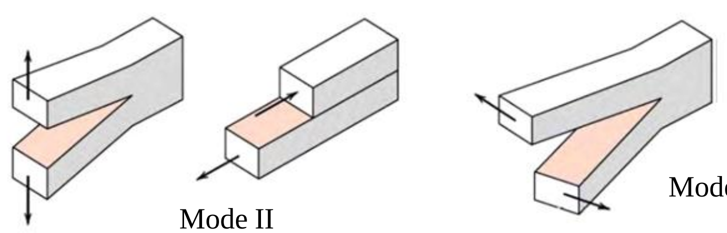

Figure 2: Illustration with basic modes of Loading - adapted (7)

The study of fractology for composite materials still has a vast field of growth, mainly due to the need for sophisticated equipment to obtain images. So, given the presented information, this extended summary aims to present the examples for analyzing the fiber-matrix interface through fractographic techniques, enabling researchers and engineers to analyze the feasibility of using fiber, regardless of wettability or contact angle, as the final result of the interface quality will be observed. It will be possible, therefore, to verify the main characteristics found in interlaminar fracture caused by poor adhesion. These characteristics form an intellectual basis for understanding catastrophic events that may occur in structural components used in the engineering field, especially in the nuclear sector.

2. Methodology

The low quality of the interface, impeding the transfer of load from the matrix to the reinforcement, can be observed morphologically, not exclusively, by the absence of specific characteristics in composite. In general, this low quality has various origins such as: poor wettability (3), incorrect formulation, and aging of the fibers. Furthermore, the low bond strength of fiber/matrix is often associated with brush-type failures (Figure 3) and other specific characteristics like small amount cusps and bare fibers (Figure 4) (8).

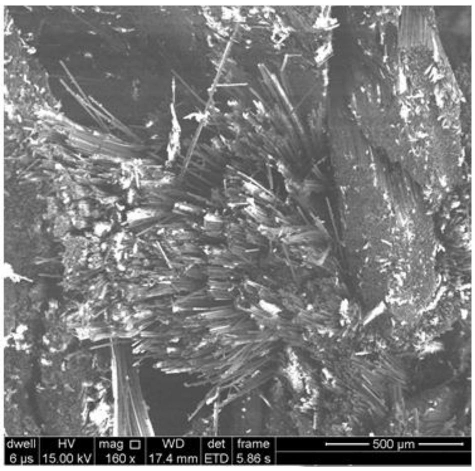

Figure 3: Illustration with brush-like failure

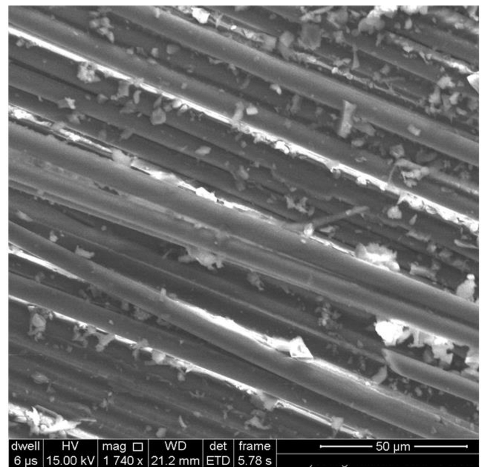

Figure 4: Illustration with few cusps

That is, as the interface improves, providing increased adhesion, a fracture is observed between the reinforcement and the interface, still maintaining a layer of matrix on the fiber. This summary presents the morphological forms of fractures characteristic of composites with poor fiber-matrix adhesion, resulting from low mechanical anchoring. For such analysis, fracture analysis was performed using scanning electron microscopy to examine failure delamination in the composite at 65% in Fiber-volume fraction manufactured with HTA 5131 6000 lote 71212 (9), following the fluxgram showed in Figure 5. Frequently, transverse analysis tests are conducted to observe the fracture resistance values in this direction. However, the preparation of these specimens is delicate and often presents procedural challenges like showed at Standard Test ASTM D3039 (10) for transversal testing. A classic example is the transverse tensile test, which may yield lower values than expected. Conducting both longitudinal and transverse tensile tests allows for a comprehensive assessment of the material's mechanical properties in different directions (11; 12).

After conducting mechanical tests had applied fractology techniques for result analysis. In this context, a significant lack of adhesion was observed in Figure 6, Figure 7. Subsequently, hydrostatic tests were performed to verify the structures in operation, and it was observed that the values of the composites fabricated with fibers with fewer adhesion characteristics experienced rupture at a lower limit than expected.

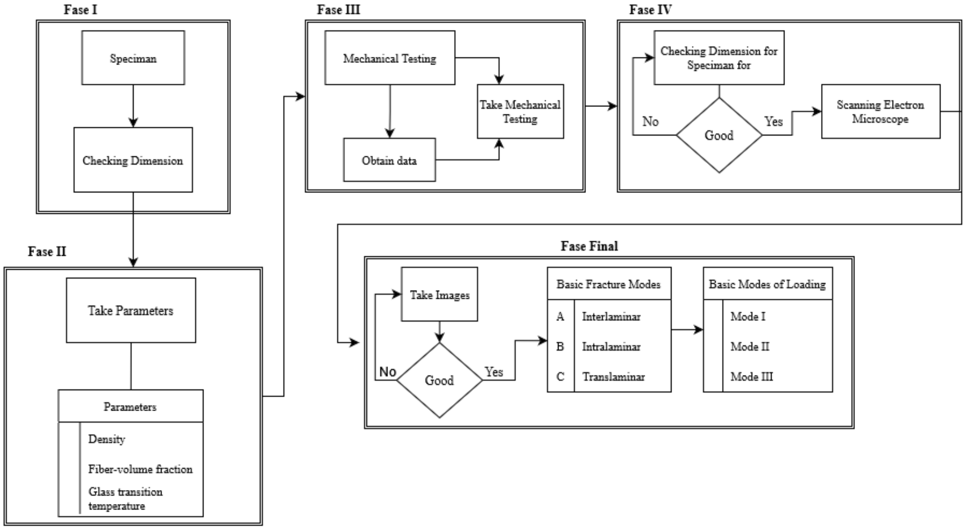

Figure 5: Fluxogram for fracrophafy analysis – adapted **(13)**

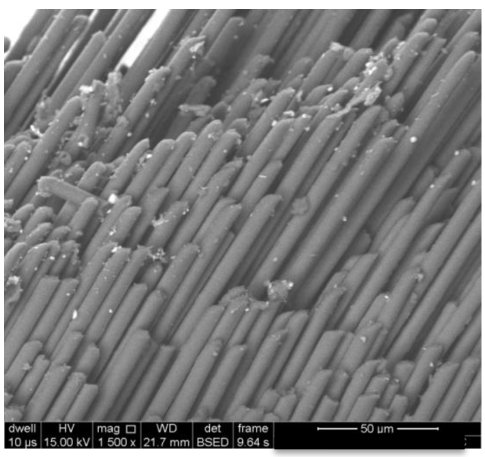

Figure 6: Failure with low adhesion

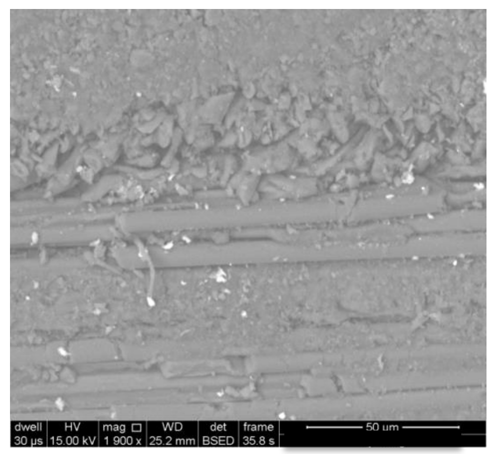

Figure 7: Failure with low adhesion

3. Results and Discussion

Therefore, by performing the fractological analysis of morphology, even in standardized specimens, a good prediction of the future structural behavior analysis is obtained. This reduces the need for specimen manufacturing and the use of infrastructure for the production of a similar structural component. In the structure analysis, in transverse tensile test, it would be possible to observe that the structure did not present adequate characteristics for the continuity of the final structure assembly, reducing the need for resources for component manufacturing.

4. Conclusions

This summary demonstrates, therefore, that validating the results with morphological analyses of the fracture is crucial to corroborate the findings. It also highlights the possibility of verifying, through fractology, the quality of adhesion, even in longitudinal tests, expanding the range of possibilities for result validation. As a subsequent task, it is suggested to analyze the quality of fiber sizing over time, including at least four mechanical tests and observing the morphological correlation among them. Conducting these analyses will enable understanding of what occurs over long periods of storage and facilitate proper use in the segment related to nuclear energy.

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References

1. **Jr. W. D., Callister.** *"Ciência e engenharia de materiais: uma introdução".* Rio de Janeiro, Brasil : LTC, 2008.

2. **Marinucci, G.** *"Materiais Compósitos Poliméricos: fundamentos e tecnologia".* São Paulo, Brasil : Artliber, 2011.

3. **E. S., Greenhalgh.** *"Woodhead Publishing Series in Composites Science and Engineering, Failure Analysis and Fractography of Polymer Composites".* Cambridge UK : Wood head Publishing, 2009.

4. **Z. Zhongb, K. Teng, N. Li, X. Li, Z. Xu, N. Li, X. Li, Z. Xu, J. Niu, H. Fu, L. Zhao, Y. Liu.** "Mechanical, thermal and interfacial performances of carbon fiber reinforced composites flavored by carbon nanotube in matrix/interface". s.l. : Composite Structures. vol. 159, pp. 761-772, (2017).

5. **G. Wu, L. Ma, L. Liu, Y. Wang, Y. Huang,.** "Interfacial improvement of carbon fiber reinforced methylphenylsilicone resin composites with sizing agent containing functionalized carbon nanotubes". 2015. Vol. 29.

6. **G. Frossard, G. et al. J. Ply.** "Thickness dependence of the intralaminar fracture in thin-ply carbon-epoxy laminates". s.l. : Composites Part A: Applied Science and Manufacturing, 2018. Vols. 109, pp. 95-104.

7. **Campos, K. A.** "Fractografia Quantitativa: Análise do Comportamento Fractal de Fratura em Compósitos Carbono/Epóxi, por Processamento Digital de Imagens". *Dissertação (Mestrado).* Curso de Engenharia Mecânica, Universidade Estadual Paulista, Guaratinguetá,Brasil : s.n., 2010.

8. **C.Y. Barlow, A. H. Windle,.** "Measurement of fracture energy in aligned composites". s.l. : Composites Science and Technology, 1988. Vols. 33, issue 2, pp. 135-150.

9. **Ltd, Havel Composites CZ Company.** [Online] [Citado em: 15 de 02 de 2024.] https://www.havel-composites.com/en/home/download.

10. **D3039/3039M, ASTM.** AMERICAN SOCIETY FOR TESTING AND MATERIALS. Standard test method for tensile properties of polymer matrix composite materials. 1995.

11. **Adams F. D., King T. R., Blackketter D. M.** *"Evaluation of the transverse flexure test method for composite materials".* s.l. : Composites Science and Technology, 1990. Vols. 39, pp. 341-353.

12. **W. Gul,Y. E. Xia, P. Gérard, S. K. Ha.** "Characterization of Polymeric Composites for Hydrogen Tank". s.l. : Polymers, 2023. Vol. 15.

13. **Kar, R. J.** *"Composite Failure Analysis Handbook". Federal Aviation Administration Technical Center,.* New Jersey : WL-TR-91-4032 DOT/FAA/CT-91/23, 1992. Vols. 1, part 1.