Effect of Durability on Multiscale properties of interphase and delamination using AFM and novel Facture toughness characterization techniques on Carbon fiber samples under accelerated aging conditions for up to 7 years.

Effects of the CNT network size and interphase on Mode 1 fracture of buckypaper nanocomposites

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Objective

To garner durability information of polymer carbon fiber materials exposed to accelerated aging for up to 7 years at the nanoscale using atomic force microscopy (AFM) (Fig.1) and the macroscale fracture properties using novel fracture toughness characterization technique.

Introduction

Composites are known for their outstanding wear resistance, excellent mechanical performance to weight ratio, and high thermal resistance. Due to the heterogeneity of its internal structure, recent attention has been on its internal deformation and failure modes. Delamination is a primary failure mode in composite materials and causes crack initiation under mode I,II, mixed mode I/II fracture. Research has previously been done on composite materials using a different mix mode bending (MMB) fixture, but they do not include long term effects of durability on mix mode fracture properties. The accelerated aging condition consist of controlled 60°C and 90% relative humidity up to 7 years to mimic the natural aging process for up to 60 years. Previously, the durability effects up to 2 years were investigated and published. By using the MMB fixture improved by my mentor's research team, there will be some elimination of influence of the factors that might skew results. Some of the factors effecting MMB are nonlinearity in loading and friction caused by fixture on specimen, among others. AFM based Peak Force Quantitative Nanomechanical Mapping (PFQNM) was used for characterizing the durability of carbon fiber composites in the nanoscale.

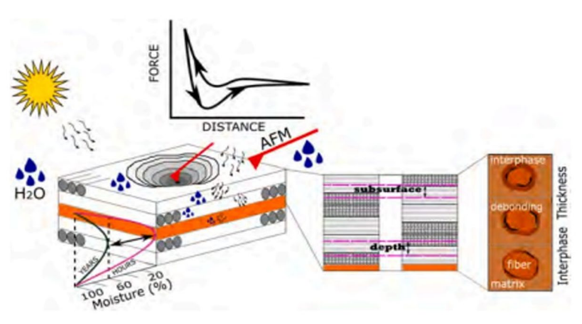


Fig.1: Fig 1. Schematic depicting the carbon fiber sample interphase under aging conditions being studied through AFM

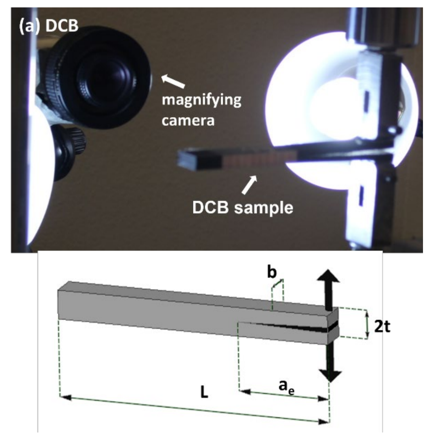


Fig. 2: Experimental set up for mode I (DCB) testing

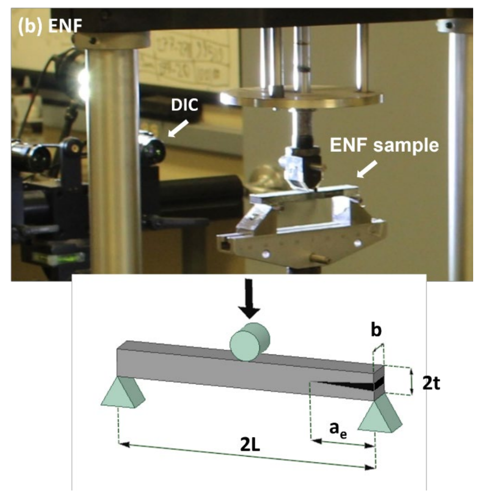


Fig.3: Experimental set up for mode II set up

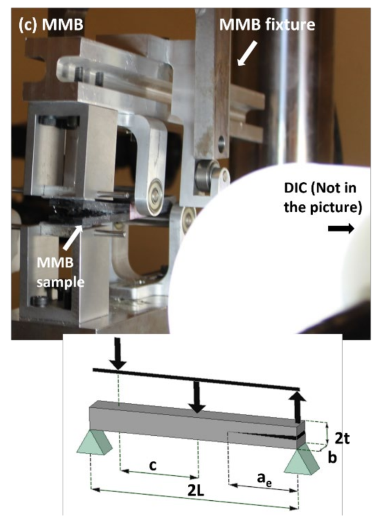


Fig.4: Experimental setup for mode I/II (MMB) testing

Impact

This research will improve the knowledge of the scientific community about the long-term effects of durability and delamination for carbon fiber composites. We expect this knowledge to assist both engineers and scientists in developing safer designs when using this material. This will ensure higher safety design guidelines when developing devices and structure using carbon fiber.

Literature Surveys

- Environmental factors affect fracture toughness, bond strength and cohesive law [1]
- High temperature increase the length of fracture process zone under mode II and little to no change of cohesive law under mode I [1]
- Crack initiation and propagation is closely related to strain. High strain concentration have a predictive effect on crack initiation [2]
- As fiber orientation increases, the initial slope and fracture strength gradually decrease under either tension or compression [3]
- Hygrothermally aged specimens showed poorer fiber-matrix interfacial strength [4]

Preliminary Results

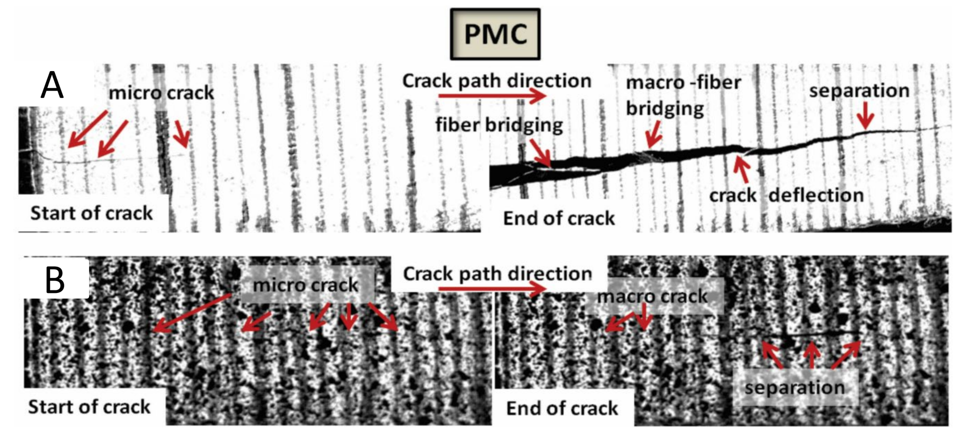
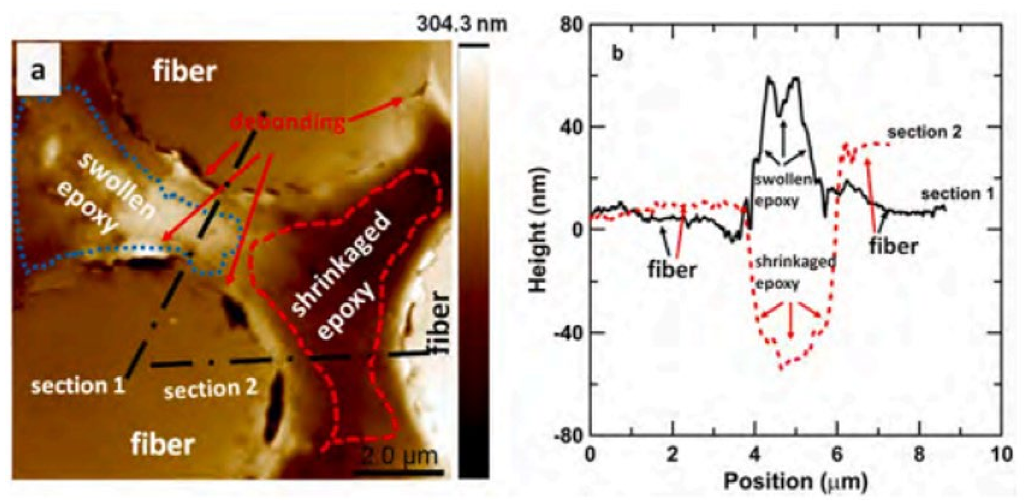


Fig. 5: Polymer Matrix composite (A) under mode I stress (B) under mode II

Figure 5 shows the results from mode I and mode II testing on the carbon fiber composite. Figure 5A shows how a microcrack on the carbon fiber composite undergoing mode I fracture results in multi crack modes. Under mode II, the microcrack of the carbon fiber composite sample undergoes crack growth but does not display the same multi crack modes as in mode I. Under mode II, the material behaves more brittle.

Results



- Observation of section one shows swollen epoxy; section two shows crosslinking causing shrinkage in epoxy
- The difference in the sections cause a complex 3D stress state resulting in nanocracks.

Fig 6. complex fiber and epoxy between fiber (a) irregularities in the morphology displayed (b) shows height vs position of section 1 and 2

Sources

[1] S. Abdel-Monsef, J. Renart, L. Carreras, P. Maimí, A. Turon. 2022. "Environmental effects on the cohesive laws of the composite bonded joints" . *Composites Part A: Applied Science and Manufacturing.* Volume 155. ISSN 1359-835X. https://doi.org/10.1016/j.compositesa.2021.106798
[2] J. Qiu, Y. Li, F. Xu, X. Hu, Y. Xiao. 2022. "Strain induced crack initiation and the subsequent crack propagation of fiber-reinforced resin composites." *Composites Part A: Applied Science and Manufacturing.* Volume 155. ISSN 1359-835X. https://doi.org/10.1016/j.compositesa.2022.106836
[3] J. Lv, Y. Xiao, Y. Zhou, Y. Xie. 2020. "Characterization and modeling of the creep behavior of fiber composites with tension and compression asymmetry". *International Journal of Mechanical Sciences.* Volume 170. ISSN 0020-7403. https://doi.org/10.1016/j.ijmecsci.2019.105340.
[4] D. Mamalis, C. Floreani, C. M. Ó Brádaigh. 2021. "Influence of hygrothermal ageing on the mechanical properties of unidirectional carbon fibre reinforced powder epoxy composites". *Composites Part B: Engineering.* Volume 225. ISSN 1359-8368. https://doi.org/10.1016/j.compositesb.2021.109281

Introduction

As incredible as composite materials are, delamination still poses a great threat on the longevity of the material. One way to reinforce composites against delamination is by adding nanoparticles to its matrix. Buckypaper(BP) is a lightweight material composed of entangled carbon nanotube (CNT) fibers with a porous mesh structure. It can be used in composite reinforcement. To examine the effects of BP nano reinforcement of a composite on its fracture properties, two type of buckypaper reinforcements were examined.

One mode of buckypaper reinforcement consisted of integrating dry BP into the midlayer of the composite . The second mode of BP reinforcement consisted of pre-infused non-functionalized multi-wall carbon nanotube BP integrated into the midlayer of the composite. The BP nanocomposite was subjected to mode I facture and its interphase and fracture properties were examined.

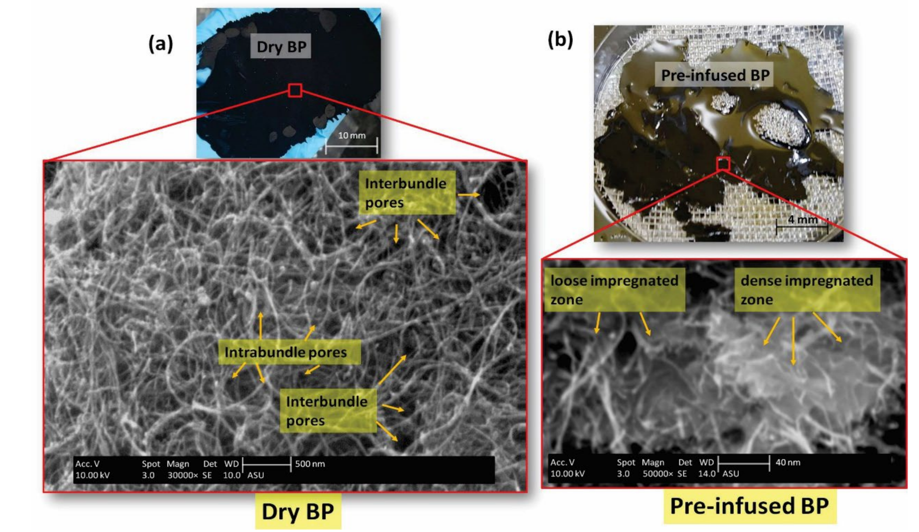


Fig . 1 Buckypaper and SEM images of the microstructure (a) interbundle and intrabundle pores in the dry buckypaper (b) CNT network in the impregnated buckypaper

- Figure 1A shows a dry buckypaper with clear homogenous structures.
- Figure 1B shows two regions with different absorption of the epoxy. There are heterogenous structures. The left region shows more epoxy absorption than the right region.

Results

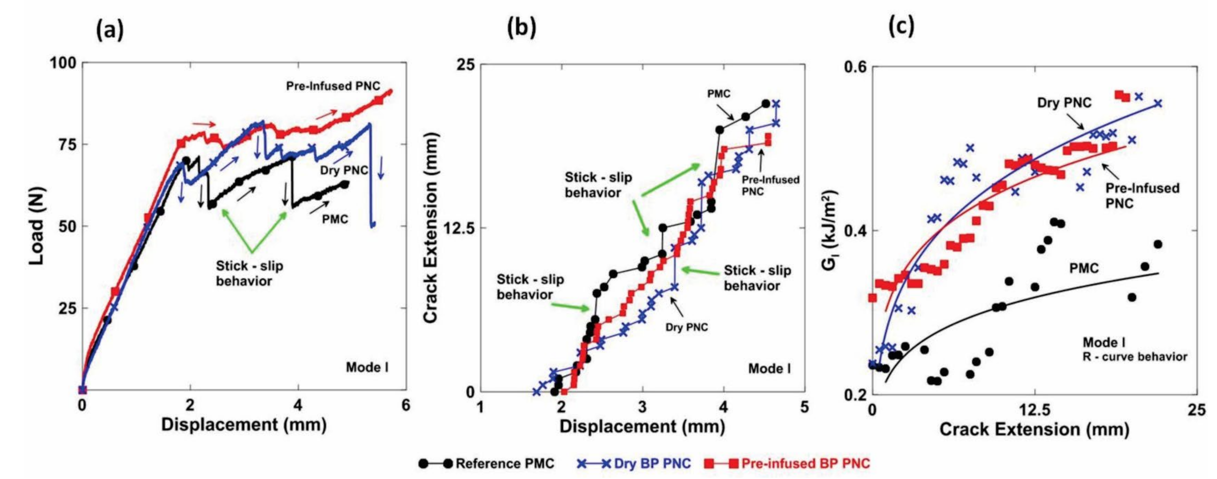


Fig. 2 shows results from mode 1 fracture test (a) load vs displacement, (b) crack extension vs displacement, (c) energy vs crack extension

- Figure 2a shows the blue (dry buckypaper sample) and black (reference composite) lines having a load drop after a certain displacement. The red (preinfused buckypaper) can withstand a higher load before failure/ load drop than both the blue and black.
- Figure 2b shows the velocity of crack elongation of the different samples. The black had a higher crack speed than the pre-infused buckypaper. This is apparent from the steeper slope of the black line.
- Figure 2c shows the energy needed for crack extension. Both the dry and preinfused buckypaper need a significantly higher amount of energy for crack extension than the reference sample

Accomplishments

Yekani Fard, M., Raman, R., Orozco, Y., and Tata, A. "Effects of the CNT network size and interphase on mode I fracture of buckypaper nanocomposites," ASME 2022 International Mechanical Engineering Congress and Exposition, October 30 – November 03, 2022, Columbus, Ohio, U.S.A.

FURI

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