Assessment of Mode I/II Fracture Technique (NASA) and Novel Fracture Technique at ASU

Effects of CNT Network Size and Interphase on Mode I Fracture of Buckypaper Nanocomposites

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Introduction

The space, energy, and defense industries design machinery systems made up of nanocomposites and polymer matrix composites (PMCs) due to their high strength to weight ratio. PMC and nanocomposite performance weaknesses are largely caused by delamination. **Delamination** is a mode failure originating from a combination of normal and shear stresses, or **Mode I** and **Mode II**, respectively. The studied **mixed-mode bending (MMB)** apparatus is used to measure any Mode I to Mode II **strain energy release rate** (SERR) **ratio** from 0 to 5. In 2021, a team at Arizona State University (ASU) researchers under Dr. Yekani Fard's guidance attempted to improve the MMB fixture design to characterize combined fracture more precisely. This **improved mixed-mode bending (IMMB)** apparatus was built so that future industrial and federal composites may be more innovative and damage tolerant under high impacts.

Research Objective/Impacts

The proposed study will determine the most efficient and effective manner of characterizing combined fracture between the original MMB fixture and the modified MMB fixture developed at ASU via **finite element analysis**.

- Addresses ASU's Fulton Schools of Engineering research theme of security: it identifies ideal techniques to form resilient composite materials to benefit national defense.
- The results of this research will assist the scientific community in better understanding mode fracture toughness and will help develop more effective design guidelines for federal infrastructure.

Brief Outline of Methods

1- Develop SOLIDWORKS models for the original MMB fixture and for ASU's novel fracture technique
2- Develop a finite element package for both fixtures and run the simulation with a load range up to the capacity of the weakest components (1000 N)
3- Calculate the energy – from the area under the curve of force deflection before building and experimentally testing

Literature Survey

In 1990, Reeder and Crew attempted to characterize mixed-mode fracture toughness in PMCs, introducing an MMB fixture to identify combined Mode I and Mode II fractures which has been used in different applications, from reducing nonlinear effects to testing delamination toughness [2, 3]. However, there are some factors affecting the accuracy of fracture toughness measured by the fixture including the degree of rigidity, preloading effects, geometric nonlinearities, and second order effects [1-3, 4]. ASU's new design proposes to enhance the MMB apparatus' stiffness by 87% [1].

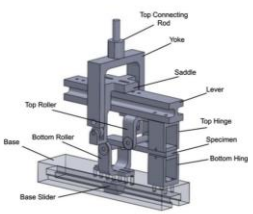


Figure 1: MMB fixture.

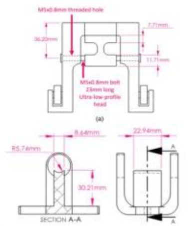


Figure 2: IMMB apparatus component redesigns.

Preliminary Results

During the fall term, the researcher has developed both fixture designs using SolidWorks, introduced them to the finite element structure analysis software, ANSYS, and has performed a literature review for the future project development of characterizing combined Modes I, II, and III fracture. The next steps will involve using ANSYS to evaluate the effectiveness of both fixtures.

References

[1] Fard, M., & Bonney, C. "Improved Mixed-Mode Bending Test Apparatus through Analytical Modeling and Finite-Element Optimization for Improved Characterization." Journal of Aerospace Engineering. (2022)
[2] Johnson, W., Masters, J., Obrien, T., Reeder, J., & Crews, J. "Redesign of the Mixed-Mode Bending Delamination Test to Reduce Nonlinear Effects." Journal of Composites Technology and Research. (1992)
[3] Reeder, J., & Crews, J. "Mixed-Mode Bending Method for Delamination Testing." AIAA Journal, 28. (1990)
[4] Tracy, G. D., Feraboli, P., & Kedward, K. T. (2003). A new mixed mode test for carbon/epoxy composite systems. Composites Part A: Applied Science and Manufacturing. (2003).

Introduction/Impacts

One of the major obstacles preventing the complete utilization of composite materials is catastrophic failure due to delamination, which is not visible until it causes a major failure. Therefore, it is crucial that the interlaminar fracture toughness of such materials is improved. The objective of the following study is to further investigate the impact of CNT network size and interphase on the Mode I fracture of BP nanocomposites.

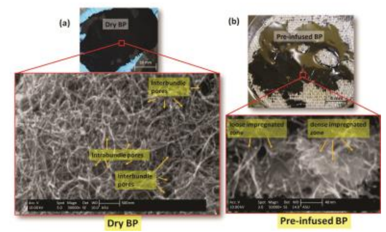
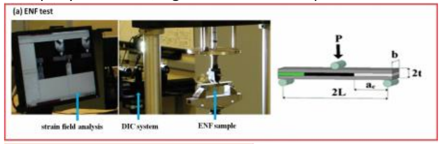


Figure 3: BP under electron microscope (a) dry, (b) pre-infused.

- Note that (a) overall, homogeneous at 5x5 micron scale; interbundle pores = 60-100nm, intrabundle pores = 20-35nm, passage openings for filler (thermoset epoxy); (b) larger pore size = more epoxy absorbed, rigid cluster of nanoparticles



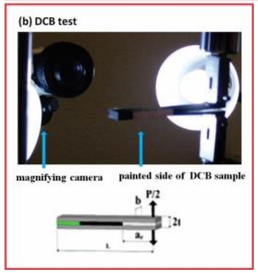


Figure 4: Mode I tests- (a) experimental setup for end notch flexure (ENF) test for in-plane shear with digital image correlation (DIC)– 3 point bending setup, (b) double cantilever beam (DCB) test; both with nanoparticle membrane in front of pre-crack

Brief Background

- In PMCs and polymer matrix nanocomposites (PNCs), the **interphase** is the region around the fiber monofilament, dispersed **carbon nanotubes** (CNTs), and CNT network.
- **Buckypaper** (BP) is comprised of entangled CNT networks with a porous mesh structure in which CNTs are randomly distributed.
- Macroscopically assembling CNTs into a thin film BP and infiltrating it with a polymer matrix creates a strong CNT membrane.
- Interlaminar fracture in composites initiates at the matrix, but other degradation mechanisms influence its propagation.

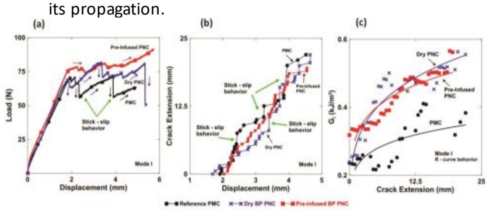
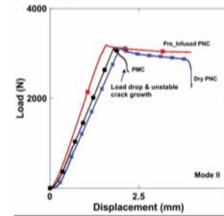


Figure 5: (a) Load v. Displacement, (b) Crack Extension v. Displacement, (c) Crack Energy v. Crack Extension

- Note (a) **load drops** (**crack jumps**) in reference and dry BP curves; (b) higher slopes of same curves (**crack speed**); (c) BP in front of crack increases **crack energy** substantially



- Note load drops (crack jumps) in reference and dry BP curves with unstable crack growth

Figure 6: Load v. Displacement under Mode II fracture for each composite

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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