Evaluating Interfacial Performance of Carbon-Epoxy Composites by Fiber Bundle Tests: The Impact of Nanofiller Dimension and Surface Chemistry

Hatice S. Sas[1], Melek Ozbilen[2], Volkan Eskizeybek[3]

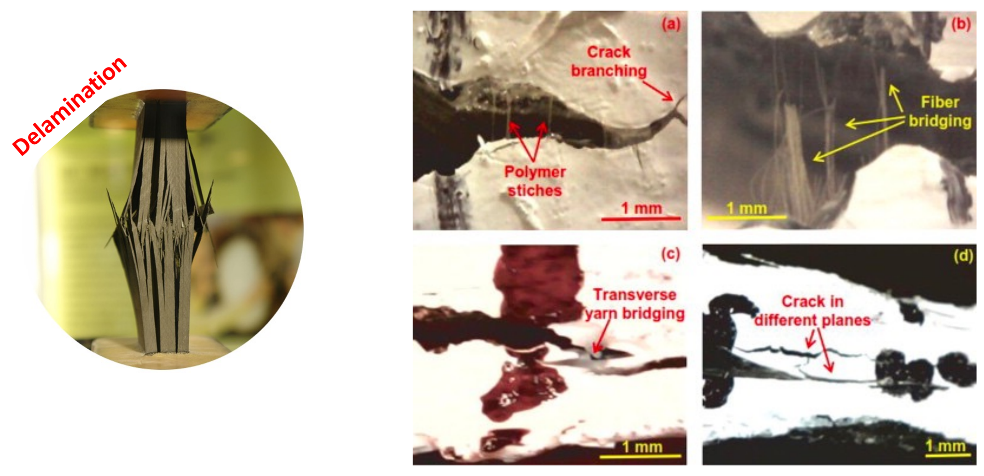
[1]Integrated Manufacturing Technologies Research and Application Center, Sabanci University, Tuzla, Istanbul, 34956, Turkey
[2]Faculty of Engineering and Natural Sciences, Department of Manufacturing Engineering, Sabanci University, Tuzla, Istanbul, 34956, Turkey
[3]Department of Materials Science and Engineering, Canakkale Onsekiz Mart University, Canakkale, 17020, Turkey
Email: haticesas@sabanciuniv.edu

ICCM 23 International Conference on Composite Materials Belfast 2021, 1 - 6 August 2021

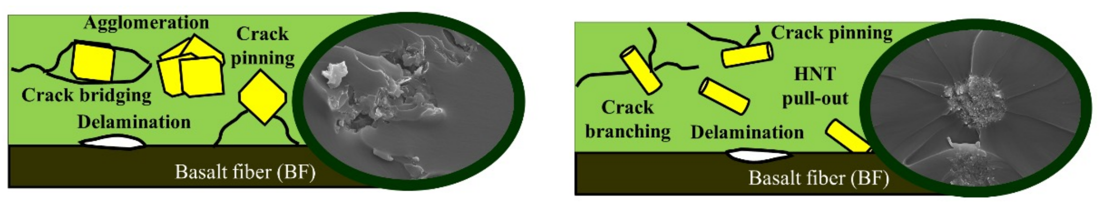
Introduction

The fiber-matrix interface is a critical region that directly influences the mechanical performance and overall properties of these materials. Weak interfacial bonding can lead to several issues, including:

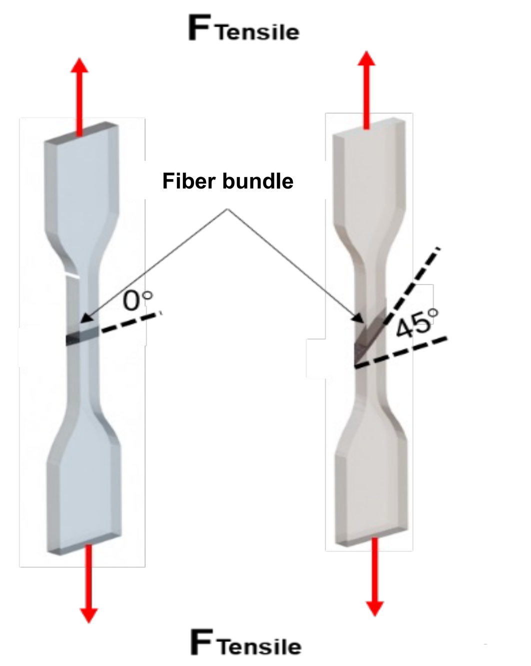
- Reduced mechanical properties
- Delamination and crack propagation
- Restricted applications
- Impaired durability



The mechanical performance of FRPs can be enhanced by incorporating nano-sized fillers into the polymer matrix. Nanoparticle type and morphology affect the polymer matrix's fracture toughness. Fracture toughness-enhancing mechanisms such as crack pinning, deflection, peeling, and plastic deformation are closely related to nanoparticle morphology [1].



The fiber bundle test (FBT) offers several advantages for evaluating the interfacial performance of carbon-epoxy composites modified with nanofillers.



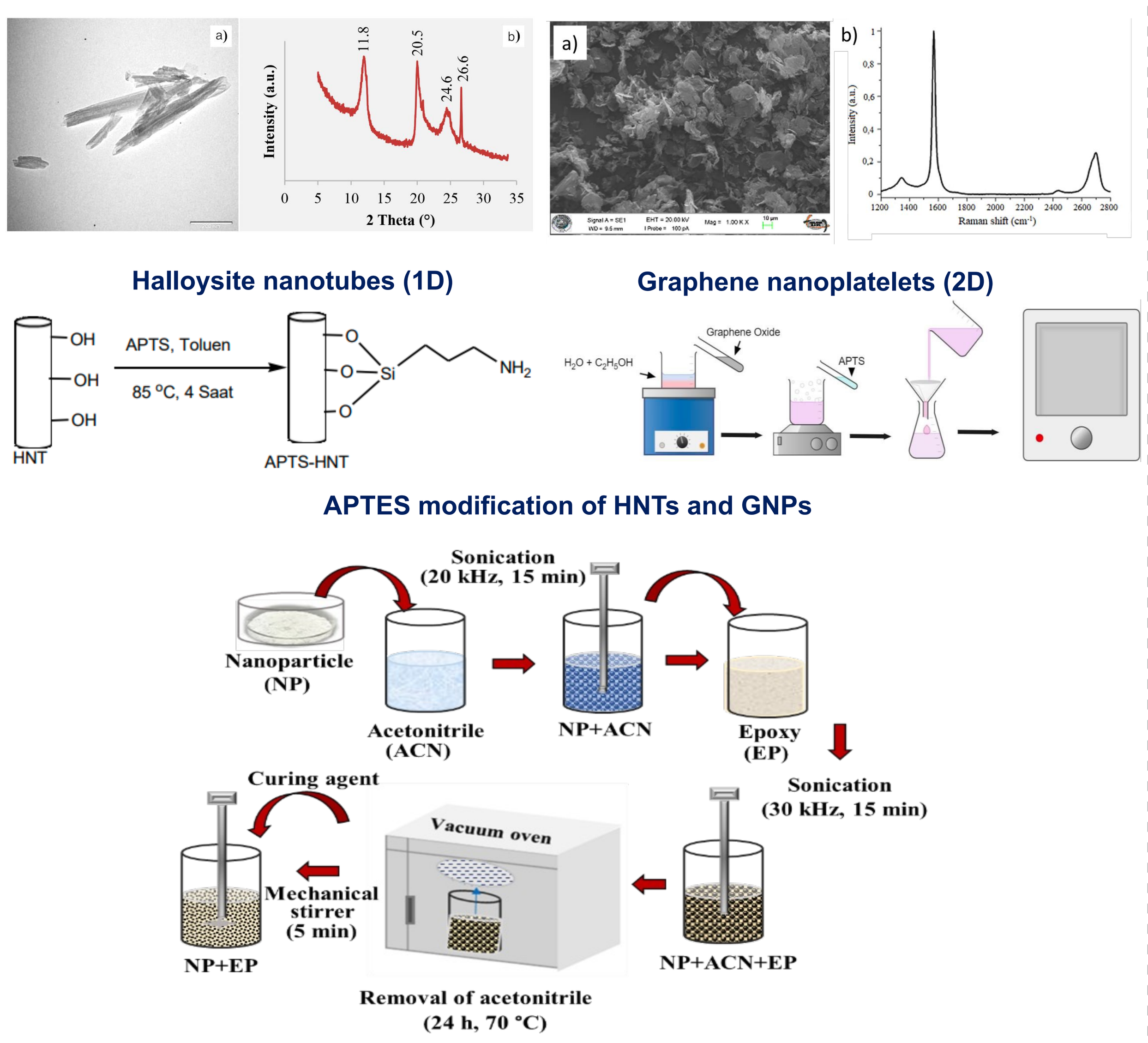
Advantages:

- Representative assessment
- Simplicity and efficiency
- Facilitates parameter study
- Micro-scale prediction
- Compatibility with real composites
- Early-stage evaluation
- Complementary to other tests

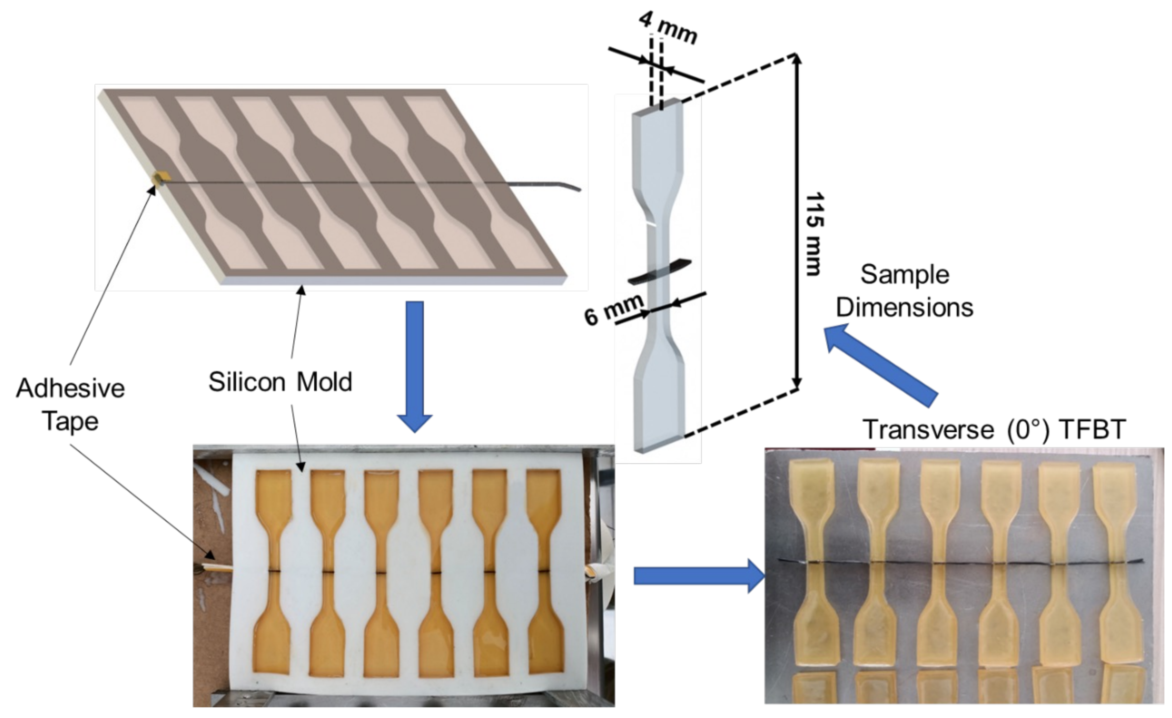
Motivation

- Explore using nanofillers with different morphologies, halloysite nanotubes (1D) and graphene nanoplatelets (2D), and chemically modified surfaces to strengthen the fiber/matrix interphase.
- By incorporating these nanofillers into the polymer matrix, the research aims to investigate their impact on interfacial bonding and evaluate how they contribute to enhanced mechanical properties using FBT.

Sample Preparation and Testing



Introducing nanoparticles into the epoxy

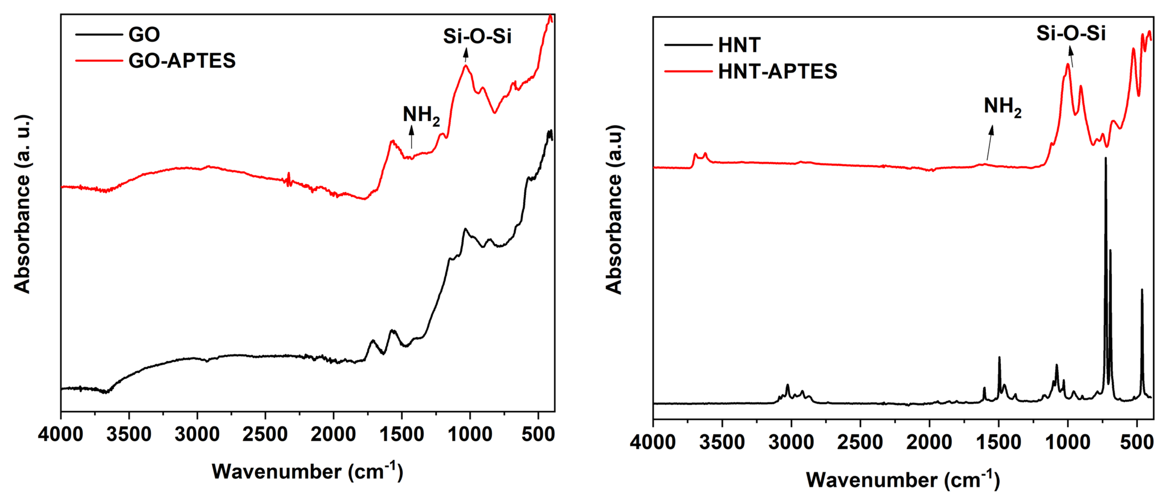


Tensile fiber bundle test sample preparation

The dimensions of FBT specimens were calculated according to the Type IV specimen example specified in ASTM D638 standard. Carbon fiber bundles were placed in the central channel of the mold. Then, the epoxy resin was poured into the mold cavities and left to cure at room conditions for 24 hours. Shimadzu AGS-X tensile testing machine was used for the specimens' meso mechanical performance tests. The applied loads were measured by a load cell with capacity of 10 kN.

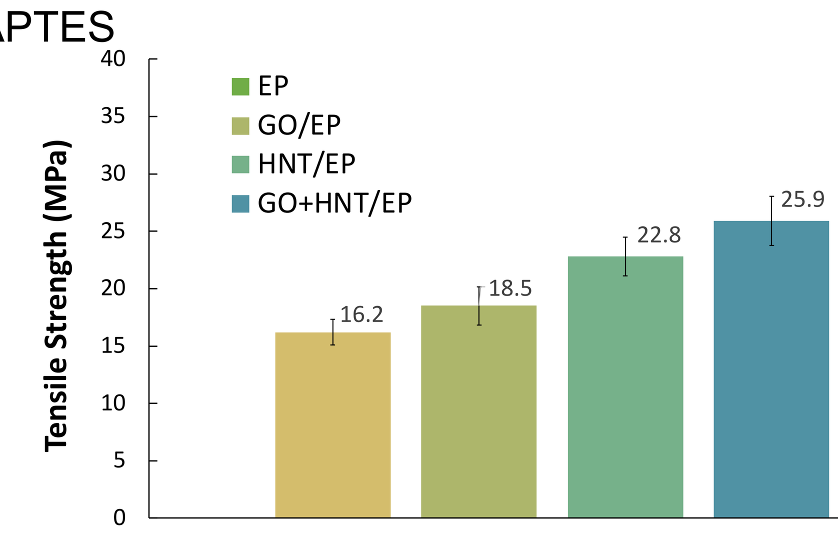
Results and Discussions

FTIR analysis reveals the existence of characteristic peaks of APTES on the GNP and HNT surfaces, indicating the high efficiency of the chemical surface modification.

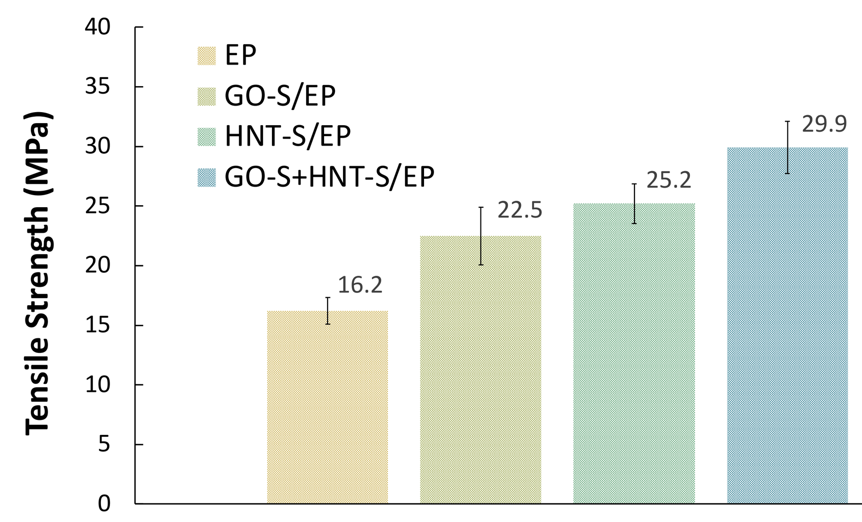


Transverse fiber bundle tensile strength

Fiber-matrix interfacial strength between graphene oxide and halloysite nanotube added epoxy matrix and carbon fiber bundle: (top) before surface treatment of nanoparticles, (bottom) when nanoparticle surfaces are chemically modified with APTES

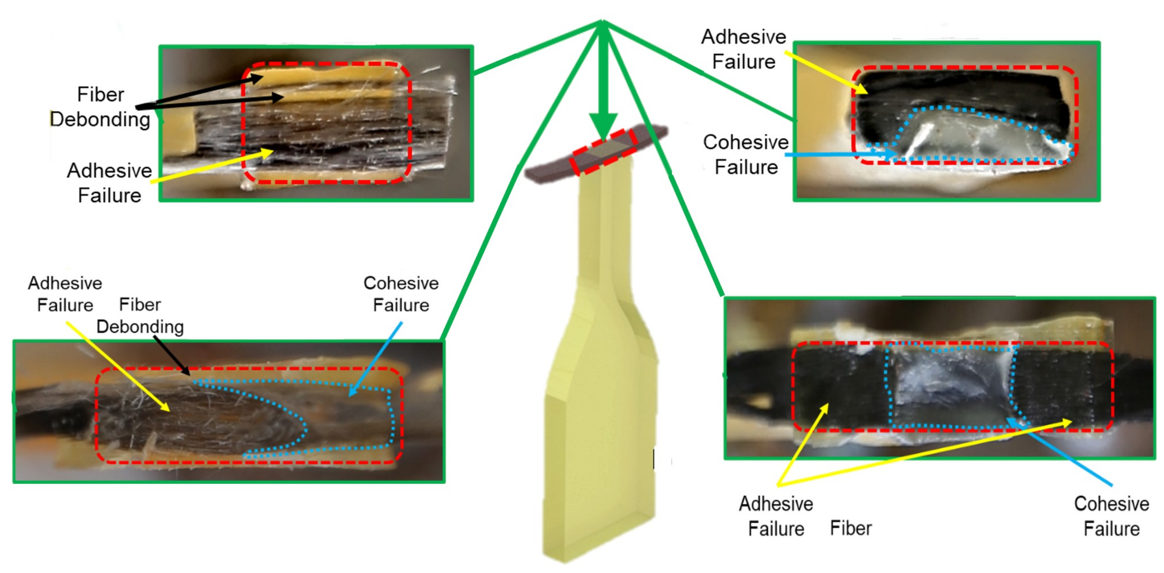


Nanoparticles incorporated into the epoxy increase the fiber-matrix interface strength. The effect of crack pinning and crack branching mechanisms for epoxy modified with graphene oxide nanoparticles, in addition to toughness enhancing mechanisms such as crack bridging and nanotube pinning for a hybrid epoxy matrix with halloysite nanotubes, explain the effect of different morphologies of these two nanoparticle types on fiber-matrix interfacial strength [2].



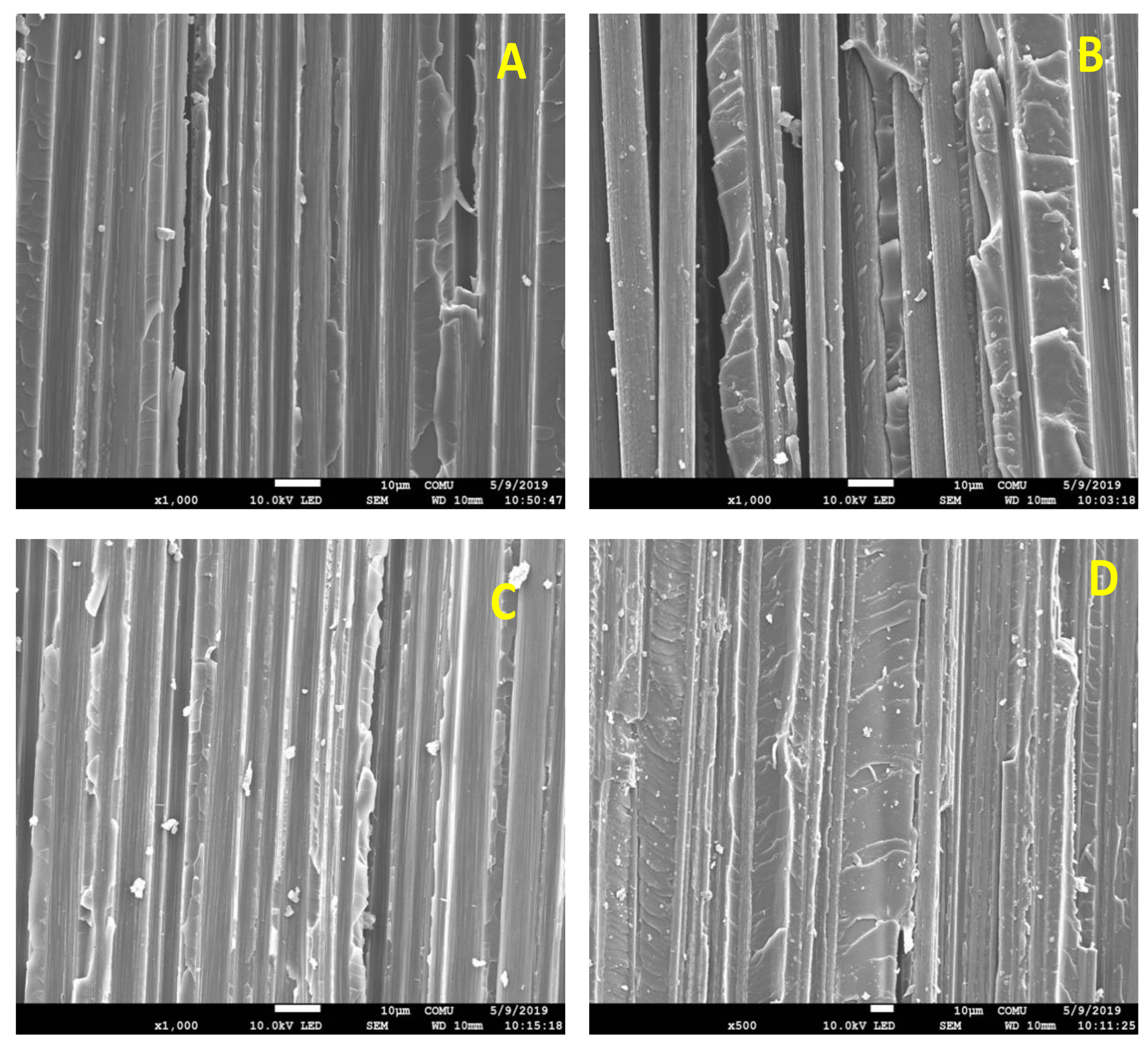
The functionalization of nanoparticle surfaces with chemical methods and crosslinkers such as APTES both facilitates the dispersion of nanoparticles in the resin. It improves the interface strength by creating chemical interaction with the matrix. When the surface functionalized GO and HNT were added to the epoxy matrix, the interfacial strength reached the highest measured value.

Fracture surface



Damage caused by adhesion at the fiber/matrix interfaces in the fiber bundle tensile tests was classified as adhesive and cohesive damage. Adhesive damage occurs when the adhesive strength between the bonded materials is insufficient, while cohesive damage is generally referred to when the material's load-carrying capacity is exceeded. The presence of cohesive damage regions is prominent in the surfaces of HNTs and GNPs modified samples [3].

The presence of cohesive damage is noticeable in all silane-modified samples. In the mesoscale tensile tests, cohesive damage can be attributed to the higher transverse fiber bundle tensile strength with the surface modification of nanoparticles.



Scanning electron microscopy photographs of the fracture surfaces after the transverse fiber tensile test, A) epoxy, B) epoxy with 0.1% by weight graphene oxide, C) epoxy with 1% by weight of halloysite nanotubes, D) epoxy with 0.1% by weight graphene oxide and 1% by weight of halloysite nanotubes

- With GO/EP (B) and HNT/EP (C) fiber-matrix interfacial interactions increased and interfacial strength improved.
- However, the increased surface roughness in halloysite modification reveals the effectiveness of toughening mechanisms, which are more common in the impact of 1D nanoparticles on the fracture performance, especially bridging and nanotube pinning [4]

Conclusion

The impact of nanoparticle reinforcement on fiber-matrix interfacial mechanical performance in fiber-reinforced polymer composites are investigated using meso-scale fiber bundle tests for evaluating interfacial properties. Fiber bundle tests provided practical and accurate mechanical insights into the fiber-matrix interface. This study serves to following tracks for composites:

- Enhanced mechanical properties
- Tailored toughening mechanisms
- Advancements in material design

References

1.Ulus, Hasan, et al., Fibers and Polymers 20 (2019): 2184-2199.
2. Ustun, Tugay, et al., Composites Part B: Engineering 96 (2016): 1-6.
3.Mutlu, G, et al., *Engineering Fracture Mechanics* 284 (2023): 109271.
4.Kaybal, H. B., et al., Composite Structures 258 (2021): 113415.

Sabancı Üniversitesi
SU IMC Sabanci University Integrated Manufacturing Technologies Research and Application Center
Çanakkale Onsekiz Mart University