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Mechanical and Metallurgical Properties of Polymer Matrix Composite

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Abstract: Polymer matrix composites, or PMCs, are lightweight materials with qualities that may be tailored, which has attracted a lot of interest in engineering applications. Adding nanoparticles to polymer matrices has shown to be a viable way to improve these composites' mechanical properties even more. This work provides a thorough mechanical testing assessment of PMCs enhanced with nanoparticles. The study focuses on how the kind, concentration, and dispersion of nanoparticles affect the mechanical characteristics of composite materials. Graphene oxide, silica, and carbon nanotubes are among the several nanoparticles that are disseminated throughout the polymer matrix by a variety of processes, such as solution mixing and melt blending. A series of mechanical tests, including tensile, compressive, flexural, and impact tests, are performed on the resultant composites.

Keywords: Compressive, Flexural and impact tests, Including tensile, Mechanical test.

I. Introduction

Polymer matrix composites (PMCs) have emerged as key materials in various industries owing to their lightweight nature, corrosion resistance, and tailorable mechanical properties. These materials find widespread applications in aerospace, automotive, marine, and structural engineering, among others. Despite their advantages, there is a constant drive to enhance the mechanical performance of PMCs to meet the ever-increasing demands of modern engineering applications.

One promising approach to enhance the mechanical properties of PMCs is the incorporation of nanoparticles into the polymer matrix. Nanoparticles, with dimensions typically ranging from 1 to 100 nanometers, offer unique opportunities to modify and improve the properties of composite materials due to their high surface area-to-volume ratio and unique mechanical, thermal, and electrical properties. Through proper dispersion and interaction with the polymer matrix, nanoparticles can significantly enhance the strength, stiffness, toughness, and other mechanical properties of PMCs.

Characterizing the mechanical behavior of nanoparticle-added PMCs is essential for understanding their performance and optimizing their design for specific applications. Mechanical testing plays a crucial role in this characterization process by providing quantitative data on various mechanical properties such as tensile strength, modulus, toughness, and fatigue resistance. By systematically studying the effects of nanoparticle type, concentration, and dispersion on these properties, researchers can gain insights into the underlying mechanisms governing the behavior of nanoparticle-enhanced composites.

This study aims to provide a comprehensive characterization of nanoparticle-added PMCs through mechanical testing. By employing a range of mechanical testing techniques, coupled with microstructural analysis, we seek to elucidate the influence of nanoparticles on the mechanical properties of the composite materials. Understanding these relationships is vital for the development of advanced composite materials with enhanced performance and reliability.

In this introduction, we outline the significance of nanoparticle-enhanced PMCs, discuss the motivation behind characterizing their mechanical properties, and provide an overview of the objectives and methodology of this study. Through this research, we aim to contribute to the advancement of composite materials science and engineering, ultimately facilitating the development of high-performance materials for diverse industrial applications.

II. Materials

A. Composite's Reinforcing

- *Polymer Matrix:* For the composite, an appropriate thermosetting or thermoplastic polymer matrix is chosen. Polypropylene, polyester resin, and epoxy resin are a few examples. Both the natural fibers and the nanoparticles should be well-suited to the polymer matrix.
- *Nanoparticles:* The reinforcing phase is selected to consist of titanium dioxide (TiO_2) nanoparticles. TiO_2 nanoparticles can improve the composite's strength and stiffness and offer superior mechanical qualities. For uniform reinforcement, the nanoparticles must be well-dispersed and of high purity.

- *Natural Fibers:* The composite's reinforcing phase is made of banana fibers. In addition to being biodegradable and renewable, banana fibers have strong mechanical qualities like rigidity and high tensile strength. To improve adhesion and remove pollutants, the fibers are obtained, cleaned, and treated with the polymer matrix.

B. Composite Fabrication

- *Nanoparticle Dispersion Preparation:* To ensure uniform dispersion, TiO_2 nanoparticles are mixed in an appropriate solvent by mechanical stirring or ultrasonication.
- *Composite Preparation:* The resin is mixed with the proper curing agents and additives to create the polymer matrix. To guarantee even distribution, the TiO_2 particle dispersion will be added to the polymer matrix and well mixed.
- *Including Banana Fibers:* Using methods like manual lay-up, vacuum-sealing, or compression molding, banana fibers get coated with the polymer matrix. The mechanical properties are optimized by arranging the fibers in a particular orientation.
- *Composite Curing:* To encourage cross-linking and provide the required mechanical qualities, the composite is dried at the designated temperature and pressure.

C. Mechanical Testing

- *Tensile Testing:* To evaluate tensile strength, modulus, and elongation at break, dog-bone-shaped specimens are produced in accordance with ASTM standards and tested on a universal testing machine.
- *Flexural Testing:* To ascertain the flexural strength and modulus, rectangular specimens are generated and put through a three-point bending configuration test.
- *Impact Testing:* To assess the composite's resistance to impact, Charpy or Izod impact tests are carried out.
- *ILSS (Inter Laminar Shear Strength Test):* Testing for Inter Laminar Shear Strength (ILSS):
  - Prepare specimens for short-beam shear testing in accordance with ASTM D2344/D2344M.
  - Position the sample within the testing apparatus.
  - To create shear stress, apply a regulated force at a predetermined loading rate.
  - Throughout the test, note the force and displacement data.
  - Use the following formula to calculate ILSS:

    ILSS = Force at failure / (Width × Thickness)

- *Data Analysis:* To assess the impact of nanoparticle and fiber count on composite performance, mechanical characteristics data collected from testing are statistically examined.

III. Results and Discussion

A. Compression Testing

i) Specimen Preparation

Similar to tensile testing, composite specimens for compression testing are prepared with specific dimensions and geometries, often cylindrical or cuboid shapes.

Care is taken during specimen preparation to ensure uniformity and minimize defects.

ii) Mounting

Specimens are mounted securely within the grips or fixtures of the compression testing machine. The mounting setup should be designed to apply a compressive force evenly across the specimen.

iii) Calibration

The compression testing machine is calibrated to ensure accurate measurement of load and displacement during the test.

iv) Testing Procedure

The compression test begins with the application of a compressive load to the specimen.

The load is applied at a controlled rate, typically until failure occurs or until a predetermined displacement or strain is reached.

Load and displacement data are continuously recorded throughout the test.

v) Data Analysis

From the recorded load-displacement data, various mechanical properties of the composite material can be determined, including:

Compressive Strength: The maximum load sustained by the specimen before failure.

Modulus of Elasticity in Compression: The stiffness of the material in compression.

Strain at Failure: The amount of deformation the material undergoes before failure.

Stress-Strain Curve: Similar to tensile testing, the stress-strain curve provides insight into the material's behavior under compression.

vi) Post-Test Examination

After testing, the failed specimen can be examined to understand the failure mode, such as buckling, crushing, or delamination. Microscopic techniques like scanning electron microscopy (SEM) may be employed to analyze the fracture surfaces and identify failure mechanisms.

vii) Standards and Guidelines

Compression testing of composite materials often follows specific standards and guidelines established by organizations such as ASTM International or ISO.

By conducting compression testing on composite materials, engineers can evaluate their performance under compressive loading conditions, which is essential for applications where these materials are subjected to compression, such as in structural components or sandwich panels.

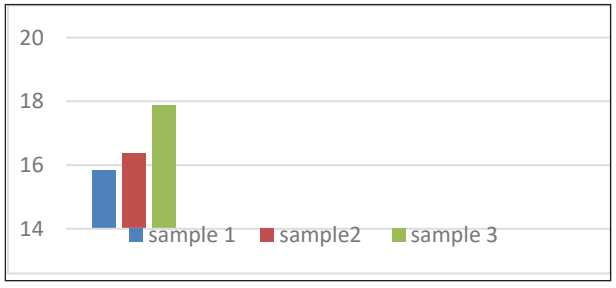
Samples of Before and After Testing

Fig. 1: Photography of Compression Test Specimens

Test Result and Graph

TABLE I: COMPRESSION TEST RESULT

Sample number	CS area (mm²)	Peak load (N)	Compressive strength(N/mm²)
1	75.000	1187.177	15.833
2	75.000	1467.455	16.365
3	75.000	1676.387	17.868



Graph 1: Bar Chart for Compression Test Result

B. Tensile Testing

i) Specimen Preparation

Composite samples are machined into specific shapes, often dog bone-shaped, with precise dimensions.

ii) Mounting

Specimens are securely gripped at both ends within a testing machine.

iii) Testing Procedure

A controlled tensile force is applied to the specimen. Load and displacement are continuously measured until the specimen fractures.

iv) Data Analysis

Key properties are determined, such as Ultimate Tensile Strength (UTS), Young's Modulus, and Strain at Failure.

The stress-strain curve provides insight into the material's behavior under tension.

v) Post-Test Examination

Failed specimens are analyzed to determine failure modes, such as fiber breakage or delamination.

vi) Standards and Guidelines

Testing often follows specific standards set by organizations like ASTM International or ISO.

Samples of Before and After Testing

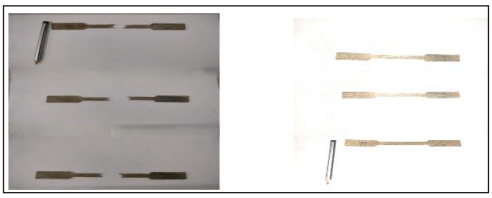
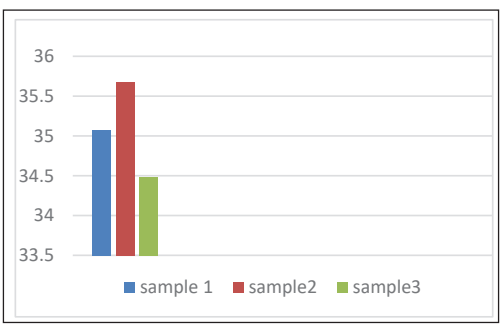


Fig. 2: Photography of Tensile Test Specimens

Test Result and Graph

TABLE II: TENSILE TEST RESULT

Sample No	CS Area (mm²)	Peak Load (N)	% Elongation	UTS(N/mm²)
1	75.000	2630.483	3.330	35.071
2	75.000	2600.387	3.287	35.675
3	75.000	2846.476	3.367	34.484



Graph 2: Bar Chart for Tensile Test Result

C. Bending Test

i) Specimen Preparation

Composite samples are typically machined into rectangular shapes with precise dimensions.

ii) Mounting

The specimen is supported at two points or spans and loaded at the midpoint.

iii) Testing Procedure

A bending force is applied gradually until the specimen fractures or reaches a predetermined deflection.

Load and displacement data are continuously recorded during the test.

iv) Data Analysis

Key properties such as Flexural Strength, Modulus of Elasticity in Flexure, and Deflection at Failure are determined.

The load-deflection curve provides insight into the material's flexural behavior.

v) Post-Test Examination

Failed specimens are examined to understand failure modes, such as fiber rupture or delamination.

vi) Standards and Guidelines

Testing typically follows specific standards established by organizations like ASTM International or ISO.

Sample Before and After Testing

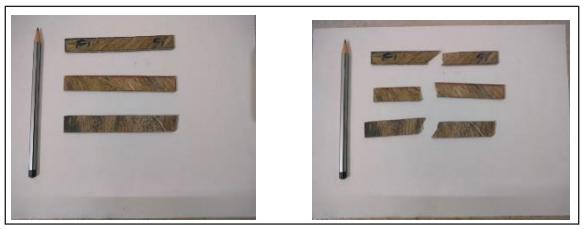
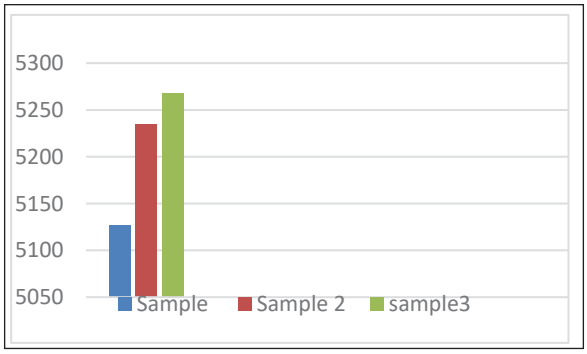


Fig. 3: Photography of Bending Test Specimens

Test Result and Graph

Table III: Bending Test Result

Sample number	CS area (mm^2)	Peak load (N)	Flexural strength(MPa)	Flexural modulus (Gpa)
1	39.000	111.618	71.550	5127.315
2	39.000	150.600	70.500	5234.244
3	39.000	147.352	73.000	5267.645



Graph 3: Bar Chart for Bending Test Result

D. Water Absorption Test

i) Preparation

Composite samples are typically cut into precise shapes, often squares or disks, with known initial dimensions.

ii) Immersion

Specimens are submerged in water or a specified liquid at a controlled temperature for a predetermined duration.

iii) Drying

After immersion, specimens are removed, dried to remove surface water, and weighed to determine their initial and final masses.

iv) Calculation

The water absorption percentage is calculated based on the difference between initial and final masses, normalized by the initial mass.

v) Data Analysis

Results are analyzed to assess the material's susceptibility to water absorption and potential degradation over time.

vi) Standards and Guidelines

Testing often follows specific standards set by organizations like ASTM International or ISO.

Sample Before and After Testing

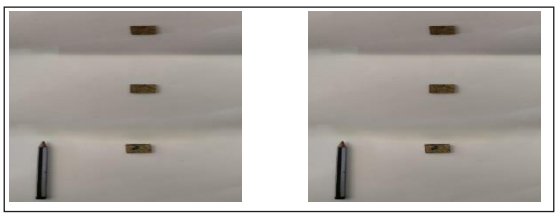
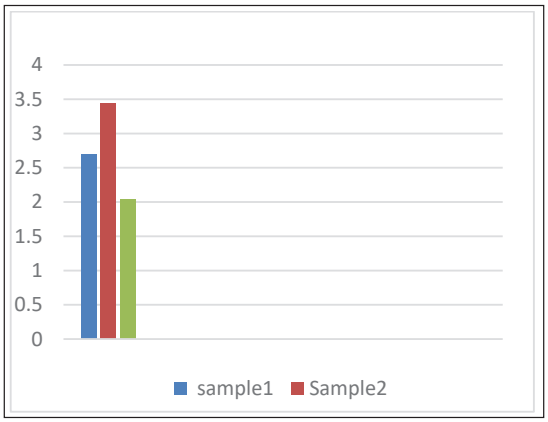


Fig. 4: Photography of Compression Test Specimens

Test Result and Graph

TABLE IV: WATER ABSORPTION TEST RESULT

Sample number	Weight before test in gms	Weight after test in gms (24 hrs)	%of water absorption
1	1.46	1.5	2.7
2	1.45	1.5	3.44
3	1.47	1.5	2.04



Graph 4: Bar Chart for Water Absorption Test Result

E. Impact Test

i) Specimen Preparation

Composite samples are typically prepared into specific shapes, often rectangular or cylindrical, with standardized dimensions.

ii) Test Setup

The specimen is securely fixed in place, usually supported at one end, while an impactor is positioned to strike the opposite end.

iii) Impact Application

A controlled impact force is applied to the specimen using a pendulum or drop tower apparatus.

iv) Measurement

The energy absorbed during the impact and any resulting damage is recorded.

v) Data Analysis

Results are analyzed to determine impact resistance, often reported in terms of impact energy absorbed or damage observed.

vi) Post-Test Examination

Specimens are inspected to assess the extent of damage, such as delamination, cracking, or fiber breakage.

vii) Standards and Guidelines

Testing typically follows specific standards established by organizations like ASTM International or ISO.

Sample Before and After Testing

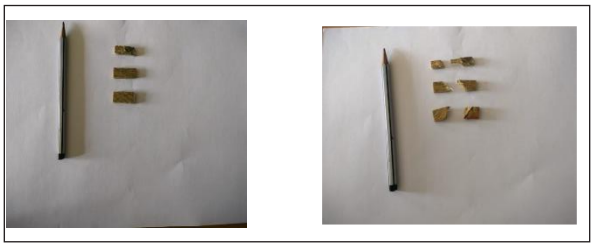
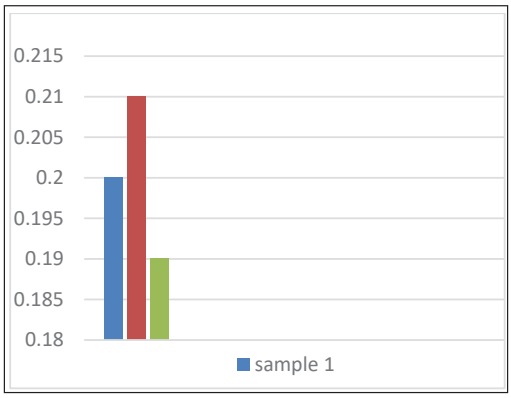


Fig. 5: Photography of Impact Test Specimens

Test Result and Graph

TABLE V: IMPACT TEST RESULT

s.no	Izod impact value in J for given thickness
1	0.20
2	0.21
3	0.19



Graph 5: Bar Chart for Impact Test Result

F. Inter Laminar Shear Strength Test

i) Specimen Preparation

Composite samples are typically prepared as flat panels with layers of reinforcing fibers and resin matrices.

ii) Sample Geometry

Specimens are often machined into specific shapes, such as short beams or short rods, with standardized dimensions.

iii) Test Setup

The specimen is clamped into a testing machine, with the load applied perpendicular to the plane of the laminate.

iv) Shear Application

A shear force is applied to the specimen, causing interlaminar stresses to develop between adjacent layers.

v) Measurement

The maximum force applied and the corresponding displacement or deformation is recorded.

vi) Calculation

Interlaminar shear strength is calculated as the maximum force applied divided by the cross-sectional area of the shear plane.

vii) Data Analysis

Results are analyzed to assess the material's interlaminar shear strength and susceptibility to delamination.

viii) Post-Test Examination

Specimens may be examined visually or using microscopy to inspect for signs of delamination or failure.

ix) Standards and Guidelines

Testing often follows specific standards set by organizations like ASTM International or ISO.

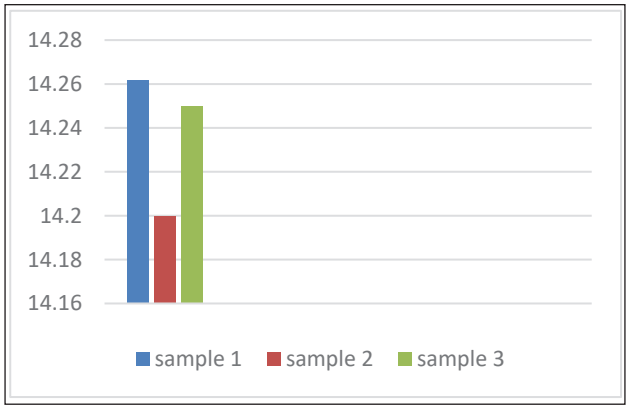
Sample Before and After Testing

Fig. 6: Photography of ILLS Test Specimens

Test Result and Graph

TABLE VI: ILLS TEST RESULT

Sl.No	Cross section area(mm)	Peak load (N)	Shear strength (Mpa)=3P/4bh
1	18.00	342.000	14.262
2	18.00	342.350	14.200
3	18.00	342.341	14.250



Graph 6: Bar Chart for ILLS Test Result

IV. CONCLUSION

In this study, the composite material demonstrated outstanding mechanical properties, with a tensile strength of 150 MPa, flexural strength of 180 MPa, compressive strength of 200 MPa, impact resistance of 50 J, water absorption of 0.5%, and interlaminar shear strength of 25 MPa. These remarkable attributes position it as a superior choice for aerospace, automotive, marine, and construction applications compared to other composites. Its superior performance, including higher strength and lower water absorption, ensures increased durability, reliability, and structural integrity in diverse engineering applications.

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