

INVESTIGATION ON TRIBOLOGY AND MECHANICAL CHARACTERISTICS OF FUNCTIONALIZED GRAPHENE AND MULTI-WALLED CARBON NANOTUBES (MWCNTs)

Authors: Aravin V , Prakash R , PJ Akhil , Mohamed Ushman H

Guide: S Alagar, Assistant Professor.

Department of Mechanical Engineering, Hindusthan College of Engineering and Technology, Coimbatore, India

ABSTRACT

Hybrid polymer composites reinforced with nano and micro fillers have attracted significant attention due to their enhanced mechanical and thermal properties. In this study, a hybrid composite material was fabricated using epoxy resin as the matrix material and reinforced with Multi-Walled Carbon Nanotubes (MWCNTs) and Aluminum Oxide (Al_2O_3). The aim of this work is to investigate the effect of these reinforcements on the mechanical and thermal performance of the composite material. Different weight fractions of MWCNTs and Al_2O_3 were incorporated into the epoxy matrix using a mechanical mixing method. The prepared specimens were subjected to tensile testing, thermal conductivity testing, and microscopic analysis. The results indicate that the addition of MWCNTs and Al_2O_3 significantly improves the tensile strength, Young's modulus, and thermal conductivity of the epoxy composite. The hybrid reinforcement approach offers a promising route for developing high-performance composite materials suitable for applications in aerospace, automotive, and electronic packaging industries.

KEYWORDS

Hybrid composites, Multi-walled carbon nanotubes, Aluminum oxide, Epoxy resin, Mechanical properties, Thermal conductivity.

INTRODUCTION

Composite materials are widely used in engineering applications because of their high strength-to-weight ratio, corrosion resistance, and excellent mechanical

properties. In recent years, polymer matrix composites have gained popularity due to their lightweight nature and ease of fabrication. Among the various polymer matrices, epoxy resins are extensively used in industrial applications due to their good adhesion, chemical resistance, and electrical insulation properties.

However, epoxy resins generally exhibit low thermal conductivity and limited mechanical strength when used alone. To overcome these limitations, reinforcing materials such as ceramic particles, fibers, and nanoparticles are incorporated into the polymer matrix. The development of hybrid composites that combine different types of reinforcements has become an effective approach to enhance the overall properties of composite materials.

Multi-Walled Carbon Nanotubes (MWCNTs) are cylindrical nanostructures composed of multiple graphene layers. They possess exceptional mechanical strength, high electrical conductivity, and excellent thermal properties. Due to these characteristics, MWCNTs are widely used as reinforcement materials in polymer nanocomposites.

Aluminum oxide (Al_2O_3), commonly known as alumina, is a ceramic material with high hardness, good thermal conductivity, and excellent chemical stability. It is widely used in engineering ceramics and as a reinforcement material in composite systems.

In this study, a hybrid composite consisting of epoxy resin reinforced with MWCNTs and Al_2O_3 particles was fabricated. The mechanical and thermal properties of the prepared composites were evaluated to determine the effectiveness of hybrid reinforcement.

LITERATURE REVIEW

Several researchers have investigated the influence of carbon nanotubes and ceramic fillers on polymer composites. Carbon nanotubes are considered ideal reinforcing materials because of their unique mechanical and electrical properties. When dispersed in a polymer matrix, they significantly improve the mechanical strength and stiffness of the composite.

Studies have shown that incorporating carbon nanotubes into epoxy matrices increases tensile strength and elastic modulus. However, achieving uniform dispersion of nanotubes in the polymer matrix remains a challenge due to their tendency to agglomerate.

Researchers have also explored the use of ceramic fillers such as aluminum oxide, silicon carbide, and magnesium oxide in polymer composites. These fillers improve the thermal conductivity and wear resistance of the composite materials.

Hybrid composites containing both nano and micro reinforcements have demonstrated superior performance compared to single filler systems. The combination of carbon nanotubes and ceramic particles provides improved mechanical, thermal, and electrical properties.

Previous studies indicate that the addition of alumina particles improves hardness and thermal stability, while carbon nanotubes enhance mechanical strength and electrical conductivity. Therefore, combining these materials in an epoxy matrix can result in multifunctional composite materials suitable for advanced engineering applications.

3. MATERIALS USED

3.1 Epoxy Resin

Epoxy resin was used as the base matrix material for fabricating the composite. Epoxy resins are thermosetting polymers known for their strong adhesive properties, chemical resistance, and mechanical stability. They are widely used in coatings, adhesives, electronic components, and structural composites.

3.2 Aluminum Oxide (Al₂O₃)

Aluminum oxide is a ceramic material with high hardness, excellent wear resistance, and good thermal conductivity. It is one of the most widely used engineering ceramics due to its cost effectiveness and mechanical properties. Alumina particles were used as reinforcement to improve the strength and thermal performance of the epoxy composite.

Key properties of aluminum oxide include:

- High hardness and wear resistance
- Excellent dielectric properties
- Good thermal conductivity
- High strength and stiffness
- Chemical resistance at high temperatures

3.3 Multi-Walled Carbon Nanotubes (MWCNTs)

Carbon nanotubes are cylindrical carbon structures with exceptional mechanical and thermal properties. Multi-Walled Carbon Nanotubes consist of multiple concentric graphene layers and have diameters in the nanometer range.

MWCNTs are used as reinforcement materials due to their:

- High tensile strength
- Excellent thermal conductivity
- High electrical conductivity
- Large surface area
- Good chemical stability

3.4 Polymer Matrix

The polymer matrix plays an important role in holding the reinforcement materials together and transferring load between them. In this study, epoxy resin acts as the matrix that binds MWCNTs and Al_2O_3 particles together to form the hybrid composite.

4. FABRICATION OF HYBRID COMPOSITE

The hybrid composite specimens were prepared using a mechanical mixing and casting process. The required amount of epoxy resin was measured and poured into a mixing container. MWCNTs and Al_2O_3 particles were then added to the epoxy matrix in predetermined weight percentages.

The mixture was stirred using a magnetic stirrer to ensure uniform dispersion of reinforcement particles within the matrix. Proper mixing is essential to avoid agglomeration of nanoparticles and to achieve homogeneous composite structures.

After thorough mixing, a hardener was added to the epoxy mixture and stirred continuously. The prepared mixture was then poured into molds designed according to ASTM standards.

The specimens were allowed to cure at room temperature for several hours until the composite material hardened completely. After curing, the samples were removed from the molds and prepared for mechanical and thermal testing.

5. EXPERIMENTAL SETUP

5.1 Tensile Testing

The tensile test was conducted using a Universal Testing Machine (UTM). The specimens were prepared according to ASTM standards in a dog-bone shape.

During the test, the specimen was clamped between two grips of the machine. A gradually increasing load was applied until the specimen fractured. The tensile strength, elongation, and Young's modulus were calculated based on the load and displacement data.

5.2 Thermal Conductivity Test

Thermal conductivity tests were carried out using a heat flow meter apparatus. The test measures the ability of the composite material to conduct heat.

The specimen was placed between two plates at different temperatures. Heat flow through the specimen was measured and used to calculate the thermal conductivity.

5.3 Scanning Electron Microscopy

Scanning Electron Microscopy (SEM) analysis was performed to examine the microstructure of the composite materials. SEM images help identify the dispersion of reinforcement particles and the bonding between the matrix and fillers.

6. RESULTS AND DISCUSSION

6.1 Tensile Test Results

The tensile test results indicate that the addition of MWCNTs and Al_2O_3 significantly improves the mechanical properties of the epoxy composite.

Compared to pure epoxy, the hybrid composite samples exhibited higher tensile strength and Young's modulus. The improvement in mechanical properties is mainly due to the strong bonding between the reinforcement particles and the epoxy matrix.

The presence of MWCNTs increases load transfer efficiency, while Al_2O_3 particles enhance stiffness and hardness.

6.2 Thermal Conductivity

Thermal conductivity tests revealed that the hybrid composite materials have better heat transfer capability compared to pure epoxy.

The addition of MWCNTs creates conductive pathways for heat flow, while alumina particles contribute to improved thermal stability. As the reinforcement content increases, thermal conductivity also increases.

6.3 Microstructural Analysis

SEM images show a relatively uniform dispersion of reinforcement particles within the epoxy matrix. Proper dispersion is essential to achieve improved mechanical and thermal properties.

The micrographs also reveal good interfacial bonding between the matrix and reinforcement particles, which contributes to the overall performance of the composite.

7. CONCLUSION

In this study, hybrid epoxy composites reinforced with Multi-Walled Carbon Nanotubes and Aluminum Oxide particles were successfully fabricated and tested. The experimental results demonstrate that the incorporation of these reinforcements significantly enhances the mechanical and thermal properties of the epoxy matrix.

The tensile strength, Young's modulus, and thermal conductivity of the composite increased with the addition of reinforcement materials. SEM analysis confirmed good dispersion and bonding between the matrix and reinforcement particles.

Hybrid composites reinforced with MWCNTs and Al₂O₃ show great potential for applications requiring high strength, thermal stability, and lightweight materials. These composites can be used in aerospace structures, automotive components, and electronic devices.

Further research can focus on optimizing reinforcement content, improving dispersion techniques, and studying additional properties such as electrical conductivity and wear resistance.

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