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Effects of Nanoparticle on Mechanical Properties of Epoxy Nanocomposites

Rupesh Gupta[1], Gavendra Norkey[2]
[1]*Research Scholar, Mechanical Engineering Department, MITS Gwalior, India*
[2]*Professor, Mechanical Engineering Department, MITS Gwalior, India*

Abstract: "This study explores the "synergistic effects of Nanoclay and graphene oxide (GO) on the mechanical properties of epoxy nanocomposites. Epoxy resins, known for their excellent adhesion, chemical resistance, and mechanical properties, are widely used in" various engineering applications. However, their inherent brittleness limits their performance in high-stress environments. To overcome this limitation, nanoparticles such as nanoclay and GO were incorporated into the epoxy matrix at different concentrations. The resulting nanocomposites were subjected to comprehensive mechanical testing, including flexural strength and modulus evaluations. The results demonstrated a significant enhancement in mechanical properties, with the optimal nanoparticle loading showing up to a 50% improvement in flexural strength compared to the pristine epoxy. "This enhancement is attributed to the uniform dispersion of nanoparticles within the matrix, leading to improved stress distribution and crack resistance. The study provides valuable insights into the design of"" high-performance epoxy nanocomposites for advanced engineering applications, emphasizing the role of nanoparticle selection and dispersion in tailoring material properties.

Keywords: Epoxy nanocomposites, Nanoclay, Graphene oxide, Mechanical enhancement, Flexural strength, Nanoparticle dispersion, Stress distribution, Advanced engineering materials.

I. INTRODUCTION

The word "composite" in the context of composite materials describes a material system made up of two or more different phases that are joined to produce a material with improved qualities over its constituent parts. The reinforcement and the matrix are a composite's primary constituents.

A. Phases in Composites

The matrix phase and the reinforcing phase are the two main stages of composite materials. The binding substance that envelops and sustains the reinforcement is known as the matrix phase. Depending on the desired qualities of the composite, it can be made of ceramic, metal, or polymers and plays a critical role in transferring loads to the reinforcement. Conversely, elements like fibers, particles, or whiskers embedded in the matrix make up the reinforcing phase. This stage gives the composite its strength and stiffness, which improves its mechanical qualities, such as impact resistance and tensile strength.

Use of Composites:

"Composites are widely used across various industries due to their superior performance characteristics. They are commonly used in applications where high strength-to-weight ratios, corrosion resistance, and specific mechanical properties are required". Some key applications include. Aerospace , Automotive , Construction , Sports equipment , Marine.

B. Epoxy and Nanoclay in Nanocomposites

"Epoxy resins' superior mechanical qualities, resistance to chemicals, and ease of processing make them popular choices for use as a matrix material in the creation of composite materials. These thermosetting polymers are highly appreciated for a variety of applications, such as "coatings, adhesives, and structural components, due to their high strength-to-weight ratio", adhesion qualities, and capacity to cure at room temperature. One kind of multilayer silicate that can be exfoliated into individual platelets at the nanoscale is a Nanoclay, usually montmorillonite (MMT). Nanoclays considerably improve "the mechanical, thermal, and barrier qualities of the resultant nanocomposites"" when they are distributed throughout an epoxy matrix. The main cause of this improvement is the high aspect ratio of the Nanoclay platelets, which can produce a sizable interface area with the epoxy matrix and so increase load distribution and stress transfer.

Composites are materials made up of two or more separate phases. The reinforcement is the second phase that is bound together and surrounded by the matrix to form a material with qualities better than the sum of its parts. Usually made of polymers, metals, or ceramics, the matrix is reinforced with either fibers, particles, or whiskers.

C. Properties of Epoxy , Nanoclay

The characteristics of the resulting nanocomposites are greatly improved when nanoclay is added to epoxy resin. One of the main improvements is in mechanical strength, where greater toughness, modulus, and tensile strength are attained through improved load dispersion and stress transfer. Furthermore, the nanocomposite exhibits higher thermal stability and decreased thermal expansion, rendering it more appropriate for use in high-temperature applications. Better resistance to gas and moisture penetration is provided by the nanocomposite's enhanced barrier qualities, which are especially significant for applications like coatings and packaging. Additionally, the nanocomposite's dimensional stability is improved, resulting in less shrinkage during the curing process and more dependable and long-lasting finished goods.

D. Advantages of Epoxy , Nanoclay Nanocomposites

Epoxy-nanoclay nanocomposites have a number of benefits. Economical reinforcement is one of the main advantages. When compared to other nanofillers, nanoclay is comparatively cheap, making it a cost-effective way to enhance material characteristics. In addition, since nanoclays are naturally occurring minerals, they are a more sustainable and environmentally benign alternative to synthetic ones. Another benefit of these nanocomposites is their scalability, as their creation procedures align with current industrial manufacturing techniques. These nanocomposites are also quite adaptable; different types and amounts of nanoclay can be added, and processing settings can be changed to suit different uses.

II. LITERATURE REVIEW

1) It is well known that graphene oxide (GO) can improve the characteristics of polymeric composites, especially those made with epoxy resins. Due to GO's large surface area and powerful bonding qualities, research has shown that adding GO can greatly increase “the mechanical properties of epoxy composites, including flexural strength”. Research indicates that flexural strength” can be increased by more than 20% with even minor additions of GO (e.g., 0.5 weight percent). Another important factor is temperature, which has an impact on these composites' overall performance and viscoelastic behavior. Studies have looked at how GO impacts the contact between glass fiber and epoxy as well as the GO/epoxy interface, improving load transfer and lowering failure rates. Analyses “using a “scanning electron microscope (SEM)” have shed light on failure processes and interfacial bonding, emphasizing the positive effects of GO “on the mechanical performance of polymer composites”” at various temperatures.

2) It has been demonstrated that adding “multi-layer graphene (MLG)” greatly improves the mechanical characteristics of glass fiber/epoxy composites”. Studies show that MLG increases flexural strength because it creates clamping pressures at the MLG/polymer contact, particularly at cryogenic temperatures. Long-term research indicates that MLG retains its reinforcing effectiveness for prolonged periods of time at lower temperatures; however, this impact is diminished by thermal stress at higher temperatures. “Thermo-gravimetric analysis (TGA) and dynamic mechanical analysis (DMA)”” are two thermal analyses that have validated MLG's beneficial effects on these composites' performance and thermal stability.

3) The “potential of carbon nanotubes” (CNTs) to improve” the environmental durability of composites based on polymers has been extensively researched. Studies reveal that adding carbon nanotubes (CNTs) can greatly increase these composites' resistance to a range of environmental conditions, including moisture, temperature swings, UV radiation, and space environments like low Earth orbit. By modifying the microstructure at both the micro and nanoscales, CNTs strengthen the polymer matrix, which in turn influences the material's macroscopic behavior. According to studies, CNTs can improve interfacial bonding and lessen differential deterioration, which improves the composites' long-term performance and structural integrity. But the entire scientific picture of how CNTs affect interfacial durability over time in various environments is still developing, so further research is needed to guarantee dependable and sustainable performance in a range of service scenarios.

4) Glass/epoxy (GE) composites are known to have improved mechanical properties when multiwalled carbon nanotubes (MWCNTs) are added, especially at lower temperatures. Research indicates that MWCNTs increase stiffness and flexural strength; however, these advantages diminish with increasing temperature, with notable declines noted at 110°C. “Dynamic Mechanical Thermal Analysis (DMTA)” shows that the addition” of MWCNTs also reduces the composite's glass transition temperature (Tg).

Failure mechanisms have been studied using scanning electron microscopy (SEM), which has shown how temperature affects the microstructural integrity of these composites. In general, MWCNTs present benefits as well as difficulties for polymer composite reinforcement.

5) "The mechanical characteristics of glass fiber/epoxy composites have been" improved with the addition of oxidized carbon nanotubes (CNTs), especially at lower temperatures. Studies reveal that, in comparison to conventional glass/epoxy composites at room temperature, oxidized CNTs form a stronger, covalently bonded interface with the epoxy matrix, improving reinforcing efficiency and increasing strength by 25%. On the other hand, interfacial decohesion causes both oxidized and pure CNT-reinforced composites to lose strength at high temperatures.

   This reduction highlights how the reinforcement is temperature-dependent. Chemical functionalization of CNTs improves the interfacial bonding, especially at low and cryogenic temperatures, according to microscopic investigations and thermo-mechanical studies, which makes these composites very useful for such applications. The literature emphasizes how temperature and chemical functionalization both affect how well CNT-reinforced composites work.

III. METHODOLOGY

A. *Materials and Fabrication*

Several materials were used in the creation of epoxy-nanoclay nanocomposites. Diglycidyl Ether of Bisphenol, an epoxy resin supplied by Atul Industries, India, was utilized in this project, along with Triethylene Tetra Amine as a hardener. The used nanoclay was obtained from Sigma-Aldrich and had an outside diameter of 6–9 nm and a length of 5 µm. Furthermore, United Nanotech Pvt. Ltd. supplied graphene oxide (GO), which ranged in thickness from 0.8 to 2 nm.

Control and nanoparticle-modified epoxy composites were produced during the production procedure. Following the supplier's directions, 10% hardener by weight of epoxy resin was combined to provide a control sample devoid of any nanoparticles. To investigate the impact of nanoparticle content, two distinct compositions were made: Composition A had 0.1 weight percent nanoclay and 0.2 weight percent graphene oxide relative to the weight of the epoxy, whereas Composition B had 0.5 weight percent nanoclay and 0.2 weight percent graphene oxide.

The properties of the epoxy resin, as per the manufacturer's specifications, are as follows:

Property	Value
Density	1.15 g/cm³
Tensile Modulus	3.6 GPa
Tensile Strength	0.07 GPa

B. *Fabrication of Composites*

The production of control epoxy composites was the first of several crucial processes in the composites fabrication process. By following the supplier's instructions, a 10% hardener by weight of epoxy resin was used to create a control sample that did not contain any nanoparticles.

Two distinct compositions of the nanoparticle-modified epoxy composites were made in order to examine the impact of the nanoparticle content. In relation to the weight of the epoxy, Composition A had 0.1 weight percent nanoclay and 0.2 weight percent graphene oxide, while Composition B had 0.5 weight percent nanoclay and 0.2 weight percent graphene oxide.

When the supplier delivered the nanoparticles, they were aggregated. The nanoparticles were dispersed using 150 ml of acetone in order to lower surface energy and promote deagglomeration. After 30 minutes of stirring at 1000 rpm, this mixture was submerged in a bath of sonication for an additional 30 minutes.

The nanoclay and graphene oxide were well disseminated throughout the acetone by the shearing forces produced by the rapid stirring and the ultrasonic vibrations produced during sonication. Then, the epoxy resin was mixed with the dispersed graphene oxide/nanoclay/acetone combination. The dispersed nanoparticle mixture was added to prepared epoxy resin, which had been preweighed and heated to 70°C for thirty minutes.

The acetone was allowed to evaporate entirely by stirring the mixture at 1000 rpm and 70°C. To guarantee uniform dispersion of the nanoparticles, the graphene oxide, nanoclay, and epoxy mixture was sonicated for one hour at 70°C.

The graphene oxide/nanoclay/epoxy mixture was vacuum degassed for eighteen hours in order to remove air bubbles that could develop voids and possibly jeopardize the mechanical qualities of the finished composite. At last, the degassed suspension was combined with the hardener in the necessary quantity, and the resulting mixture was transferred into a mold measuring 72 mm by 13 mm by 4 mm. After being kept at room temperature for a full day, the samples finally had a thickness of 4 mm.

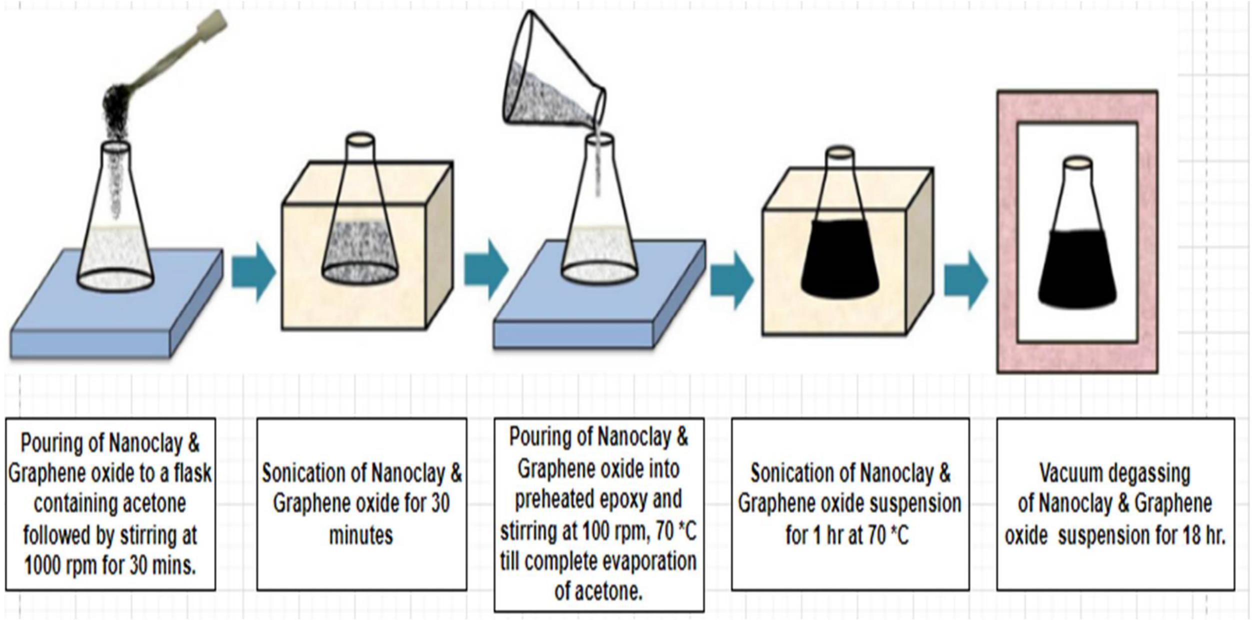

Figure 1: Sequence of processing steps involved in the fabrication of Nanophased Nanoclay & Graphene oxide composites

Figure 2 : Final Samples

IV. RESULT & DISCUSSIONS

The flexural test was conducted following ASTM D7264 to assess "the bending properties of the nanocomposites. A "3-point bending fixture attached to the Universal Testing Machine" "(Instron 5967) equipped with an environmental chamber was used for this purpose. The flexural properties of nanocomposites containing a fixed amount of graphene oxide (GO) and varying Nanoclay (NC) content were measured at room temperature, with a holding time of 10 minutes and a loading rate of 1 mm/min. Seven samples of each composition were tested, and the average and standard" deviation were calculated. "The load (P) vs. displacement (h) curve obtained from flexural testing was converted into stress-strain plots using the following relationships:

$$\sigma_f = \frac{3PL}{2bd^3}$$

$$\epsilon_f = \frac{6hd}{l^2}$$

Where l, b, and d represent the span length, width, and thickness of the sample, respectively. The strength of the material corresponds to the stress at the maximum" load.

The impact of nanoparticle modification on the stress-strain behavior of composites made of epoxy is depicted in Figure 3. The epoxy's reactivity to stress and strain is considerably changed by the addition of nanoparticles. The maximum stress-bearing capacity of the epoxy is increased by the addition of 0.2% graphene oxide and 0.5% Nanoclay. Stiffer nanoparticles absorb higher stresses and transfer them back to the matrix, improving the total load-bearing capacity of the nanocomposites. This is made possible by the difference in modulus between the nanoparticles and the epoxy" matrix.

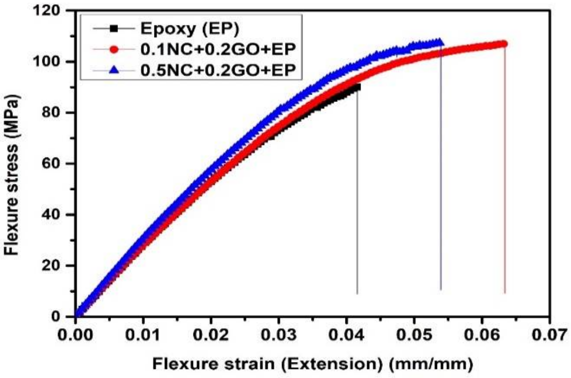

Figure 3: Stress-strain diagram for epoxy and nanoparticle modified composites

Figure 4 shows how the presence of nanoparticles affects the flexural modulus. The current study found that when the amount of nanoparticles grows, so does the flexural modulus. The composites treated with 0.2% GO and 0.5% Nanoclay had the highest flexural modulus. An increase of around 8% was obtained with the addition of 0.1% Nanoclay and 0.2% GO, and this increment rose to approximately 12% with a greater Nanoclay content. The reason for this improvement is that the neighboring polymer becomes more rigid due to the creation of a three-dimensional interphase zone surrounding the nanoparticles. Because the nanoparticles have a large surface area, the composites have a bigger interfacial area, which enhances the efficiency of stress transfer and raises the modulus.

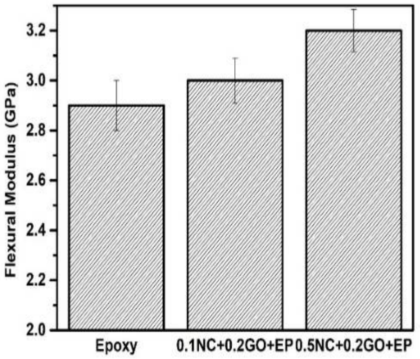

Figure 4: Variation of flexural modulus with the addition of nanoparticles

Figure 5 displays the flexural strength that was obtained from the stress-strain diagram. The flexural strength of epoxy-based composites is considerably changed by the inclusion of graphene oxide and Nanoclay. Flexural strength increased by 18% when 0.1% Nanoclay and 0.2% graphene oxide were added. Further increases in the nanoparticle content, however, did not result in a discernible improvement in the flexural strength. This improvement might be ascribed to other methods of strengthening, including the hardening of nanoparticles. Because of mechanical interlocking at the nanoparticle/polymer interface, the strong contact between the nanoparticles and the epoxy matrix increases deformation resistance and resulting in an enhanced load-bearing capacity. By mechanically interconnecting, graphene oxide's corrugated surface further improves interfacial adhesion.

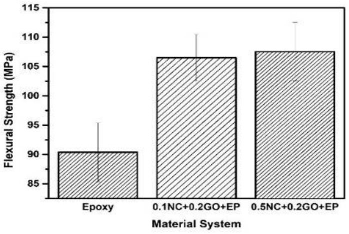

Figure 5: Effects of nanoparticles on flexural strength of epoxy-based composites

In Figure 6, the failure strain for the nanocomposites and neat epoxy is plotted based on the stress-strain diagram. The addition of graphene oxide and Nanoclay also modifies the failure strain. For the 0.1% Nanoclay and 0.2% GO composites, a notable increase in failure strain was noted. This rise is explained by a number of toughening micro-mechanisms, such as improved plastic deformation of the polymer matrix, crack bridging, fracture deflection, and nanosheet pull-out, that are activated by the presence of nanosized GO and nanoclay.

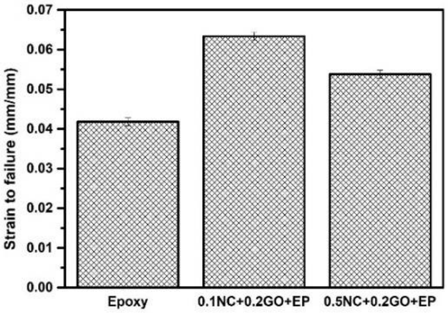

Figure 6: Effects of nanoparticles on failure strain of epoxy-based composites

V. CONCLUSION

This work offers a workable method for adding small amounts of nanoclay and graphene oxide to structural epoxy to improve its mechanical qualities. The particular processing conditions employed in this investigation allowed the nanoparticles to be evenly distributed throughout the epoxy matrix.

The study produced a number of accurate conclusions, including the fact that the process parameters were successfully tuned to produce the nanocomposites. The flexural properties of the epoxy-based nanocomposites were considerably changed by the addition of 0.1% nanoclay and 0.2% graphene oxide (GO). In particular, the addition of 0.1% nanoclay and 0.2% GO enhanced the flexural strength, flexural modulus, and failure strain by 18%, 8%, and 54%, respectively. These nanocomposites' enhanced mechanical behavior is ascribed to a number of micro-mechanisms that strengthen and toughen them. The material's overall performance has improved due to many factors such as greater plastic deformation of the polymer matrix, crack bridging, fracture deflection, and nanosheet pull-out.

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