

Effect of Mechanical Properties of Glass Fiber Reinforced Epoxy Composites Filled with Al_2O_3 and SiO_2 Particles

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ABSTRACT

This study examined the influence of mechanical properties on Glass Fiber Reinforced Epoxy Composites (GFREC) filled with Al_2O_3 and SiO_2 particles. Tensile strength, flexural properties, impact resistance, and Vickers hardness were investigated to evaluate the performance enhancements resulting from the addition of these fillers. The composites were formulated using a blend of glass fibers and epoxy resin with varying concentrations of Al_2O_3 and SiO_2 . Mechanical testing was conducted following standard procedures. The results indicated a notable increase in mechanical strength with the incorporation of Al_2O_3 and SiO_2 particles. Specifically, the tensile strength rose from 280 MPa to 419 MPa, flexural strength increased from 421 MPa to 490 MPa, impact resistance improved from 1.9 J to 2.8 J, and Vickers hardness elevated from 16 HV to 25 HV across the experimental runs. These findings underscore the potentials of glass fiber reinforced epoxy composites filled with Al_2O_3 and SiO_2 particles for applications in various engineering and industrial sectors requiring enhanced mechanical performance.

Keywords: Glass Fiber, Composite, Vickers Hardness, Epoxy Resin, Al_2O_3 , SiO_2

I. INTRODUCTION

Glass fibers are the materials made from extremely fine fiber of glass which is a non-crystalline material with a short-range network structure, as such it has no distinctive microstructure and the mechanical properties are

determined mainly by composition and surface finish are isotropic, formed when thin strands of glass formulation is extruded into many fibers with small diameters. The technique of heating and drawing glass into fine fibers has been known; however, the use of these fibers for textile applications is more recent. Until this time all glass fibers had been manufactured as staple (naturally formed clusters or locks of wool fibers). The first commercial production of glass fibers was in 1936, and by 1938, Owens-Illinois Glass Company and Corning Glass Works joined to form the Owens-Corning Fiberglas Corporation. When the two companies joined to produce and promote glass fibers, they introduced continuous filament glass fibers and still remain major glass fiber producer[1][2][3].

Comparable mechanical properties are shared by glass fiber and other fibers like carbon fiber and polymers. When utilized in composites, it is substantially less brittle and far less expensive than carbon fiber, although not being as stiff. The marine and plumbing sectors use glass fiber reinforced composites because of its high specific strength, stiffness, improved damage tolerance for impact loading, and strong resilience to the environment [4].

The term 'epoxy' refers to a chemical group consisting of an oxygen atom bonded to two carbon atoms that are already bonded. The simplest is a three-member ring structure known by the term 'alpha epoxy' or '1,2-epoxy'. Because of the different electronegativity of carbon and oxygen, the carbon atoms of the ring are electrophilic. This

atomic arrangement shows enhanced reactivity because of their high strain, compared with common ethers. Thus, epoxies are highly reactive and readily undergoes ring-opening reactions with nucleophile [5]

Recently, epoxy filler materials containing micro, sub-micro, and nanoscale particles have been utilized to produce composites with improved features and higher performance. Numerous studies have shown that a variety of micro- and nano-inorganic fillers, including nano-Si₃N₄, MnO₂, SiC, ZnO, TiO₂, SiO₂, and Al₂O₃, can greatly enhance the mechanical and tribological properties of polymer composites[6]. The tribological characteristics of composites can also be enhanced by the use of nanoparticles, such as nano-ZnO/poly tetra fluoro ethylene, nano-TiO₂/epoxy, and nano-Al₂O₃/polyimide. Furthermore, compared to nano-micro Al₂O₃/epoxy composite, micro-sized Al₂O₃/epoxy composite was shown to have low potential discharge resistance [7].

A composite material is a material made up of two or more constituent materials. It is sometimes referred to as a composition material or, more commonly, just composite. These constituent materials are combined to produce a material having qualities distinct from the constituent parts, despite their noticeably different chemical and physical compositions. Composites are distinguished from mixes and solid solutions by the different components that remain separate and distinct inside the completed construction. Composite laminates are materials composed of multiple different layers[8].

The goal of the current work is to examine the mechanical characteristics of an E-glass composite that is randomly oriented and reinforced with fibers and filler powder particles.

Random direction short E-glass fiber reinforced epoxy resin composites packed with SiC and Al₂O₃ powder were made by hand lay-up method. While SiC was altered between 0 and 5 and 10% of the volume percentage of filler elements in the composites, Al₂O₃ was kept constant at 5%. Mechanical characteristics was thoroughly examined. Tensile strength and microhardness tests were performed on both filled and unfilled SiC and Al₂O₃ particles in accordance with ASTM guidelines. It is anticipated that this work will expand the use of random direction E-glass fiber composites under dry sliding circumstances.

II. MATERIALS AND METHOD

The methodology used for creating E-glass fiber reinforced epoxy resin composites with SiO₂ and Al₂O₃ particles involved using epoxy resin and hardener mixed in a 2:1 weight ratio to initiate polymerization and create a solid cross-linked polymer network. E-glass fibers, used in unidirectional short fibers (length 1-6 mm), provided reinforcement. SiO₂ particles varied between 2% and 12% by volume, while Al₂O₃ particles were kept constant at 10%. The liquid epoxy and hardener were combined with the specified amounts of SiO₂ and Al₂O₃ particles, and a small amount of the mixture was poured into a mold to create the initial layer. Subsequent layers of unidirectionally oriented glass fibers were then added. The layered composite was placed between two wooden planks, with the bottom plank measuring 500 x 300 x 3 mm, and sealed using another plank with eight fasteners to ensure an airtight fit. This setup allowed the composite to cure and solidify into the desired shape. Once cured, the composite samples were removed from the mold and prepared according to specified dimensions for further testing and analysis.

Sample Code	Filler volume wt % with SiO ₂	Filler Volume wt% with Al ₂ O ₃
C	-	-
R1	2	10
R2	4	10

R3	6	10
R4	8	10
R5	10	10
R6	12	10

Table 1.0 Formulation Table of Composite Powder Particles

III. RESULTS AND DISCUSSION

Tensile Strength

Tensile testing was carried out in compliance with ASTM D3039 guidelines. Figure displays the measured tensile behavior of the epoxy resin reinforced with E-glass fiber and its composite specimens, both empty and filled with constant Al_2O_3 nanoparticles and SiO_2 particles in

various concentrations. It was found that adding filler particles to the composite gradually boosts its tensile strength. The addition of 10 weight percent SiO_2 and 5 weight percent Al_2O_3 particulates to composites was shown to produce high tensile strength when compared to 5 weight percent SiC and 5 weight percent Al_2O_3 and during unfilled particles. Mohanty, Akash [9]

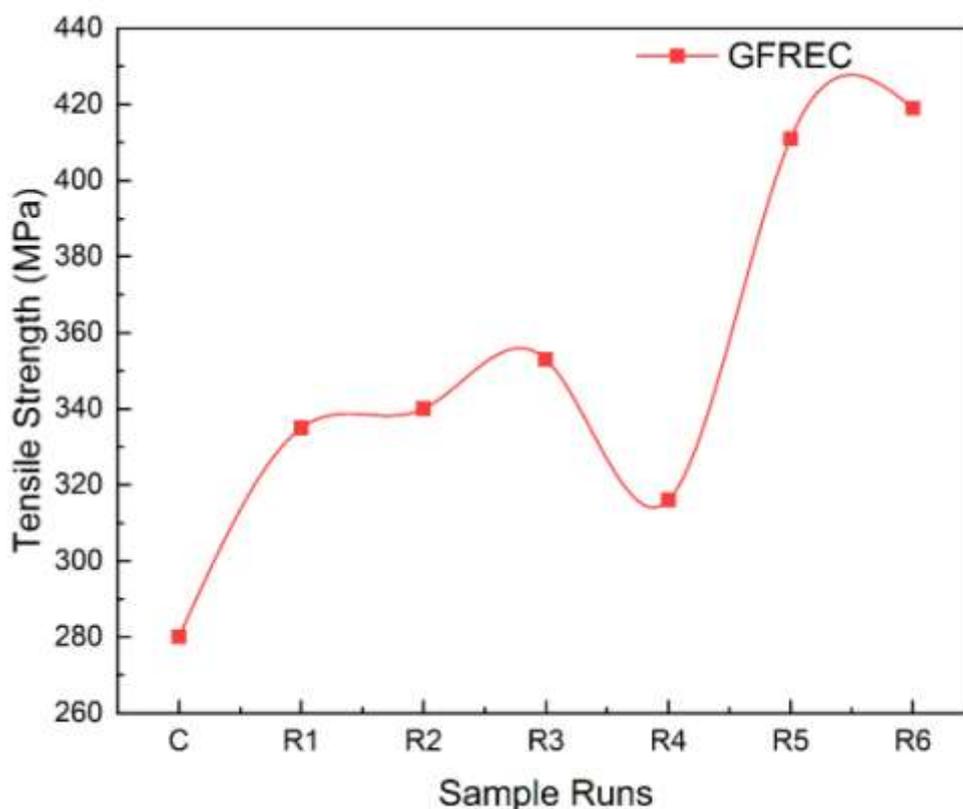


Figure 1: The variation of Tensile strengths of the glass-fiber reinforced epoxy resin composites with weight fraction of Al_2O_3 and SiO_3 particle content.

Increasing SiO₂ filler volume weight percentage from R1 to R6 shows a general trend of increasing tensile strength, the tensile strength steadily increases from 335 MPa (R1) to 419 MPa (R6), indicating a positive correlation between SiO₂ filler content and tensile strength, optimal SiO₂ Concentration with the highest tensile strength is observed at R6 (12% SiO₂), indicating that this concentration showed prospects for enhancing tensile strength in the composite material, however, it's important to note that beyond a certain point, further increases in filler content may not necessarily lead to proportional increases in tensile strength, Comparison with Control (C) which had no filler (C-280) had a lower tensile strength compared to all samples with SiO₂ fillers. This confirms the reinforcing effect of SiO₂ fillers on the tensile strength of the composite material, the tensile strength results demonstrated the significant

influence of SiO₂ filler content on the mechanical properties of the composite material, with higher filler concentrations generally leading to increased tensile strength.

Flexural Strength

Examining the flexural properties of recently created composites is crucial. To further understand the composite's resilience to flexural loading over the addition of particles and E-glass fiber loading in the epoxy matrix, flexural tests were conducted using ASTM D790 standard which measures the flexural properties of the material while under a bending strain or deflection. This test is conducted on a universal testing system using a three-point bend fixture at a rate proportional to the depth of the specimen. ASTM D790 testing was used to determine the flexural strength, the flexural test results are displayed in Figures 2

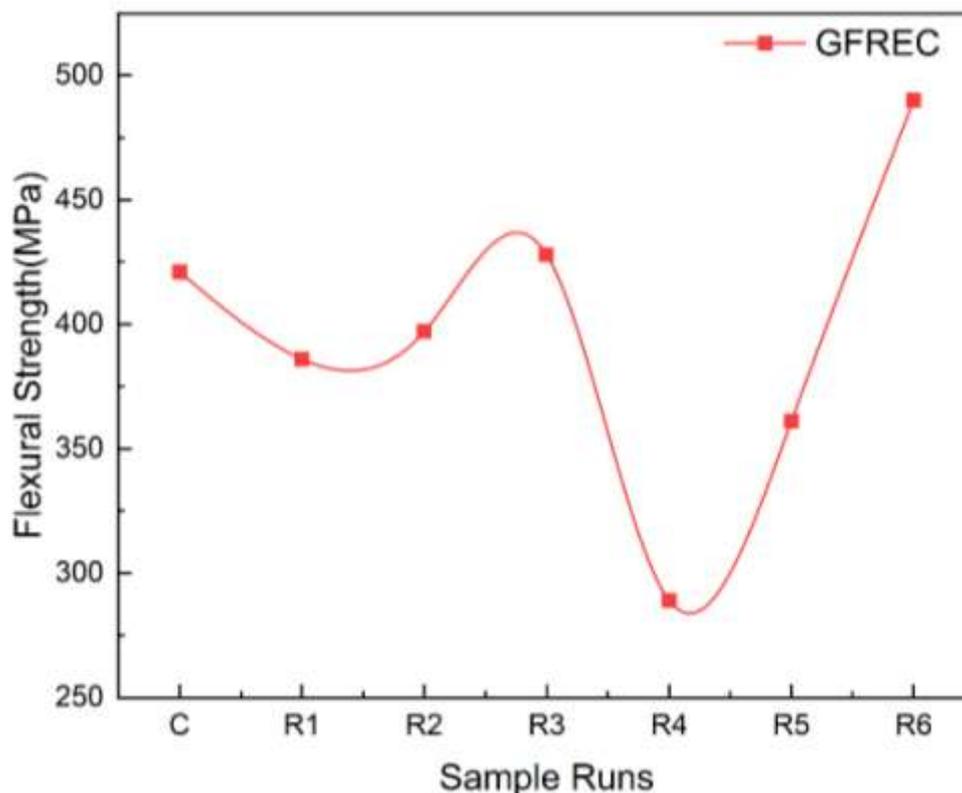


Figure 2: The variation of flexural Strengths of the glass-fiber reinforced epoxyres in composites with weight fraction of Al₂O₃ and SiO₃ particle content.

The flexural strength and flexure modulus of glass-fiber reinforced epoxy composites are significantly impacted by Al₂O₃ particles. Up to a 10% weight increase in Al₂O₃ particle content resulted in increases in flexural strength and flexural modulus. Effect of SiO₂ Filler showed a

Similar trend observed in tensile strength, increasing SiO₂ filler volume weight percentage lead to an increase in flexural strength, the flexural strength shows variation with SiO₂ content, with some concentrations leading to higher values compared to others, while optimal SiO₂

Concentration of the flexural strength peaks at R6 (12% SiO₂), reaching 490 MPa. This suggests that this concentration may be optimal for enhancing flexural strength in the composite material, Comparison with Control (C) as the control sample (C) without fillers has a flexural strength of 421 MPa. Comparing this with samples containing SiO₂ fillers shows the reinforcing effect of SiO₂ on the flexural strength of the composite material to be quite high.

Impact strength

The Charpy impact standardized high strain rate test that was used to find out how much energy a material absorbed during fracture. The standard specimen size for Charpy impact testing was 10 mm x 7.5 mm x 55 mm, per ASTM A370 [10].

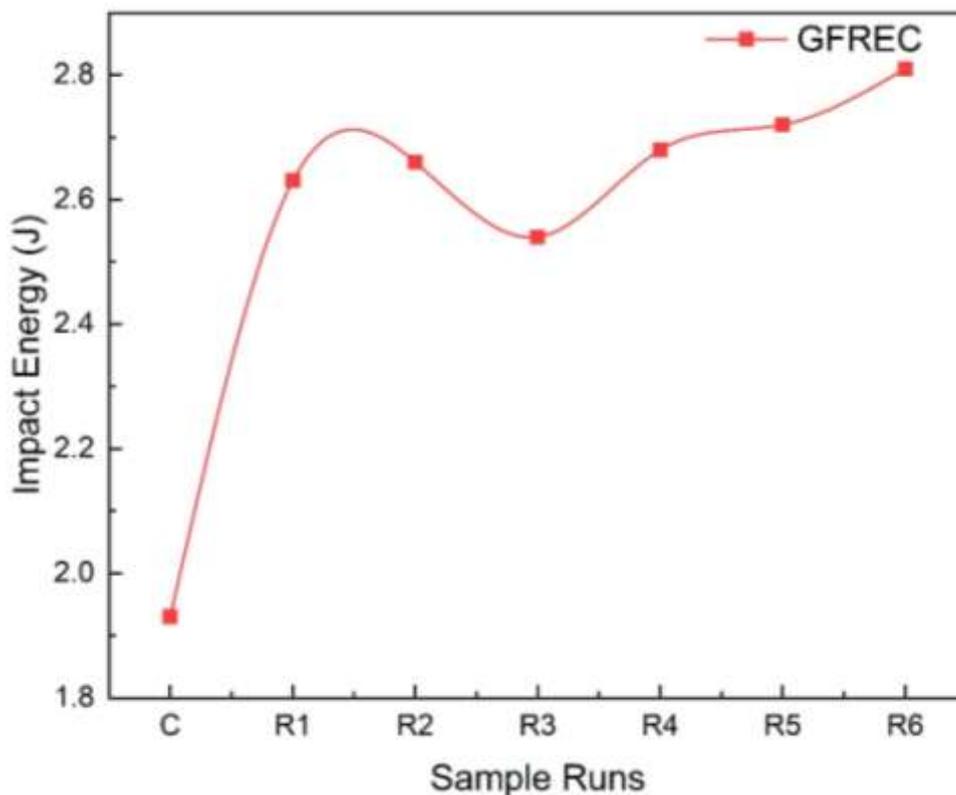


Figure 3: The variation of Impact Strength of the glass-fiber reinforced epoxyres in composites with weight fraction of Al₂O₃ and SiO₃ particle content.

Effect of SiO₂ Filler on the impact strength varies with the SiO₂ filler content, with different concentrations showing different impact strength values. There isn't a clear linear trend observed across all samples. However, the impact strength slightly increased with increasing SiO₂ filler content, and the optimal SiO₂ concentration increased with increasing SiO₂ filler content up to R6 (12% SiO₂), which has the highest impact strength of 2.81J, Comparison with Control

(C) without fillers had an impact strength of 1.93J which was the lowest while samples containing SiO₂ fillers showed higher impact strength.

Vickers Hardness

Vickers hardness testing was done at room temperature utilizing hardness (Shore D) and in accordance with ASTM DI-2240 standard. Samples were cut to 40 mm in diameter and 5 mm in thickness.

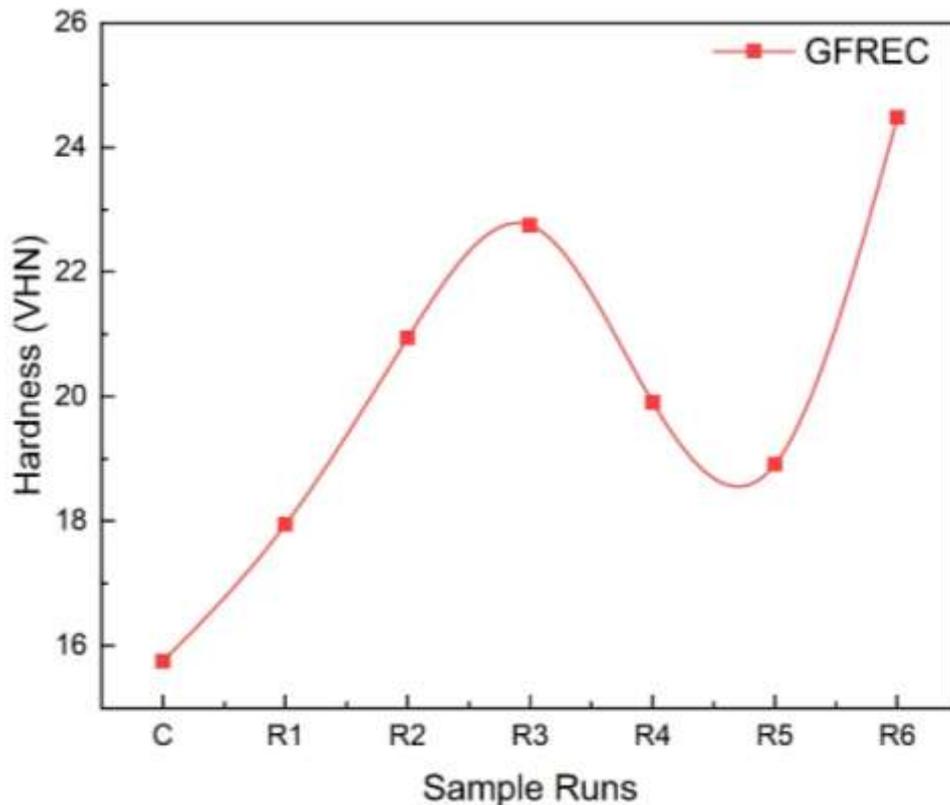


Figure 4: The variation of Hardness of the glass-fiber reinforced epoxyres in composites with weight fraction of Al_2O_3 and SiO_3 particle content.

Effect of SiO_2 Filler: The Vickers hardness tends to increase with increasing SiO_2 filler content, with higher filler concentrations generally leading to higher hardness values, there is a noticeable trend of increasing hardness from R1 to R6, indicating a positive correlation between SiO_2 filler content and Vickers hardness. The highest Vickers hardness is observed at R6 (12% SiO_2), with a value of 24.48 HV, the control sample (C) without fillers has a Vickers hardness of 15.75 HV, comparing this with samples containing SiO_2 fillers shows the effect of SiO_2 on hardness.

IV. CONCLUSION

In conclusion, the investigation into the mechanical properties of glass fiber reinforced epoxy composites (GFREC) filled with Al_2O_3 and SiO_2 particles shows the significant improvements achievable through filler incorporation. The study demonstrated notable enhancements in tensile strength, flexural properties, impact resistance, and Vickers hardness with increasing concentrations of Al_2O_3 and SiO_2 particles. These improvements suggest that the addition of fillers effectively reinforces the composite matrix, resulting in

enhanced mechanical performance. The findings of this study hold promise for the development and application of glass reinforced epoxy composites in various engineering fields where robust mechanical properties are paramount. The increased tensile strength and flexural performance make these composites well-suited for structural applications requiring high strength-to-weight ratios, such as aerospace and automotive components. Additionally, the improved impact resistance enhances the durability and longevity of these materials in demanding operational environments. Furthermore, the observed increase in Vickers hardness suggests enhanced wear resistance, expanding the potential applications of the composites in abrasive or high-wear applications. Overall, the comprehensive evaluation of mechanical properties highlights the efficacy of incorporating Al_2O_3 and SiO_2 particles in the composites, paving the way for the development of advanced materials with tailored mechanical characteristics to meet diverse industrial needs.

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