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Effect of S-Glassfibre Loading on the Morphology and Hardness Properties of Epoxy Composites

Bisike Chidiebere Egere, Ibeneme Uche, Philip Abubakar, Oseshi Catherine Okaigbo, Yusuf Lawal Omezia and Egwu Euphemia Chinwe

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Abstract: *In this research work, the effect of S-glass fibre loading on the hardness properties of epoxy material is studied. The s-glass fibre addition enhanced the hardness property of epoxy composites with preeminent formulations found to be 60:40 wt % epoxy to s-glass fibre composition with hardness value of 93.0 HRA and improvement of 16% when compared to the control sample A. Various percentages of S-glass fibre were use to fabricate S-glass fiber/epoxy composites using hand layout method with open mould. The hardness properties of the composites were characterized using Rockwell harness tester. Scanning electron microscopy (SEM) was used to study the distributions of S-glass fibre inside the composites. It was establish that S-glass fibre addition have a good improvement on the hardness property on epoxy material. Furthermore, the more the addition of S-glass fibre into the epoxy, the better the hardness values of the composites until saturation points and after the saturation, the hardness values begins to diminish due to poor interface between the matrix and the reinforcements (s-glass fibre). Please see SEM images for details.*

Keywords*: Composite, S-glass fibre, Epoxy, Hardness, Scanning electron microscopy*

Bisike Chidiebere Egere
Department of Chemical Engineering, Nasarawa State University Keffi, Nasarawa State, Nigeria
Email: egerebisike@nsuk.edu.ng
Orcid id: 0000-0001-5573-3867

Ibeneme Uche
Department of Polymer Technology, Nigerian Institute of Leather and Science Technology, Zaria, Nigeria
Email: ucheibeneme2016@gmail.com
Orcid id:0000-0001-6274-7685

Philip Abubakar
Department of Civil Engineering, Nasarawa State University Keffi, Nigeria
Email: abubakarphilip@nsuk.edu.ng
Orcid id: 0009-0009-8050-1887

Oseshi Catherine Okaigbo
Department of Chemical Engineering, Nasarawa State University Keffi, Nigeria
Email: oseshicatherine@gmail.com

Yusuf Lawal Omezia
Department of Polymer and Textile Engineering, Ahmadu Bello University (ABU), Zaria, Nigeria
Email: lawbil2002@gmail.com

Egwu Euphemia Chinwe
Department of Science Laboratory Technology, Nigerian Institute of Leather and Science Technology, Zaria, Nigeria
Email: e.e.chinwe@gmail.com

1.0 Introduction

Polymers and polymer-based composites have gained significant attention in various engineering applications due to their lightweight nature, ease of processing, and cost-effectiveness (Abral et al., 2019; Aktas et al., 2023). However, many polymer materials, including epoxy resins, have limitations in mechanical properties such as hardness, which can restrict their applications in high-stress environments (Adekomaya & Adamu, 2017; Osabuohien, 2017). To enhance these properties, reinforcements such as fibers, ceramics, and nanomaterials are commonly introduced into polymer matrices (Almeida et al., 2018; Al-Mosawi & Adama, 2017).

Among polymer matrices, epoxy resins are widely used in structural applications due to their high mechanical strength, excellent chemical resistance, and thermal stability (Aktas et al., 2018; Abdullahi et al., 2021). They are employed in coatings, adhesives, and fiber-reinforced composites for aerospace, automotive, and marine applications (Singh et al., 2020). Despite these advantages, epoxy resins exhibit brittleness and limited resistance to wear and deformation, necessitating reinforcement strategies to improve their performance (Suresh et al., 2021).

Fiber reinforcement in polymer composites has been extensively studied as an effective approach to improving mechanical properties (Joseph et al., 2022). Among various reinforcing materials, S-glass fiber stands out due to its high tensile strength, chemical stability, and superior resistance to impact and thermal degradation (Mukhopadhyay et al., 2021). Previous studies have demonstrated that the incorporation of glass fibers into epoxy matrices enhances properties such as hardness, tensile strength, and durability (Chandramohan & Marimuthu, 2011; Mohanty et al., 2023). However, the influence of different S-glass fiber loadings on the hardness properties of epoxy composites remains underexplored, particularly in relation to optimal fiber content and the effect of interfacial bonding at saturation points.

This study aims to investigate the effect of S-glass fiber loading on the hardness properties of epoxy composites. Various weight fractions of S-glass fiber are incorporated into the epoxy matrix, and their hardness is evaluated using Rockwell hardness testing. The morphological characteristics of the composites are examined using scanning electron microscopy (SEM) to understand fiber dispersion and interfacial interactions. This research contributes to the optimization of glass fiber-reinforced epoxy composites for industrial applications, such as automotive components, aerospace structures, and protective coatings, where enhanced hardness is crucial.

2.0 Materials and Methods

2.1 Materials

The materials used in this study included S-glass fibre, epoxy resin, epoxy resin hardener, and a mould-releasing agent. The S-glass fibre had a specific gravity of 2.6 g/cm³ and a weight of 300 GSM. The epoxy resin used was Araldite LY 506, with a specific gravity ranging from 1.15 to 1.20 g/cm³, while the epoxy resin hardener, Aradur HY 951, had a specific gravity of 0.97 to 0.99 g/cm³. Polyvinyl alcohol (PVA) was applied as a mould-releasing agent to facilitate easy demoulding of the composite samples. The details of the materials are presented in Table 1**.**

Table 1: List of Materials Used in the Study

S/N	Material	Type (Specifications)
1	S-glass fibre	300 GSM, Specific gravity: 2.6 g/cm³
2	Epoxy resin	Araldite LY 506, Specific gravity: 1.15-1.20 g/cm³
3	Epoxy resin hardener	Aradur HY 951, Specific gravity: 0.97-0.99 g/cm³
4	Mould-releasing agent	Polyvinyl alcohol (PVA)

2.2 Methods

2.2.1 Fabrication of Epoxy/S-Glass Fibre Composites

The epoxy/S-glass fibre composites were fabricated using the hand lay-up method. Composites were prepared with varying weight ratios of epoxy resin to S-glass fibre, including 100:0 (control), 90:10, 80:20, 70:30, 60:40, 50:50, and 40:60 wt%. The required quantity of S-glass fibre was measured for each composition. Epoxy resin and hardener were mixed in a 2:1 ratio and stirred mechanically using a high-speed motorized stirrer at 1000 revolutions per minute (rpm) for five minutes to ensure homogeneity.

Prior to pouring the resin mixture, the mould surface was coated with PVA to serve as a releasing agent. A thin layer of the epoxy-hardener mixture was first poured into the mould, followed by a layer of S-glass fibre mat. Additional layers of the resin mixture and S-glass fibre were alternately placed until the total fibre content was incorporated. The final layer consisted of the epoxy-hardener mixture, ensuring a uniform outer surface. The prepared composites were then allowed to cure at room temperature for 24 hours before demoulding.

2.2.2 Hardness Testing of Epoxy/S-Glass Fibre Composites

The hardness of the fabricated epoxy/S-glass fibre composites was evaluated using a Rockwell hardness tester (Model Number: 5019, Serial Number: 01554), following the DIN 53505, EN ISO 868, ASTM D2240, and ISO 7619 standards. The tester was manually operated, applying a preliminary test force of 98.07 N (10 kgF) and additional test forces of 490.3 N, 882.6 N, and 1373 N (50, 90, and 140 kgF, respectively). The total test force applied ranged from 588.4 N to 1471 N (60, 100, and 150 kgF).

Each composite sample was prepared in a square shape with dimensions of 10 × 10 × 3 mm. Hardness measurements were conducted on different points of the samples to ensure consistency and accuracy. The results obtained provided insights into the effect of S-glass fibre loading on the hardness properties of epoxy composites. The compositions of the fabricated epoxy/S-glass fibre composites are presented in Table 2**.**

Table 2: Percentage Compositions of Epoxy/S-Glass Fibre Composites

Composite	Epoxy (wt%)	S-Glass Fibre (wt%)
1	100	0.00
2	90	10.0
3	80	20.0
4	70	30.0
5	60	40.0
6	50	50.0
7	40	60.0
8	30	70.0

2.0 Results and Discussion

The influence of S-glass fibre and nano clay reinforcements on the hardness of epoxy composites was analyzed, with Figures 1 and 2 illustrating the variations in hardness values. The hardness values for S-glass fibre-reinforced epoxy composites (Figure 1) ranged from 31 to 93 HRA, whereas the nano clay-reinforced epoxy composites (Figure 2) exhibited a broader hardness range from 31 to 109.6 HRA. These results demonstrate the potential of both reinforcement materials in enhancing the mechanical properties of epoxy composites. The control sample, composed of 100 wt% epoxy (EP100GF0), exhibited the lowest hardness value of 31 HRA, highlighting the inherent softness of the unreinforced polymer matrix. The addition of S-glass fibre resulted in significant improvements in hardness, with composites containing 10, 20, 30, and 40 wt% fibre (EP90GF10, EP80GF20, EP70GF30, and EP60GF40) recording hardness values of 60.8, 71.2, 81.8, and 93.0 HRA, respectively. This progressive increase in hardness up to 40 wt% fibre content can be attributed to effective load transfer from the matrix to the reinforcement phase, strong fibre-matrix adhesion, and restricted polymer chain mobility (Aktas et al., 2023; Al-Mosawi & Tabil, 2022).

Beyond the 40 wt% fibre threshold, a decline in hardness was observed, with composites containing 50, 60, and 70 wt% fibre (EP50GF50, EP40GF60, EP30GF70) recording hardness values of 80.6, 78.7, and 70.6 HRA, respectively. This reduction in hardness at higher fibre loadings suggests that excessive fibre content leads to poor wetting, fibre agglomeration, and void formation, which compromise the mechanical integrity of the composite. Similar trends have been reported in previous studies, where excessive reinforcement loading resulted in diminishing mechanical performance due to weak interfacial bonding and stress concentration effects (Abral et al., 2019; Asasutjant et al., 2018; Avii et al., 2024).

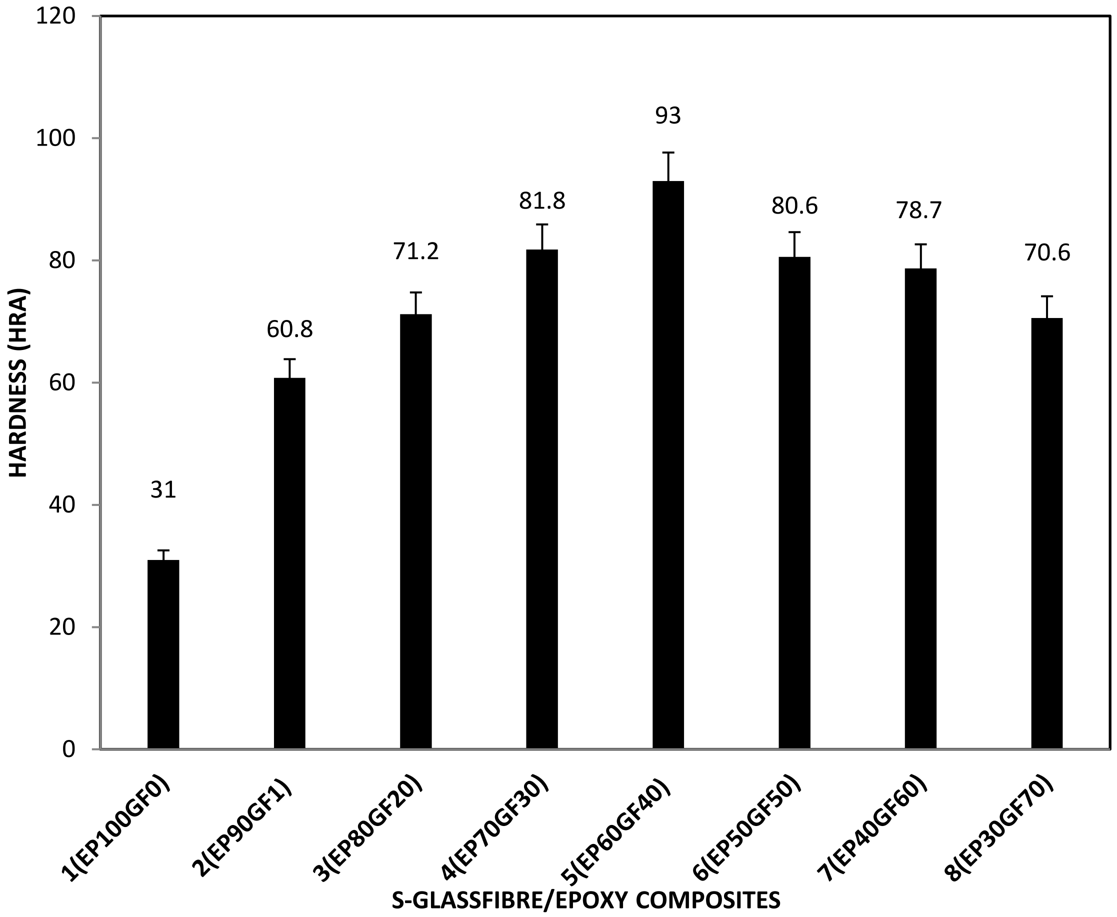


Fig. 1: Effect of Glass fibre Loading on Hardness of S-Glass fibre/Epoxy Composites

In contrast, the nano clay-reinforced epoxy composites exhibited superior hardness properties, with values ranging from 31 to 109.6 HRA. Notably, the composite with 96:4 wt% epoxy/nano clay (EP96NC4) achieved the highest hardness value of 109.6 HRA, making it the hardest composite fabricated in this study. This remarkable enhancement aligns with previous findings that even minute additions of nano clay can significantly improve the mechanical properties of polymers (Abral et al., 2019; Aktas et al., 2023; Almeida et al., 2018). The uniform dispersion of nano clay particles within the epoxy matrix likely contributed to this improvement by increasing cross-linking density, reducing free volume, and enhancing resistance to deformation under applied loads. The higher effectiveness of nano clay in enhancing hardness, compared to S-glass fibre, can be attributed to the nanoscale interactions between the filler and the polymer matrix. Nano clay particles have a high surface area-to-volume ratio, which promotes strong interfacial bonding with the epoxy matrix, leading to improved mechanical strength and stiffness. Additionally, the presence of nano clay particles restricts polymer chain mobility more effectively than micron-sized glass fibres, further enhancing the composite's resistance to indentation and wear (Aktas et al., 2023).

The observed results have significant implications for the selection and design of epoxy-based composite materials for industrial applications. The optimal hardness observed at 40 wt% S-glass fibre content suggests that this composition is well-suited for applications requiring high structural rigidity and impact resistance, such as aerospace components, marine structures, and automotive panels. However, exceeding this fibre content could lead to mechanical drawbacks due to poor resin infiltration and fibre agglomeration, making such composites less desirable for high-load applications.

On the other hand, the superior hardness achieved with nano clay-reinforced epoxy composites indicates their potential in applications demanding high wear resistance, such as coatings, protective layers, and electronic encapsulation materials. The ability of nano clay to enhance hardness with minimal loading also makes it an attractive option for lightweight structural applications where maintaining mechanical integrity while minimizing weight is crucial (Almeida et al., 2018).

Moreover, the findings reinforce the importance of optimizing reinforcement content to achieve a balance between mechanical performance and processability. While both S-glass fibre and nano clay significantly improve hardness, their respective effectiveness depends on factors such as dispersion quality, interfacial adhesion, and processing conditions. Future studies should explore hybrid reinforcement strategies, combining micro- and nano-fillers, to achieve synergistic improvements in composite properties.

3.2 Scanning Electron Microscopy

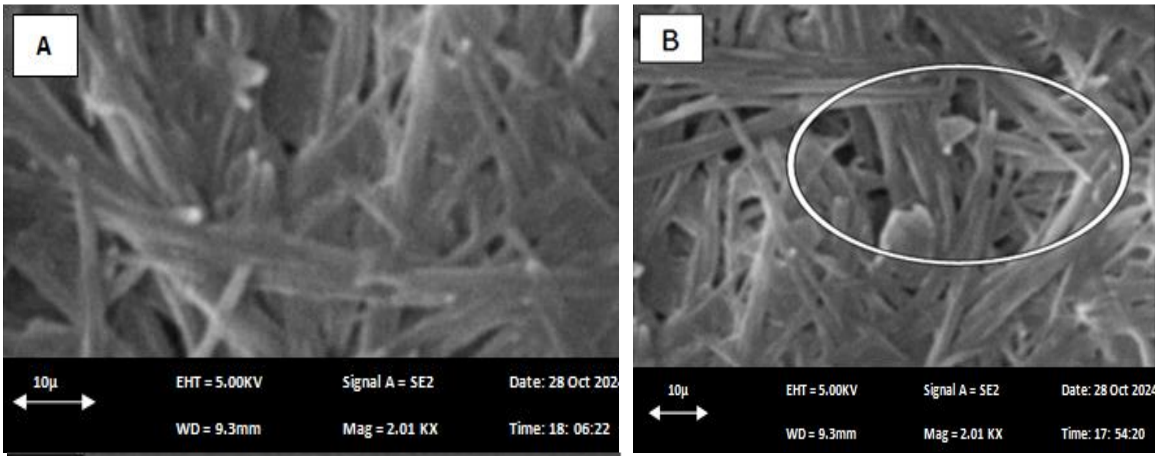
The scanning electron micrographs (SEM) presented in Plates A, B, and C (Fig. 2)depict the morphological structure of the fabricated epoxy-based composites with varying compositions of S-glass fibre reinforcement. The microstructural evaluation provides insights into fibre distribution, interfacial bonding, and the integrity of the composites, which directly correlate with the mechanical properties, particularly hardness.

The micrograph in Plate A displays a well-integrated fibre-matrix structure, where the S-glass fibres appear uniformly distributed within the epoxy matrix. The high fibre density suggests effective dispersion and bonding between the reinforcing phase and the polymeric matrix. This uniformity and good fibre-matrix interaction contribute to the increased hardness observed for this composite, which recorded a maximum hardness value of 93 HRA. The presence of fewer visible voids and fibre pull-outs indicates strong adhesion, which enhances the composite's mechanical stability. This is consistent with literature findings that suggest optimized fibre-matrix interactions significantly improve mechanical performance (Aktas et al., 2023; Abral et al., 2019).

The microstructure in Plate B, which corresponds to Composite 8 with 30:70 wt% epoxy:S-glass fibre, shows an excessive concentration of fibres. While fibre reinforcement is essential for improving mechanical properties, a higher fibre content beyond the optimum threshold often leads to fibre agglomeration, poor wetting, and weak interfacial bonding. The circled region in Plate B highlights regions where fibre clustering has occurred, leading to the formation of microvoids and interfacial gaps between the fibres and matrix. These defects likely contributed to the observed reduction in hardness (70.6 HRA).

Studies have shown that fibre overloading disrupts the homogeneity of composites, causing stress concentration sites and reducing overall material performance (Al-Mosawi & Tabil, 2022; Avii et al., 2024).

consisting of pure epoxy resin without any reinforcement. The image reveals a relatively smooth and homogeneous surface, characteristic of an unreinforced polymer matrix.



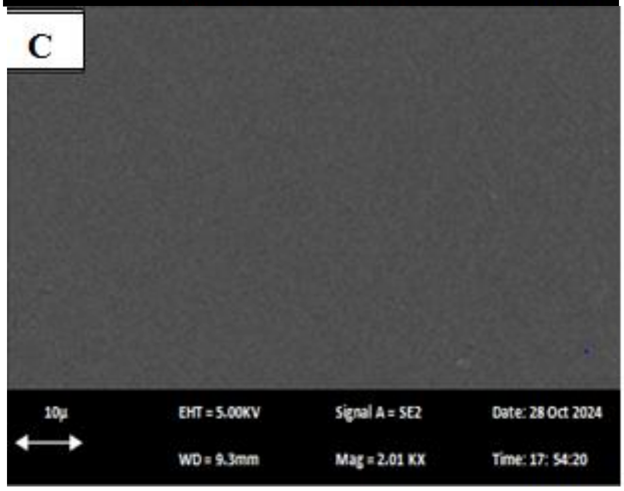


Fig. 2. SEM Micrographs of Epoxy-Based Composites with Varying S-Glass Fibre Content

Plate A: SEM image of Composite 5 (60:40 wt % epoxy: S-glass fibre content)
Plate B: SEM image of Composite 8 (30:70 wt % epoxy: S-glass fibre content)
Plate C: SEM image of Composite 1 (control sample) cured epoxy materia

The absence of any reinforcing phase results in lower mechanical strength, as observed from the least hardness value of 31 HRA. The uniform nature of the surface also indicates that epoxy alone lacks the structural integrity needed for applications requiring high mechanical durability. This aligns with previous research findings that polymers require reinforcement to improve their mechanical robustness (Aktas et al., 2023; Almeida et al., 2018).

3.0 Conclusion

The findings from this study demonstrate that the hardness properties of epoxy-based composites significantly improve with the addition of reinforcements such as S-glass fibre and nano clay. The hardness values for S-glass fibre/epoxy composites ranged from 31 to 93 HRA, with the highest value observed in the composite containing 60:40 wt% epoxy/S-glass fibre. A similar trend was observed in nano clay/epoxy composites, where hardness values ranged from 31 to 109.6 HRA, with the highest value achieved in the composite containing 96:4 wt% epoxy/nano clay. These results confirm the enhancement of polymer mechanical properties through the inclusion of reinforcing agents, aligning with previous findings in the literature.

The scanning electron micrographs provided insight into the microstructural characteristics of the composites. The control sample, composed entirely of epoxy, exhibited a smooth and featureless morphology, confirming its low hardness and mechanical integrity. In contrast, the SEM images of the reinforced composites revealed well-distributed fibres and improved interfacial bonding, particularly in composites with optimal fibre content. However, when the fibre content exceeded a critical threshold, defects such as fibre agglomeration, weak interfacial bonding, and porosity became evident, leading to a decline in hardness values.

The study concludes that the optimal reinforcement content plays a crucial role in enhancing the hardness and structural integrity of polymer composites. Excessive fibre loading leads to diminished mechanical performance due to poor wetting and inadequate bonding between the matrix and the reinforcement. These findings have important implications for the development of high-performance composites in engineering applications such as aerospace, automotive, and construction industries, where mechanical strength and durability are critical.

Based on the observations, it is recommended that future research explores the optimization of reinforcement dispersion to further enhance mechanical properties. The use of surface modification techniques on reinforcing agents may improve interfacial bonding and overall composite performance. Additionally, investigating the effects of different fabrication techniques and environmental conditions on the mechanical stability of these composites will be beneficial for their practical application.

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