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Research Article

Evaluation of Mechanical Properties for Epoxy Resin in Nano Composite Diffusion

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This research work developed a method for the analysis of epoxy matrix nanocomposites used in epoxy resin with the incorporation of Al_2O_3 and SiO_2 nanoparticles. The different tests were performed in order to derive the mechanical characteristics and wear properties of Al_2O_3 and SiO_2 nanoparticles. The mixing is performed using an ultrasound process where the nanoparticles are mixed with the resin for a homogeneous diffusion. The strengths observed for the nanocomposite were higher for bending and impact strength because of the Al_2O_3 and SiO_2 nanoparticle incorporation. The wear rate and friction coefficient is observed to be reduced due to the incorporation of Al_2O_3 and SiO_2 nanoparticles into the epoxy resin. This characteristic has a significant benefit of using Al_2O_3 and SiO_2 nanoparticles for loading conditions. The effects of Al_2O_3 and SiO_2 nanoparticles were more effective in epoxy resin, which were more effectively been derived by reinforcing methods.

1. Introduction

Epoxy resins are mostly useful in various structural fields due to their higher strength and higher modulus, which is useful for optimal thermosetting polymers. The resins have a high chemical resistance and are simple in processing. This resin has been in commercial use for a long time which has good characteristics of electrical insulation and chemical resistance [1]. The epoxy resin shows lower cure shrinkage and is more effective in terms of strength, bonding, and reliability factors. On curing, the epoxy resin forms a network with different curing elements like anhydrides, amines, thiols, etc. [2–8]. The characteristic makes epoxy resin more effective in different usages like coating for protection, electronic usage, flooring purposes, painting etc. In recent years, nanocomposites have primarily been used as a composite material to improve the composite's ability to interact with other materials [9–14]. Nano materials are used to combine polymers and solid phases with nanometer dimensions [15]. Various studies revealed that nanocomposites illustrate a high mechanical and thermal characteristic [16, 17]. The densities of the micrometer fillers are higher in value compared to a low density polymer, which hence needs a higher filler count to enhance the mechanical property. This filling also increases the composite weight in the material [18]. The advantage of the nanocomposite polymer is an advantage in physical properties when compared to existing composites, which makes the nanocomposite polymer more optimal for fillers. The nanocomposite has the characteristic of improving mechanical strength with a low filler, which makes the material light in weight [19]. The nanocomposite inclusion can enhance the material stiffness with no effect on its toughness and can improve the holding properties without reducing the transparency or mechanical characteristic with flame retardant properties without changing the color [20, 21]. In recent times, different nanomaterials are used, such as TiO_2 and SiO_2 [22, 23], with epoxy resin to improve the properties of the epoxy matrix composition [24]. The epoxy matrix/nano-TiO_2 exhibits higher performance of mechanical behavior [25]. The inclusion of nano-sized materials is a more optimal means of improving the mechanical and thermal characteristics of thermoset polymers in comparison to the existing micrometer-sized fillers. Epoxy/clay type nanocomposites were used as the most commonly used thermosets. Polymer composites are widely employed as structural materials in the aerospace sector due to possession of light weight. The ability of polymers and polymer composites to self-lubricate is advantageous for tribological components including gears, cams, bearings, and seals. Incorporating good distributed nanosize inorganic powder into a polymer matrix which improves the tribological features of polymer composites [14, 26, 27]. Numerous studies have demonstrated experimentally that metallic or inorganic nanoparticles may efficiently strengthen thermoplastic and thermosetting polymer matrices [16–18, 21, 24]. Researchers have outcomes with methods to vary the resin type, agent for curing, and processing methods to develop new materials in fabrication and processing methods. Nanocomposites are now used in various real time usages [25, 28–30]. In deriving the optimal performance, a good dispersion is needed. Various methods for the dispersion of nanoparticles into a polymer were used in the recent past, which is used for the dispersion of nanomaterials from an agglomerated to homogeneous state. The most commonly used method is the ultrasonic method, which is used for mixing to obtain a homogenous dispersion [20, 31–33]. Supersonic plasma spraying was used to deposit an aluminum oxide-phenolic resin composite layer on top of an epoxy resin matrix composite. The coating and matrix's bonding strength was 25.64 MPa. The mass ablative rate of the samples fell from 0.058 to 0.035 g/s in the oxyacetylene ablation experiment, showing that the Al_2O_3-PF composite coating could significantly increase the ablation resistance of an epoxy resin matrix composite [34]. By using a vacuum bagging approach, Vinay and Venkatesh report the manufacturing and mechanical, wear behavior of glass fiber-reinforced epoxy composites that have nano alumina added in various percentages (1%, 2%, 3%, and 4% by weight fraction). The mechanical and wear behavior of composites have been significantly enhanced by the inclusion of nanofillers. With an increase in the percentage of nanofillers, it was found that the tensile strength, bending strength, hardness, and wear rate were all gradually increasing. According to the findings, 4% of the nano-Al_2O_3 particles in the composite were effective for engineering applications [35]. Exfoliated graphite (EG) and any one of Al_2O_3, $BaTiO_3$/ZnO are combined in epoxy to generate bi-filler composites that increase microwave absorption capabilities. By employing SEM, Raman spectroscopy, and X-ray photoelectron spectroscopy, these composites are evaluated for their compositional and morphological characteristics [36]. In order to enhance the mechanical properties of their glass fiber/epoxy composite, Nayak et al. treated the epoxy matrix with Al_2O_3, SiO_2, and TiO_2 microparticles. The hand layup process is used to create the composites. In comparison to other micro modifiers, it has been found that SiO_2-treated epoxy composites have higher flexural strength, flexural modulus, and ILSS. This might be as a result of silica's smaller particle size compared to other materials. In comparison to other modifiers, the alumina-modified epoxy composite has higher hardness and impact energy. SEM shows clustering of Al_2O_3 microparticles in the matrix [37]. This presented work develops a method for study of mechanical property in the epoxy resin using nanocomposite materials. The presented work analyses the impact of mechanical characteristics on the used distribution type and the loading conditions. The mixing process is developed using the ultrasonic process, where the wear property of epoxy Al_2O_3 and SiO_2 is evaluated as a function of Al_2O_3 and SiO_2 nanoparticles.

2. Materials and Methods

This work used the material as epoxy resin (bisphenolA/epichlorohydrin) with an equivalent weight of 185–192 g, at a viscosity of 100–150 poise for a temperature of 25°C. Modified curing agent–cycloaliphaticamine. Al_2O_3 represents the ceramic nanocrystalline phase and consists of primary particles with a size of 100 nm. They are having a specific surface area of 100 m^2/g. The known value of epoxy resin was taken in a beaker. Al_2O_3 nanoparticles were mixed to the resin and stirred using a homogenizer for about 1 to 2 hours. The separation of particle agglomerates is the result of the high shear mixing. After adding the hardener (10 weight percent resin), the mixture was agitated for 14 minutes. After that, the mixture was put into the mold. The composite was cured for 24 hours at 25°C, and then, it underwent a post-cure for 1 hour at 70°C. The mixing of epoxy and nanoparticles of both reinforcements are done by ultrasonic dispersion as shown in Figure 1. Al_2O_3 nanoparticles are very small size and easily bind with the matrix. 100 nm is selected based on the previous studies.

3. Mechanical Properties' Test

3.1. Flexural Test. Bending tests are completed using ENISO 178 with a Zwick universal testing machine at room temperature and deformation rate of 0.05 mm/s with ASTM D790 standards. Five samples of each kind were tested to determine flexural characteristics.

3.2. Izod Impact Test. This test is performed using an impact tester machine in accordance with ASTMD256 standard [26]. The Notched Izod impact test was performed on samples with size of 64 × 12.7 × 4 mm.

3.3. Hardness Test. The hardness test is performed using a durometer called "durometer hardness". The durometer intender foot is penetrated into the test sample for the measurement of hardness of the sample. As per standard ASTMD2240 [27], the hardness is measured using a durometer of type D.

3.4. Pin on Ring Wear Test. Tribological properties of the nanocomposite was performed on the POD apparatus with dry condition. A counter body is made up of carbon sterling which is hardened and smoothly polished sample for POD testing by maintaining pressure of 3 MPa and velocity of

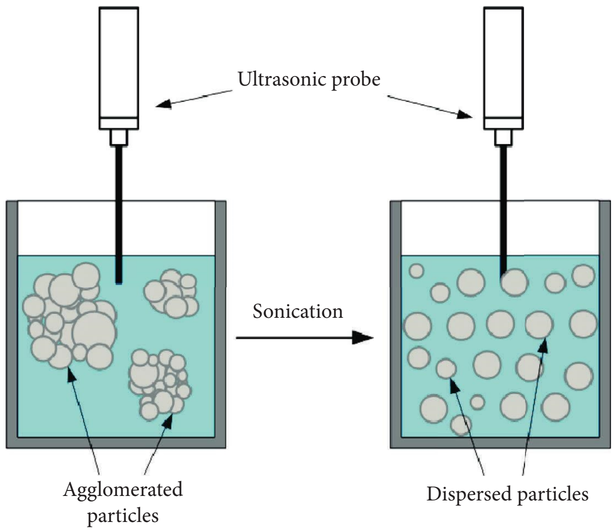

Figure 1: Ultrasonication dispersion.

0.1 m/s. To reduce the running period, all test samples were pre-worn to their average surface area before wear testing. This process minimizes the running time. Under ambient condition, the test was performed for a period of 3 hours. In the test period, the wear process removes certain portion of the material which is computed by the difference in weight [38]. The wear out of a tribological system is described by the wear performance which is defined as follows:

$$W_{ts} = \frac{\Delta wm}{\rho F_{nr} D} \frac{mm^3}{Nm}, \quad (1)$$

where

$$\begin{aligned} &\Delta wm\text{–worn mass of test sample}, \\ &\rho - \text{Specific gravity}\left(\frac{g}{cm}\right), \\ &F_{nr} - \text{Force (N)}, \\ &D - \text{Sliding Distance (m)}. \end{aligned} \quad (2)$$

3.5. Scanning Electron Microscopy. To observe the effect of nanoparticles, the morphology of the structure surface is examined which is generated by the Izod impact test. A scanning electron microscope was used for studying the impact due to reinforcement and wearing process.

4. Result and Discussion

4.1. Flexural Test. To test the flexural properties of the epoxy material, a three-point bending test was performed. The test was performed on the composited having Al_2O_3 and SiO_2 nanoparticles. In various past research works, it is outlined that the usage of particles of micrometer size has a rigid behavior in the stress-strain of the polymer composite. The flexural strength is observed to reinforce with a decrease in particle size as the filling content is observed to increase. As the size of the particle is decreased, the nano-sized particles has an increase in the surface area, which results in higher bonding of nanoparticles with the polymer [14]. This results in large interaction of nanoparticles with the polymer matrix and gets higher flexural strength. With varying content of Al_2O_3 and SiO_2 in the filling of nanocomposites, Figure 2 shows flexure strength with varying contents of the nanoparticles before and after test. From the observation of Figure 3, 1% addition of Al_2O_3 and SiO_2 nanoparticles results into 15% increase in flexural strength of the epoxy resin when compared to neat epoxy. 3% alumina is added for improving the flexural strength. The increase in flexural strength can be observed as a quality measure for loading and distribution of Nano particles.

The raise in flexural strength is due to bonding of nanoparticles and matrix Al_2O_3 and SiO_2 in nanocomposites. The interfacing quality of nanocomposites has a greater role in the performance of mechanical property. The distribution of the nanoparticle has a greater impact on the performance of mechanical property, defined by the distribution quality of nanoparticles [24]. A proper choice of mixing, results in a proper dispersion which increases the interaction of nanoparticles and matrix. For an effective load transferring, an optimal dispersion attains a higher surface area which results into higher flexural strength in epoxy resin. The loading condition can highly affect the mechanical performance of a nanocomposite. Higher loading results in rise of van Der Waals force among the particles resulting into lower dispersion in the particles. Hence, a high loading condition will decrease the flexural strength between the matrix and nanoparticles. This results in a non-effective load transferring condition. Polymers filled by inorganic particles are observed to improve the stiffness but with a reduction in toughness of the polymer [16, 17]. Due to the combination of inorganic and organic elements in the polymer, the morphology gets changed which results in increase of mechanical performance at nanosize. The increase in interfacial interaction of epoxy resin and Al_2O_3 and SiO_2 nanoparticles results in an increase in the stiffness.

4.2. Impact Test. Impact tests are carried out in industries to observe the characteristic of a material for loading, bending, torsion, and tension. The Izod test is the most commonly used test for the impact test due to an ease in sample preparation and getting the observation data faster [18]. There are two forms of sample preparation for the Izod impact test which is developed as notched or unnotched samples. The effect on a notched sample is observed to be lower compared to an unnotched sample as the sample strength is effective for both crack initiation and propagation. The impact is observed by the propagation of crack only. So, notches in a sample behave like a stress concentrator. If the mixing is not effected, the effect of a stress concentrator can be observed by the particle agglomerates, which operates as a stress concentrator in the polymer matrix. In the present work, it is observed that computation of energy is needed in transferring the material in the crack. The impact strength of nanocomposites with the variation of

Figure 2: Flexural test specimens before and after test.

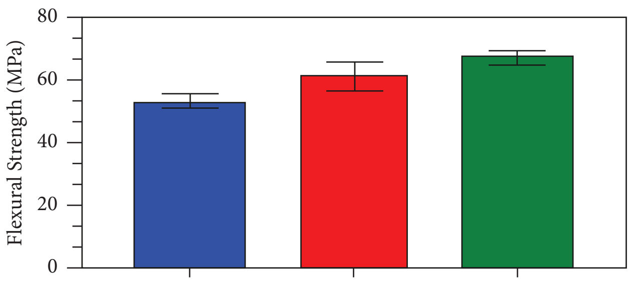

Figure 3: Flexural strength result.

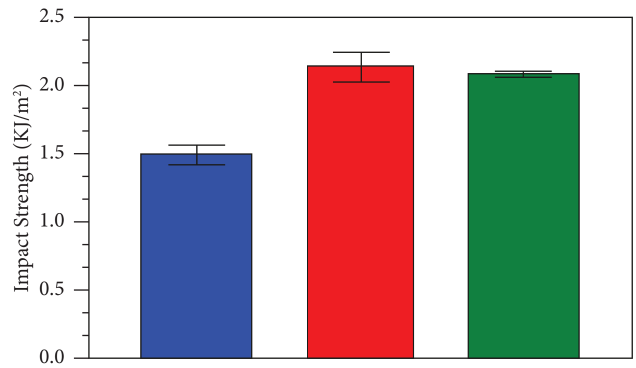

Figure 4: Impact test result.

Al_2O_3 and SiO_2 nanoparticles are shown in Figures 4, and Figure 5 shows impact test specimens.

The addition of Al_2O_3 and SiO_2 nanoparticles shows an improvement in the impact characteristic of the composite. The improvement is more effective at low level of Al_2O_3 and SiO_2 due to a finer distribution of Al_2O_3 while compared to the epoxy reinforcement at low volume of reinforcements. This effect is defined by various factors. The effect of stress concentration is observed to be low as the concentration of nanoparticles are of lower value and the impact strength is not affected by the diffusion of nanoparticles at a lower volume of Al_2O_3 and SiO_2. There is a need of appropriate mixing for a homogenous dispersion. The other factor affecting the impact strength is the loading factor which increases the agglomeration by an increase in stress concentration within the nanocomposite. So, no variations were observed in Figure 5. In comparison to a brittle polymer, the fracture surface of a thermosetting polymer is observed to be featureless in nature. The fracture effect on the surface of thermosetting is based on the testing conditions and the testing polymer structure defining shape and temperature. Three different approaches of propagation modes are seen in the process of curing and testing [21, 24]. For a continuous fracture, the sample is observed to be brittle with smooth surface. The other propagation effect is the unstable brittle which is developed due to stick/slip processing. The microstructure of epoxy with reinforcements (1% and 3%) is displayed in Figure 6.

A crack line is observed in this method. A stable ductile based propagation is observed at a high temperature [28]. The system observes a high plain stress in the epoxy-alumina composite which is used as a stress in yield shearing process. The higher impact strength of the epoxy alumina composite makes them more suitable in usage and set as an optimal replacement to the fibers in a fiber based reinforcement.

4.3. Hardness Test. The variation of the hardness for the epoxy composite with the variation of Al_2O_3 nanofiller content is shown in Figure 7. Due to proper dispersion of Al_2O_3 and SiO_2 nanofiller, the hardness factor is observed to be increased by the addition of Al_2O_3 and SiO_2 nanofillers. A low concentration of Al_2O_3 and SiO_2 nanofillers of 1% shows a larger hardness compared to a 3% Al_2O_3 and SiO_2 nanoparticles. With the increase in filer content, the hardness is observed to increase; however, for a higher filler content ratio, the hardness is observed to be reducing. The process is observed due to reducing adhesion of epoxy matrix and Al_2O_3 and SiO_2 nanofillers [25]. It is found that with increase in filler content, the cluster of Al_2O_3 increases. A minimization of hardness is observed with the epoxy composite. Figure 8 shows hardness test specimens.

4.4. Pin on Disc Wear Test. The mechanical characteristic of the epoxy matrix filled with Al_2O_3 and SiO_2 was observed in previous sections. As there is no association observed for mechanical and tribological performance, the wear characteristic of the epoxy due to change in nanoparticles is addressed in this section. In recent methods, it is observed that the nanocomposite filled with nanoparticles are more uniform in coating surfaces compared to existing coating additives [29, 30] for abrasion resistance. Whereas, it is observed that large particles are more

Figure 5: Impact test specimens before and after test.

Figure 6: Microstructure of neat epoxy, epoxy + 1% Al_2O_3 and SiO_2, and epoxy + 3% Al_2O_3 and SiO_2.

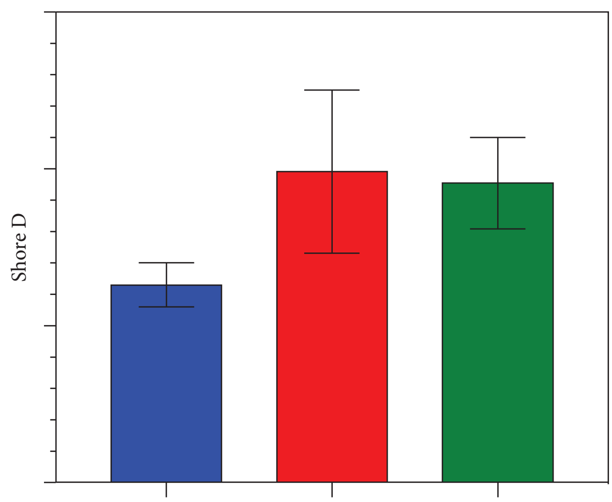

Figure 7: Hardness test outcome.

Figure 8: Hardness specimens.

suitable in protecting the polymer matrix if not been removed [20].

Figure 9 shows the wear rate with varying Al_2O_3 and SiO_2 and Figure 10 shows pin on ring wear test specimens. For reaching a steady state behavior, the wear test would take a considerable time of hours. On the steady state condition, the frictional coefficient and frictional force are observed to be at a constant value and the heat exchanges are at the equilibrium level [39, 40]. All the samples in test are tested under a constant environment. The observation made illustrates a decrease in wear rate with increase in nanoparticles which improves the wear resistance. The wear rate is observed to decrease as observed in Figure 8 with the increase in Al_2O_3 and SiO_2 nanoparticles. The minimization is more effective at a lower filling of Al_2O_3 and SiO_2 nanoparticles for about 1% as compared to 3% volume of Al_2O_3 and SiO_2 nanoparticles. Similar observations were seen with the friction coefficient as seen in Figure 11 for the epoxy matrix filled with Al_2O_3 and SiO_2 nanoparticles. Figure 12 shows set up of pin on ring wear test.

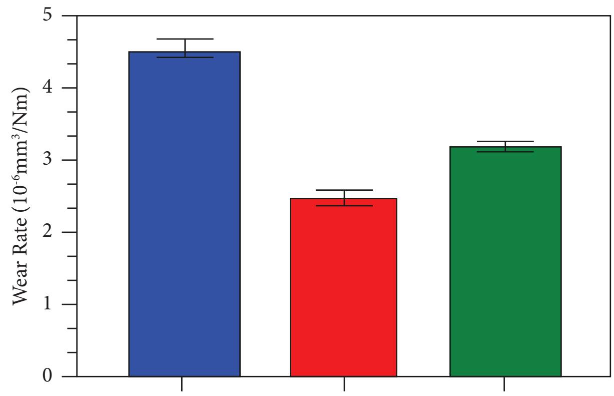

Figure 9: Wear rate result.

Figure 10: Samples for wear test.

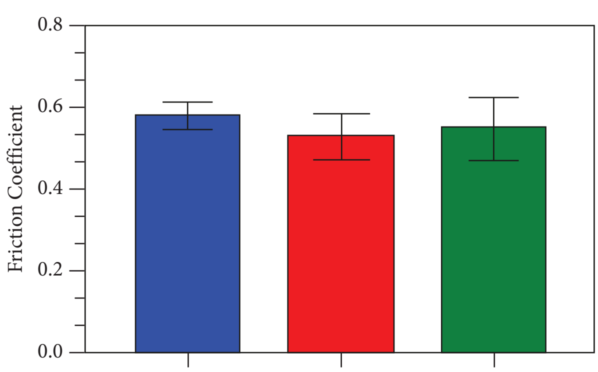

Figure 11: Friction coefficient observation.

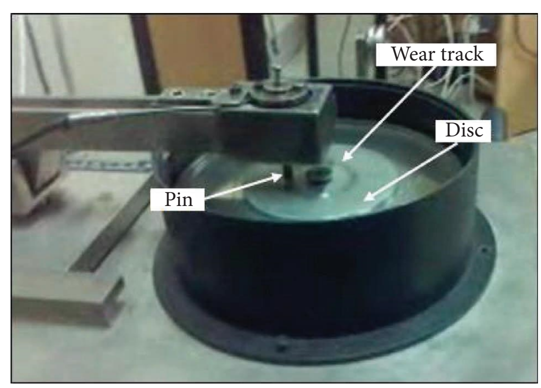

Figure 12: Pin on disc apparatus.

The bonding strength between the filler and matrix has a significant effect on the friction coefficient which improves the wear resistance. Due to shearing stress, the nanoparticle is observed to wear, and particles are observed to separate. The separation process has a great impact on the removal material because of wearing.

5. Conclusion

This paper analyzed the mechanical and tribological characteristic of the epoxy-alumina and silicon nanocomposite. The effect of the epoxy matrix is observed to be effected with the usage of nanoparticles. The presented work applied an ultrasonic mixing for a higher dispersion quality for the epoxy-alumina and silicon nanocomposite. With the introduction of 1% volume of alumina-silicon nanoparticles, the flexural and impact strength is observed to increase. The stiffness of the material is also observed to improve. Whereas, the wear rate and the friction coefficient are observed to minimized with a 1% inclusion to alumina-silicon nanoparticles. With an increase of volume to 3%, the observation is not optimal due to increase in the agglomeration of particles. With the increase in the mechanical property and wear property, the epoxy-alumina-silicon nanocomposite is observed to replace the existing fiber-reinforced composites.

(i) When compared to other fillers, Al_2O_3, SiO_2-modified epoxy composite has higher mechanical parameters, such as flexural strength and flexural modulus.

(ii) As the size of the ceramic particle decreases, the mechanical characteristics improve.

(iii) When compared to other modifiers, the alumina-modified epoxy composite increases hardness and impact energy due to agglomeration of Al_2O_3, SiO_2 microparticles in the matrix.

(iv) For all types of composites, SEM examination clearly shows that the mode of fracture is a combination of matrix crack, matrix/fibered bonding, and fiber pull out.

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

Disclosure

It was performed as a part of the Employment Bule Hora University, Ethiopia.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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