Epoxy Reinforced with Nano-Al2O3 Particles: Mechanical and Tribological Behavior

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Abstract: By introducing Nano size Al2O3 (particle size 100 nm, 0.5–10 wt percent) fillers into an epoxy resin, a systematic study was conducted to investigate matrix properties. To disperse the particles into the resin, a high shear mixing process was used. The experimental results showed that at relatively low concentrations of nano-Al2O3, the frictional coefficient and wear rate of epoxy can be reduced. The composites with 1 wt. percent filler have the lowest specific wear rate of 0.7 x 10-4 mm3/Nm, which is 65 percent lower than unfilled epoxy. The addition of Al2O3 particles to epoxy composites improves their mechanical properties. Scanning electron micrographs have been added to the results to help understand the possible wear mechanisms.

Keywords: Epoxy, Nano-alumina, Mechanical properties, Friction and wear, SEM

Introduction

Polymer composites are commonly employed as structural materials in the aerospace, automotive, and chemical sectors because they are lighter than metals. Tribological components such as gears, cams, bearings, and seals benefit from the self-lubrication capabilities of polymers and polymer composites. It has been shown that including well-dispersed nano- or micro-sized inorganic particles into a polymer matrix can significantly improve the tribological characteristics of polymer composites [1-8]. Numerous researchers have confirmed experimentally that metallic or inorganic nanoparticles have the ability to effectively strength thermoplastic and thermosetting polymer matices[10]. The reinforcement specifically addresses increasing flexural modulus without sacrificing flexural strength.This effect is accompanied by increases in fracture toughness and impact energy, both of which are highly dependent on the filler volume content [11].The distinctive nanoIt has been demonstrated evenatextremely low filler volume content, in the range of

composite effects, on the other hand, can only be achieved if the nanoparticles are evenly scattered throughout the surrounding polymer matrix.5% vol percent, significant improvements in mechanical and tribological properties can be produced. Because of their densely cross-linked structure, epoxies have superior properties such as a high glass transition temperature (Tg), high modulus, high creep resistance, low shrinkage at elevated temperatures, and good chemical resistance. They are used for high-performance coatings for tanks and structures because of their ability to adhere to a variety of fillers. Epoxy is available in special grades for use at temperatures up to 176°C. For particle dispersion, nano-Al2O3 filled epoxy composites were made using a high shear mixing process in this study. The filler content was varied between 0.5 and 10% by weight.[12-15].

ExperimentalDetails:

Huntsman Advanced Materials Pvt. Ltd provided the epoxy resin LY 556 (diglycidayl ether of bisphenol A) and the hardener HY951 (triethylenetetramine) (Mumbai, India). Sigma Aldrich provided the Al2O3 nanoparticles (Bangalore, India). Al2O3 is a ceramic nanocrystalline phase made up of primary particles that are 100 nm in size. They have a 100m2/g specific surface area. In a beaker, the epoxy resin of known weight (g) was placed. The resin was infused with Al2O3 nanoparticles. A homogenizer (Miccra D-9, speed range of 11 000–39 000 rpm) was used to stir the slurry for 2 hours. The separation of particle agglomerates occurs as a result of the high shear mixing. After that, the hardener (10% resin) was added to the mixture and mixed for 15 minutes. After that, the mixture was put into the mould. The composite was cured at 25°C for 24 hours and then post-cured at 70°C for 1 hour. We made composites with filler values of 0.5, 1, 5, and 10% by weight. Flexural tests of pure epoxy resin and composites were performed in a UNITEK 9450 PC universal testing machine in accordance with ASTM D790 at a deformation rate of 1 mm/min, while un-notched impact tests were performed in a FIE IT-30 tester. An FIE RASNB Rockwell hardness tester with the 'F' scale (1/16" diameter ball indenter and 60 kg load) was used to determine the hardness of the materials. The loading duration was set to 30 seconds

To investigate the tribological properties of the nanocomposites, unlubricated pin-on-disc sliding wear experiments were performed. Sliding was done in air at a sliding velocity of 0.84 m/s and a normal pressure of 0.8 MPa for 60 minutes at an ambient temperature of roughly 25°C. To measure the wear loss, the test samples were carefully weighed before and after the wear run using an electronic scale (0.1 mg precision). The normal load and the friction force were used to calculate the friction coefficient. The wear rate is used to describe the wear performance.

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where Δ m is the mass loss in grams (g), ρ is the measured density of the sample in (g /mm^3), F_N isthe normal load in (N) and L is the sliding distance in meters (m).The average of the three readingswas adapted in our results. Scanning electron microscopy examinations on a Jeol-5400 was used tostudy themorphologyoffracturesurfacesfromflexuraltestingandthemorphology of wornsurfaces.

$$Ks = \frac{\Delta m}{\rho \cdot F_N \cdot L}\left(\frac{mm^3}{Nm}\right) \qquad (1)$$

Results and Discussions

Mechanical Properties:The mechanical characteristics of composites with various Al2O3 concentrations are shown in Table 1. The addition of nano-Al2O3 increases the flexural and impact strengths of the composites, with the maximum values achieved with composites containing 0.5wt percent nano-Al2O3. Nanocomposites provide a significant amount of interface. The fact that flexural strength and modulus have increased suggests that stresses are efficiently conveyed via the junction. However, raising the nano-Al2O3 content above 0.5 wt% reduces the flexural and impact strengths of the composites. As a result, it can be deduced that a higher Al2O3 content is undesirable for improving composite mechanical properties.On the other hand, as the Al2O3 component of the composite increases, the hardness of the composite remains nearly unchanged. As a result, nano-Al2O3 may be inefficient in enhancing the load carrying capacity of nano-Al2O3-containing composites. The hardness of composites is merely one component that influences material tribologica lbehavior. An essential element could be the interfacial contact between the epoxy matrix and the nano-Al2O3.

Tribological behaviour:

Friction and wear qualities, in general, characterize the entire tribological system rather than a single material attribute. The specific wear rate (Ks) of the nanocomposites is shown in Fig. 1a as a function of Al2O3 nanoparticle content. The Ks of the nano-Al2O3/epoxy composites were found to be lower than that of the clean epoxy. When the nano particle level was less than 1 wt%, the Ks dropped dramatically. The lowest Ks were found in 1 wt% nano-Al2O3/epoxy. Although the Ks increased as the Al2O3 content increased over 1 wt.%, they were remained lower than the plain epoxy. The Ks value of a 1 wt. percent nano-Al2O3/epoxy composite was 0.7x10-4 mm3/Nm (- 65 percent) compared to 2.0 x 10-4 mm3/Nm for neat resin. Rong et al. [9] looked into it. Different compounding methods were used to investigate the impact of microstructure on the tribological performance of nanocomposites. Different compounding methods were used to investigate the impact of microstructure on the tribological performance of nanocomposites. They found that the nanoparticles' dispersion state and the fillers' microstructural homogeneity considerably improve wear resistance. Rong et al [9] reported a similar effect to the one described in this paper. As shown in Fig. 1b, nanoparticles not only improve wear resistance but also reduce friction coefficient. The nano-composite with 1 wt% Al2O3 has the lowest friction coefficient, obviously. At 1 wt percent, the coefficient of friction falls from 0.57 for unfilled epoxy to 0.44. The nanoparticles that have broken away could also act as a solid lubricant. These factors explain why nanocomposites halower specific wear rates and friction coefficients.

Table1.Shows mechanical properties of epoxy composites containing different concentrations of nano-Al_2O_3

Nano-Al_2O_3contentwt.%	Flexural strengthMPa	ImpactstrengthkJ/m^2	HardnessKg/mm^2
0	36.9	18.68	83
0.5	94.7	31.87	83.5
1	56.6	16.85	82.8
5	34.7	16.36	80.34
10	41.4	18.19	81.8

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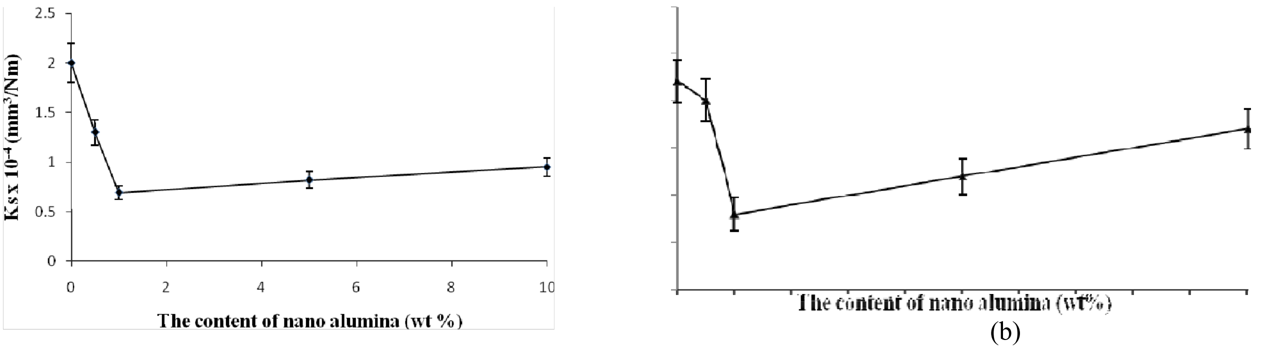
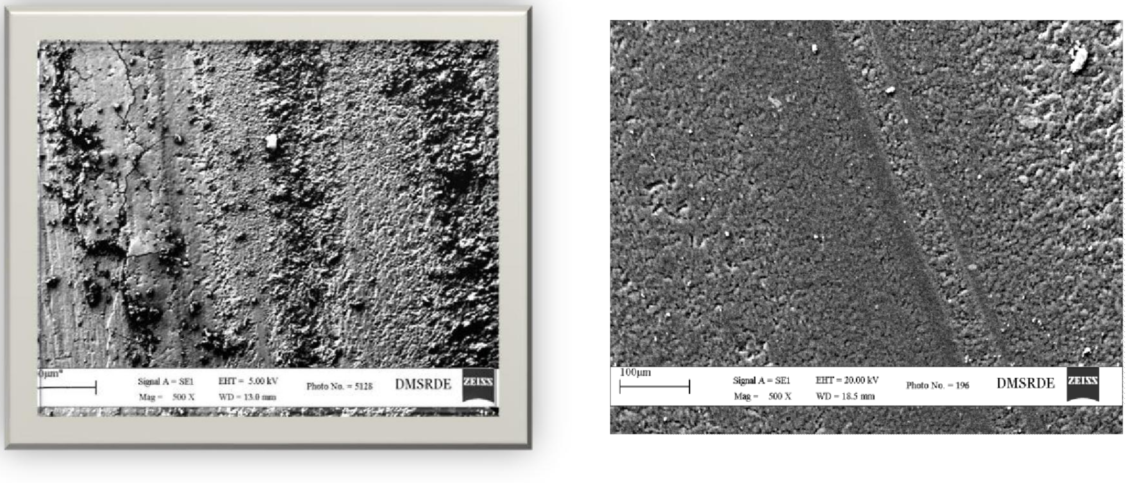


a) (b)

Fig. 1. (a) Specific wear rate of unfilled epoxy and nano-Al_2O_3/epoxy composites (Normal pressure,0.8MPa;Slidingvelocity,0.84m/s;slidingdistance,3014m)(b)Frictioncoefficientofunfilled epoxyand nano-Al_2O_3/epoxycomposites.

Worn surface studies: SEM was used to analyse the morphologies of the worn pins' surfaces at a magnification of 500 X. (Figs. 2a-c). Severe damage, defined by disintegration of the top surface, wear debris, and deep grooves in the sliding direction, are the most prominent aspects on the tidy epoxy's worn surface (Fig. 2a). The looks of filled nanocomposites are radically different and become quite smooth. Although the ploughing grooves are still visible on the sample surface, the groove depths on 1 wt% filled epoxy are shallow (Fig. 2b), and the grooves are completely invisible in certain areas. The low filler loading appears to be sufficient and can result in a significant increase in wear resistance. A rolling effect of nanoparticles during sliding could reduce shear stress, friction coefficient, and contact temperature. This rolling effect minimized matrix damages in the interfacial region. However, if the filler loading surpasses 1 wt%, the wear resistance degrades, and the huge amount of nanoparticles has no wear-reducing impact. Delamination and fatigue cracking of the matrix occur as a result of abrasive wear (Fig. 2c).



(a) (b)

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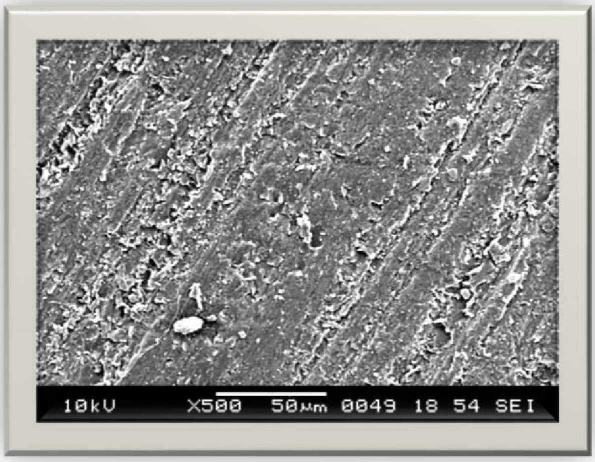

(c)
Fig.2.Micro-photographs showing wornsurface features of (a)unfilled epoxy,
(b) 1 wt% Al_2O_3/epoxy and c)5wt%Al_2O_3/epoxy nanocomposites

Conclusions

The purpose of this study was to develop nanocomposites that outperformed the neat matrix in terms of properties. Following are some inferences that may be drawn:

1. The use of Al2O3 as a reinforcement improves mechanical qualities. The wear behavior of the materials is not significantly influenced by mechanical characteristics.
2. When compared to the neat resin's value of 2.0 x 10-4 mm3/Nm, the optimal wear resistant composition was discovered to be 1 wt percent Al2O3, which showed a reduction in sp. wear rate of -65 percent (0.7x10-4 mm3/Nm). The debris between the sample and the counter face has a favorable rolling effect, according to microscopic examination of the worn surfaces..

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