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Dry Sliding Wear behaviour of Epoxyreinforced with nanoZrO₂ Particles

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Abstract

A systematic study has been conducted to investigate the matrix properties by introducing nanosize ZrO₂ (60-100 nm, 0.5–10 wt.%) fillers into an epoxy resin. High shear mixing process was employed to disperse the particles into the resin. The experimental results indicated that the frictional coefficient and wear rate of epoxy can be reduced at rather low concentration of nano-ZrO₂. The lowest specific wear rate $0.1 \times 10^{-4} \text{ mm}^3/\text{Nm}$ is observed for the composites with 0.5 wt.% which is decreased by 95% as compared to the value of unfilled epoxy. Although the incorporation of nano-ZrO₂ particles leads to increased flexural modulus and flexural strength of epoxy, the wear performance of the composites does not correlate with these static mechanical properties. In contrast, there is a positive correlation between wear resistance and impact strength (i.e. increase in impact strength correlates with a decrease in specific wear rate).

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1. Introduction

Over the past decades, polymer composites have been increasingly used as structural materials in aerospace, automotive and chemical industries, because they provide potential lower weight alternatives to traditional metallic materials. Among these applications, numerous are related to tribological components such as gears, cams, bearings and seals etc., where the self-lubrication properties of polymers and polymer based composites are of special advantage. The feature that makes polymer composites promising in industrial applications is the possibility to tailor their properties with special fillers with different volume fraction, shape and size. The incorporation of well-dispersed inorganic particles into a polymer matrix has been demonstrated to be quite effective to improve the

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performance of polymer composites, including their friction and wear properties. It has been found that nano- or micro-sized inorganic particles can be used to modify the tribological properties of polymeric materials [Wang et al., 1999; Durand et al., 1995; Zhang et al., 2002]. In comparison with the widely used conventional micro-scale particles, nanoparticles have some unique features [Rong et al., 2001]. Firstly, a much higher specific surface area can promote stress transfer from matrix to nanoparticles. Secondly, the required amounts of nanoparticles in polymer matrices are usually much lower than those of the corresponding micro-particles. Therefore, many intrinsic merits of pure polymers such as low weight, ductility, good processability will be retained after the incorporation of nanoparticles. Thirdly, the mechanical behavior of the bulk materials can be improved while the often disturbing abrasiveness of the hard micro-particles decreases remarkably by reduction of their angularity.

It has been well established that the dispersion state of nanoparticles is a crucial factor for the final properties of nanocomposites. Unfortunately, due to their high surface energy, nanoparticles tend to form agglomerates or clusters in a polymer matrix, which can result in property degradations. This is especially the case when the fabrication of composites with high nanoparticle content is attempted. In order to obtain perfect dispersion of nanoparticles in polymer matrices, several methods have been applied to break down the clusters or agglomerates, including ultrasonic vibration [Kuo et al., 2005; Chisholm et al., 2005], special sol-gel technique [Matejka et al., 2000] and high shear energy dispersion process [Wetzel et al., 2003; Wetzel et al., 2006]. Among these methods, ultrasonic vibration is most widely used. Epoxies are widely used for high performance coatings for tanks and structures in the chemical process industry. They are used for potting of electrical components and for making fibre reinforced circuit boards. They produce highest strength and stiffness with stronger reinforcement such as boron and graphite. Their importance in polymer composites is mostly due to their low viscosity for wetting and low shrinkage tendencies. There are special grades of epoxy for service temperatures up to $\sim 176^\circ\text{C}$, but more expensive resins such as polyamides, silicones and bismaleimides replace epoxies for service temperatures above 176°C .

Rong et al., 2001, compared the effects of micro- TiO_2 ($44\mu\text{m}$) and nano- TiO_2 (10 nm) particles on the wear resistance of epoxy. Their results revealed that TiO_2 nanoparticles remarkably reduced the wear rate of epoxy, while the micron- TiO_2 particles did not. Similar conclusion was made by Ng et al., 1999. Zhu et al., 2006 pretreated silica nanoparticles with silane coupling agent, which were then mixed with epoxy using Mannich amine as the hardener. They found that the composite with 3% nano- SiO_2 loading presented the best mechanical properties. The tribological performance and thermal stability of the materials were also improved with the addition of nanoparticles. Xue et al., 1997 found that various kinds of SiC particles, i.e., nano, micron and whisker, could reduce the friction and wear when incorporated into a PEEK matrix at a constant filler content e.g. 10 wt.% (~ 4 vol.%). Nanoparticles resulted in the most effective reduction. Nanoparticles were observed to be helpful in the formation of a thin, uniform and tenacious transfer film, which led to this improvement. The variation of ZrO_2 nanoparticles from 10 to 100 nm was conducted by Wang et al., 1996. The results showed a similar trend as most of the micron particles i.e. the smaller the particles were applied, the better was the wear resistance of the composites. Up to now, various inorganic nanoparticles e.g. Si_3N_4 , SiO_2 , SiC, ZrO_2 , Al_2O_3 , TiO_2 , ZnO, CuO and CaCO_3 were incorporated into PEEK [Schwartz et al., 2000], PPS [Schwartz et al., 2000; Bahadur et al., 2005], PMMA [Avella et al., 2001], epoxy [Rong et al., 2001; Zhang et al., 2002], and PTFE [Li et al., 2002; Sawyer et al., 2003] matrices in order to improve their wear performance. In most of these cases, the optimum filler content of the small particles was always in a range between 1 and 4 vol.% except for PTFE matrix composites. Relatively a few works could be cited on the sliding wear aspect of ZrO_2 filled epoxy nanocomposites. In this context, the present work has developed a nano- ZrO_2 particle filled epoxy composite. A high shear mixing procedure was used to uniformly disperse the nanoparticles into the epoxy resin. The effect of the incorporation of ZrO_2 on flexural properties, impact energy, friction and dry sliding wear has been determined and analysed.

2.0 Experimental

Epoxy resin LY 556 (diglycidyl ether of bisphenol A) and hardener HY951 (triethylenetetramine) were supplied by Huntsman Advanced Materials Pvt. Ltd (Mumbai, India). ZrO_2 nanoparticles were purchased from Sigma Aldrich (Bangalore, India). ZrO_2 represents the ceramic nanocrystalline phase and consists of primary particles in the size range of 60–100 nm. Their large number is characterised by a very high specific surface area of $100\text{ m}^2/\text{g}$. The

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