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Effect of nano silica fillers on mechanical and abrasive wear behaviour of vinyl ester resin

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Abstract—In this paper, influence of different nano particles such as on the wear behavior of a vinyl ester resin composites is reported. Nano silica particles, functionalized with a bi-functional coupling agent, methacryloxypropyl-trimethoxysilane (MPS) is found to improve the wear resistance as well as the tensile strength of the fabricated vinyl ester resin nano composite. The uniform particle dispersion and chemical bond between nano particle and vinyl ester resin was observed. Wear behavior of the resin with silica, zinc oxide and alumina nano particles were studied using taber abrasive wear tester. Wear test was conducted for different load conditions and distances. Experimental result showed that vinyl ester resin with nanosilica particles had significantly improved the wear resistance than alumina and zinc oxide nanocomposites.

Keywords: nano composite, vinyl-esterresin, polymer composites, nanoparticles

I. INTRODUCTION

Polymers and polymer–matrix composites have been found great potentials in industry as a class of important tribo-engineering materials [1]. Polymer composites containing different fillers and/or reinforcements are frequently used for these purposes. Among the ingredients currently available for friction materials, the polymer–matrix and filled fibers play a crucial role in determining the friction and wear performance of the materials [2]. Polymer nanocomposites embedded with inorganic nanoparticles (NPs) have attracted much interest due to their high homogeneity, flexible processability and tunable physical properties such as a mechanical, magnetic, optical, electric and electronic properties [3-5]. Nanomaterials have special physicochemical properties arising from quantum size effect. Polymer nanocomposites containing different fillers and / or reinforcement are frequently used for improved properties. The cheap ceramic nanoparticles with a polymeric matrix make the nanocomposites suitable for potential applications in electronic devices such as photovoltaic cell and magnetic data storage [6]. Vinyl ester resin as a thermosetting polymer matrix, have significantly contributed to the improved production of boats, yachts, swimming pools, safety equipments

and industrial process equipments. The characteristics of the resin greatly depend on reinforcement-resin interface. The high strength of the reinforcement can only be optimized if the correct condition exists at the reinforcement-resin interface. It is reported that nano silica particles were reduced wear rate and more effective under high pressure and high velocity [7].

In situ polymerization method in the presence of nanoparticles have been reported for polymer composite fabrication. In situ methods can create strong chemical bonding within the nanocomposites and are expected to produce a more stable and higher quality nanocomposites [8]. Good bonds between nanoparticles and the polymer is still a challenge for specific nanocomposites fabrication. However, appropriate chemical engineering treatment (functionalization) of the nanofiller surface by introducing proper functional groups could improve both the strength and toughness of the composites with improved compatibility between the nanofillers and the polymer matrix [9-10].

In this paper, the effect of the bi-functional coupling agent, methacryloxypropyl-trimethoxysilane (MPS), on the in-situ free radically polymerized vinyl-ester resin nanocomposites in the presence of silicon (IV) oxide nanoparticle was investigated. Functionalization causes the particle to disperse more uniformly in the polymer matrix. The tensile strength was improved with the addition of the functionalized nanoparticles. Wear rate of the nanosilica filled polymer composite is found to be lesser than the composite with alumina and zinc oxide nanoparticles.

II. EXPERIMENTAL

A. Material used

The vinyl ester resin used as polymeric matrix is Derakane momentum 411-350, manufactured by Dow Chemical company. Vinyl ester resin monomers, with two reactive vinyl end groups as shown in the following structures, enable the cross-linking for the formation. The liquid vinyl ester resin has a density of 1.045 g/cm³ and a viscosity of 350 centipoises (cps) at room temperature. Silicon (IV) oxide with diameter of 20nm procured from Alpha aecer pvt. ltd is used as

filler. Trigonox 239-A is used as curing catalyst and Cobalt naphthenate was used as a catalyst promoter to decompose the catalyst at room temperature.

B. Surface modification

The process used for functionalisation is similar to the one used in [11]. SiO₂ nano particles (5.09g, 83.8mmole) were added into mixture of 4g MPS and 50ml THF [10]. The resulting colloidal suspension was ultrasonically stirred for 1h and precipitated by sedimentation at room temperature. The precipitated nanoparticles were rinsed with THF to remove excessive MPS and dried completely in vacuum oven at room temperature.

C. Preparation of the Nanocomposite

As-received SiO₂ nanoparticles or MPS-functionalized SiO₂ nanoparticles were dispersed into 30ml resin on a specific weight percentage basis. The dispersion is carried out in an ice-water ultrasonic bath for about 1h. The nanoparticle - resin solution was placed in a vacuum oven at 75°C for 15 min to remove the gases. The above particle suspension solution was then ultrasonically stirred in an ice-water bath until the temperature cools down. Then, 2.0 wt. % catalysts were added into the nanoparticle-resin solution, which was stirred and degassed for 3min. Then, 0.3 wt. % promoter was added and mixed quickly. The mixed thicken resin solution was poured into silicon rubber molds. The curing via free-radical bulk copolymerization initiated by catalyst was done at 75°C for 1h under normal atmospheric conditions and cooled down to room temperature in the oven.

D. Tensile test

The mechanical properties of the fabricated nanocomposites were studied using the universal testing machine (mfd. by Shimadzu and capacity 50 KN) with wedge grips operated by pneumatic non-shift wedge grips, following the American Society for testing and materials (ASTM D638). The tensile test was performed at a cross head speed of 20mm / min and strain (mm/mm) was calculated by dividing cross head displacement (mm) by the gage length (mm). Five sample were tested for each composition of the composites. The Dog bone shaped specimens were prepared as described in the nanocomposites fabrication section, using the procedure described in *preparation of the nanocomposite*.

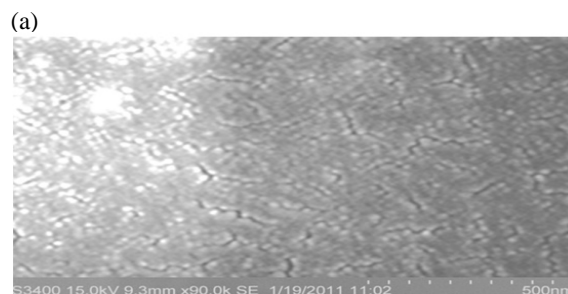
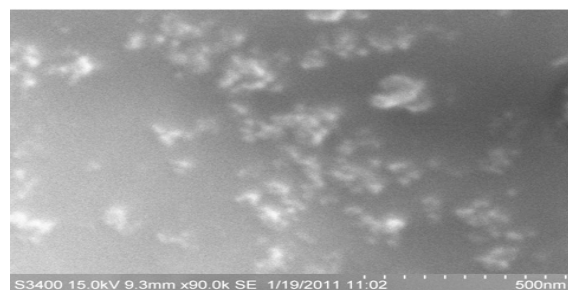
E. Wear test

The wear tests were performed on a Taber abrasive wear tester apparatus according to ASTM D1044, under different abrasive distances. H-18 Calibrade wheel (resiliently bonded abrasive material) is used. The wearing action is caused by two abrasive wheels which are applied at a defined pressure to the material sample, which has been mounted on a rotating specimen holder. The sample material is subjected to a specific number of test

cycles with constant load. The abraded proportion of the specimen is measured in terms of weight loss.

III. RESULTS AND DISCUSSIONS

In order to investigate the particle dispersion quality within the polymer, the composites were polished to study their interior microstructures. SEM images of the cross-sectional area of the polished specimens of composites with a 10 wt. % particle loading, with and without functionalisation are observed. This is shown in fig. 1. It is observed that the nanoparticles aggregate in the form of clusters at a nanometric scale with more air gaps among the clusters indicating a poor adhesion between the nanoparticles and polymer matrix in case of as received nano-particles. However, functionalized nano particles show a uniform dispersion indicating improved interaction between nano particles and polymer matrix.



(a)
(b)
Fig. 1. SEM micrographs (500X) of particle distribution in the composites reinforced with (a) as-received particles (b) functionalized particles after polishing

A. Tensile strength and modulus

The tensile strength of pure resin and nanocomposites were measured by UTM. Stress and strain curves are shown in fig. 2. Tensile tests are carried out for pure resin as well as nanocomposites with and without functionalized

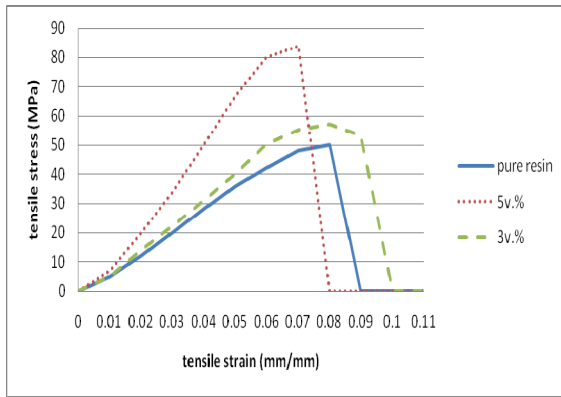


Fig.2 Stress-strain curves of the cured pure resin, 3 vol% and 5 vol% functionalized nanoparticle filled nanocomposites

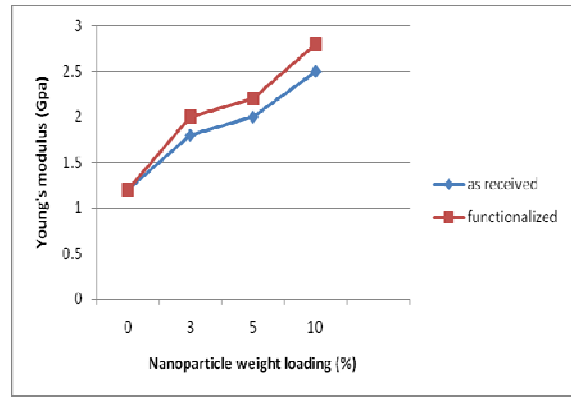


Fig.4 Young's modulus as a function of nanoparticle volume loading.

Nanoparticles with different weight loading. As-received

Nanoparticles decreased the tensile strength; where as functionalized nanoparticles improved the strength. Strength increased with increasing nanoadditive concentration. However, after certain level, a saturation effect is observed (i.e.; after 5 wt. % there is no significant improvement) as shown fig. 3. In case of young's modulus only little difference is observed between functionalized and as-received nanoparticles as shown in fig. 4. The tensile strength was improved by more than 15% (68Mpa) with the addition of the functionalized nanoparticles as compared with pure resin.

B. Abrasive wear volume and sbecific wear rate

Abrasive wear tests were conducted for pure resin, alumina, zinc oxide and silica filled nanocomposites. Abrasive wear volume data as a function of an abrading distance at 500g and 1000g load is shown in fig. 5. The data reveal that the volume tends to increase linearly with increasing abrading distance and strongly depends on the constituents of the composites tested. The data show that wear rate of silica filled nanocomposites is less than that of other nanocomposites.

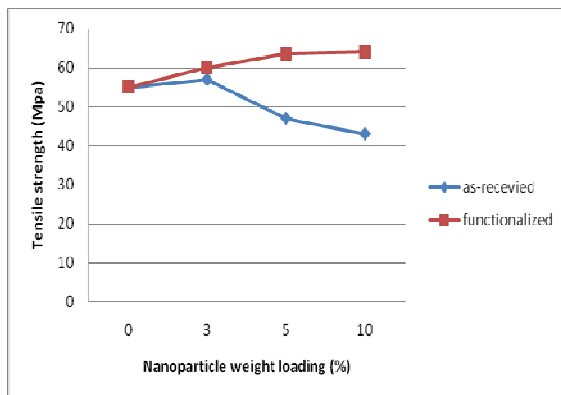
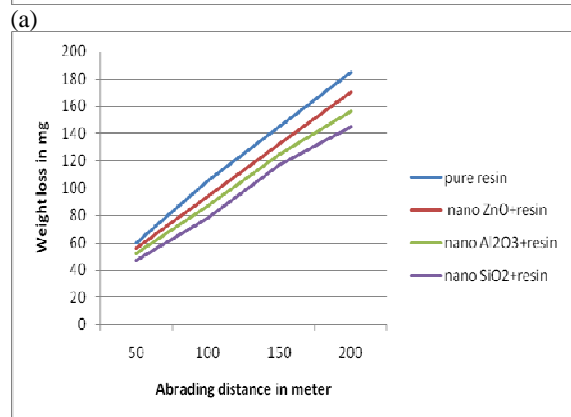
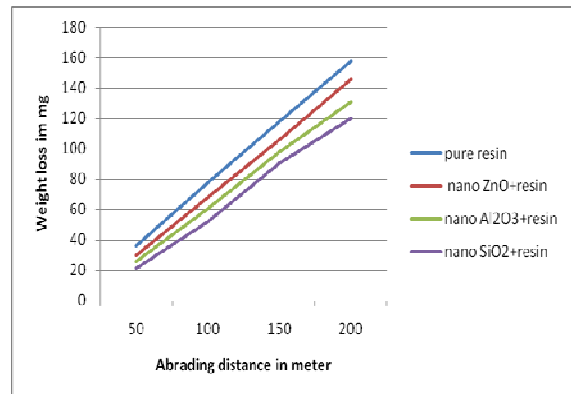


Fig. 3 Tensile strength as a function of nanoparticle volume loading



(b)

Fig .5 Effect of abrading distance on abrasive weight loss of filled vinyl ester resin composites at (a) 500g (b) 1000g

CONCLUSION

Vinyl-ester based nanocomposites reinforced with SiO₂ nanoparticles were prepared and characterized. The mechanical properties and wear resistance have been investigated.

The functionalized Silica nanoparticles showed an improved dispersion within the polymer matrix. Functionalization causes the particle to disperse more uniformly in the polymer matrix. As-received nanoparticles decreased the tensile strength, where as functionalized nano particles improved the strength. Strength increases with increasing nanoadditive concentration. (Particle loading of 3 wt. %, 5 wt. % and 10 wt. %) However, after certain level, a saturation effect is observed (i.e.; after 5 wt. % there is no significant improvement) the tensile strength was improved by more than 15% (64Mpa) with the addition of the functionalized nanoparticles under tensile test.

Experimental result showed that nanosilica was more beneficial than alumina and zinc oxide nancomposites in improving the wear resistance. The wear rate was reduced by more than 20% .

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