EFFECT OF ALUMINA NANOPARTICLE ADDITION ON THE MECHANICAL AND WEAR BEHAVIOUR OF REINFORCED ACRYLONITRILE BUTADIENE STYRENE POLYMER

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ABSTRACT

Nanofillers are emerging class of fillers, which are used extensively in rubbers and plastics. In the present work, effect of alumina nanoparticle addition on the mechanical and wear behavior of reinforced acrylonitrile butadiene styrene (ABS) polymer has been investigated. Alumina nanoparticles were melt mixed with ABS polymer through a twin screw extruder. Tensile test results revealed the Young’s modulus and strength increasing with particle loading. Microscopic examinations revealed the presence of large plastic deformations at the micron scale in the nanocomposites in agreement with the good bonding of polymer matrix with filler nanoparticles. Pin on disk wear test revealed decreased in wear rate as compared to virgin polymer up to 29%. Thermo-gravimetric analysis (TGA) did not show any significant change in the thermal degradation of the nanocomposite as compared with the neat polymer.

Keywords: ABS, Alumina, Crystallinity, Mechanical Properties, Polymer Nano-Composite, Wear.

1. INTRODUCTION

Particulate polymer nanocomposites have received significant attention during the past decade. They are a new class of multiphase materials containing dispersion of particles, typically in the range of 1–100 nm. They represent an attractive set of inorganic–organic materials provide a convenient macroscopic system to study basic scientific issues concerning confined and tethered polymers at a new scale intermediate between nano- and microscale. The incorporation of low volume additions (1–5 wt.-%) of highly anisotropic nanoparticles, such as layered silicates or carbon nanotubes, have resulted in property enhancements with respect to the neat polymer that are comparable with that achieved by conventional loadings (15–40 wt.-%) of traditional fillers. A number of experimental investigations on these materials have indicated that polymer nanocomposites exhibit new and improved properties that are not displayed by the individual phases.
or by their conventional composite counterparts. [1–7] In polymer–clay nanocomposites, the clay particles are about the same size as the polymer molecules themselves, which enables them to be intimately mixed and chemically bonded to each other.[8] The improvement in mechanical properties such as tensile strength, tensile modulus, [9–13] decreased thermal expansion coefficient, increased solvent resistance, outstanding diffusion barrier properties, [6,7,14] and flame retardant capability [15,16] are a few selected examples of the advantages provided by this new class of materials. The presence of nanoparticles generally improves the elastic modulus and does not worsen the rheological and processing behavior and the optical properties of the polymer matrix. As compared with other nanomaterial’s such as carbon nanotubes, alumina is cheaper for nanocomposite fabrication [17]. ABS polymer was chosen due to excellent strength, rigidity, toughness and possessing good chemical, stress-cracking resistance to inorganic salt solutions, alkalis, mineral acids. Upon incorporation of the alumina nanoparticles into the ABS polymer matrix, the obtained nanocomposite has potential applications in automobile, piping, electronic packaging and sport industries. The existing challenge in composite fabrication is to improve the wear resistance with the incorporation of nanoparticles with high hardness. This can be achieved by improving the response of the material to an applied stress which strongly depends upon the linkage between the filler and the polymer matrix. The interfacial interaction between the inorganic nanoparticle and the organic polymer matrix plays a crucial role in determining the quality and properties of the inorganic-organic nanocomposite. [18-20]

Alumina nanoparticles [17, 21-24] have been used as filler, respectively, for nanocomposite fabrication. In this paper, the alumina nanoparticles were used as filler material dispersed in to polymer matrix using melt mix technique. The melt mix technique has been preferred over solvent method due to simple and environmentally-friendly nature of the process. The addition of the nanoparticles was observed to have no deleterious effect on the thermal stability as compared to the neat resin.

2. EXPERIMENTAL

2.1. Materials

The polymeric matrix used was ABS, MIF 45 grade (manufactured by the BEPL Chemical Company). The received polymer has a density of 1.045 g cm\(^{-3}\) and a viscosity of 350 centipoise (cp) at room temperature. Alumina (Aluminium oxide, Al\(_2\)O\(_3\), Nanophase Technologies) nanoparticles with an average particle size (APS) of 40 nm and a specific surface area of 44 m\(^2\) g\(^{-1}\) were used as nanofiller for the nanocomposite fabrication. All the chemicals were used as received without further treatment.

2.2. Nanocomposite fabrication

Alumina nanoparticles (specific weight percentage) were dispersed into ABS polymer by melt mixing technique using twin screw extruder (M/s APV Baker, UK, and Model: MP19PC). In this process, the temperature profiles in the barrel were 200 °C, 220 °C, 230 °C, 240 °C, 250 °C from hopper to die. The screw L/D was 25 and screw rotation rate of 60 rpm was used. Tensile, Flexural and Izod impact samples (according to ASTM D-638 M91, ASTM D 790 and ASTM D 256-92 respectively) were prepared using an injection molding machine (M/s Boolani Engineering, Mumbai) with a barrel temperature of 220 °C, 250 °C, 280 °C.

2.3. Characterization

Alumina nanoparticles filled nanocomposites were characterized by thermo-gravimetric analysis (TGA, PerkinElmer) from 25°C to 600°C with an argon flow rate of 50 ccpm and a heating rate of 10°C/min (VNIT, Nagpur). Thermal degradation of the nanocomposites with different nanoparticle loadings was studied by TGA. The mechanical properties of the fabricated
nanocomposites were evaluated by tensile tests following the American Society for Testing and Materials (ASTM, 2005, standard D 637). An Instron 5544 testing machine was used to measure the tensile strength and Young’s modulus (VNIT, Nagpur). The dogbone shaped specimens were prepared as described in the Nanocomposite fabrication section. The specimen surfaces were smoothed with an abrasive sand paper (1000) and the sanding strokes were made in the direction parallel to the long axis of the test specimen. The specimens were conditioned for more than 4 hours in an ambient environment before measurement, as required by the ASTM. Five to seven specimens per sample were tested. Specimens that broke at some obvious fortuitous flaws or near a grip were discarded. A crosshead speed of 0.1 mm min\(^{-1}\) was used and strain (mm mm\(^{-1}\)) was calculated by dividing the crosshead displacement (mm) by the gage length (mm). A scanning electron microscope (SEM, JEOL, VNIT, Nagpur) were utilized to examine the fracture surfaces. The SEM specimens were prepared by sputter coating a thin gold layer approximately 3 nm thick on a polished nanocomposite sample. XRD analysis was used to examine crystallographic changes and percentage crystallinity of resultant nanocomposite. Wear analysis were done using pin on disk tribometer (VNIT, Nagpur).

3. RESULTS AND DISCUSSION

3.1. X-Ray Diffraction

**Crystallinity**

The XRD data of a composite containing variable amounts (0 - 5 wt. %) of alumina filler percentage is shown in Fig. 1. Two major crystalline peaks are at ca. 2\(\theta\) = 20°, which, are characteristic of the amorphous form of ABS. It was observed that the ABS component was amorphous while the alumina phase was, with no discernable peaks, amorphous. Crystallinity data obtained from X’pert software by using striping k alpha 2 methods has shown in Fig. 2. With addition of alumina nanoparticles, percentage crystallinity of nanocomposite initially increases to high value but then shows regular decrease with further addition. This may be due to the agglomeration of nanoparticles with increased addition of reinforcement.

![Fig. 1: XRD spectra of alumina nanoparticles filled polymer composite](image)
3.2. TGA

Thermo gravimetric analysis (TGA) of nanocomposites with 0, 1, 2, 3, 4, 5 wt. % alumina nanoparticles were shown in Fig. 3. TGA analysis has shown no effect on thermal degradation properties of ABS polymer due to the addition of alumina nanoparticles.

![TGA curve for pure and alumina nanoparticles filled polymer](image)

**Fig. 3:** TGA curve for pure and alumina nanoparticles filled polymer

3.3. Mechanical properties

The trend of variation of tensile strength and Young’s modulus of polymer nanocomposite with varying concentration of alumina nanoparticles is presented in Figure 4.

![Plot of Young’s modulus and Stress at peak as a function of nanoparticle loading](image)

**Fig. 4:** Plot of Young’s modulus and Stress at peak as a function of nanoparticle loading
It is observed that on increasing the weight fraction of alumina nanoparticles, the tensile strength increases up to certain value and then it declines. The peak value of tensile strength of the composite, corresponds to 2 wt. % loading of alumina nanoparticles. With the further addition of nanofiller, tensile strength of the nanocomposite shows decreased in value. This is in accordance with the crystallinity data obtained from the XRD results. With higher particle loading agglomeration and formation of gas voids favors due to poor interaction with matrix polymer. The Young’s modulus shows steady increase in the value with increase in alumina loading due to very high modulus of alumina particles.

The trend of variation of Young’s modulus of polymer nanocomposite with varying concentration of alumina nanocomposite is presented in Figure 4. It was observed that the Young’s modulus increase with the increased addition of alumina nanoparticles. Fig. 6 (a), (b) and (c) are SEM micrographs of fracture surfaces for the neat resin, 3 wt. % and 5 wt. % composite with alumina nanoparticles. Even at the micron scale, the neat resin shows a smooth fracture surface while the nanocomposite shows a rough fracture surface. This micro-rough structure can be attributed to the matrix shear yielding or local polymer deformation between the nanoparticles rather than the intra-particle propagating cracks due to the difficulty in breaking the alumina nanoparticle arising from the high hardness as compared with the resin matrix. The SEM images (Fig. 6(c)) showing the protruding nanoparticles also indicates that the cracks pass around the nanoparticle without damaging it, which was also observed in Al₂O₃/CaSiO₃ filled epoxy nanocomposite.[25] The protruding nanoparticles seen on the nanocomposite surface are observed to be covered with the matrix polymer, indicating the presence of good adhesion between the nanoparticle and the polymer matrix through the chemical bonding.[26] In general, the presence of micron-size hard particles
introduces stress concentrations, rendering the resulting composite more brittle than the matrix polymer itself. Also, the voids between the nanoparticle and the polymer matrix and the nanoparticle agglomeration result in the decrease of the tensile strength.

3.4. Wear Analysis

Wear result obtained from wear analysis using weight loss method reveals decrease in wear rate by 28.9% in case of alumina nanoparticles. Variation of wear rate as a function of crystalline behavior of composite materials is shown in Fig. 7.

![Graph showing wear rate against % crystallinity as a function of filler particle loading.](image)

**Fig. 7:** Wear rate against % crystallinity as a function of filler particle loading

![SEM micrographs of wear tracks](image)

**Fig. 8:** (a) & (c) SEM micrographs of the ABS Polymer, (b) & (d) SEM micrographs of the ABS Polymer with 5 vol % nanoparticle loading

Fig. 8 (a) and (b) are SEM micrographs of the wear tracks obtained for virgin and 5 Wt, % alumina nanoparticles filled polymer matrix. This is justified by the reports that the physicochemical interaction between the particle and the matrix plays a significant role in the obtained composites. In other words, the strong chemical bonding improves the mechanical properties of the composites as compared with the weak linkage by van der Waals and hydrogen bonding. With the increase in nanoparticle loading wear rate decreases due to increased hardness and modulus. For the higher
particle loading damage to the polymer surface observed along with slight improved wear rate. Also due to the agglomeration of nanoparticles, tearing of polymer surface can be observed at higher particle loading.

4. CONCLUSION

Alumina nanoparticles filled ABS polymer composite have been successfully prepared using melt mixing method. With the addition of nanoparticles, the ABS polymer nanocomposites show initial increased in strength for lower particle loading but decreases further due to higher particle loading result in to agglomeration and gas voids. For lower particle loading formed particle/matrix interfacial bonding allows for a larger local plastic deformation in the matrix. The net result is a significant increase in both modulus and strength. The addition of the nanoparticles has no deleterious effect on the thermal stability of the composite. The addition of the nanoparticles has also shown improved wear resistance of the composite due to better chemical bounding between the nanofiller and polymer matrix.

REFERENCES


