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RESEARCH ARTICLE

Characterization of Mechanical Behavior of Nylon/Teflon Nano Particulate Composites

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Abstract

Teflon as a filler material to Nylon 6 matrix increases the tensile strength and the hardness of the Nylon/Teflon polymer composites. There is the occurrence of agglomeration of Teflon particles owing to the preference of fluorine atoms of Teflon to form bond with other fluorine atoms of Teflon. Mixture mode of ductile-to-brittle fracture has been noticed in the Nylon/Teflon polymer composites.

1. Introduction

Nylons are favored materials for gears, cams, bearing applications. The wear behavior of Nylons is adequate for dry sliding conditions at higher speeds. When nano-solid lubricants are added to a polymer matrix to form a composite, they play an important role in enhancing tribological characteristics. The inclusion of the ceramic nano-solid lubricants into the flexible and lower thermal resistance polymer can significantly increase its stiffness and thermal stability (Wang et al., 2000). The solid lubricants reduce friction coefficient and wear rate through the decrease of adhesion with a counterface or by creating a transfer film with low shear strength at the interface (Lancaster, 1972).

Polytetrafluoroethylene (PTFE) is an excellent solid lubricant and used commonly in bearing and seals applications. PTFE exhibits high wear rate under normal friction conditions limiting its application fields. Li et al (2002) prepared PTFE/ZnO nano composites. The wear resistance was doubled up with a maximum wear resistance at ZnO concentrations of 15vol%. Sawyer et al. (2003) used 38 nm Al_2O_3 filler to improve the wear performance of PTFE and the wear resistance increased 600 times than that of unfilled PTFE at a loading of 20wt%. Graphite and molybdenum disulfide (MoS_2) have been used with PTFE to reduce the friction coefficient and the wear rate (Bijwe, 2000). Wang et al. (1997) have studied the composites made of poly-etheretherketone (PEEK) with various weight fractions of SiC, Si_3N_4, SiO_2, and ZrO_2. They found an improvement in the wear resistance and reduction in the friction coefficient with the addition of the filler in fractions less than 10%wt. Cho and Bahadur (2004) reported that the addition of 2vol% nano-CuO could enhance the wear resistance of short fiber-reinforced polyphenylene sulfide. The use of Nylon 6 and Teflon as a matrix material and graphite as a filler material to fabricate sleeve bearing and thrust washer is presented (Reddy, 2015).

Nylon 6 finds application in a broad range of products requiring materials of high strength. It is widely used for gears, fittings, and bearings. The present experimental study involves the testing of Nylon 6 blended with Teflon varying the percentage by weight. The mechanical properties are tested.

2. Material and Methods

The matrix material was Nylon 6 and the filler material was Teflon. The melting point of Nylon 6 is 220^{o}C and density at 25^{o}C is 1.23 g/cc. The melting point of Teflon 327^{o}C and density at 25^{o}C is 2.20 g/cc.

2.1 Preparation of Nylon-teflon composites

Different matrix/filler blends were prepared in a torque rheometer with a twin-rotary mixer as shown figure 1(a). Prior to the melt processing, Nylon 6 and Teflon were dried in the oven at 75^0C for 4 hr separately. After Nylon 6 was melted at 220^oC for 5 min at 75 rpm, the Teflon was added in 3 min at the same temperature and at 50 rpm. The blend was kept at 75 rpm for another 5 min. The extruded sample was palletized and stored in sealed packs containing desiccant. The test specimens for tensile tests, and hardness test were prepared using an injection molding machine at 220-230^0C and an injection pressure of 100 bars as shown in figure 1(b).

2.2 Conduction of Tests

The following tests were conducted on the metal matrix composites:

- Tensile test for elastic modulus and ultimate tensile strength
- Vickers hardness test

The as-mold test samples (according to ASTM D 618) are shown in figure 1(c) along with two die halves. The computer-interfaced tensometer was used for the tensile test as shown in figure 2. The loads at which the specimen has reached the yield point and broken were noted down. The extensometer was used to measure the elongation. The load v/s deflection graph was also obtained for each specimen from the computer attached to the machine. The Vickers hardness was used to measure the hardness of test samples.

The optical microscope was used to study the porosity and voids in the test samples. The scanning electron microscope was employed to examine the fracture of the tested tensile specimens.

3. Result and Discussion

The experiments were scheduled on random basis to accommodate the manufacturing impacts (like mixing of ingredients and variation of temperature, density and particle size). Two trials were carried out for each experiment.

3.1 Density and voids

The density depends on the composition of the Nylon 6/teflon polymer composite. The calculated density values of the Nylon/teflon polymer composites were higher than the measured values as noticed from figure 3. This might be due to the formation of voids in the composites. The density of composites increases with increases in the content of Teflon. The void content increases with increase in the Teflon content in the composite. The densities of Teflon and Nylon are 2.20 g/cc and 1.29 g/cc respectively. The optical microscope images shown in figure 4 reveals the presence of voids in the composite having (a) 10%, (b) 15%, (c) 20% and (d) 25% teflon respectively.

3.2 Mechanical behavior of Nylon/teflon composites

The load vs displacement of Nylon/teflon composites is shown in figure 5. It is observed that the load increases with an increase in the Teflon content in the composite. This is because of stiffness induced into the composite due to addition of the Teflon.

The influence of Teflon addition on the tensile strength is shown in figure 6 (a). The engineering tensile strength, true tensile strength and breaking strength increase with increasing Teflon content in the composite. It may due to the good interface bonding between the Nylon 6 and Teflon resulting in good adhesion of particles.

Teflon (PTFE) is composed of carbon and fluorine as seen from figure 7(a). Carbon-fluorine and carbon-carbon bonds are among the strongest in single bond organic chemistry. This accounts for many of its properties. Because of the strong bonds, much thermal energy must be used to break down the material. It is also non-polar; this leads to its chemical inertness. The low coefficient of friction of Teflon results from low interfacial forces between its surface and another material and the comparatively low force to deform.

In Nylon 6 as shown in figure 7(c), the carbonyl oxygens and amide hydrogens can have hydrogen bond with each other. This allows the chains to line up in an orderly fashion to form fibers. The effects of size and shape of filler particle on the strength and fracture toughness based on particle-matrix adhesion and it was found that an increase of the flexural and tensile strength as specific surface area of particles increased. The specific surface area is higher for smaller particles (Kotiveerachari Reddy, 1997).

The influence of Teflon on percentage elongation (ductility) and hardness is shown in figures 6(b) & 6(c) respectively. The percent elongation (ductility) decreases with an increase content of Teflon in the composite while the hardness of the composite increases. This is because of fact that the hardness of the Teflon is higher than the hardness of Nylon 6. As the content of Teflon increases the composite becomes tougher.

3.2 Fracture Behavior of Nylon/Teflon composites

The fractured surfaces of Nylon/Teflon specimens revealed with SEM are shown in figure 8. The SEM images reveal that the fracture is due to interface debonding. The severity increases with increasing content of Teflon in the composite. Figure 8(a) is of 10% Teflon; figure 8(b) is of 15% Teflon; figure 8(c) is of 20% Teflon; and figure 8(d) is of 25% Teflon. The fracture is also due to elongation voids in the composite. The agglomeration is also observed in the composites having 20% to 25% Teflon. This is owing to the preference of fluorine atoms of Teflon to form bond with other fluorine atoms of Teflon. Occurrence and extent of agglomeration is the competition of two opposing forces acting on the particles during mixing process. These two types of forces include adhesive force between the particles, which reinforces particle agglomeration, and shear force exerted on the particles during the mixing, which leads to breakdown of aggregates (figure 8 (c &d)). The dimples are also observed in the fractured surfaces. The mixed-mode fracture of ductile-to-brittle is observed in the Nylon/Teflon polymer composites.

Figure 1: Preparation of test samples: (a) Torque rheometer with a twin-rotary mixer, (b) Injection molding machine and (c) Two mold halves and test specimens.

Figure 2: Tensometer.

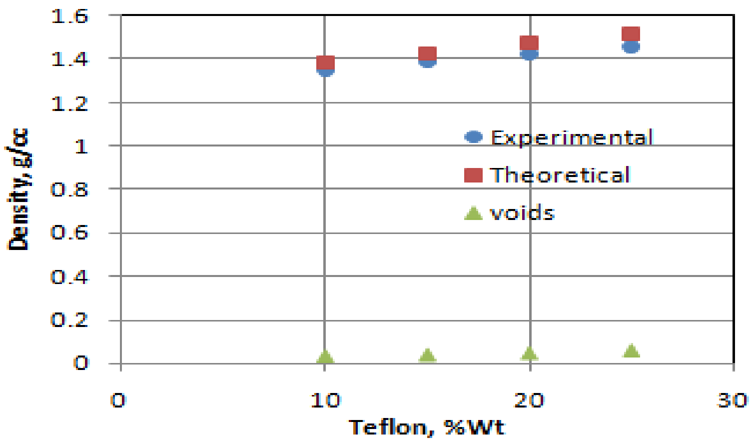

Figure 3: Density and voids of Nylon/teflon composites

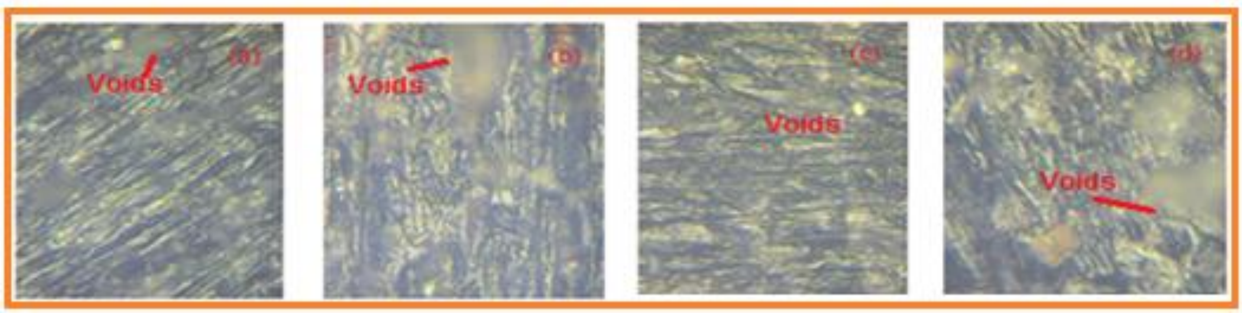

Figure 4: Optical micrographs showing voids or porosity in Nylon/teflon composites

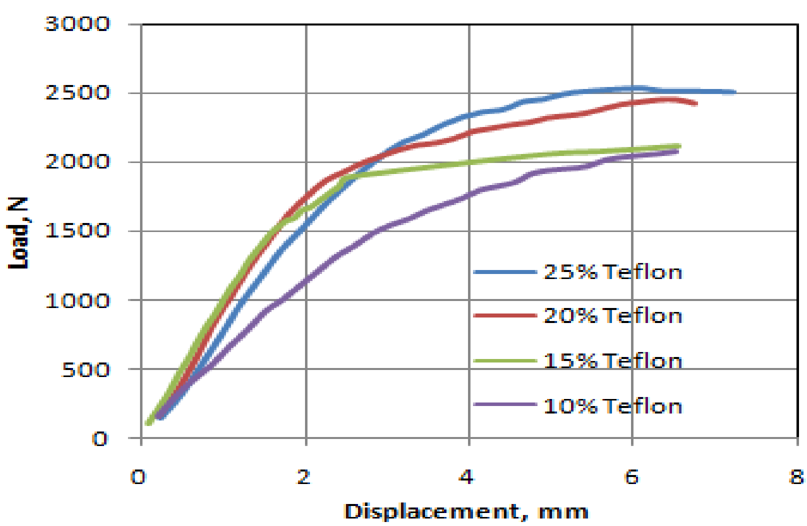

Figure 5: Displacement vs load curve of Nylon/Teflon composites

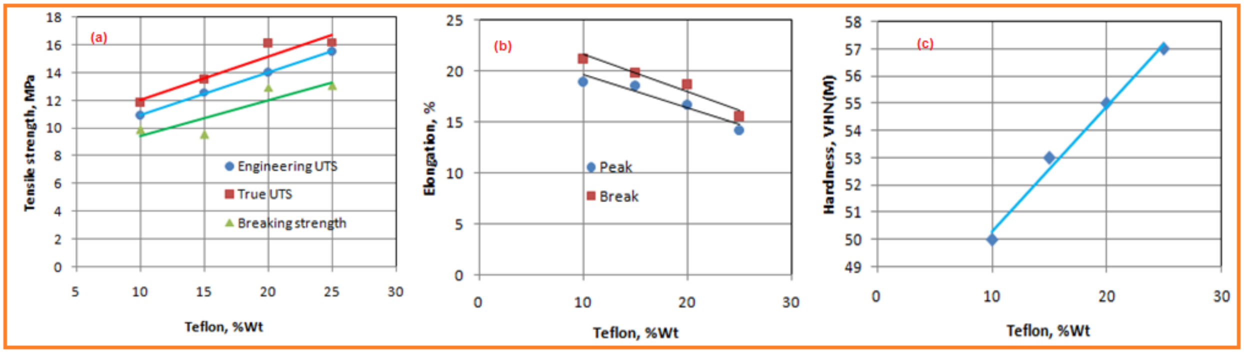

Figure 6: Influence of Teflon on mechanical properties (a) tensile strength (b) ductility and (c) hardness.

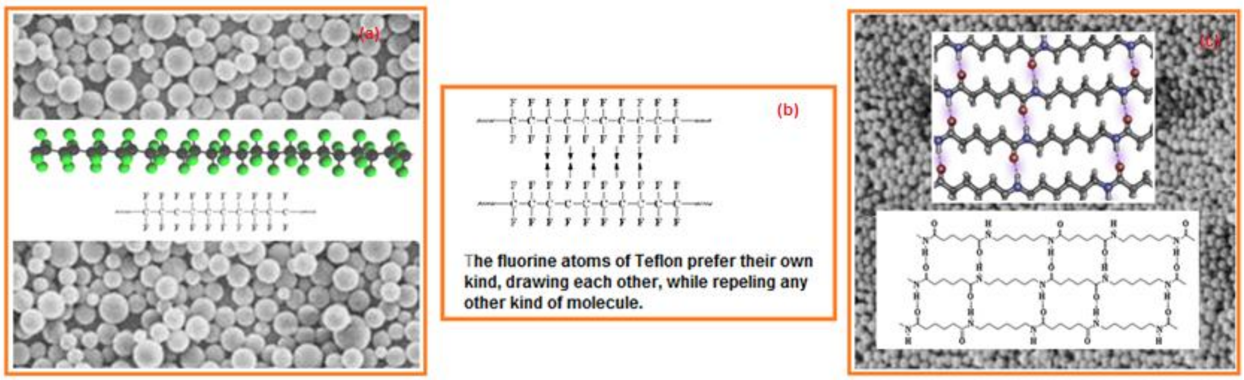

Figure 7: Structure of Teflon (a), Cohesive nature of bonding with Teflon (b) and Structure of Nylon 6 (c).

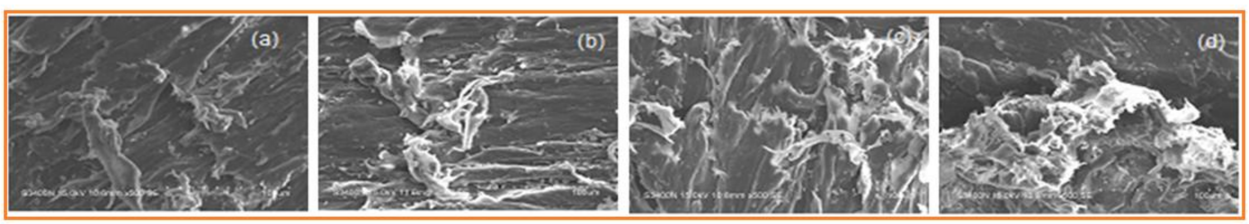

Figure 8: Fracture surfaces of Nylon/Teflon composites

4. Conclusions

The addition of Teflon to Nylon 6 matrix increases the tensile strength and the hardness while it reduces the ductility of the Nylon/Teflon polymer composites. There is the occurrence of agglomeration of Teflon particles owing to the preference of fluorine atoms of Teflon to form bond with other fluorine atoms of Teflon.

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