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Investigation of Mechanical and Tribological Behaviour of Nano Al_2O_3 Reinforced PEEK/PTFE Hybrid Composite for Structural Applications

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Abstract

Polymers and their composites are widely used due to their unique characteristics such as light weight, non corrosive in different environments, self lubrication etc. Still their mechanical properties are not up to the level of metal matrix composites. Hence, it required to increase the mechanical and tribological properties of the polymers to the level of metals. Nano reinforcement is one of the excellent and more sutiable method to increase the properties of the polymers. Nano particles present in polymer matrix enhance the mechanical and triboligical properties. Poly Ether Ether Ketone (PEEK) is one of the thermo plastics with high melting temperature of 343^0 C and hence PEEK Polymer is widely used in structural applications. PTFE (Teflon) is a self lubricating polymer by 10% wt is added with PEEK. In this work PEEK/PTFE reinforced with Nano Al_2O_3 of avg 15 nm is chosen as reinforcement. 5 wt% of Nano Al_2O_3 reinforced with PEEK/PTFE by using twin screw extruder and followed by injection molding process. Rods of 60 mm diameter and 100 mm lengths are produced. Specimens are prepared for mechanical and tribological behaviors. Experimental results showed that nano particles present in the polymer matrix enhances mechanical properties. Also there is a significant reduction in coefficient of friction while testing the prepared composite specimen on pin on disc machine.

Keywords: PEEK, Nano Al_2O_3, Pin on Disc machine, Wear, SEM Images, Mechanical Properties

1. INTRODUCTION

Polyetheretherketone (PEEK) is a kind of engineering thermoplastic with outstanding performance such as high mechanical properties, high temperature resistance, high chemical resistance and high wear resistance. However, in its neat form, PEEK always exhibits a high friction coefficient in dry sliding [1–3], which restricts its tribological applications. In order to reduce the friction coefficient of PEEK to facilitate more applications, some solid lubricants such as polytetrafluoroethylene (PTFE) and graphite are commonly incorporated with PEEK. Some studies have shown that PEEK filled with PTFE has a low friction coefficient [2–6]. PTFE is polymer solid lubricant because of its resistance to chemical attack in a wide variety of solvents and solutions, high melting point, low coefficient of friction and biocompatibility. One mechanism of the reduction in the friction coefficient is the formation of a transfer film on the counter face [7]. However, the significant reduction in the friction coefficient is at the cost of deterioration of the mechanical properties [3] and the wear resistance [4, 6] of PEEK material. In order to avoid its disadvantages, many fillers have been added to the PTFE matrix to enhance its hardness, wear resistance, and load-carrying capacity. However, higher mechanical properties are required under some special severe conditions such as used as gears, piston rings and slide bearings. Inorganic nanometer particles of which diameter is less than 100 nm possess the properties of great specific surface area, high surface energy and large number of atom surface defects in comparison with normal size inorganic particles. The filling of inorganic nanometer particles into PEEK matrix has been done in many literatures to improve the strength, rigidity and tenacity of PEEK with PTFE. This has been achieved successfully by using nano fillers, such as carbon-nanofibers [8] and ceramic nano particles. It has appeared in the literatures that PEEK matrix was filled with nanometer particles: Al_2O_3, SiO_2, SiC, Si_3N_4, AlN and ZrO_2 etc. those all emphasized on the improvement in friction and wear properties.PEEK has advantages over other polymer based

Composites because of its high fracture toughness and excellent resistance to moisture. Nano-Al_2O_3 particles, whose hardness and modulus are higher than those of polymers, has been widely used in the field of polymer composites [9].In order to improve the wear resistance of polymeric materials, another typical measure is to enhance their hardness, stiffness and compressive strength [7].Kuo et al. [10] studied the effect of nanosized alumina on mechanical and thermal stability of PEEK nanocomposites and they found improvement in both properties with the increase of the Nano alumina content. Nano structural interfacial bonding between the polymer and alumina improve the mechanical and thermal stability characteristics of the polymer. PEEK filled with PTFE along with nano Al_2O_3 to improve the wear resistant behaviors is closely related to the ability to improve the characteristics of the transfer film in tribological application [11].Literature says that mechanical properties of the polymers can be enhanced by varying the weight fraction of ceramic nano fillers such as Al_2O_3, SiO_2, SiC, Si_3N_4, AlN and ZrO_2 etc. along the PEEK matrix. In this work, nano particles Al_2O_3 carrying dia of 15 i.e. spherical shapes is reinforced with PEEK-PTFE blend and their effect on mechanical properties is studied.

2. FABRICATION OF HYBRID COMPOSITES

Commercially available PEEK of grade 450 (G) with average diameter of 100 µm, PTFE powder with average particle size of 60 µm and nano Al_2O_3 powder provided by Sigma Aldrich,USA of about 4 nm average diameter were used for the preparation of composites. PEEK and PTFE powders of 90 % by wt. and 10 % by wt. % respectively were blended using twin screw extruder at 400ºC and screw speed of 120 rpm. Subsequently, the nano - Al_2O_3 powder was added to the mixture of PEEK/ PTFE blend with weight fraction of 5% in

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two stages. At first stage ultrasonic vibration were used with alcohol as mixing medium, then the dispersed solution was dried at 100°C in the hot drier for 3 Hrs. to remove the excess alcohol and moisture. At the second stage the dried blended solution were poured in twin screw extruder at 400°C and screw speed of 120 rpm. The extruded pellets were cut into granules by using pellet cutter machines. The extruded granules were then dried in hot electric furnace for about 1 hr. at 80°C to remove the moisture in it. The dried granules underwent injection molding at a pressure of 120 MPa and temperature of 400°C for about 3 Hrs. Then the composites PEEK-PTFE and PEEK-PTFE-Al_2O_3 prepared were cooled at room temperature.

3. TESTING PROCEDURES AND CONDITIONS FOR MECHANICAL BEHAVIOUR

After molding the composite specimen, the samples of different sizes were machined out from the molded composites for evaluating the mechanical and tribological study as per ASTM standard. The static mechanical properties such as flexural, compression and tensile test are carried out on the composite A, B and C. The compression tests were performed on the cylindrical specimen of diameter 10 mm X length 30 mm were machined from the molded specimens as per ASTM standard D 695 at room temperature (25°C) on universal testing machine with the compressive fixtures at a constant feed rate of 0.5 mm/min. The displacement of each specimen was accurately measured through load cell. The flexural tests were performed on the cuboidal specimen of size 65 mm X 13 mm X 3 mm were machined from the molded specimens as per ASTM standard D 790 at room temperature (25°C) on universal testing machine with the flexural fixtures at a constant feed rate of 5 mm/min with a span of length 48 mm. The displacement of each specimen during bending was accurately measured. The Tensile test was performed on the tensile testing machine as per ASTM standard D638 at room temperature. The mechanical behaviors are tabulated in the table 1.

Table1. Compression and flexural strengthof peek and its Various composites

S.No	Specimen	Flexural Strength in MPa	Compression Strength (MPa)
1	PEEK	125	138
2	PEEK + PTFE	119	131
3	PEEK+PTFE+Nano Al_2O_3	133.5	165

4. TESTING PROCEDURES AND CONDITIONS FOR WEAR BEHAVIOUR

Stepped cylindrical pins of diameter and length 5X8 mm and other having a length 10X40mm were prepared from PEEK, PEEK/PTFE and Nano reinforced PEEK/PTFE for wear test. A disc, SS 304 Alloy of diameter 60mm, thickness 5mm with central hole of diameter 6mm is preferred for counter body which is connected to the pin on disc machine. Three different loads viz 2.5kg,5 kg and 10 kg load is applied on the pin with a sliding distance of 11.8 km and the wear results are discussed with the help of SEM image and optical microscope. The results are tabulated in the table 2 and 3.

Tribo Test Conditions

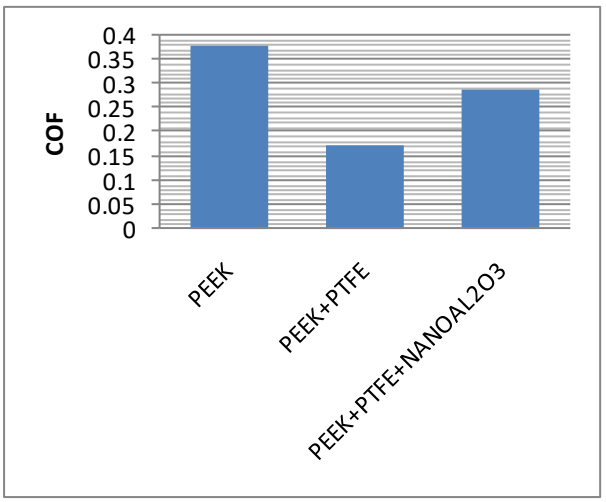
S.No	Description	Conditions
1	Normal Load in "N"	25 ,50 ,75,100
2	Sliding Velocity in "m /sec"	2
3	Sliding Speed in "RPM"	800
4	Wear track Radius in "mm"	26
5	Intimate contact area in "mm^2"	19.63

Table 2: COF for Various Combinations

S.No	Specimen	Coefficient of Friction
1	PEEK	0.38
2	PEEK + PTFE	0.175
3	PEEK+PTFE+Nano Al_2O_3	0.287

Table3: Wear Rate for Various Loads

Load Applied (Kg)	Wear Rate(mm^3/m)
2.5	13.63
5	17.29
7.5	21.07
10	22.30



Time Vs COF for 7.5 kg load is shown in Fig 1. SEM image of the Pin specimen 2.5 kg load with 1000 x magnification is shown in figure 2. SEM image of the Pin specimen 5 kg load with 1000 x magnification is shown in figure 3.SEM image of the Pin specimen 10 kg load with 1000 x magnification is shown in figure 4. Optical microscope image of counter disc 10 kg load is shown in figure 5.

5. RESULTS AND DISCUSSION

After a total period at 50 N, the contact surface of PEEK-PTFE-Al_2O_3 nano power composite reveals that liberation of wear debris was high due to high contact pressure the transfer film developed was thin transfer films were formed and transferred, repetitive of the contact pin with contact surface and wear track was formed on the disc. For heavy loads, Plowing action due to hard nano particles between contacting surfaced caused this trend and observed to be not beneficial for wear resistance property. SEM images clearly reported that adhesive wear is due to increased normal load.

6. CONCLUSION

Nano Al_2O_3 reinforcement improves both axial compressive and flexural modulus noticeably. The PTFE blending in PEEK offered reduction in frictional properties for virgin and as well as nano blended composites. Nano particles addition reduced wear resistance compared to PEEK/PTFE samples.

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