High stress wear studies on addition of polycarbonate in red mud filled isotactic polypropylene

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Effect of addition of polycarbonate (PC) on abrasive wear resistance of red mud (RM) filled polypropylene (PP) composites has been studied. Different volume fractions of PC have been incorporated in RM filled PP. Structural changes of samples were studied by using X-ray diffraction technique. Characteristic intensity peaks of PP have been reduced on addition of polycarbonate. Wear losses at different loads have been evaluated for various blend compositions. Wear loss increased with the increase of PC contents in PP/PC/RM composites up to 30 wt%, thereafter wear loss decreased due to morphological changes in composites. Effect of load variation and sliding distance on wear characteristics of blend composites have been measured and discussed based on the observations of worn surfaces.

Heat distortion temperature of isotactic polypropylene (PP) is inferior as compared to most engineering plastics. This deficiency has restricted its applications in many fields. Properties of PP are modified by incorporation of various types of particulate fillers to achieve desired properties such as high temperature stiffness, impact strength, dimensional stability toughness and creep resistance. Calcium carbonate is added to improve modulus, heat stability, and dimensional stability. Similarly several other fillers such as talc, carbon black, glass beads, mica and red mud (RM) have been extensively added in thermoplastics to improve their properties. RM is a new filler in thermoplastics as compared to talc, carbon black, calcium carbonate etc. It is a solid waste material produced by the alumina industries, following the Bayer's process. Several studies related to characterization and utilization of RM, have been reviewed by Thakur and Das. Addition of RM improves the mechanical properties of PP and its blend. Blending of high performance engineering plastic improves the deficiencies inherent in PP. It has been reported by Liang and Williams that flexural modulus increased with the addition of polycarbonate (PC) in PP. Heat distortion temperature of polycarbonate (PC) at 1820 kPa is around 140°C. Therefore, addition of PC is expected to improve the heat resistance of PP. In previous paper it has been reported that thermal stability of RM particles filled PP was improved with the addition of PC in the composite. Thermal stability, heat deflection temperature, modulus etc. affect the wear properties of composites. These properties are governed mainly by composition, morphology, interface and structure of elements of composites. In one study wear properties have been modified by addition of particulate mixture of lead oxide and graphite in poly tetra fluoro ethylene (PTFE) filled poly phenylene sulfide (PPS).

Some recent studies on RM particulate filled polymers and polyblends have been reported in literature. Mechanical properties of RM filled blends were improved by the addition of RM particles. Increase in finness of RM particles, increased the modulus and tensile strength of the blend. These studies show that addition of RM improves modulus of PP and blending of RM filled PP with PC improves the thermal stability of composite. It shall be interesting to observe the wear properties of PP/PC/RM composites. In present investigation effect of addition of different volume fraction of PC to RM filled PP on high stress wear properties of PP/PC/RM composites have been determined and analyzed.

Materials and Methods

Materials

Isotactic polypropylene (Koylene M0030) having density 0.908 g/cm³ supplied by IPCL, India was used in this work. Commercial grade polycarbonate (Makrolon AL 2643 of Bayer,
Germany) supplied by M/s Enkkay Polymers, Bhopal, India was used. RM particles of size less than 45\(\mu\)m were separated by wet sieving of RM supplied by BALCO India. Major chemical constituents of RM particles are Si\(_2\)O\(_2\) - 9.16%, Fe\(_2\)O\(_3\) - 53.97%, Al\(_2\)O\(_3\) - 14.97%. The mineral phases present and structure of RM particles used in this study have been reported earlier.\(^8\)

**Compounding procedure**

PC, PP and RM particles were kept in air circulating oven at 100°C for 24 h to dry the materials. These materials were mixed on a 20 mm single screw extruder having \(L/D\) ratio as 27.5. Temperatures of feed zone, compressive zone, metering zone and of the die was fixed at 235, 245, 250 and 250°C respectively. Screw rotation per minute was kept at 15. Continuous strands obtained from extruder were granulated to a size of 5 mm length.

**Molding process**

The granules obtained by extruder were compression moulded into 4 mm thick sheets at temperature 250°C for 1 min at 1.0 MPa pressure. Sheet was quenched immediately in the water at 20°C.

**Measurements**

X-ray diffraction patterns were obtained by using philips diffractometer PW 1710 to study the effect of addition of PC in RM filled PP on crystallinity of PP which affect the wear properties.\(^{16}\)

High stress abrasion tests were conducted on a two-body Suga abrasion tester model NUSI (Japan). A rectangular specimen of size 35 mm x
40 mm x 4 mm was slide against a rotating wheel on which abrasive paper of 400 grit size was mounted using double sided adhesive tapes. The embedded hard SiC particles abraded the composite during the test. The weight loss measurements were taken for four set of cycles. Test was conducted for 100, 200, 300 and 400 cycles, corresponding to the sliding distance of 6.4, 12.8, 19.2 and 25.6 m at a constant sliding speed of 2.56 m min\(^{-1}\). Three different loads such as 1, 3, and 5 N were applied. Weight loss was measured after each set of 100 cycles. Fresh paper of the same grit size was used for different loads.

Scanning electron microscope (SEM) JEOL 35CF model was used to observe the surfaces of composites. Leitz optical microscope was used to observe the crystal of PP under polaroid light.

Results and Discussion

Diffraction pattern of PP/PC/RM composites of 90/10/5.26, 0/30/5.26 and 60/40/5.26 are shown as curve a, b and c respectively in Fig. 1. Loading of RM particles is fixed at 5 part per hundred parts of PP/PC blend by weight while PP/PC blend composition is varied. Content of PC in PP matrix increased from 10 wt% to 40 wt%. On comparing the X-ray diffraction pattern of PP (Fig. 2) and PP/PC/RM (Fig. 1) it is noticed that latter exhibits all reflections of PP. The main differences lie in the intensities of peaks, which reduced with the increase of PC content in PP. Peak intensities observed at 14.2, 17.1, 18.62 and 22.09 (2\(\theta\)) values reduced from 1500 to 1305 and 920, from 1410 to 1303 and 855, from 1070 to 963 and 729 and from 1211 to 1033 and 749 for compositions of 90/10/5.26, 70/30/5.26 and 60/40/5.26 respectively.

Addition of polycarbonate in PP matrix reduced the intensity. Polypropylene is a highly crystalline polymer producing spherulitic crystals when allowed to crystallize from its melt as shown in micrograph Fig. 3. The addition of polycarbonate which is present in solid globules form as dispersed and shown in micrograph (Fig. 4) restricts the growth of crystallites. These globules of PC become the centre of nucleation for PP crystals because at crystallization temperature of PP, PP is in molten state whereas PC is in solid state due to-

Fig. 5—Plot for the variation of weight loss with increasing sliding distance of PP/PC/RM polyblend composites subjected to two body abrasion test at applied load of 1 N

Fig. 6—Plot for the variation of weight loss with increasing sliding distance of PP/PC/RM polyblend composites subjected to two body abrasion test at applied load of 3 N
large difference in melting points of two polymers. Therefore, number of nucleate centres increased on addition of PC in PP matrix and resulted in lowering the crystallinity.

Weight loss versus sliding distance curves for the systems studied here, when subjected to high-stress abrasion are given in Figs 5-7. The variation in the weight loss with increasing sliding distance exhibits a near linear relationship. The histogram given in Fig. 8 comparing the weight loss at different applied loads reveals that there is a steady increase in weight loss with increasing load.

The effect of RM loading on the wear behaviour of this system cannot be understood as the loading of red mud particles has been kept constant. However, the fraction of constituent polymers PP and PC has quite significant effect on wear behaviour of the entire system. This effect is illustrated in Fig. 9 in which weight loss is plotted against matrix composition. With the increase of PC from 10 to 30% in the blend, the weight loss increases. Thereafter on increasing PC content to 40%, reduction in weight loss is observed. The increase in wear loss with the increase in weight per cent of PC upto a certain loading and a subsequent decrease in wear loss thereafter can be explained on the basis of morphology of PP/PC/RM composites. PP and PC are incompatible polymers. In a PP/PC blend, PP forms the matrix and globules/domains of PC are dispersed in PP as shown in Fig. 4. During abrasion...
test, the isolated and unattached PC domains are removed from the matrix leaving behind their cavities. The wear of PP occurs due to microcutting and ploughing. On increasing PC content up to a composition of 70/30/5.26, wear loss increases with the increase of PC. A similar observation was made in case of PC when compared with LDPE that PC showed less wear resistance as compared to polyolefin. In present case, at high PC loading of composition 60/40/5.26, the size of domains increased to a size larger than that of abrasive particles as shown in Fig. 4b and hence wear loss decreased. Increase in size of PC domain at 40 wt% is attributed to coalition of small PC domains on reduction of inter domain distances. For instant, on assuming average diameter of PC domain as 10 μm, the distance between two PC domains at PP/PC/RM, 90/10/5.26 composition would be 8.9μm which reduces to 1.6μm at 60/40/5.26 composition. At this distance several PC domains collapse with each other and form a big size domain as observed. It is evident from Fig. 10a that microcutting and microploughing is more severe when the content of PC is around 10% in the blend but as its content increases up to 40% the severity of abrasion reduced as shown in Fig. 10b. However, the one factor in weight loss is still the effect of red mud particles. In case of 90/10 combination of PP/PC, these particles remain in isolation embedded in either of the two polymers. During abrasion, when these particles encounter the abrasives they get fractured and removed as wear debris.

Conclusions
1 Crystallinity of PP decreased on addition of PC due to hindrance offered by domains of PC in the growth of crystals of PP.
2 PC is dispersed in the matrix in the form of small spherical domains of size less than 10 μm at 10 wt% loading. Size as well as number of domains increased with the increase in PC content.
3 Wear loss increased with increased PC content from 10 to 30% and then decreased at 40% of PC in PP/PC/RM because size of domains of PC became larger than that of abrasive particles.

References
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