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Sliding wear of PP/UHMWPE blends: effect of blend composition

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Abstract

In the present investigation, a wear resistant polymer, ultra high molecular weight polyethylene (UHMWPE) was melt blended with isotactic polypropylene (PP) in different proportions. Sliding wear tests were conducted by using Cameron Plint pin-on-disc apparatus. Polymer samples in the form of the pin were tested against EN-24 steel disc at different pressures and sliding speeds. The wear volume of PP reduces significantly on the addition of UHMWPE. At 0.28 m/s sliding speed, wear rate of PP was 15×10^{-12} m^3/m which reduces to 0.28×10^{-12} m^3/m on addition of 15 wt.% of UHMWPE. At 1.09 m/s sliding speed, PP deforms, while 15 wt.% of UHMWPE sample does not show significant deformation. Wear loss of 15 wt.% UHMWPE filled PP blend significantly low as compared to PP. Reduction in wear loss of UHMWPE filled PP blend has been attributed to the reduction in temperature of contact surface. Worn surface of the test sample showed two distinct morphological regions. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Sliding wear; PP; UHMWPE; Blend

1. Introduction

Chemical resistance, high damping properties for low noise emission, ability of dry sliding, etc. makes thermoplastics suitable for several applications. The thermoplastics are sometimes classified by the tribologist into three groups, because of their friction and wear behaviour [1,2]. These are “smooth” molecular profile polymers such as ultra high molecular weight polyethylene (UHMWPE), polytetrafluroethylene; the “normal” polymers such as low density polyethylene and polypropylene; and the “amorphous” polymers such as polymethyl methacrylate (PMMA) and polyvinyl chloride (PVC) [3]. Wear of UHMWPE proceeded by two mechanisms: an adhesive process which occurred immediately after sliding began and a fatigue process which appears after a long period of sliding [4,5]. UHMWPE is known as a wear resistant polymer with a moderate coefficient of friction against steel counterface [6]. A large number of research studies have been publish recently [3–12] covering the various aspects of friction and wear behaviour of UHMWPE under various conditions. In-spite of having good sliding wear properties, the application of UHMWPE is restricted, because it cannot be processed easily. The viscosity of the molten UHMWPE is so high that it is effectively solid, and therefore, does not flow [6]. On the other hand “normal” polymers, e.g. isotactic polypropylene (PP) can be processed very easily, however, the sliding wear properties of PP is inferior. The blends of these two polymers has potential of adding advantages of both the polymers. In this study, blends of PP and UHMWPE of various composition have been developed by using melt blending technique. Sliding wear properties of these blends have been determined and compared with virgin materials.

2. Materials and method

2.1. Materials

Isotactic polypropylene (density 0.91 g/cc, grade SRM 100 N) was obtained from M/s IPCL, Baroda, India and UHMWPE (density 0.93 g/cc grade PILENE ULTRA) was obtained from PIL, India.

2.2. Preparation of blend

PP and UHMWPE powder were kept in air circulating oven at 100°C for 24 h to dry the materials. The dried

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Table 1
Composition of PP and UHMWPE blends

Sr. no.	Designation of sample	Composition of blends	
		PP (g)	UHMWPE (g)
1	A	100	00
2	B	98	02
3	C	96	04
4	D	90	10
5	E	85	15
6	F	00	100

materials were mixed in a single screw extruder having *L*/*D* ratio 27.5. The temperatures of feed, compression and metering zones were kept at 200, 210 and 220°C, respectively. Rotational speed of screw was kept 20 rpm. Molten blend strand was quenched in water at 20°C and cut in the form of granules (3–5 mm length and 3 mm diameter) by using a pelletiser. Compositions of samples are shown in Table 1.

2.3. Preparation of test samples

The cylindrical pins were prepared by using a die and plunger system having an electrical heating arrangement. The schematic diagram of die and plunger system is shown in Fig. 1. Weighed amount of blend sample was fed into the die. Die was heated up to 180°C, the punch was pressed into the die. Die was cooled in water at 20°C. After the solidification of polymer blend, sample was taken out from the die.

2.4. Sliding wear test

Dry sliding wear tests were conducted on a pin-on-disc friction and wear testing machine of Cameron Plint make, no. TE-97/6699. The cylindrical pin specimens of size 8 mm diameter and 53 mm length were tested against EN-24 steel containing 0.59% carbon, 0.25% silicon, 0.8% manganese, 1.02% chromium, 0.30% molybdenum, 1.50% nickel disc of hardness 305 Hv. The test were conducted at different pressure (1.06–6.34 MPa) and sliding speed (0.28–1.09 m/s). The weight loss was measured taken after 300 m of sliding distance. Volume loss, and wear rates were computed from the weight loss measurements. The temperature rise near the contacting surface of the specimen was monitored by using a chromel–alumel thermocouple inserted in the pin, 2 mm away from the contacting surface. Temperature was recorded, which was not the true temperature of contacting surface but provides sufficient evidence of rise in temperature of contact surface and the trend of temperature rise. Specimen pin used in this study is flat ended and the radius of wear path is 4.6 cm. Sliding wear data reported here is the average of at least three runs. Before taking the weight loss measurements, the surfaces of pin and steel disc was prepared to ensure maximum contact.

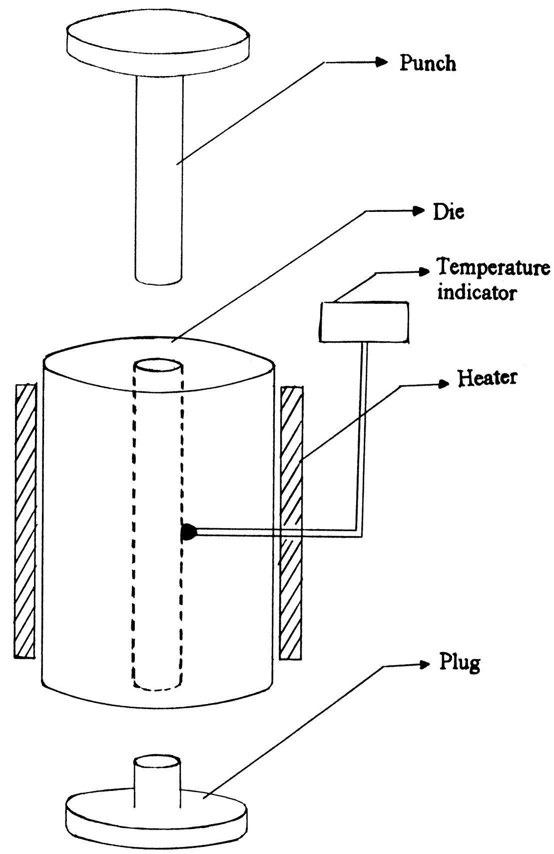


Fig. 1. Schematic diagram of die and punch system for making PP/UHMWPE samples (not to scale).

3. Results and discussion

Fig. 2 shows the effect of applied pressure on the wear volume of PP, UHMWPE and their blends at 1.09 m/s sliding speed. Wear volume increases with the applied pressure in all cases. Maximum wear was observed in PP samples. UHMWPE shows the minimum wear loss at various pressures. In case of PP, wear loss was very high and it was difficult to test it beyond 2.11 MPa. At higher pressures the specimen deformed and test could not be conducted. This situation was however, improved by the addition of UHMWPE in PP. Test could be conducted at 3.17, 4.23 and 5.28 MPa pressure on the samples containing 2, 4 and 8 wt.% UHMWPE in PP. It is observed that PP is highly sensitive to the pressure as compared to UHMWPE. Slope of the curves decrease with the increased fraction of UHMWPE in PP, the slope of the curve is nearly same as that of UHMWPE under the studied conditions.

Fig. 3 shows the variation of wear volume as a function of sliding speed and at 2.11 MPa pressure. Large fluctuations in wear volume data was observed in samples A and B. Pure PP (sample A) could not be tested beyond 1.09 m/s sliding speed. The fluctuations in wear volume decreases with the increasing weight fraction of UHMWPE. At high

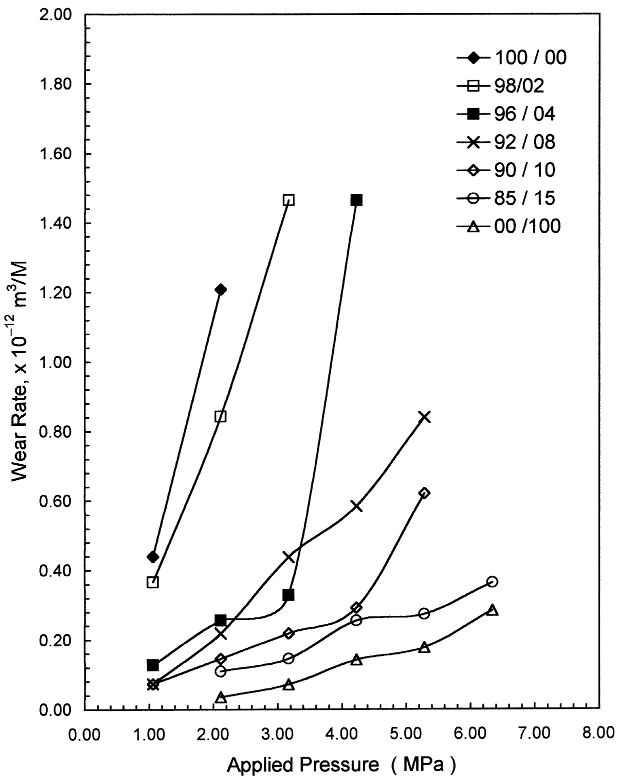


Fig. 2. Plots for the variation of wear rate against applied pressure for PP, UHMWPE and PP/UHMWPE blend system of composition at constant pressure (100/00 (◆); 98/02 (□); 96/04 (■); 92/08 (×); 90/10 (◇); 85/15 (○); 00/100 (△)).

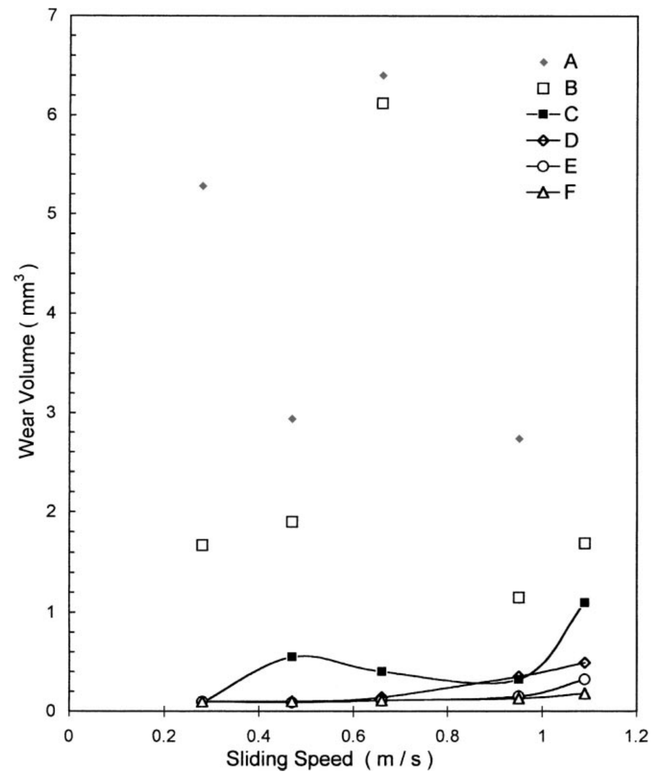


Fig. 3. Plots for the variation of wear volume against sliding speed for PP, UHMWPE and PP/UHMWPE blend system of composition at constant pressure (100/00 (◆); 98/02 (□); 96/04 (■); 90/10 (◇); 85/15 (○); 00/100 (△)).

weight fractions of UHMWPE in PP, there was hardly any fluctuations.

Fig. 4 shows the variation of wear volume as a function of sliding distance for 10 wt.% of UHMWPE in PP at constant pressure of 2.11 MPa and at sliding speed of 0.66 m/s. Wear volume increases uniformly with sliding distance.

Fig. 5 is the plot for variation of trend of rise in temperature near the contact surface and sliding time. Sample A shows maximum increase in surface temperature, which gradually decreases with increasing UHMWPE content in PP. This behaviour can attributed to the higher coefficient of friction of PP as compared to UHMWPE. Coefficient of friction of PP [13] and UHMWPE [6] are reported as 0.67 and 0.35, respectively. The amount of frictional heat generated during sliding was more as compared to UHMWPE. In blend samples, the temperature rise decreases gradually with the increasing UHMWPE content. The area covered by UHMWPE at the contact surface also increases, which helps in reducing frictional heat and consequently the temperature of contact surface.

The temperature of contact surface increases with sliding distance due to the frictional heat. The increased temperature softened PP, which deforms and looses its structural integrity. The softened portion of the sample transfers to

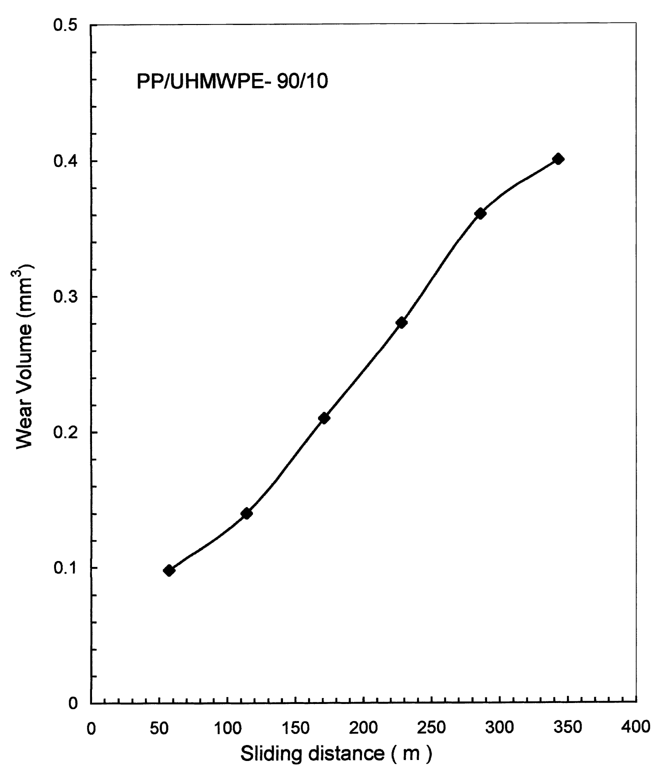


Fig. 4. Plot for the variation of wear volume against increasing sliding distance at constant sliding speed and pressure.

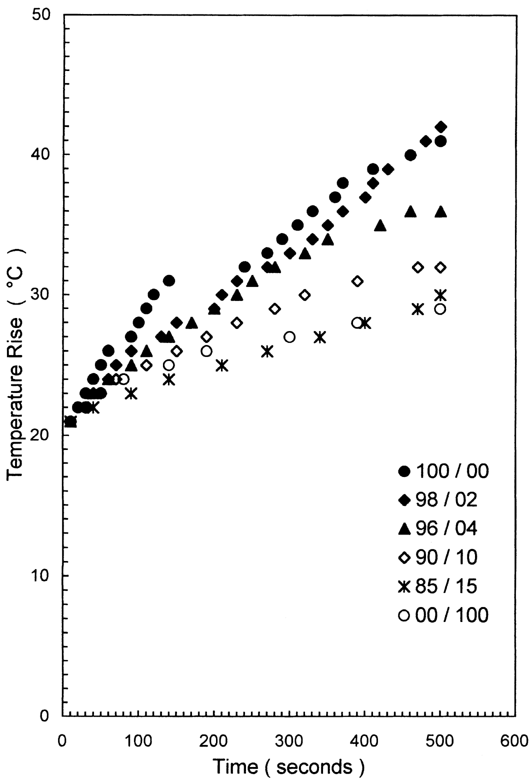
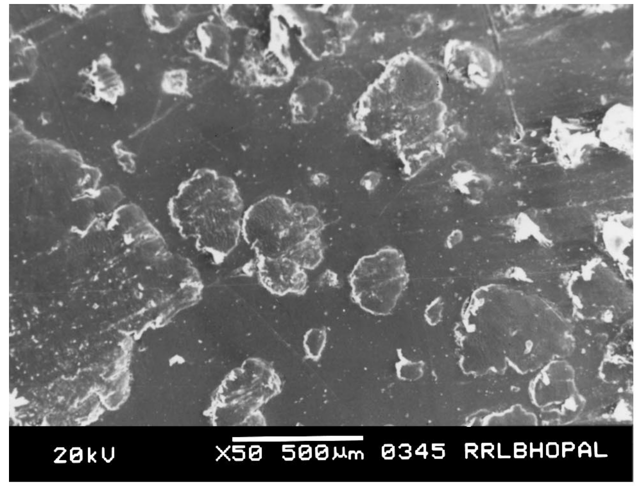
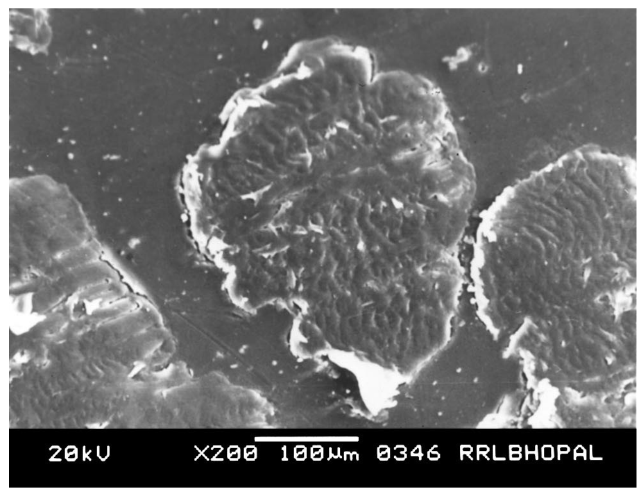


Fig. 5. Plot for rise in temperature against increasing time for PP, UHMWPE and PP/UHMWPE blend system of composition at constant sliding speed and pressure (100/00 (●); 98/02 (◆); 96/04 (▲); 90/10 (◇); 85/15 (✱); 00/100 (○)).



(a)



(b)

Fig. 6. (a) and (b) Shows the micrograph of worn surface of PP/UHMWPE (85/15) blend.

the counterface and a new surface of PP comes in contact with the counterface, having low surface temperature. The same cycle of material transfer repeats through out the test. At higher applied pressure, deformation of specimen occurs due to increased temperature and PP cannot be tested further. At high sliding speed, it is most likely that the molecular chains do not have sufficient time to reorient themselves and hence fracture, causing increased wear [4]. UHMWPE is known for its good sliding wear resistance. This polymer is characterised by its high viscosity at melting temperature and acts as a solid [6]. This particular nature of UHMWPE may be responsible for the low wear rate at high velocity, where the temperature of interfacial region is comparatively higher. Addition of 15 wt.% of UHMWPE in PP demonstrated almost similar wear behaviour of pure UHMWPE (Figs. 2 and 3). It is interesting to note that a small weight fraction of UHMWPE in PP improves the wear resistance of PP to a significant extent. This improvement may be attributed to the morphology of the blend. Both the polymers are immissible, and therefore, two distinct phases were observed from SEM photomicrograph as shown in Fig. 6a and b. PP is in continuous phase whereas UHMWPE is in discrete phase. The micrographs (Fig. 3a and b) of worn surface of PP/UHMWPE (85/15) blend shows that UHMWPE particles are isolated from one another by the PP matrix. Secondly, PP and UHMWPE are bounded together by mechanical bonds rather than any chemical bonds. As the sliding start, PP softens due to frictional heat and deforms easily as compared to UHMWPE, which does not flow due to highly entangled molecular chains. Once a part of PP is removed from the surface, more numbers of UHMWPE particles are exposed. Owing to low coefficient of friction, UHMWPE reduces the frictional heat and temperature, hence provides wear resistance to the blend.

It is observed that the different regions of the worn surface of pin shows different morphology. The regions which comes first in contact with the counter surface wears at low temperature as compared to the second region which follows the first one as shown in Fig. 7 by the schematic

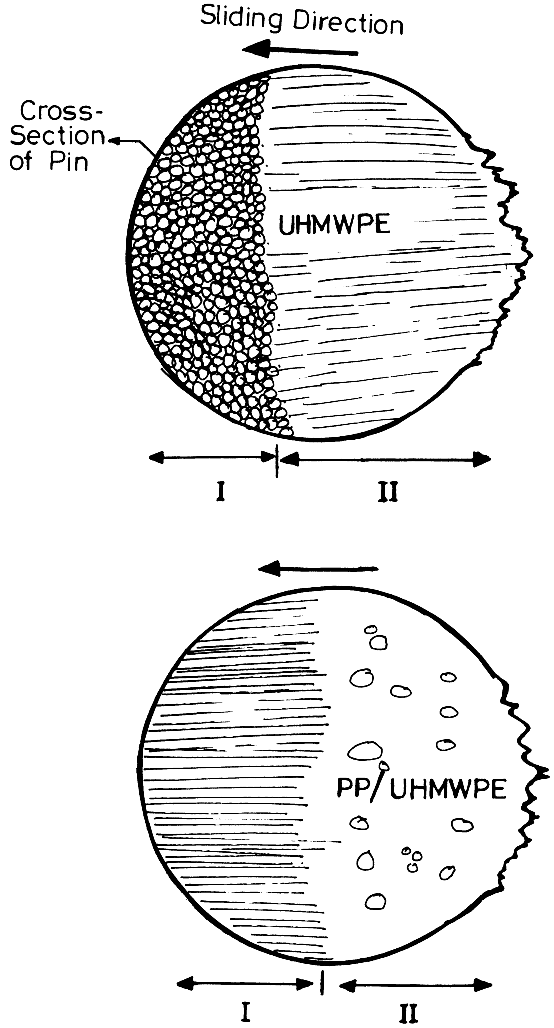


Fig. 7. Schematic diagram of worn surfaces of UHMWPE and PP/UHMWPE blend.

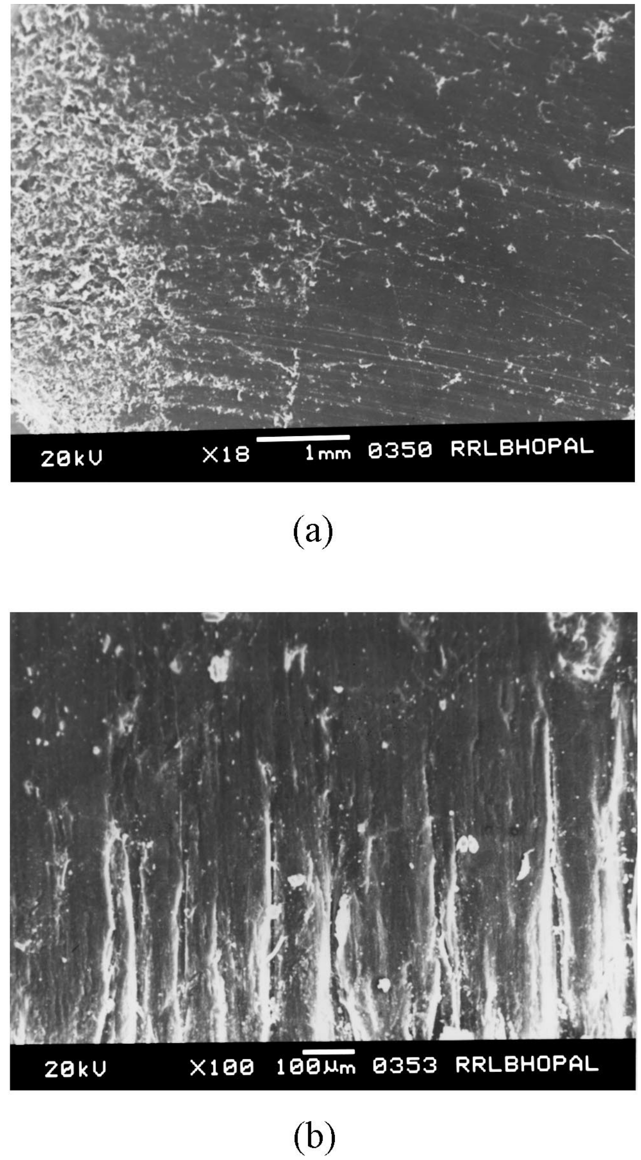


Fig. 8. (a) and (b) Shows the micrograph of the worn surface of UHMWPE and PP/ UHMWPE (96/04) blend.

diagram. Microstructures of worn surfaces of UHMWPE and PP/ UHMWPE (96/04) are shown in Fig. 8a and b, respectively. Micrograph 8a shows both the regions of worn surface of UHMWPE. The left region shows particles of UHMWPE adhered with each. This region belongs to the lead edge of test specimen. The right region is a featureless region and belongs to trailing edge of the specimen. This indicates that softening is initiated from the trailing edge. Similarly observations have reported by Barrett et al. [6]. Micrograph (Fig. 7b) shows specimen containing 96 wt.% of PP. In this micrograph, bottom region shows the trailing edge of the pin. Fig. 8b shows, the severe damages in the form of deep grooves starting from the edge of sample. Elongated morphological region on the surface of the pin are due to the presence of PP.

These observations clearly indicate that sliding wear is a complicated process which depend upon the applied pressure, sliding speed, materials as well as the characteristics of the different regions as defined above.

4. Conclusions

- Addition of UHMWPE in PP improves the wear resistance of PP significantly and also controls the rise in temperature at the interfacial region by reducing the frictional heat.
- Deformation of PP specimen was observed at 1.09 m/s sliding speed and 2.11 MPa pressure, which gradually decreases on incorporation of UHMWPE. UHMWPE with 15 wt.% in PP does not show any distortion up to 6.34 MPa pressure at 1.09 m/s sliding speed.
- Fluctuation of wear data and temperature-rise have been controlled by adding UHMWPE in PP.
- Morphology of worn surface reveals the two distinct regions.

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