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Sliding Wear Behavior of Nanoclay Filled Polypropylene/Ultra High Molecular Weight Polyethylene/Carbon Short Fiber Nanocomposites

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In the present investigation, authors made an attempt to study the sliding wear behavior of polypropylene/ultrahigh molecular weight polyethylene (PP/UHMWPE, 90/10) blends loaded with 30% carbon short fibers (CSF) as reinforcement and nanoclay as filler material. The nanocomposites have been prepared with varying amounts viz., 0, 1, 2 and 3 wt% of nanoclay. The composites were prepared by melt mixing at 60 rpm extruder speed and compression moulding at 180°C. From all the composites, 6 mm diameter and 25 mm length sliding wear specimens were prepared. Sliding wear loss, specific wear rate and coefficient of friction were investigated by using computerized pin-on–disc machine at normal applied loads of 20, 30 and 40 N; at a sliding velocity of 1.5 m/s and at two abrading distances viz., 200 and 300 m. The wear behavior data reveals that 3 wt% nanoclay filled composite exhibits higher wear resistance and lowest specific wear rate as compared to other nanocomposites. Also morphological study was carried out for wear out surfaces of all the composites using scanning electron microscopy (SEM).

Keywords: Nanoclay, UHMWPE, nanocomposites, wear behavior, coefficient of friction

1 Introduction

The tribological characteristics of the ultra-high molecular weight polyethylene (UHMWPE) was extensively investigated because its many excellent properties makes the material suitable for tribo applications. For example, the examination of the friction and wear behavior of UHMWPE for human joints such as knee and hip, due to its high chemical stability and compatibility with human tissue (1–3). In engineering, UHMWPE was used for some components or parts of machines in chemical engineering, textile engineering, food processing and paper making industry, pharmacy, transportation engineering, agricultural engineering, coal and ceramic production. UHMWPE was substitute for carbon steel, stainless steel and bronze, because of its better anti-chemical corrosion, water-repellant function, anti-adhesion, self lubrication and higher impact resistance (4). The dry sliding friction coefficient of UHMWPE is lower than that of other polymers, except polytetrafluoroethylene (PTFE) (4, 5). The wear resistance of UHMWPE is much higher than that of carbon steel and bronze in sliding friction, and than that of nylon-66 and teflon (4–6). It was demonstrated that the cross-linked or blends with other polymers (7–9) can further improve the wear resistance of UHMWPE. The fabrication of UHMWPE matrix composites is an effective method which significantly increases the wear resistance of UHMWPE and, so, the much research on the preparation and wear behavior of the particle or fiber reinforced UHMWPE composites has been reported (10–15). In general carbon fibers have appeared the most promising as they combine high strength with low friction. In most cases, carbon fiber based composites perform much better than glass or aramid fibre composites for both friction and wear. From the thorough literature survey, it was found that, the nanoclay filled PP/UHMWPE composites reinforced with carbon fibers have not been reported. Based on the theoretical discussion, the reinforcing fibers enhance the strength and addition of nanoclay increases the properties of the composite. Polypropylene (PP) being a most common ductile thermoplastic matrices is used in many engineering applications, because of its unique characteristic properties such as low density, low temperature applications, easy to fabricate, etc.

Recently many researchers revealed that the polymer nanocomposites also exhibit good tribological properties (16–18). Friction and wear behavior have been conducted on nano silicon nitride filled epoxy composites

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by Guang et al. (16). The composite materials exhibit significantly improved tribological performance and mechanical properties at low filler content. Chen et al. (17) examined the wear characteristics of carbon nanotubes (CNTs)/ polyetheretherketone (PEEK) nanocomposites, but wear improvements were relatively modest. The nano SiO_2 loaded PEEK showed marked improvement in wear resistance and coefficient of friction than neat PEEK. Fei et al. have studied the wear resistance of nano ZnO filled PTFE and they found that improvement in wear resistance and by retaining its coefficient of friction (18). Recently the friction and wear characteristics of nylon 6/nanoclay nanocomposites under dry sliding conditions are reported by Srinath and Gnanamoorthy (19). The nanoclay loaded nylon composites exhibited high wear resistance compared with the neat nylon.

Sliding wear properties of varying amounts of laponite nanoclay loaded polypropylene/ultrahigh molecular weight polyethylene/30% carbon short fiber (PP/UHMWPE/CSF) nanocomposites have been reported in this paper.

2 Experimental

2.1 Materials

Polypropylene (PP) of J-170 grade (whose density is 0.9 g/cc and T_m is 155–170°C) and ultrahigh molecular weight polyethylene (UHMWPE) of XM-220 grade (whose average particle size is 30–50 μm, density is 0.94g/cc and T_m is 135°C) were obtained from Honam Petrochemical Co. and Mitsui Petrochemical Industries, Ltd., respectively. The nanoclay (synthetic hectorite, Laponite XLS, was obtained from Rockwood Co. USA. The composition of Laponite XLS is 92.32 wt% $Mg_{5.34}Li_{0.66}Si_8O_{20}(OH)_4Na_{0.66}$ and 7.68 wt% $Na_4P_2O_7$. Carbon short fibre (CSF) of Toray T-1700 grade was obtained from Cabot, South Korea.

2.2 Sample Preparation

The varying amounts of nanoclay viz., 0, 1, 2, and 3% by wt., were melt mixed with PP, UHMWPE powders and 30% carbon short fiber in a Haake Rheochord mixer at 180°C, 60 rpm for 20 min to achieve a reasonably uniform dispersion. The resulting PP/UHMWPE (90/10)/30% carbon short fiber mixtures with varying amounts of nanoclay were subsequently compression-molded at 180°C, in order to obtain a sheet with a thickness of 3 mm for the wear behavior measurements.

2.3 Techniques

Pin-on-disc machine, model POD-WTM-01, Contech micro systems make, 110 mm disc diameter, 8 mm disc thickness, surface roughness of 25 μm and hardness 62 HRC was used for evaluating the sliding wear frictional properties of the composites as per ASTM G99-04 method. The test specimens were weighed and initial weights were recorded using a high precision digital electronic balance after thorough cleaning. After recording initial weight, specimen fixed to the holder such that the flat face of the specimen come in contact with the rotating hardened steel disc as shown in Figure 1. The setup had an arrangement to vary the motor speed and consequently the rpm of the disc. At sliding velocity of 1.5 m/s, at two sliding distances of 200 and 300 m, the composite samples were subjected to varying applied loads of 20, 30 and 40N. The final weights of the specimens were recorded and the wear loss in weight was calculated.

The specific wear rate (K_S, $g/N\text{-}m$), was calculated from the equation, $K_S = W/F_N x d$; where, W is the weight loss in grams, F_N is the normal load in Newton; d is the sliding

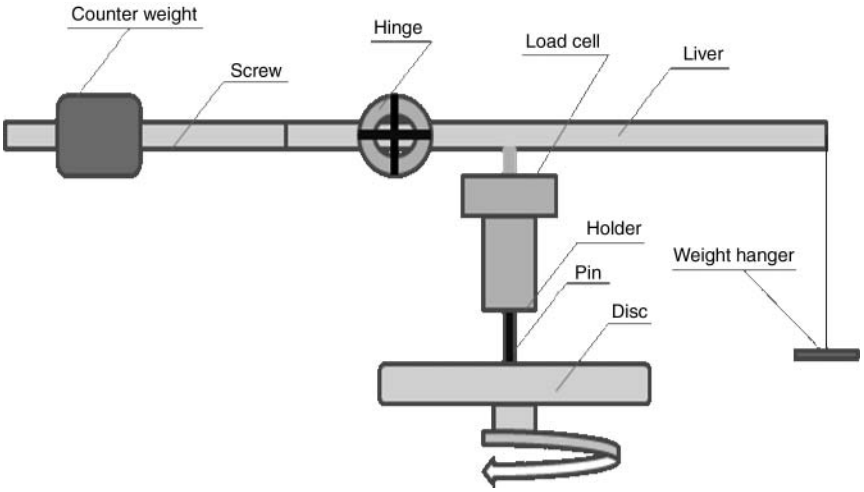

Fig. 1. Schematic diagram of pin-on-disc test set-up.

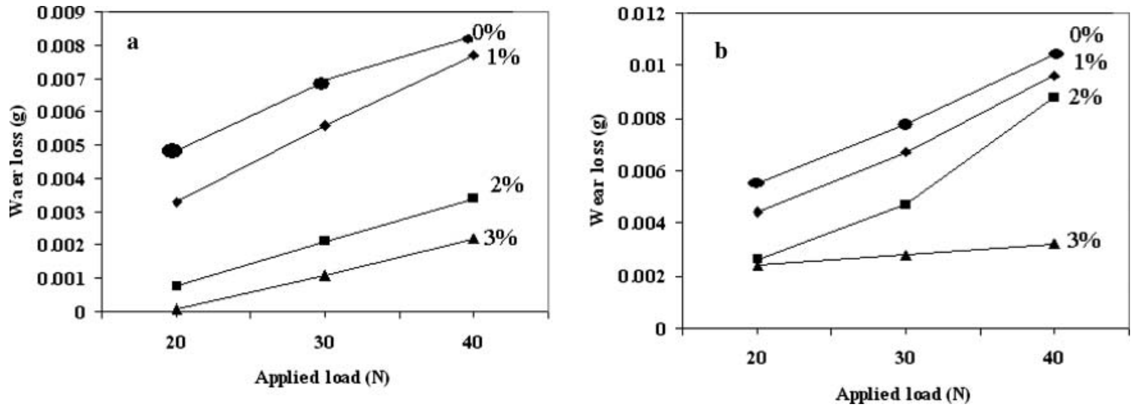

Fig. 2. Influence of load on wear loss of nanoclay incorporated nanocomposites at sliding velocity of 1.5 m/s and sliding distances of (a) 200 and (b) 300 m.

distance in meters. The coefficient of friction was calculated from the equation:

$$\mu = \mathrm{F}_f/\mathrm{F}_N \qquad (1)$$

where, F_f is the frictional force (N) and μ is the coefficient of friction.

At a sliding velocity of 1.5 m/s, at abrading distances of 200 and 300 m and at different applied normal loads of 20, 30 and 40 N, the wear loss, specific wear rate and coefficient of friction were investigated. Surface hardness of the specimen is performed as per ASTM D 2240.

3 Results and Discussion

3.1 Wear Loss

The plot of wear loss as a function of applied load for all PP/UHMWPE/CSF nanocomposites at two abrading distances is shown in Figures 2(a)–(b). From the figure it was noticed that the wear loss of nanoclay loaded PP/UHMWPE/CSF nanocomposites increases with increase in abrasion load as shown in Figure 2 at both abrading distances. Furthermore, the observed wear loss decreases as increase in nanoclay content in the composites. That means composite with 1% clay has more wear loss than composites containing higher clay (>1%) content for all loads under investigated. Also, it is observed from the wear loss vs. applied load plots, the slope of the line is very low for 3% clay filled composite as compared to other composites. This result clearly indicates that the nanoclay content has significant influence on wear behavior of the composites.

3.2 Specific Wear Rate

The plot of specific wear rate as a function of applied loads is shown in Figure 3. The specific wear rate of the nanocomposite increases with an increase in normal load, as the wear loss is proportional to the normal load (20). Also specific wear resistance decreases significantly as increase in nanoclay content. It is evident that the increase of nanoclay content from 0 to 3 wt% led to a remarkable decrease of specific wear rate. This kind of variation has been reported for glass fabric reinforced epoxy composites (21). The wear of PP/UHMWPE/CSF composites consists of wear modes: polymer matrix wear, which includes matrix plastic deformation and cracks in the matrix and fiber wear, which involves fiber sliding wear, fiber cracking, fiber rupture and fiber pulverizing. The order of wear resistance behavior of composites is as follows; 3 > 2 > 1 > 0% by weight of nanoclay. Also, it should be noted that 3 wt% nanoclay filled PP/UHMWPE/CSF composite exhibited the highest wear resistance under different abrading distances/loads.

The reduction in specific wear rate with increase in nanoclay content in PP/UHMWPE composite is due to the transfer film formed on the counterface, which act as an effective barrier to prevent large-scale fragmentation of polymer matrix. It is well known that the wear behavior of a polymer sliding against a metal is strongly influenced by its ability to form a transfer film on the counterface (22-23). This is also evident from the small size of the wear debris particles as determined by SEM analysis (refer to Fig. 5).

3.3 Coefficient of Friction

The plot of coefficient of friction as a function of applied normal load for different amounts of nanoclay filled PP/UHMWPE/CSF nanocomposites at two abrading distances viz., 200 and 300 m is shown in Figures 4(a–b), respectively. Owing to changes in the real area of contact and shear strength of polymer, in most sliding tests the run-in friction precedes the steady state friction (24). The effect of nanoclay reinforcement is evident as nanocomposites exhibits considerable reduction in coefficient of friction as increase in clay content. The coefficient of friction increases

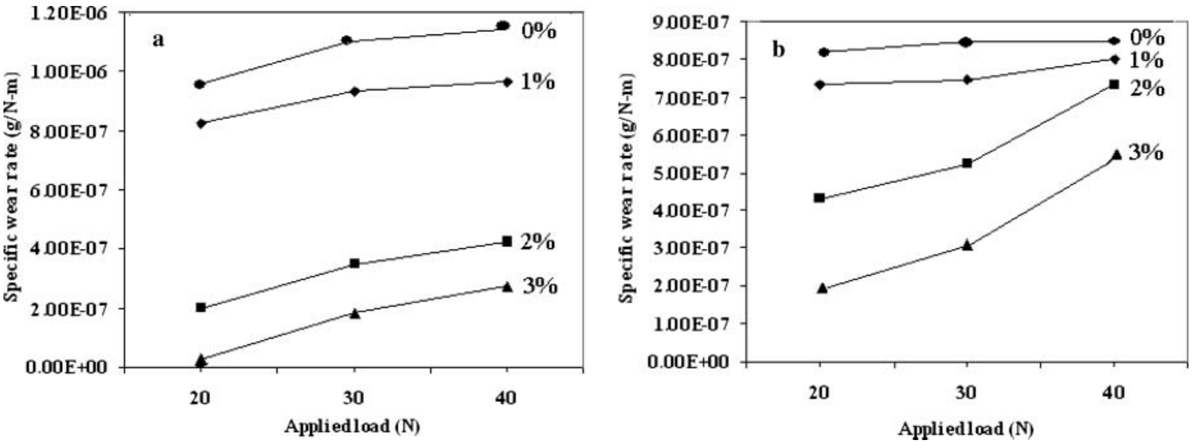

Fig. 3. Influence of applied load on specific wear rates of nanoclay incorporated nanocomposites at different sliding distances of (a) 200 and (b) 300 m.

as increase in load at both sliding distances for all nanocomposites, as shown in Figure 4. The coefficient of friction increases with increase in normal load due to the changes in the real area of contact (25). All composite materials exhibit the similar trend. During molding as polymer cools in the mould, a skin is formed over the surface (26, 27). This skin is harder than the inside material. The changes in real area of contact and formation of transfer film in addition to the formation of skin influence the coefficient of friction.

The nanocomposites containing 3 wt% of nanoclay exhibits lower coefficient of friction values, which lies in the range 0.29–0.35 and 0.32–0.38 for 200 and 300 m abrading distances, respectively. PP/UHMWPE/CSF composite containing 3% nanoclay exhibits lower coefficient of friction and maximum wear resistance as compared to lower nanofiller loaded composites; this is due to dispersion of agglomerated and uniformly distribution of the nanoclay particles on the surface of the specimen and thin transfer film formation on the abrasive material, acts as a self lubricating agent. This result indicates that the coefficient of friction also depends on applied load and abrading distances. However, it was observed that coefficient of friction decreases with increase in nanoclay content in the composites.

PP/UHMWPE/CSF nanocomposite with 3% nanoclay exhibited a higher coefficient of friction and specific wear rate than nanoclay unfilled composite at all test conditions investigated. This behavior may be attributed to interfacial strengthening of the nano level reinforcements (28, 29). As the clay particles are dispersed in nano level in polymer matrix and also due to the high specific surface area of the nanoparticles the interfacial adhesion between matrix and nanoparticle is high and contributes to the improved tribological behavior. Due to the presence of nanolevel filler, which has the same size as the segments of the surrounding polymer chains, the material removal of nanocomposites is mild and also aids in the formation of uniform tenacious transfer layer.

3.4 Surface Hardness

The measured surface hardness value of PP/UHMWPE/CSF is 71 shore D. After incorporation of nanoclay in

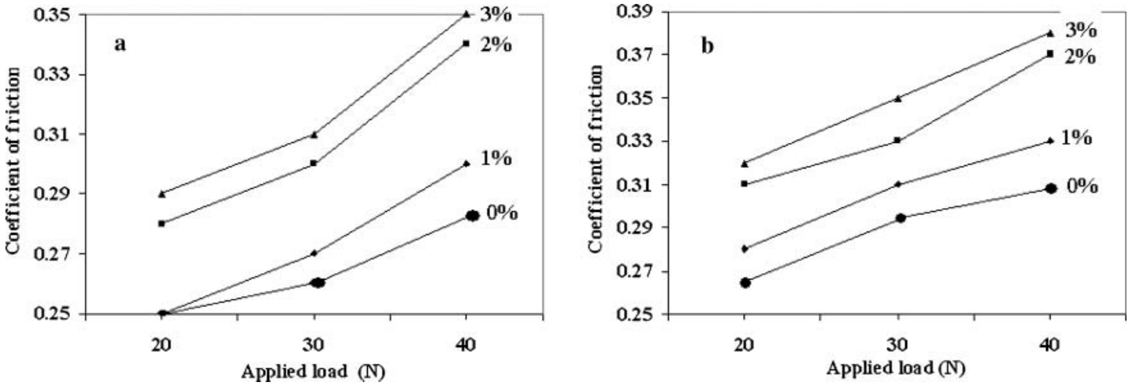

Fig. 4. Effect of load on coefficient of friction of nanoclay incorporated nanocomposites at sliding velocity of 1.5 m/s and sliding distance of (a) 200 and (b) 300 m.

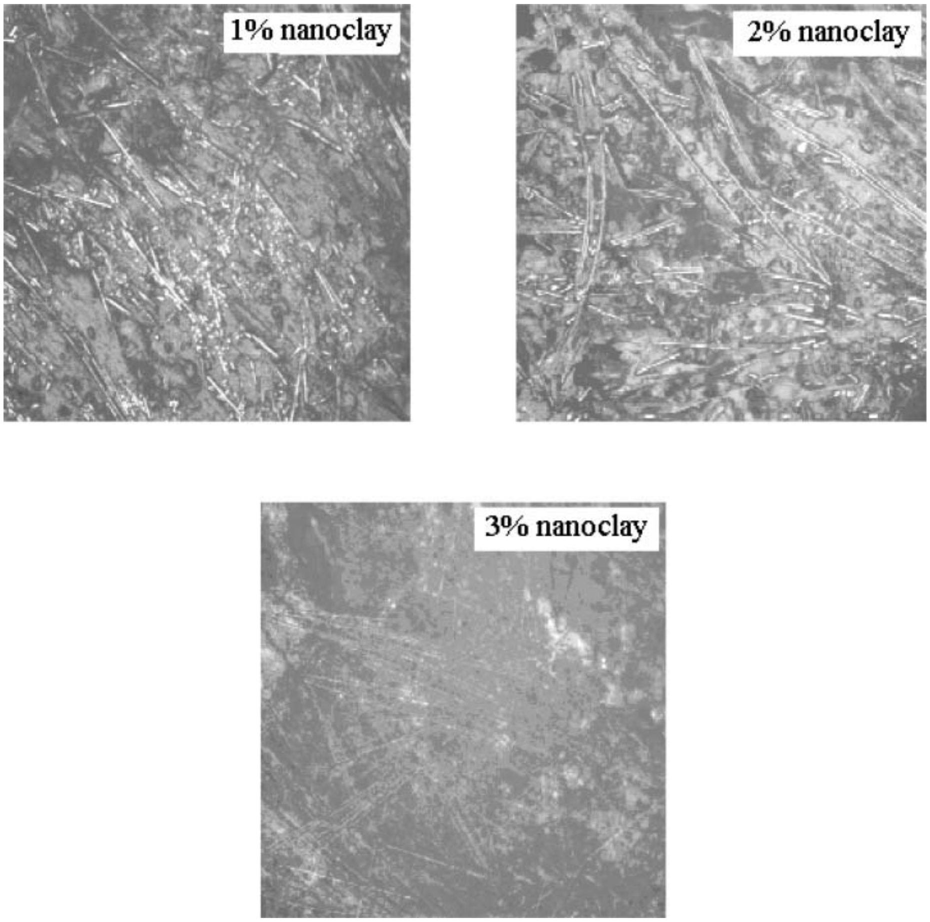

Fig. 5. SEM photomicrographs of worn surface of different nanoclay filled PP/UHMWPE/CSF nanocomposites at velocity 1.5 m/s and 40N load.

to composites a slight improvement in surface hardness was noticed and obtained values of nanocomposites lies in the range 74–80 shore D. The influence of nanoclay is not significant on surface hardness. However, slightly lower surface hardness value (77 shore D) was noticed for 3% nanoclay loaded composite. This result indicates that wear resistance and shore hardness are inversely proportional.

3.5 SEM Studies

SEM photomicrographs of worn surfaces for 1, 2 and 3 wt% nanoclay reinforced composites are shown in Figures 5(a–c), respectively. When the carbon short fibers are in contact with nanoclay and polymer matrix, they provide better resistance to the process of abrasion. The higher wear volume loss for lower load as compared to higher wear load was noticed. The images of 1% nanoclay filled composite showed a greater number of fractured fibers than 3% nanoclay filled system. From these photomicrographs, it was noticed that the only fibers are fractured and fiber pullout was not noticed. This result indicates that there is a good interaction between matrix and fibers. From SEM photographs it was found that at higher nanoclay filled composites, the matrix damage is more pronounced than fiber damage, whereas for lower nanoclay systems both polymer and fiber damage occurred. Specific wear rate and wear loss data supported by SEM study.

4 Conclusions

Sliding wear behavior of varying amounts of nanoclay filled PP/UHMWPE/CSF nanocomposites has been investigated. Nanocaly is an effective filler in reducing the specific wear rate of polymer composites at all normal loads investigated. Formation of uniform tenacious transfer layer by PP/UHMWPE/CSF/nanoclay nanocomposite on the counterface contributes to the reduction in wear loss and specific wear rate. Wear resistance improved as increase in nanoclay content in the composites. Composite with 3% nanoclay content exhibits lowest specific wear rate for both velocities and at all three loads as compared to other composites. Presence of nano level filler of same size of the surrounding polymer molecules causes mild material removal.

References

1. McGloughlin, T.M. and Kavanagh, A.G. (2000) *Proc. Inst. Mech. Engg.*, 214, 349–359.
2. Wang, A., Essner, Polineni Y.K., Stark, C. and Dumbleton, J.H. (1998) *Tribol. Intl.*, 31, 17–33.
3. Yoshinori, S., Terno, M. and Jian, C. (1998) *Wear*, 216, 213–219.
4. Shi, A. and Gong, Y. Engineering Plastic-Properties, Processing and Applications, Shanghai Science and Technology Press, Shanghai, 1986.
5. Shi, W., Li, X.Y. and Dong, H. (2001) *Wear*, 250–251, 544–552.
6. Goldman, M. and Pruitt, L. (1998) *Biomed. Mater. Res.*, 40, 378–384.
7. Lee, K.Y. and Lee, K.O. (1999) Wear, 225–229, 728–733.
8. Ohta, M. Hyon, S., Kang, Y., Oka, M., Tsutsumi, S., Murakami, S. and Kohjiya, S. (2000) *Soc. Mater. Sci. Jpn.*, 49, 1301–1305.
9. Liu, C.Z., Ren, L.Q., Tong, J., Green, S.M. and Arnell, R.D. (2002) *Wear*, 253, 878–884.
10. Cohen, Y., Rein, D.M. and Vaykhansky, L. (1997) *Comp. Sci. Tech.*, 57, 1149–1154.
11. Liu, Ren L., Amell, R.D. and Tong, J. (1999) *Wear*, 225–229, 199–204.
12. Suwanprateeb, J. (2000) *J. Appl. Polym. Sci.*, 75, 1503–1513.
13. He, C.X. (2002) *Tribology*, 22, 32–35.
14. Cenna, A.A., Doyle, J., Page, N.W., Beehag, A. and Dastoor, P. (2000) *Wear*, 240, 207–214.
15. Chang, N., Bellare, A., Cohen, R.E. and Spector, M. (2000) *Wear*, 241, 109–117.
16. Shi, G., Zhang, M.Q., Rong, M.Z., Wetzel, B. and Friedrich, K. (2003) W*ear,* 254–784.
17. Chen, W., Li, F., Han, G., Xia, J., Wang, L., Tu, J. and Xu, Z. (2003) *Tribology Letter*, 15, 275–278.
18. Li, F., Hu, K-A., Li, J-L. and Zhao, B-Y. (2002). *Wear,* 249, 877–882.
19. Srinath, G. and Gnanamoorthy, R. (2005) *J. Matl. Sci.*, 40, 2897–2901.
20. Hutchings, I.M. in "Tribology: Friction and Wear of Engineering Materials," Edward Arnold: London, 1992, p. 129.
21. Suresha, B., Chandramohan, G., Renukappa, N.M. and Siddaramaiah (2007) *J. Appl. Polym. Sci.*, 103, 2472–2480.
22. Bahadur, S. (2000) *Wear*, 245 (1–2), 92–99.
23. Bahadur, S. and Gong, D.L. (1992) *Wear*, 154 (1), 151–165.
24. Shiao, S.J. and Wang, T.Z. (1996) *Composites,* 27B, 459.
25. Moore, D.F., in "Principles and Application of Tribology", Pergamon Press: Oxford, p. 61, 1975.
26. Ho, K-C. and Jeng, M-C. (1997) *Wear,* 206, 60.
27. Rosato, D.V., in "Plastics Engineering Product Design", Elsevier, Oxford, p. 106, 2003.
28. Cai, H., Yan, F., Xue, Q. and Liu, W. (2003) *Polym. Test.,* 22, 875.
29. Shi, G., Zhang, M.Q., Rong, M.Z., Wetzel, B. and Friedrich, K. (2004) *Wear,* 256, 1072.