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Effect of B_4C Content on the Mechanical and Tribological Performances of Polypropylene

A.S. Dike[a], F. Mindivan[b] and H. Mindivan[c,*]

[a]Adana Science and Technology University, Faculty of Engineering and Natural Sciences
Department of Materials Engineering, Adana, Turkey

[b]Ataturk University, Faculty of Sciences, Department of Chemistry, Erzurum, Turkey

[c]Ataturk University, Engineering Faculty, Department of Metallurgy and Materials Engineering, Erzurum, Turkey

Boron carbide (B_4C) reinforced polypropylene (PP) was prepared by twin-screw extrusion and injection molding. In the present study, the effect of B_4C content on the mechanical properties and wear behavior of the PP composites was studied. The tribological properties of the PP composites were investigated by a reciprocating wear tester under dry friction conditions. The results of the mechanical and wear test showed that the hardness and yield strength increased with increasing B_4C content, while the incorporation of B_4C into PP largely increased wear and friction under dry sliding. The composites have higher wear rates in comparison with unfilled PP and the greater the difference, the greater are the sliding velocities.

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1. Introduction

Polypropylene is one of the fastest growing classes of thermoplastics due to its low price, light weight, manufacturing versatility, high strength, and stiffness. However, the physical and mechanical properties of PP when compared to conventional metal and ceramic materials are far below our expectation at macro-levels [1]. The problems arise from its viscoelastic property, lower strength and stiffness in directions of high loading, lower resistance to degradation (particularly high temperature oxidation), higher thermal expansion which introduces dimensional stability problems, and lower thermal conductivity which leads to poor dissipation of frictional heat at low temperatures during service application. That is the reason for the need of using particulate filled PP composites, which ensure a balance between mechanical and physical (thermal conductivity/expansion and environment stability) properties.

Nowadays, to modify one or more of these properties of PP, adding appropriate filler into PP matrix has demonstrated to be a feasible method [2]. Among the various available fillers, boron carbide (B_4C) has been viewed as one of the most promising ceramic materials because of its outstanding physical and mechanical properties, such as high temperature and chemical stability, high hardness, good neutron absorption capability, high modulus of elasticity, low density, high impact and wear resistance. The radiation shielding properties of various kinds of polymers reinforced with B_4C, a property of great importance in the nuclear fuel transport and over voltage protection environments, have been already studied [3, 4]. To the knowledge of the authors, limited information is available regarding the mechanical properties and wear behavior of the PP based composites with different B_4C content (coded as PP/B_4C). Therefore, the main objective of this study is the addition of B_4C fillers to PP, and to specifically analyse the effects of their addition on the wear and mechanical properties of the filled PP materials.

*corresponding author; e-mail: hmindivan@hotmail.com

2. Materials and experimental procedures

Melt blending of PP, and the B_4C of 1, 2, and 4 wt% is carried out in a co-rotating twin screw extruder (Thermoprism TSE 16 TC, L/D 24) at a screw speed of 100 rpm and barrel temperature 230 °C at all 5 zones, followed by granulation (length 3–5 mm and diameter 3 mm) in a pelletizer and drying. Prior to extrusion, the matrix polymer and the B_4C were dehumidified in a vacuum oven at 90 °C for a period of 24 h. These granules were further injection molded using injection moulding machine (Microinjector, Daca Instruments) at a barrel temperature of 200 °C and mold temperature of 30 °C, for preparation of test specimens of tensile.

The chemical structure was studied by a Fourier transform infrared spectroscopy (FTIR) and the B_4C distribution in the polymer matrix was analysed by a light optical microscope (LOM). X-ray diffraction (XRD) measurements of the PP and its composites were obtained with a Rigaku X-ray diffractometer using a Cu K_α radiation source ($\lambda = 1.5405$ Å). Room temperature mechanical properties of the samples were determined by tensile tests and microhardness measurements. The tensile test samples with a gauge length of 80 mm were tested according to the ASTM D 3822 standard on a tensile testing machine of Lloyd LR 5K with a load cell of 10 N and the deformation rate was 40 mm/min. All the results represent an average value of five tests with standard deviations. Microhardness measurement was also carried out on metallographic samples under the load of 10 g with a Vickers indenter. At least, ten successive measurements were made for each condition.

The friction and wear tests for evaluation of the tribological properties of the unfilled PP and PP/B_4C composites were conducted on a reciprocating wear tester under dry conditions. The ambient temperature was roughly 20 °C and the relative humidity was approximately $30 \pm 5\%$. The wear tests on all samples were carried out at a constant load of 2 N using a 10 mm diameter steel ball with a varying speed of 0.0128, 0.0245, 0.0375, and 0.0567 ms^{-1}. In all tests, the total sliding distance was kept constant at 200 m. The wear was calculated as an average width and depth detected by a stylus profilometer using the software version of MarSurf PS1 Explorer. After the wear test, the counterface surfaces were examined under an optical microscope for investigating the wear mechanisms. Later, wear tracks formed on the surfaces of the unfilled PP and PP/B_4C composites were examined using a scanning electron microscope (SEM).

3. Results and discussion

Figure 1a–d shows the LOM images of the unfilled PP and composites containing 1, 2, and 4 wt% B_4C in the PP matrix. Dark areas on the micrograph are the regions of almost pure polymer material free of the B_4C. Light areas are the regions with B_4C. It can be seen that the B_4C particles are almost uniformly dispersed in the PP composite with 1 wt% B_4C. However, as the content of the B_4C in the PP matrix increased from 2 to 4 wt%, agglomerations of fine B_4C particles could not be avoided as shown in Fig. 1. This is due to the decrease in the interparticle distances between the B_4C particles with increasing B_4C content in the matrix.

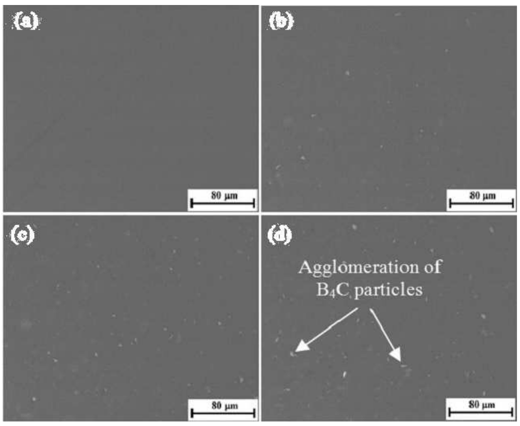


Fig. 1. LOM images of (a) the unfilled PP and composites containing (b) 1 wt% B_4C, (c) 2 wt% B_4C, (d) 4 wt% B_4C.

Figure 2 shows the FTIR and XRD results of the unfilled PP and PP/B_4C composites. For the composite with 1 wt% B_4C, the peak at around 1675 cm^{-1} indicates stiff bonding between boron and carbon atoms. This peak shifted to left with an increase of B_4C content. The bands at around 3576–3485 cm^{-1} appearing at the composites are due to O–H stretching vibrations and this spectrum is obvious much at the composites with 2 and 4 wt% B_4C. The absorption bands at 2872, 1480, 1000 cm^{-1} with addition of 2 and 4 wt% B_4C to the PP are attributed to C–H stretching of CH_2 groups, B–O stretching vibration and B–O–C bonds, respectively. From the FTIR spectrum (Fig. 2a) it is observed that the interaction between B_4C and PP at the composites with 2 and 4 wt% B_4C increases. Figure 2b shows the XRD patterns of the unfilled PP and composite with 4 wt% B_4C. The diffraction peaks appear almost at the same positions. However, B_4C peak is obtained at angle of 16.2° and this result is in accordance with another study [3].

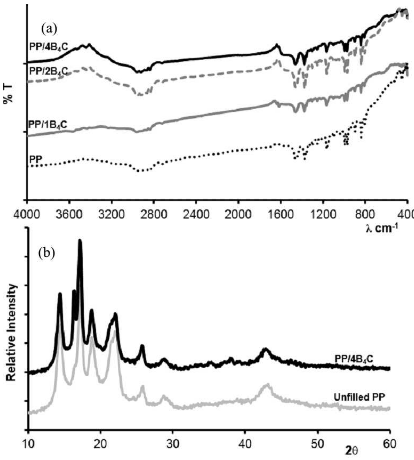


Fig. 2. (a) FTIR and (b) XRD results of the unfilled PP and composites.

The variations of mechanical properties of the composites with B_4C are shown in Table [2]. Interestingly, increase in B_4C content from 0 to 4 wt% was accompanied with only a moderate increase in measured microhardness and yield strength (Table). For instance, on the incorporation of the B_4C, the microhardness and yield strength were increased by 37 and 18%, respectively. This enhancing effect of B_4C on the microhardness and yield strength of the composites was more significant at low B_4C content when compared with high B_4C content (Table). It is known that the incorporation of B_4C particles significantly increases the hardness of composites [5].

However, the mechanical properties of the composites was not increased at higher B_4C content as expected, in comparison with those at low B_4C content. The incorporation of a small quantity of B_4C into the PP matrix can substantially improve the mechanical properties of the composites because of the reinforcing effect of B_4C and its uniform dispersion in the PP matrix (Fig. 1b,c). The non-uniformity of B_4C in the composite with 4 wt% B_4C is confirmed by the standard deviation of the Vickers microhardness and yield strength values (Table). Evidently stress transfer between B_4C and the PP matrix is less effective at the higher B_4C concentrations. On the other hand, there is a meaningful influence of B_4C addition on elongation at break and the plasticity of the PP composites abruptly decreases, the fracture becomes virtually brittle.

TABLE

Variations of the microhardness, yield strength and elongation at break of the composites with B_4C content [2].

B_4C content	Microhardness [MPa]	Yield strength [MPa]	Elongation at break [%]
0	67 ± 1.5	22 ± 3.8	483 ± 64
1	73 ± 2.0	26 ± 0.3	395 ± 4.4
2	88 ± 5.0	28 ± 0.3	365 ± 4.1
4	92 ± 9.0	26 ± 4.0	309 ± 4.0

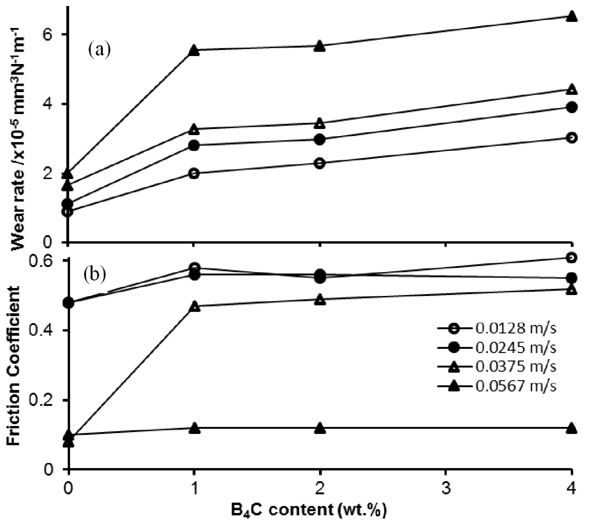
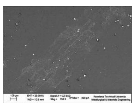
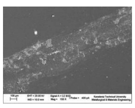
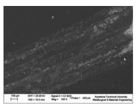
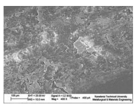
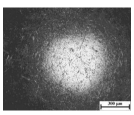
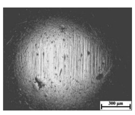
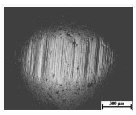
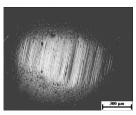


Fig. 3. Effect of B_4C content on the (a) wear rate and (b) friction coefficient of the B_4C filled PP composites.

The variation in wear rate and friction coefficient of the unfilled PP and B_4C filled PP composites tested under different sliding velocities is shown in Fig. 3. The experimental results reveal that the wear rate increases with sliding velocity at a constant load. As the sliding velocity increases, the surface temperature increases which promotes softening of the surface leading to more surface and subsurface damage eventually resulting in higher wear rates. Another interesting feature observed is that the wear rate with addition of 1 wt% B_4C increases sharply at all sliding velocities, whereas the wear rate values increase slightly when the B_4C content is above 1 wt% (Fig. 3a). Abenojar et al. [5] also expressed similar view in epoxy-B_4C composites.

	B_4C Content			
	0	1	2	4
Sample				
Steel ball				

Typical wear tracks on the samples and surface appearance of counter steel balls after wear test at a sliding velocity of 0.0375 m/s are shown above. These photos show clearly the effect of B_4C content on wear resistance. Unfilled PP shows much less wear on its surface and it does not cause any wear of the counterface at any of the applied sliding velocities.

On the contrary, the PP composites filled B_4C show severe damage by wear test and the hard B_4C phase in the PP composites causes abrasive wear of the steel counterface. Moreover, the surface topography of the composites becomes rougher with increasing B_4C content. Thus, the friction coefficient of the composites measured at low sliding velocities (0.0128 and 0.0245 m s^{-1}) increased to approximately 0.6, which is higher than that of the unfilled PP, approximately 0.48 as shown in Fig. 3b. However, the composites exhibit the largest drop of the coefficient of friction with increasing B_4C content at high sliding velocity (0.0567 m s^{-1}) as a result of the frictional heating, while a significant increase of the coefficient of friction to 0.47 from 0.08 at a sliding velocity of 0.0375 m/s was observed from the composite with 1 wt% B_4C and the coefficient of friction with an increase of B_4C content turned to be a slightly increase (Fig. 3b). The B_4C phase within a PP matrix acted as a third body possessing a higher hardness than the steel counterface surface. In addition, detachment of hard abrasive particles from the worn surface of the composites can be effective on friction increase [5]. This resulted in an increase in wear rate of both the steel counterface and PP composites under dry sliding conditions.

4. Conclusion

The mechanical and tribological test results showed that the microhardness and yield strength of the PP/B_4C composites were improved by 37% and 18%, respectively, compared to the unfilled PP, whereas the addition of B_4C to PP increased the overall wear of both the counterpart steel ball and composites because of the abrasion of B_4C in the PP composites under dry conditions.

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References

[1] M. Dogan, E. Bayramli, *Polym. Adv. Technol.* **22**, 1628 (2011).

[2] A.S. Dike, H. Mindivan, *Adv. Mater. Res.* **685**, 19 (2013).

[3] S. Mondal, A.K. Banthia, *J. Eur. Ceram. Soc.* **25**, 287 (2005).

[4] S.D. Kaloshkin, V.V. Tcherdyntsev, M.V. Gorshenkov, V.N. Gulbin, S.A. Kuznetsov, *J. Alloys Comp.* **536**, 522 (2012).

[5] J. Abenojar, M.A. Martinez, F. Velasco, V. Pascual-Sanchez, J.M. Martin-Martınez, *J. Adhesion* **85**, 216 (2009).