ABRASIVE WEAR BEHAVIOUR OF POLYAMİDE 6 / POLYPROPYLENE / NANOCLAY COMPOSITES

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In this study, polyamide 6 (PA 6) was used as matrix material. Materials with eight different compositions were produced by adding 30% (w/w) polypropylene (PP), 2.5% (w/w), 5% (w/w) and 7.5% (w/w) nanoclay and 5% wt. compatibilizer* Kraton *(SEBS) to PA 6. Pin-on disc abrasive wear tests were carried out under 5 N load, at 1 m/s sliding speed and 12.5m, 25m, 50m and 75 m sliding distances. Emery papers with grid sizes of 80 and 220 grade were used for the tests. Amount of wear, rate of wear and friction coefficient of the composites were obtained from the tests. Also, this study investigated the effect on abrasive wear of PP, nanoclay and compatibilizer added to PA 6.

Keywords: *PA 6, polypropylene, nanoclay, compatibilizer, abrasive wear*

1. Introduction

Polymer composites are preferred for many industrial sectors such as automotive, electrical/electronic, aircraft and household applications. In addition, to improve the properties of the unfilled polymers in many cases reinforcement such as glass fibre, mineral additives and lubricants are added. These additives provide high mechanical, electrical, thermal properties, low friction and low cost [1,2]. Compared with other polymers, polyamides exhibit excellent wear behavior, high chemical resistance and superior mechanical properties, therefore, they are widely used in many areas [3]. The most important polyamides in terms of their mechanical and physical properties are polyamide 6 and PA 66, as their hardness, durability and heat resistance are better than those of all other polyamide types [4]. Nanocomposites have emerged as a new class of composite materials obtained by the addition of reinforcements in the range of 1–100 nm into matrix [5]. Recent studies on nano-structured materials indicate that the addition of nano reinforcement materials increases hardness and has a positive effect on the combustion, chemical and thermal properties of materials. This positive effect is due to the large surface area of the nanostructures which increases the interaction between the matrix and the nano reinforcement [6]. Another positive feature of nanoscale particles is that they can be easily dispersed in the polymer-matrix. Especially, low rates of nano addition into PA 6 was found to improve the wear behavior under dry sliding conditions.

In addition, Nano size reinforcements form a solid film layer on wear surfaces and improve the friction and wear properties of materials [7]. Polypropylene exhibits many beneficial properties such as low density, relative high thermal stability, and resistance to chemical attack, easy processing and recyclability In addition, its mechanical property profile is very closely matched to that of engineering thermoplastics [8). Polymer blends are mixtures of at least two macromolecular species, polymers and/or copolymers. Mixing two polymers usually leads to immiscible blends, characterized by a coarse, metastable morphology, and poor adhesion between the phases. For improved performance the immiscible blends usually need compatibilization. The latter is the process of modification of the interfacial properties of an immiscible polymer blend, leading to the creation of a polymer alloy. The process is used to reduce interfacial tension, which facilitates a finer dispersion during mixing, and enhances adhesion between the phases in the solid state [9 - 12]. Wear in polymeric materials occurs through various mechanisms called abrasive wear, fatigue wear and sliding wear. Abrasive wear, which is the most important one, occurs as a result of the formation of small cuts on the surface of a workpiece. Fatigue wear occurs as a result of mechanical stresses leading to formation cracks on the surface of a workpiece and the removal of the material with repeated deformation. Sliding wear occurs due to vibrations known as Schallamach waves as a result of friction occurring on smooth surfaces [13]. Wear is a complex mechanism that

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depends on many factors such as wear surface, wear shape, sliding distance, wear load, shear rate and etching time [14-18]. Wear resistance is an important part of the technical information. It has a direct effect on the service life of products. As is known, wear occurs on moving parts in dry friction and shear. The frictional force is very large with the start of motion. Meanwhile, a large amount of particles breaks off the wearing surface and wear occurs rapidly. The coefficient of friction and wear rate should be decreased in order to reduce the impact of this negative state [19]. In a review of some of the literature concerning abrasive wear of polymers, Chand et al. [20] reported the three-body abrasive wear behaviour of short glass fiber-reinforced polyester composite. Suresha et al. [21] tested Two-Body Abrasive Wear Behavior of Particulate Filled Polyamide66/ Polypropylene Nanocomposites. Kumar et al. [22] investigated effect of particulate fillers on mechanical and abrasive wear behavior of PA66/PP nanocomposites. This study investigated the effect of PA 6/PP composite with different nanoclay proportions and the compatibilizer on wear behavior.

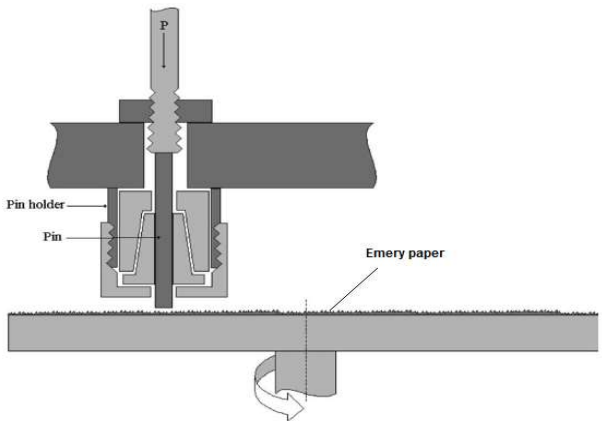

Fig. 1 - Schematic illustration of the wear test apparatus.

2. Experimental Details

2.1. Materials

The materials used in the current study were as follows; PA 6 (DSM Akulon F223-D) as the matrix material; 2,5%, 5 and 7,5% Montmorillonite (Nanomer I 30TC) was supplied by Nanocor Inc.) as the organoclay; 30% PP (Novolen 1100N, BASF); 5% SEBS are Kraton (trade name: Kraton FG1901X, Shell Chemical Company,) as the compatibilizer.

2.2. Sample preparation

PP and PA 6 granules were dried at 80 °C for 12 hours. The materials were mixed and the mixture was extruded using a Werner & Pfleiderer GmbH. ZSK 25 intermeshing co-rotating twin screw extruder. The length/diameter (L/D) ratio was 48, D = 25 mm. Via the twin screw extruder, a compound was obtained by mixing polymer, nanoclay and compatibilizer. The nanocomposites were prepared by mixing the compounds at a cylinder barrel temperature of 230 °C, 240 °C and 250 °C. The extruder screw speed was set at 500 rpm. The samples were injection molded using a Yonca Injection Molding Machine. The temperature maintained in the three zones of the molding machine barrel were between 220 and 240 °C (L/D: 24, D: 65 mm) and the injection pressure was set at 100 bar. Table 1 shows the details of the prepared samples.

2.3. Abrasive wear test

For this study, pin samples from PA 6 and nanocomposites were prepared in 6 mm diameter and 50 mm length. Wear test were carried out on in-house designed pin-on-disc arrangement test apparatus see, Fig. 1. To apply different abrasive conditions during each test, emery paper with grit grade of 80 and 220 were fixed on the rotating disc surface and the pin is fixed in a holder. Before each test, each sample was cleaned by alcohol and dried in air. For each material the dry wear test was carried out for a sliding distances of 12.5, 25, 50 and 75 m and under load value of 5 N and at sliding speed of 1 m/s. After each test the loss in pin mass were recorded. The wear rate was computed from the mass loss of the pin.

Table 1

Composites prepared for the present study

SAMPLES	wt %			
	PURE PA 6	PURE PP	SEBS(C)	Nanoclay (NC)
PA 6	100	-	-	-
PP	100	-	-	-
PA 6/ PP	70	30	-	-
PA6/PP/ C	70	30	5	-
PA6/PP/NC	70	30	-	7,5
PA6/PP/C/NC	70	30	5	2,5
PA6/PP/C/NC	70	30	5	5
PA6/PP/C/NC	70	30	5	7,5

Table 2

Specific wear rates for polyamide 6, PP and it's composites polymers tested at different grit emery paper and sliding distances, (sliding speed, 1 m/s).

Emery paper number	Sliding distance (m)	Pure PA 6	Pure PP	PA 6/ PP (70/30)	PA 6/PP/C (70/30/5)	PA 6/PP/C/NC (70/30/5/2,5)	PA 6/PP/C/NC (70/30/5/5)	PA 6/PP/C/NC (70/30/5/7,5)	PA 6/PP/NC (70/30/7,5)
80	12,5	0,00031	0,00037	0,000153	0,000304	0,000238	0,000237	0,000639	0,000313
	25	0,000587	0,000677	0,000332	0,000508	0,000625	0,000754	0,001185	0,00081
	50	0,000577	0,000671	0,000289	0,000517	0,00081	0,000827	0,001309	0,000947
	75	0,000638	0,000758	0,000314	0,000485	0,000789	0,000843	0,001307	0,001101
220	12,5	0,00007	0,000156	0,000124	0,000138	0,000173	0,000181	0,000341	0,000241
	25	0,000071	0,000149	0,000121	0,000146	0,000169	0,000185	0,000405	0,000253
	50	0,000051	0,000147	0,000096	0,000125	0,000162	0,000171	0,000393	0,000215
	75	0,000034	0,000132	0,000091	0,00011	0,000149	0,000152	0,000277	0,000197

3. Results and discussion

Table 2 collectively shows the specific wear rate values of PA 6, PP and PA 6/PP nanocomposites obtained from the tests carried out using grade 80 and 220 emery papers. Figures 2 and 5 show the specific wear rate graphs of PA 6/PP nanocomposites.

The effect on specific wear rate of PP, compatibilizer and nanoclay added at different rates to pure PA 6 was investigated using grade 80 and 220 emery papers. Figures 2 and 3 show the changes in the specific wear rates along the sliding distance in the tests carried out using grade 80 and 220 emery papers. Figure 2 demonstrates that the highest specific wear rate is for pure PP while the lowest specific wear rate is for PA 6/PP (70/30) composite along the sliding distance. A decrease in the specific wear rate was observed when PP is added to PA 6. In addition, the wear rate decreased with an increase in the wear distance. It is considered that the reason for this event is the decrease in rigidity by the addition of PP into PA 6 and collection of polymer particles on the emery paper caused by abrasive wear. 5% compatibilizer added to PA 6/PP (70/30) composite increased the specific wear rate. Figure 3 shows the changes in the specific wear rates of the composites with the addition of nanoclay to the structure. The lowest specific wear rate is for PA 6/PP/U/NC (70/30/5/2.5) composite. The specific wear rate increased by the increasing rate of nanoclay in PA 6. This is thought to be caused by the increase in structural failure (bad dispersion, agglomeration) with the increase of nanoclay proportion. The compatibilizer added to PA 6/PP decreased the specific wear rates of the composites with 2.5% and 5% nanoclay. This result may be caused from reduction of structural failure and surface tension between PP and PA 6 by the compatibilizer. However, the wear rate of the composite with 7.5% nanoclay is higher than that of the composite (PA 6/PP/NC) with no compatibilizer.

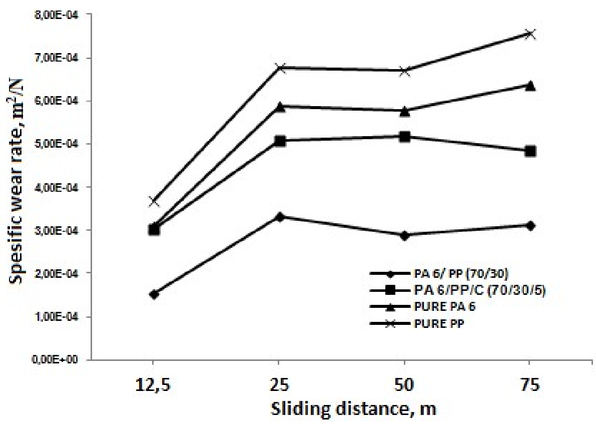

Fig. 2 - The abrasive wear rate of the PA6/PP/C composites at the 80 grit emery paper at different sliding distance (speed: 1m/s, load: 5N).

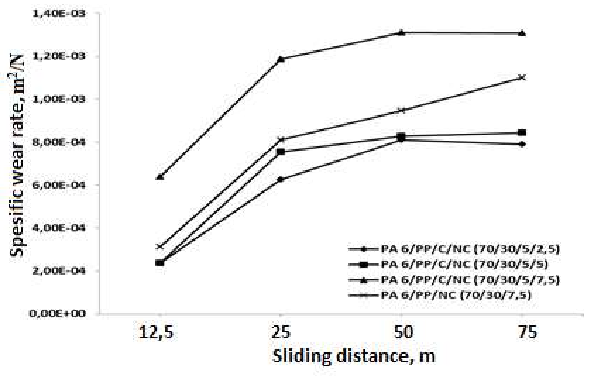

Fig. 3 - The abrasive wear rate of the PA6/PP/C/NC composites at the 80 grit emery paper at different sliding distance (speed: 1m/s, load: 5N).

Figures 4 and 5 show the sliding-distance-dependent changes in the specific wear rates of PA 6/PP/NC composites obtained from the tests carried out using grade 220 emery paper. The tests performed using grade 80 emery paper showed that the specific wear rates of all the samples increased with an increase in the sliding distance. However, the tests conducted using grade 220 emery paper indicated that the specific wear rates of the samples decreased with an increase in the sliding distance. This is thought to be related to decreasing emery size and the decrease in wear due to the detachment of polymer fragments and their adhesion on the emery surface as a result of wear. Figure 4 shows that, as a result of the tests carried out using grade 220 emery paper, the highest specific wear rate is for pure PP while the lowest specific rate is for pure PA 6. PP and the compatibilizer added to PA 6 increased the specific wear rate. Unlike other samples, PA 6/PP/U/NC composite increased the specific wear rate at 25m sliding distance (Figure 5). This might be due to the high rate of additives in PA 6 matrix decreasing the wear strength of the polymer. The specific rate increased with an increase in the rate of nanoclay in PA 6.

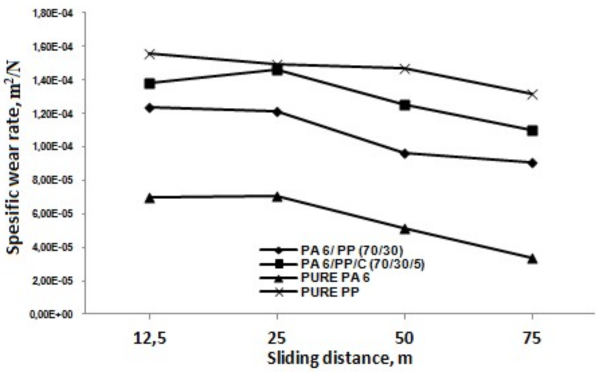

Fig. 4 - The abrasive wear rate of the PA6/PP/C composites at the 220 grit emery paper at different sliding distance (speed: 1m/s, load: 5N).

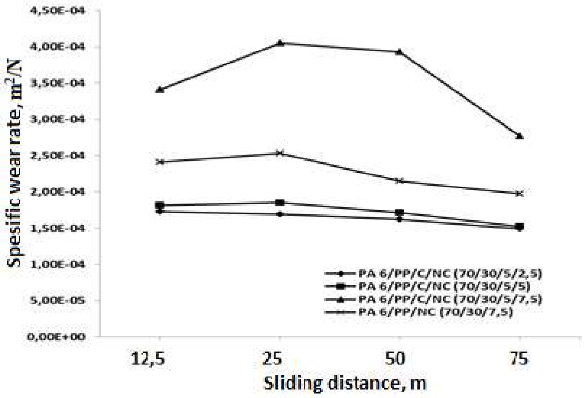

Fig. 5 - The abrasive wear rate of the PA6/PP/C/NC composites at the 220 grit emery paper at different sliding distance (speed: 1m/s, load: 5N).

Table 3 shows the sliding-distance-dependent changes in the friction coefficient values of PA 6/PP/NC composites worn on grade 80 and 220 emery papers. The friction coefficient values differed depending on the material composition, sliding distance and emery size at dynamic condition.

Figures 6 and 7 show the friction coefficient sliding distance graphs obtained from the abrasive wear tests carried out using grade 80 emery paper. The friction coefficient of all samples increased with increasing sliding distance. This is thought to be caused by the absence of any protective film layer on the emery surface due to abrasive wear. Figure 6 shows that the highest friction coefficient value is for pure PA 6 while the lowest friction coefficient is for pure PP. 30% PP added to PA 6 decreased the friction coefficient value. Similarly, 5% compatibilizer added to PA 6/PP also reduced the friction coefficient. It is thought that since PP has a lower friction coefficient than that of PA 6, addition of PP lowered friction coefficient of composite produced. The decrease in the wear resistance of the polymer chains of PA6 with the addition of PP and nanoclay is thought to have caused the reduction in the friction coefficient values.

Table 3

Coefficient of friction for polyamide 6, PP and composites polymers tested at different grit emery paper and sliding distances (sliding speed, 1m/s).

Emery Paper Number	Sliding distance (m)	Pure PA 6	Pure PP	PA 6/ PP (70/30)	PA 6/PP/C (70/30/5)	PA6/PP/U/NC (70/30/5/2,5)	PA 6/PP/C/NC (70/30/5/5)	PA 6/PP/C/NC (70/30/5/7,5)	PA 6/PP/NC (70/30/7,5)
80	12,5	0,593	0,546	0,613	0,577	0,776	0,577	0,512	0,701
	25	0,744	0,591	0,692	0,622	0,757	0,691	0,682	0,746
	50	0,768	0,616	0,7	0,648	0,937	0,855	0,659	0,916
	75	0,843	0,655	0,805	0,686	1,01	0,862	0,658	0,926
220	12,5	0,763	0,539	0,694	0,688	0,782	0,64	0,623	0,669
	25	0,805	0,543	0,745	0,701	0,77	0,631	0,596	0,696
	50	0,696	0,534	0,653	0,614	0,787	0,656	0,647	0,72
	75	0,636	0,544	0,672	0,609	0,804	0,629	0,593	0,727

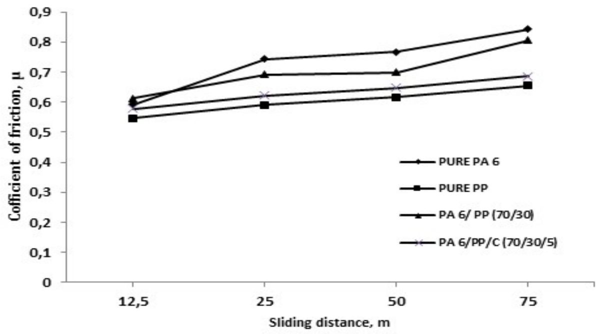

Fig. 6 - The coefficient of friction of PA6/PP/C composites at 80 grit emery paper at different sliding distance (load: 5N, speed: 1 m/s).

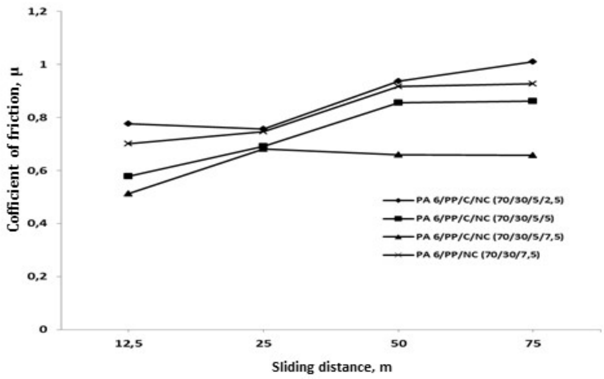

Fig. 7 - The coefficient of friction of PA6/PP/C/NC composites at 80 grit emery paper at different sliding distance (load: 5N, speed: 1 m/s).

Figure 7 demonstrates the sliding-path-dependent changes in the friction coefficient values of the composites obtained by the addition of nanoclay at different rates into PA 6. The sample with the highest friction coefficient is PA 6/PP/U/NC (70/30/5/2.5) composite while the sample with the lowest friction coefficient is PA 6/PP/U/NC (70/30/5/7.5) composite. In line with these results, it can be stated that the friction coefficient decreased with an increase in the rate of nanoclay in PA 6. 5% compatibilizer added to PA6/PP/NC composite also decreased the friction coefficient.

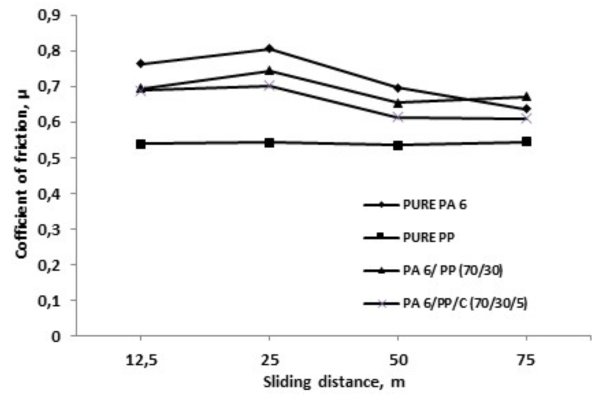

Fig. 8 - The coefficient of friction of PA6/PP/C composites at 220 grit emery paper at different sliding distance (load: 5N, speed: 1 m/s).

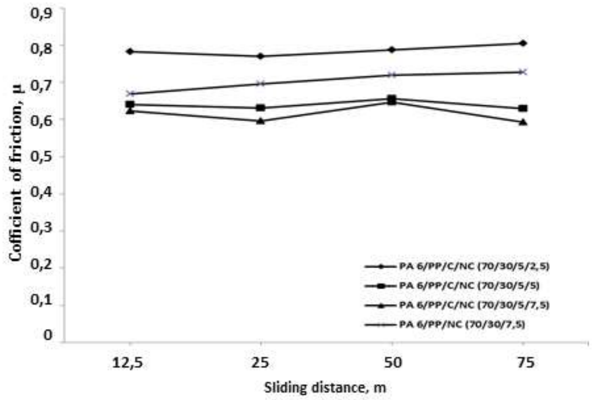

Fig. 9 - The coefficient of friction of PA6/PP/C/NC composites at 220 grit emery paper at different sliding distance (load: 5N, speed: 1 m/s).

Figures 8 and 9 show the friction coefficient vs sliding distance graphs obtained from the abrasive wear tests conducted using grade 220 emery paper. On the whole, it can be stated that the friction coefficient values of all the materials remained the same or tended to decrease with increasing sliding distance. This is thought to be caused by decreasing emery size and detachment of polymer fragments from the polymer pin and their adsorption on the emery surface during wear. As can be seen in Figure 8, PP and the compatibilizer added to PA 6 reduced the friction coefficient value. The reason for this reduction may come from lower friction coefficient of PP regarding PA 6. The friction coefficient decreased with an increase in the rate of nanoclay added to PA 6 (Figure 9). It is believed that reduction in the wear deformation and layered nano-clay structure resulting from the increase in the hardness of the composite together with the increase in nano-clay rate reduces the friction coefficient.

4. Conclusions

The results of the abrasive wear tests of PA 6/PP/C/NC composites are as follows:

- The wear rate decreased with PP added to PA 6 because of lower friction coefficient of PP.
- 5% compatibilizer added to PA 6 increased the friction coefficient, because of softening in material.
- The wear rate increased with an increase in the rate of nanoclay because of agglomeration in composite produced. With increasing sliding distance, the wear rate increased in the tests carried out using grade 80 emery paper while it decreased in the tests carried out using grade 220 emery paper.
- Along the sliding distance, the friction coefficient increased in the tests performed using grade 80 emery paper while it remained the same or tended to decrease in the tests performed using grade 220 emery paper.

- The friction coefficient decreased with an increase in the rate of nanoclay in the matrix. It is believed that reduction in the wear deformation and layered nano-clay structure resulting from the increase in the hardness of the composite together with the increase in nano-clay rate reduces the friction coefficient.
- The decrease in friction coefficient by addition of PP and the compatibilizer into PA 6 may resulted from the decrease in surface tension between PA 6 and PP with the addition of compatibilizer and lower friction coefficient of PP. Decreased the friction coefficient since addition of compatibilizer decreases surface tension between PA 6 and PP
- For all polymer used in this investigation the specific wear rate decreases with the increase in grit grade number.

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