Tribological Behaviours of Nanoclay Filled Polyamide-6/Polypropylene/Compatibilizer Composite against Stainless Steel Counter-Face

Abstract
In this experimental study, tribological behaviors of nanoclay filled polyamide-6/Polypropylene (PA6/PP) polymer blend with styrene-ethylene/butylene-styrene (SEBS-g-MA) compatibilizer were studied. Tribological studies were carried out using a pin-on-disc wear test machine under dry sliding conditions. Tribological tests were run at the applied load of 25, 50, 100, and 150N value and the sliding speed of 0.5 m/s. The results show that the addition of compatibilizer into the polyamide-6/polypropylene blend resulted in enhancement in coefficient of friction and specific wear rate values while montmorillonite 5wt.% nanoclay addition into the PA6/PP-5%SEBS-g-MA blend resulted to an increment in specific wear rate value but decrease in coefficient of friction. Moreover, an optical microscope was used to investigate microstructural properties of polyamide-6/PP/SEBS-g-MA polymer blend and composite.

Keywords: Polyamide; Polypropylene; Compatibilizer; Nanoclay; Wear

Abbreviations: PA6/PP: Polyamide-6/Polypropylene; SEBS-g-MA: Styrene-Ethylene/Butylene-Styrene; PP: Polypropylene

Introduction
Polyamide polymers have moderate mechanical properties, excellent wear resistant properties, and solvents. However, polyamides have some disadvantages such as notch sensitivity and high water absorption. Generally, polyamides are ductile in the un-notched state but they show brittle behavior in the state of notched impact. Some disadvantages of polyamides can be improved by some fillers and additives. Maleic anhydride functionalized styrene-ethylene-butylene-styrene and ethylene-propylene elastomer copolymers were used to improve notched impact strength values of the polyamide polymers composites.

Polypropylene (PP) polymer is an attractive material with respect to easy processability, cheap, lightweight and resistance to most of chemicals. However, PP has some disadvantages such as lower strength and impact strength especially at lower than -10°C temperatures. Some elastomers are added to polypropylene polymer to reduce its stiffness, hardness, and strength. Moreover, some macro and nano size rigid inorganic mineral fillers such as talc [1-4], calcium carbonate [5-7], glass bead [8-9], and clay [10-11] were added to improve the mechanical properties of polypropylene polymer.

PP/PA6 blending has been attempted to achieve important improvement in mechanical properties, where PP consumes good processability while PA6 contributes mechanical and thermal properties [12]. Furthermore, Nano composites based on PA6/PP blends has been extensively studied [13]. Denac et al. [14] studied PP/Talc/SEBS (SEBS-g-MA) composites structure and mechanical properties. Kusmono et al. [15] reported compatibilizing effect of SEBS-g-MA on the mechanical properties of different types of OMMT filled polyamide 6/polypropylene composites. They concluded that the addition of SEBS-g-MA into the nanocomposites enhanced strength and impact strength but slightly reduced stiffness of the material.

In order to study the influence of SEBS-g-MA and nano-clay filler on the tribological properties of PA6/PP polymer blend. PA6/PP-5% SEBS-g-MA blend and PA6/PP-5% SEBS-g-MA-5% nanoclay composite were produced by a twin screw extruder. Friction and wear tests against AISI 440C stainless steel disc were performed on a pin-on-disc arrangement at dry sliding conditions. Influence of SEBS-g-MA compatibilizer and nanoclay filler on the tribological performance was evaluated. In addition, the effect of applied load and sliding speed on the tribological properties were also investigated for PA6/PP polymer blend, PA6/PP-5%SEBS-g-MA blend and PA6/PP-5% SEBS-g-MA-5% nanoclay composite materials.

Experimental
Materials
The polyamide 6 thermoplastic polymer used in this study is an industrial product (Akulon F 223 D) from DSM, Turkey. Polypropylene polymer is also industrial grade product (Novolen 1100N) supplied by BASE, Germany. Styrene-ethylene/butylene-styrene triblock copolymer grafted with 1.84% maleic anhydride (trade name: Kraton FG1901X) was supplied by Shell Chemical Company, USA. Nanoclay material, Nanomer I 30TC, was supplied by Nanocor Inc. USA.

Preparation of PA6/PP/SEBS-g-MA/nanoclay composite
For material compositions used in this study, see Table1. Prior to melt processing steps, polyamide 6, propylene and...
SEBS-g-MA polymers were dried in a conventional oven at 80°C for 4 hours. PA6/PP and PA6/PP-SEBS-g-MA polymer blends and nanoclay filled PA6/PP-SEBS-g-MA composites were prepared by melt compounding using a twin screw extruder (Werner & Pfleiderer ZSK25). The PA6/PP blend composition was kept constant (PA6/PP ratio by weight=70/30), 5 wt.% SEBS-g-MA and 5 wt.% nanoclay. Compounding was melt-mixed in a twin screw extruder at temperature ranged from 220 to 245°C. The extrudates were cooled in water pool and then pelletized with a pelletizer. Prior to injection molding, extrudates dried in an oven at 80°C for 4 hours. To evaluate tribological performance of the materials used, the test samples were prepared by injection molded using an injection molding machine (ERAT, Istanbul, Turkey). Injection molding parameters are shown, see Table 2.

### Table 1: Compositions (wt.%) of materials used in the study.

| Polymer Blends                  | Polyamide-6 (wt.%) | Polypropylene (wt.%) | SEBS-g-MA (wt.%) | Nanomer (I 30TC) (wt.%) |
|---------------------------------|--------------------|----------------------|-----------------|-------------------------|
| PA6/PP                          | 70                 | 30                   | 0               | 0                       |
| PA6/PP-5% SEBS-g-MA             | 70                 | 30                   | 5               | 0                       |
| PA6/PP-5% SEBS-g-MA-5% nanoclay | 70                 | 30                   | 5               | 5                       |

### Table 2: Injection molding process parameters for materials used in the study.

| Injection Molding Process Parameters | PA6/PP | PA6/PP-5% SEBS-g-MA | PA6/PP-5% SEBS-g-MA-5% Nanoclay |
|--------------------------------------|--------|--------------------|---------------------------------|
| Feeding zone temperature (°C)        | 220    | 220                | 225                             |
| Precompression zone temperature (°C) | 230    | 230                | 235                             |
| Compression zone temperature (°C)    | 245    | 245                | 250                             |
| Mold temperature (°C)                | 50     | 50                 | 50                              |
| Injection pressure (MPa)             | 100    | 100                | 100                             |
| Injection speed (mm/s)               | 5.8    | 5.8                | 5.8                             |
| Injection time (s)                   | 6      | 6                  | 6                               |

Tribo-Tests were performed using a pin-on-disc wear test machine. The cylindrical wear pin material was 6 mm in diameter and 50mm in length. For wear test, AISI 440C stainless steel disc was used as a counter-face material. During wear test, friction force was measured by a load cell. Force readings were taken as the average of 1500 readings every 60 s for a period of the testing time. For this purpose, a microprocessor controlled data acquisition system was used. For tribological test, coefficient of friction (\(\mu\)) and specific wear rate values were evaluated. Coefficient of friction values were calculated as follows:

\[
\mu = \frac{F_T}{F_N}
\]

Where \(F_T\) is the friction force and \(F_N\) is the applied load on the sample. Specific wear rate is defined as the wear volume normalized by the normal load and sliding distance. The amount of wear was measured by weighting the pin before and after the tests an accuracy of 1x10^{-4} g in a precision balance. The mass loss (\(m\)) was measured after each set of run and volume loss (\(V\)); \(V=m/p\) was found by using density (\(\rho\)) of the specimen. The following relationship was used to estimate the specific wear rate (m^{3}/Nm):

\[
W_{sp} = \frac{V}{F_n L}
\]

Where \(L\) is the sliding distance. Sliding wear data reported here is the average of at least three runs. Before and after each test, the samples were ultrasonically cleaned and dried in a warm air. Wear tests were carried out at room temperature (23°C±2 and 51±3 % humidity), applied load values of 25, 50, 100 and 150N and sliding speed of 0.5m/s.

### Results and Discussion

Figure 1 presents the variation of coefficient of friction with applied load for PA6/PP blend, PA6/PP-5%SEBS-g-MA blend and PA6/PP-5%SEBS-g-MA-5% nanoclay composite at the sliding speed of 0.5 m/s. It is clear from this figure that the coefficient of friction increased with the increment of applied load values. Among the materials used, the lowest coefficient of friction values are 0.20 for PA6/PP-5%SEBS-g-MA blend followed by 0.27 for PA6/PP-5%SEBS-g-MA-5% nanoclay composite and then followed by about 0.30 for PA6/PP blend under the load of 25N. In comparison with PA6/PP blend, the decrease in COF is about 33% for PA6/PP-5%SEBS-g-MA blend and 10%PA6/PP-5%SEBS-g-MA-5% nanoclay composite. The highest coefficient of friction values are 0.38 for PA6/PP blend followed by 0.31 for PA6/PP-5%SEBS-g-MA-5% nanoclay composite and then followed by about 0.27 for PA6/PP-5%SEBS-g-MA blend under the load of 150N. The decrease in coefficient of friction is about 10% and 29% for PA6/PP-5%SEBS-g-MA-5% nanoclay composite and PA6/PP-5%SEBS-g-MA blend, respectively when comparing with PA6/PP blend. 0.5m/s sliding speeds, the COF values increased with the increase in applied load. This could be explained by rising of surface temperature during rubbing process of all
influence the surface temperature leads to softening of polymer materials used and increasing in COF values.

Figure 1: The relationship between coefficient of friction and applied load for PA6/PP blend and PA6/PP-5%SEBS-g-MA blend and PA6/PP-5%SEBS-g-MA-5%nanoclay composite (sliding speed: 0.5 m/s).

Figure 2 shows the variation of specific wear rate with applied load for PA6/PP blend, PA6/PP-5%SEBS-g-MA blend and PA6/PP-5%SEBS-g-MA-5%nanoclay composite at the sliding speeds of 0.5m/s. This figure shows that, the specific wear rate values increase with the increase in applied load from 25N to 150N. The highest specific wear rate values are for PA6/PP blend with a value of 9.1x10^-14 m^2/N at 0.5 m/s sliding speed and 150N applied load followed by 7.4x10^-14 m^2/N for PA6/PP-5%SEBS-g-MA-5%nanoclay composite. And then the specific wear rate are 6.5x10^-14 m^2/N for PA6/PP-5%SEBS-g-MA blend at 0.5 m/s sliding speed and 100N applied load. Furthermore, the results show that the specific wear rate decrease with the addition of SEBS-g-MA and nanoclay filler into the PA6/PP blend. When it is compared the PA6/PP blend, the specific wear rate decrease about 19% for PA6/PP-5%SEBS-g-MA-5%nanoclay composite and 29% for PA6/PP-5%SEBS-g-MA blend. The lowest specific wear rate values are 5.3x10^-14 m^2/N for PA6/PP-5%SEBS-g-MA blend at the sliding speed of 0.5m/s and 50N applied load followed by 5.8x10^-14 m^2/N for PA6/PP-5%SEBS-g-MA-5%nanoclay composite and followed by 6.7x10^-14 m^2/N for PA6/PP-5%SEBS-g-MA blend at 25N and 0.5m/s sliding speed.

Figure 2: The relationship between specific wear rate and applied load for PA6/PP blend and PA6/PP-5%SEBS-g-MA blend and PA6/PP-5%SEBS-g-MA-5%nanoclay composite (sliding speed: 0.5 m/s).

Conclusion

From the results of this study, the following conclusions are reached;

a. The coefficient of friction value increased with the increase in applied load from 25N to 150N at sliding speed of 0.5m/s for PA6/PP blend, PA6/PP-5%SEBS-g-MA blend and PA6/PP-5%SEBS-g-MA-5%nanoclay composite materials.

b. The specific wear rate values increased with the increase in applied load from 25N to 150N at the sliding speed of 0.5m/s for PA6/PP blend, PA6/PP-5%SEBS-g-MA blend and PA6/PP-5%SEBS-g-MA-5%nanoclay composite.

c. The addition of SEBS-g-MA compatibilizer into the PA6/PP polymer blend result to a decrease in coefficient of friction and specific wear rate values.

d. The addition of 5wt.% nanoclay to the PA6/PP-5%SEBS-g-MA polymer blend lead to the increase in coefficient of friction and specific wear rate values.

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Conflict of Interest

None.

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