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Olivine Particle Reinforced Polyphenylene Sulfide Matrix Composites

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Polyphenylene sulfide is a semicrystalline thermoplastic polymer. It offers an excellent balance of properties, including chemical resistance, high temperature resistance, dimensional stability, electrical characteristics and flowability. Polyphenylene sulfide must be filled with reinforced agents, such as fibers and fillers, to overcome its inherent brittleness. Because of its low viscosity, polyphenylene sulfide can be molded with high loading of fillers and reinforcements. These fillers and reinforcements will make a difference in the electrical properties, strength, dimensional stability, surface properties and overall cost. Because of its inherent flame retardancy, polyphenylene sulfide is ideal for high temperature electrical applications. On the other hand, olivine is volcanic based mineral with porous structure, which consists of forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4). Both, its lower price compared to other minerals and harmlessness to human health increase the usage of olivine from day to day. For this reason olivine reinforced polyphenylene sulfide composite samples were manufactured at various weight ratios (0, 1, 3, 5 and 10 wt.%). Mechanical and scratch properties of samples were investigated and according to test results, it is concluded that olivine mineral can be used as a reinforcing agent material instead of other conventional fillers.

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1. Introduction

Polyphenylene sulfide (PPS) is a semicrystalline engineering thermoplastic. Economic advantages such as recyclability and time saving manufacturing processes compared to thermosets make thermoplastics the favored matrix material. PPS has good mechanical, tribological and thermal properties. It also exhibits dimensional stability at high temperatures, balanced flow properties and resistance against chemicals, high temperature, liquid and oxidation. Application areas of PPS are increasing due to its excellent properties. The most important applications areas are aeronautic, aircraft, automobile, rail vehicle, oil rings and electronics [1–6].

Olivine is a magnesium iron silicate-based mineral with the formula $(Mg2+,Fe2+)_2SiO_4$. Its melting temperature varies between 1200 °C and 1900 °C. For this reason olivine is used for high temperature applications such as refractory bricks and as catalyst in fluidized bed reactors for gasification or biomass combustion. On the other hand it is harmless to human health [7, 8]. Reinforcement with olivine is also reducing the final product cost.

There is limited study in literature in which olivine is used as a reinforcement agent [9, 10]. In this study olivine reinforced PPS composites were prepared with various filling rates, in order to get higher thermal stability, elastic modulus and mechanical properties, which result in better tribological properties. Therefore mechanical properties of olivine reinforced PPS composites were investigated by tensile test and tribological properties were investigated by pin on disc and scratch test methods.

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2. Experimental

2.1. Materials

Matrix material PPS was supplied from Ticona Company, Sulzbach, Germany and the brand name of matrix is Fortron® PPS 1200L. Olivine particles were used as a reinforcing agent and they were supplied from Setat mining company, İstanbul, Turkey.

2.2. Preparation of composite

Olivine particles with dimensions of 25–100 μm were melt mixed to PPS matrix at various weight ratios (1, 3, 5 and 10 wt.%) for reinforcement, using twin screw extruder, produced by DSM XPLORE Company. Prepared olivine-reinforced compounds were molded by DSM XPLORE injection machine. During the mixing the rotational speed of twin screws was 100 rpm and the temperature of melt was 340 °C. The melt-mixed compounds at 340 °C were injected into the mold at temperature of 80 °C.

2.3. Methods

Tensile tests were performed on Shimadzu AG-X Universal Tester with 1 mm/min tensile speed at ambient temperature and moisture.

Scratch tests were performed on CSM Micro Scratch Tester. Scratch tests were performed under 5 N loading force and 30 mm/min scratching speed along the 5 mm scratch line.

Adhesive wear tests of composite samples were performed in open air at ambient temperature and moisture, by using a ball on-disc tester (Nanovea tribometer). The test samples were attached to rotating disc and alumina ceramic ball (with a radius of 3 mm) was used as a pin on disc test, which was located in pin holder on the load arm. All wear tests were performed at 5 mm wear track radius, 150 m sliding distance under 20 N loading force and 0.13 m/s sliding speed. The friction force and friction coefficient values between ball and sample were measured and recorded during the tests. Measurement of wear traces which occurred during the pin-on-disc tests was performed by using Nikon SMZ 745T Microscope and wear volume (Eq. 1) of samples was calculated according to ASTM G99 test standard, by assuming that there was no significant pin wear.

$$V = \frac{\pi R D^3}{6r}. \qquad (1)$$

Here, V is the worn volume (mm^3), R is the radius of wear track (mm), D is the track width (mm) and r is the radius of ceramic ball (mm).

3. Results and discussion

Figure 1 shows the tensile test results. According to Fig. 1a, olivine reinforcement increases the tensile strength of the material up to 5 wt.% filling rate. Above this point olivine reinforcement decreases the tensile strength. It can be seen in Fig. 1a that olivine weight fraction of 5 wt.% has shown the maximum tensile strength value. Surface porosity of the olivine particles results in better adhesion with PPS matrix, which increases the tensile strength of the material up to filling rate of 5 wt.%. On the other hand, as expected, additional filling rates (more than 5 wt.%) cause a dramatic decrease in tensile strength because of the agglomeration and stress concentration effects.

Results of tensile modules values are given in Fig. 1b. Olivine reinforcement increases the modules value for all rates compared to pure PPS. However the maximum module value was reached for 5 wt.% olivine-reinforced composite samples. The higher stiffness value of the olivine particles (like in other inorganic minerals) compared to polymer matrix is the main reason of the increase in the modulus of the composite. Figure 1c shows the elongation at break values of composite samples. It can be seen clearly that by increase in olivine particle content, the elongation at break value is decreased. As expected, olivine reinforcement makes PPS matrix more brittle. As a result of tensile test values, optimum composite sample (for elongation at break) is 3 wt.% olivine-reinforced PPS composites.

Penetration depths of diamond ball during the tribological tests in the composite samples are shown in Fig. 2. It can be clearly seen that the increase of olivine content in PPS decreases the penetration depth. According to this result olivine increases the penetration resistance of the material by increasing the modulus and hardness of PPS, which prevent penetration of diamond ball in PPS matrix.

Adhesive wear test results are given in Fig. 3. Figure 3a shows the coefficient of friction values of composite samples. Figure 3a shows that reinforcing of PPS matrix with olivine has no significant effect on coefficient of friction of

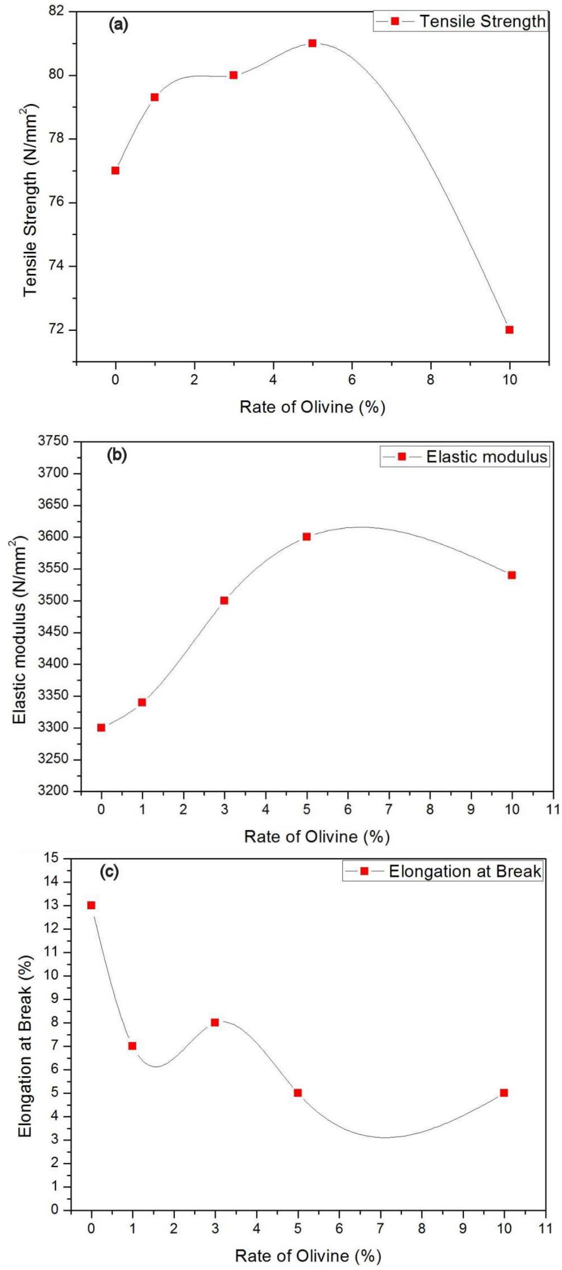

Fig. 1. Tensile test results for composites: (a) tensile strength, (b) elastic Modulus, (c) elongation at break.

composite up to 10 wt.% of olivine filling rate. Figure 3b shows the wear volume of samples. It can be seen clearly that 3 wt.% olivine-reinforced PPS composite has shown the best wear resistance. Up to 3 wt.% filling rate of olivine increase the wear resistance of composite samples compared to pure PPS, because of the increase in hardness and penetration resistance. Over the filling rate of 3 wt.% wear resistance decreases. At that point olivine particles start to behave as abrasive particles and three body abrasive wear mechanisms take place. On the other hand reinforced PPS has higher wear resistance than pure PPS at all filing rates.

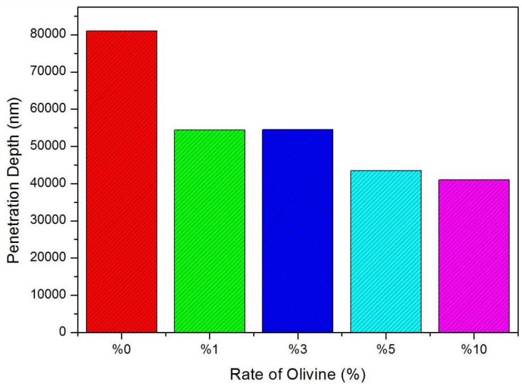

Fig. 2. Penetration depth of diamond tip in samples.

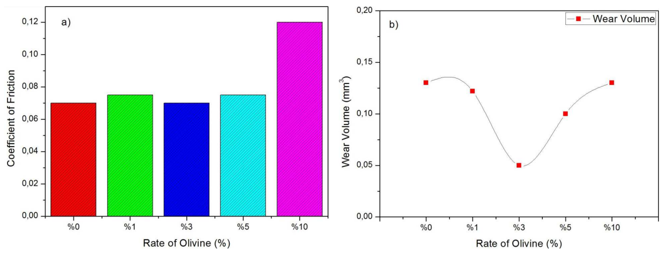

Fig. 3. Adhesive wear test results: (a) coefficient of friction, (b) wear volume.

4. Conclusions

- According to tensile test results reinforcement with olivine particles increases the tensile strength and modulus values, but decreases the elongation at break values and makes the composite samples more brittle. Filling rate of 3 wt.% is found to be optimal and gives the best tribological results.

- Penetration of diamond ball in reinforced PPS matrix decreased with increase of olivine reinforcements.

- According to wear test results, olivine reinforcement has no significant effect on coefficient of friction value of PPS, but olivine filled samples have shown a better wear resistance, compared to pure PPS. 3 wt.% olivine-reinforced samples have shown the best wear resistance behavior.

- As a result of this study, olivine is found to be a cheap alternative reinforcement agent, which can also be used in industrial applications instead of universal fillers.

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