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INTERNATIONAL ADVANCED RESEARCHES
and
ENGINEERING JOURNAL

Journal homepage: www.dergipark.gov.tr/iarej

e-ISSN: 2618-575X

International Open Access

Volume 02
Issue 03

December, 2018

Research Article

Environmental effects on tribological behaviour of composite materials

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ARTICLE INFO

Article history:
Received 05 March 2018
Revised 18 July 2018
Accepted 03 August 2018

Keywords:
Carbon fiber
Environmental effects
Polymer composite
Tribology

ABSTRACT

In recent years, developments in industrial applications has led to the demand for materials with better properties. Composite materials provide these requirements due to their high mechanical properties. Especially in the last half century, the production of composite materials used in industrial areas such as space, marine, aeronautics has increased to a great extent. This increase has led scientists to work on composite materials. One of these work areas is tribological behaviour. It is inevitable that the wear of the composite materials occurs due to surface roughness of the parts in contact with each other; therefore, they may not fulfill the functions expected from them. It is important to determine how tribological behaviour of composites used in almost all areas of the industry will be present in working conditions. In this study, wear and frictional characteristics of carbon fiber reinforced epoxy composites subjected to different environmental effects (soil, water, solar) were investigated under dry contact condition at different operating parameters. Vacuum Assisted Resin Infusion Technique (VDRIT) was used for the production of composite materials. Environmental effects, exposure times and applied loads on the friction coefficients and wear amounts were investigated. Wear tests were carried out under three different loads of 10 N, 20 N, 30 N, sliding distance of 2000 m and at a speed of 0.2 m/s. Wear rate in the experiments was calculated as weight loss. The tests were carried out on samples for each load and their average values were taken. Similar to the results found in the literature, when carbon fiber reinforced composite materials were exposed to different environmental effects, the friction coefficients decreased and the wear rate increased. The use of information and data obtained with this study will guide material selection of machine tools manufactured from composite materials in different environmental conditions.

1. Introduction

Since composite materials are used extensively today, machine parts made from composite materials must be suitable for the environment in which they work. In other words, it is necessary that the desired mechanical properties such as strength, wear resistance, corrosion are appropriate. It is essential to determine the precautions against wear especially on the surface of the materials and to apply these precautions during the use of the machine elements [1, 2].

Wear is often a mechanical strain, and in some cases, a change in shape due to the removal of small particles from the surface of the material [3]. The wear phenomenon, however, has also been described as the deformity of the surfaces of the machine elements in use, usually resulting from the breakage of small parts that occur as a result of mechanical effects [4].

Suresha et al. [5] examined the effects of normal loading and sliding speed on friction and wear behaviors of carbon fiber reinforced epoxy composites. It was determined that the weight loss of the composite material increases with the increase of the applied load and sliding speed.

Wang et al. [6] immersed different fiber orientations (0°, 45°, 90°) carbon fiber reinforced epoxy composites into 10% sulfuric acid solution in different days and investigated their tribological behavior. As a result, 45° fiber-oriented composites had the lowest

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coefficient of friction, while those with 90° fiber-oriented composites had the lowest wear rate.

Suresha et al. [7] also studied three-body abrasive wear behavior of carbon and glass fiber reinforced epoxy composites. It was determined that wear loss increased with increasing load and slip distance in both types of composite materials. In addition, they found that the abrasive wear resistance of carbon reinforced composites was higher than the abrasive wear resistance of glass reinforced composites.

Wu et al. [8] prepared silver-based composites containing WS2 in different amounts by hot pressing method and examined their tribological properties on a disk with normal load of 5 N under moist air, dry nitrogen and vacuum. It was observed that the tribological properties of silver-based composites under environmental conditions are significantly influenced. The coefficient of friction is the highest in humid air and lowest in dry nitrogen.

Sumer et al. [9] studied the tribological behavior of 30% glass fiber reinforced PEEK matrix and pure PEEK matrix materials under dry sliding and water lubricated conditions. It was observed that the friction coefficients and the wear amounts increased with the increase of the applied load and the wear resistance of the composite materials was higher in the experiments performed in water lubricated conditions.

Larsen et al. [10] examined the wear performance of CuO nanoparticle-filled carbon/aramid epoxy composites under various speed and load conditions. They found that fiber orientation in glass fiber reinforced composite materials affects the wear performance and that the addition of PTFE and CuO nanoparticles has a low effect on wear performance.

Khun et all. [11] developed short carbon fiber reinforced epoxy composite materials to investigate tribological properties. The friction coefficient and wear rates of the composites produced were examined using a steel ball at a speed of 3 cm/s and loads of 2 and 6 N. Tribological results made it clear that incorporation of SCFs was an effective way to improve the tribological properties of epoxy composites.

Özay and Hasçalık [12] investigated the effects of carbon content on the wear behavior of Cu-C-Al_2SiO_5 composites obtained by the powder metallurgy method with experiments carried out at loads of 10 N, 20 N and 30 N at 30 m slip distance. Microanalyses of composite test samples were observed using scanning electron microscopy (SEM) and microscope. It was also observed that the amount of wear increases by increasing the volume of reinforcing particles C and the applied external force.

Kishore et al. [13] investigated the wear surfaces with SEM microscope under dry contact condition of glass fiber reinforced composite materials. It was determined that increasing slip distance caused the separation at the interface between fiber and matrix at the wear surfaces.

Sureshkumar et al. [14] examined the friction and wear properties of epoxy resin reinforced glass/carbon hybrid composites. Tribological properties such as friction and wear rate were investigated using pin-on-disk method. Experiments were carried out at 20, 40, 60 N loads at constant speed of 5m / s and sliding times of 2, 4 and 6 min. It was observed that the wear rate increased with increasing the carbon ratio, but the friction coefficient decreased with increasing carbon ratio in the composite.

Chen et al. [15] produced carbon nanotube reinforced carbon fiber epoxy composites. The friction and wear properties of the composites were investigated using a UMT-2 friction and wear tester. The tribological properties of the composites were clearly improved after reinforcing of carbon nanotubes. The reason is that carbon nanotubes increase the mechanical interlocking and chemical bonding interactions between fiber and epoxy, so that the fibers aren't pulled easily under shear stress during friction and wear.

Srivasta et al. [16] investigated the wear and friction characteristics by adding mica to the unidirectional glass fiber reinforced epoxy resin composite material. They found that the mica particles increased the hardness and compressive strength of the composite material and exhibited better tribological properties.

The aim of this study is to experimentally determine the wear behavior of composites affected by environmental conditions (soil, water, sun). Carbon fiber reinforced epoxy composites used in this study were produced with VDRIT (Vacuum Assisted Resin Infusion Technique). Wear tests were carried out at certain periods and the differences and the tribological properties of the composite materials were investigated.

2. Materials and Methods

In this study, woven carbon fiber with a density of 300 gr/m^2 was used as reinforcing material. Aradite LY 1564 epoxy and Aradur 3487 BD hardener were selected as the thermosetting polymer matrix material. 6 layers of carbon fiber were prepared for reinforcing material in composite plate. The ratio of hardener and epoxy for matrix material was 1/3 of the mass. Prepared reinforcing fabrics were vacuumed at 1 bar pressure. After vacuum seal was established, infusion of the epoxy mixture into the reinforcing fabrics was provided. After infusing the resins into all reinforcing fabrics, the system was allowed to cure at 100 °C for 2 hours in the vacuum. For control of the wetting condition of the composite plate, samples were taken from different areas and visual inspection revealed that all plate was wetted throughout the thickness. Samples were prepared from the composite plates prior to the wear tests. The samples were cut in 18x18x10 mm dimensions with a cutting saw. Samples were tested using the TRD Wear program to retrieve the reference values before exposure to environmental effects. Then, it was exposed to water, soil and sun for 100 and 200 days. Water was used as city water. As evaporation took place, water was added every 10 days. The soil of university ground that was not used as an agricultural land was used. A 1-meter pit was opened, and the samples were buried in the soil. The sun was applied throughout the day and night. After exposures the samples were subjected to wear tests under different load conditions (10 N, 20 N, 30 N).

3. Experiments and Results

3.1 Composite Materials without Environmental Effects

The pin-on-disc method was used for wear test of carbon fiber composite material. A 10 mm diameter high-speed tool steel was used as a wearing tool. Before composite samples were exposed to environmental effects, initial wear tests were carried out at room temperature and dry friction conditions with a sliding speed of 0.2 m/s, a sliding distance of 2000 m and loads of 10 N, 20 N and 30 N. Tests were performed for each load and the average friction coefficient and wear rate obtained are given in Table 1, Figure 1 and 2.

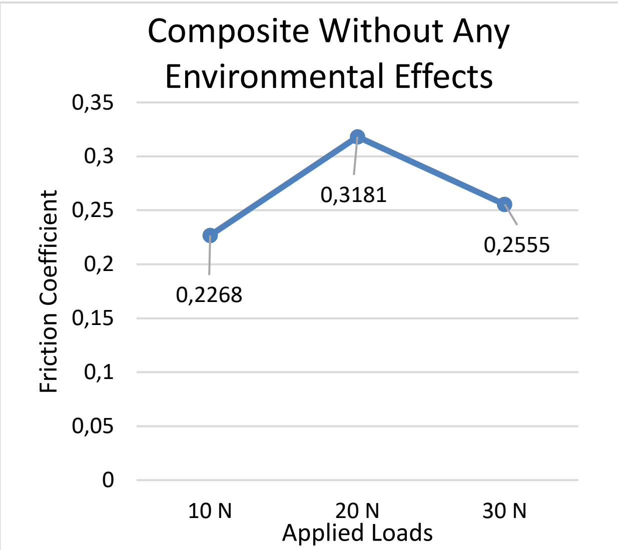

Figure 1. Average friction coefficients of carbon fiber composite samples without any environmental effects

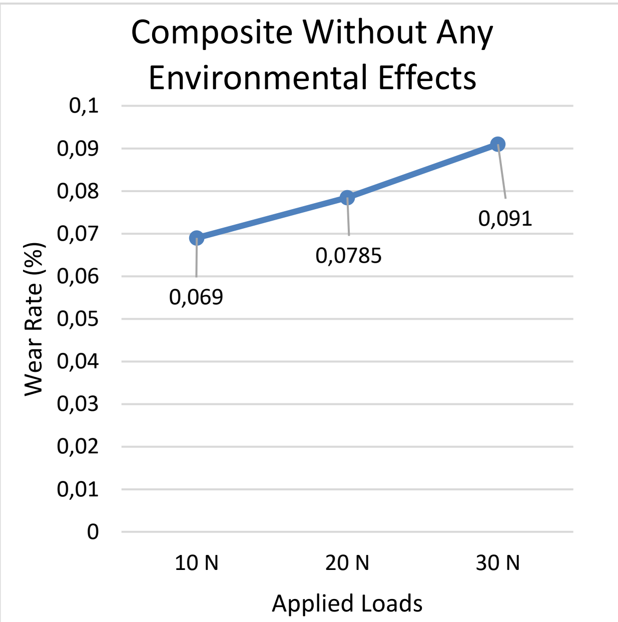

Figure 2. Average wear rate of carbon fiber composite samples without any environmental effects

The friction coefficient of carbon fiber composite without any environmental effects increased first (40,25%) and then decreased (19,67%). This result can be explained by the self-lubrication of carbon.

The wear rate of carbon fiber composite samples increased as the applied load increased. There was an increase of 13.76% from 10 N to 20 N, while an increase of 15.92% from 20 N to 30 N was observed. This change seems to be close to the linear.

Table 1. Average friction coefficients and average wear rate of carbon fiber composite samples without any environmental effects

Loads (N)	Average friction coefficients	Average wear rate (%)
10	0,2268	0,0690
20	0,3181	0,0785
30	0,2555	0,1150

3.2 Composite Materials with Environmental Effects

After exposure to environmental effects (water, soil and sun for 100 and 200 days), samples were tested using the TRD Wear program under different load conditions (10 N, 20 N, 30 N. The results are shown in figures and tables below.

3.2.1 Composite Materials with Sun Effect

The load-dependent change in average friction coefficients and wear rates of carbon-fiber composite samples exposed to the sun are given in Figure 3. The average friction coefficient for carbon fiber composite samples exposed to the sun for 100 days increased as the applied load increased, but the friction coefficient results for samples with 200 days sun effect decreased. The increase in 100 days is 9.09 % while the decrease in 200 days is 31.81%. It is known that fiber matrix interface affects the performance of the composite material [17]. It may be that the fiber matrix interface bond was weakened in the composite material exposed to the sun for 200 days. This weakening, due to the pressure at the interface, could lead to wear loss increasing while reducing the friction coefficient as the load increased. The wear rate increased as the applied load increased. It increased by 59.72% in 100 days and increased by 43.90% in 200 days. Although the rate of increase in 200 days was low, the wear rate was higher than 100 days.

3.2.2 Composite Materials with Soil Effect

The load-dependent change in average friction coefficients and wear rates of carbon-fiber composite samples exposed to the soil are given in Figure 4. The average friction coefficient for carbon fiber composite samples kept under soil for 100 days decreased (25%) at the load value of 20 N and increased (13,33%) at 30 N but on the contrary for 200 days exposure this value increased (16,66%) at the load value of 20 N and decreased (4,76%)

at 30 N. Wear debris can affect the tribological performance of composite materials [18]. It could be seen that the effect of the soil on the wear debris is not constant. This imbalance wear debris was observed as decrease and increase in results. The wear rate increased as the applied load increased. This rate is 33,33% in 100 days, while it is 30,11% in 200 days.

3.2.3 Composite Materials with Water Effect

The load-dependent change in average friction coefficients and wear rates of carbon-fiber composite samples exposed to the water are given in Figure 5. As seen in figure, the average friction coefficients under the effect of water for 100 days (71,42%) and 200 days (33,33%) were found to increase as the applied load increased. Wear rate was measured as 30.69% in 100 days and 34.58% percent in 200 days. The wear rate increased as the applied load increased. If the sample is exposed to the same load, there is an increase in wear rate during exposure to water.

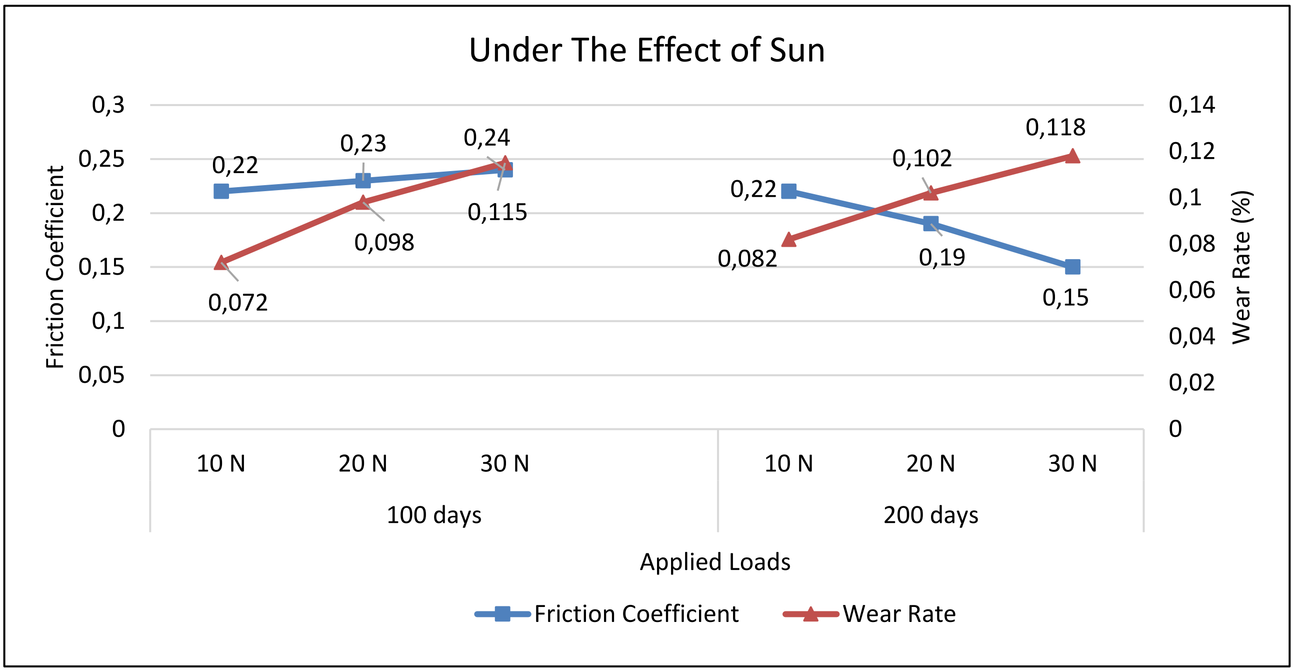

Figure 3. Average friction coefficients and average wear rate of carbon fiber composite samples with sun effect

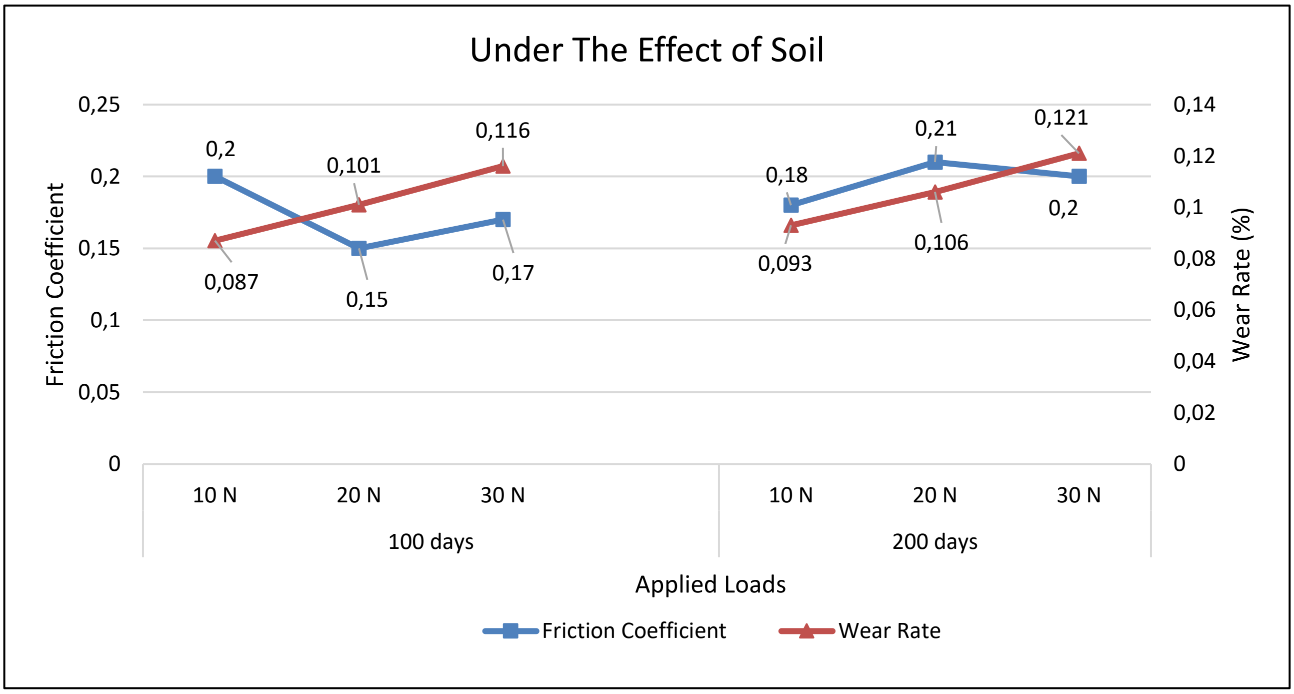

Figure 4. Average friction coefficients and average wear rate of carbon fiber composite samples with soil effect

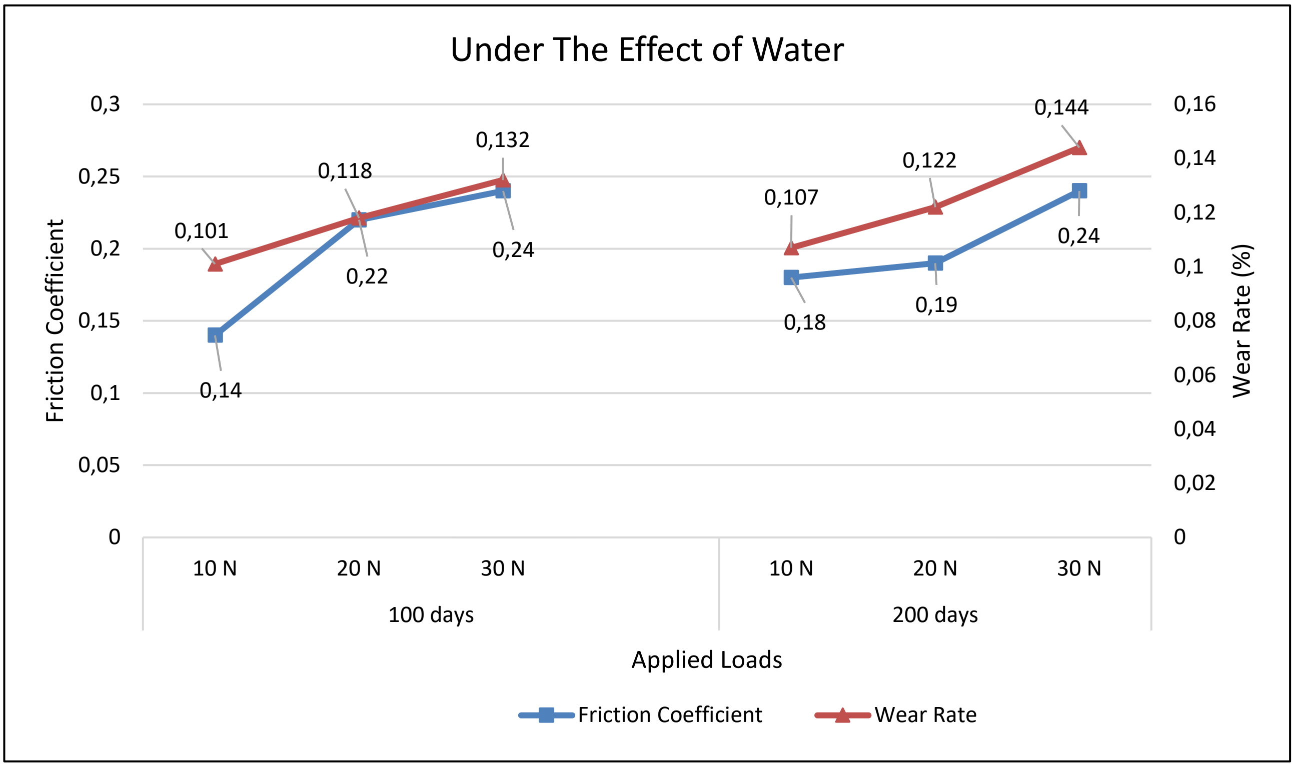

Figure 5. Average friction coefficients and average wear rate of carbon fiber composite samples with water effect

Table 2. Average friction coefficients and average wear rate of carbon fiber composite samples with sun effect

Time (Day)	Loads (N)	Average friction coefficients	Average wear rate (%)
100	10	0,22	0,072
	20	0,23	0,098
	30	0,24	0,115
200	10	0,22	0,082
	20	0,19	0,102
	30	0,15	0,118

Table 3. Average friction coefficients and average wear rate of carbon fiber composite samples with soil effect

Time (Day)	Loads (N)	Average friction coefficients	Average wear rate (%)
100	10	0,20	0,087
	20	0,15	0,101
	30	0,17	0,116
200	10	0,18	0,093
	20	0,21	0,106
	30	0,20	0,121

Table 4. Average friction coefficients and average wear rate of carbon fiber composite samples with water effect

Time (Day)	Loads	Average friction coefficients	Average wear rate (%)
100	10 N	0,14	0,101
	20 N	0,22	0,118
	30 N	0,24	0,132
200	10 N	0,18	0,107
	20 N	0,19	0,122
	30 N	0,24	0,144

4. Conclusions

In this study, tribological properties of composite materials were investigated by experimental studies on carbon fiber reinforced epoxy composites exposed to environmental effects.

The following are key observations from this study:

- As expected, as the exposure to environmental conditions increased, the composite material was more affected.
- The environmental factor that affects the composite material most often was water with an average wear rate of 51.99%, then soil with an average wear rate of 34.24% and then the sun with an average wear rate of 26.15%.
- No clear increase or decrease in friction coefficients was observed. This is because the environmental conditions affect the quantity of wear debris differently. Another effect that may be caused is the different effects of the applied loads on the transitions in the fiber matrix interfaces.

5. Suggestions

This study could be further developed within the scope of the following suggestions.

- The present work can be applied to different composite materials by changing the resin and reinforcement elements used.

- The effects of various parameters such as wear rate, temperature, different fiber-matrix ratio on wear behaviors of composites can be examined.
- This work can be improved for different environmental conditions.
- The effects of environmental conditions, such as cracks, on the wear behaviors of composite materials can be investigated.

Acknowledgment

This work supported by HÜBAK under Research Project (project no: 16035), Turkey.

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