Friction and Wear Behavior of Carbon/PEEK Composites according to Sliding Velocity

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Abstract

This study was to correctly estimate the friction and wear behavior of carbon fiber and PEEK sheet composites, and the validity of using them as alternatives to the metal-based materials used for artificial hip joints. Moreover, this work evaluated the friction coefficient according to the fiber ply orientation, along with the fractured surfaces of the carbon/PEEK composites. The unidirectional composites had higher friction coefficients than those multidirectional composites. This was caused by the debonding between the carbon fiber and the PEEK sheet, which was proportional to the contact area between the sliding surface and the carbon fiber. The friction test results showed that there was no significant differences in relation to the fiber ply orientation. However, in a case where the speed was 2.5 m/s, the friction coefficient was relatively large for configuration I. The friction surface of the specimen was analyzed using an electron microscope. In all cases, the debonding of the fiber and PEEK could be confirmed.

Keywords: Carbon fiber, Composites, Friction, PEEK, Tribological, Wear

1. Introduction

Composite materials are designed to display properties that are superior to those of the individual materials. Of these composite materials, fiber-reinforced plastics have a high specific strength and specific rigidity. They have been increasingly and consistently used as alternatives to the metallic materials used in the aerospace, ship building, automobile, and sports-related leisure product industries because they show excellent chemical resistivities and formabilities. [1~5]

Recently, there has been active progress in the research on new medical devices because of the health concerns and population problems that arise from a rapidly aging society. However, in general, metal materials are the mainstream, and it is rela-

tively difficult to apply composites to medical devices, despite of their excellent characteristics. [6~8]

Currently, an artificial hip joint consists of the three with a stem. The Ti, Co-chrome or stainless steel alloys are component of the stem. However, metal materials deliver small scale stress to an arbitrary area of the bone due to a difference in rigidity. Metal materials also atrophy the femur, causing bone loss. Moreover, a problem arises whereby the implant device loosens as a result of the stress shielding between the metal material and the bone, shortening the life of the joint. [9~12]

In addition, there has been a surge in the number of patients with articular disease because of the increase in the human lifespan. Therefore, more than one joint is often required using a resubstitution technique. However, the success rate is drastically decreased in a resubstitution operation. There-

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fore, the development of a patient-customized artificial hip joint is urgently required in order to improve the useful life of the artificial hip joint. Thus, a substitute composite material needs to be found to resolve this problem.

In the human body, an artificial hip joint is placed in a constant friction environment for a long period. Particularly, the neck part of the stem is weakened due to the friction between the head and the cup. In addition, the artificial joint needs to be investigated in terms of the change in intensity according to the fiber ply orientation angle of the carbon/PEEK composite, because of the stress it receives from various angles. [13, 14]

Therefore, in this research, carbon-fiber-reinforced composites using PEEK resin as the matrix material were fabricated, and the different mechanical properties according to the friction were investigated through friction tests. At the same time, the effect of the friction on the mechanical properties of the carbon/PEEK composites was considered according to the ply orientation angle and friction angle of the fiber. From these results, an examination was made of whether or not the carbon/PEEK composites were applicable to artificial hip joints

2. Materials and Specimens

2.1. Preparation of Experiment Materials

In this experiment, materials were prepared to measure the friction coefficient of the carbon/PEEK composites. First, PAN-based UD tape was used for the carbon fiber for the reinforcing material. In addition, a thermoplastic PEEK film from the Victrex Company was used as the matrix material.

Fig. 1. The Shape of the Carbon/PEEK semi-prepreg

2.2 Manufacture of Specimens

The carbon/PEEK semi-prepreg was made. The carbon/PEEK semi-prepreg were indicated in Fig. 1. The PEEK film was used as the matrix materials for the manufacture of prepreg. The prepreg sheet was made using PEEK film of the same size and was laminated on both surfaces of the carbon fiber in a hot press at a pressure of 10 MPa at 400°C. Thereafter, the carbon fiber prepreg was laminated at various angles in order to confirm the change in the mechanical properties according to the ply orientation angle of the fiber. Subsequently, the composite materials were made by operating the hot press at 380°C using the hot press molding method with the prepreg. The curing conditions are shown in Fig. 2.

2.3. Experiment Method

A pin-on-disc device was used to observe the frictional properties of the carbon/PEEK composites. Stainless steel was used as the relative friction surface, and the normal load was fixed at 20 N and 40 N. The friction coefficient was investigated according to the fiber ply orientation. Configuration I had all six plies oriented at (0°) [(0°)₆]. Configuration II had one ply oriented at (±45°), one at (0°/90°), and the other at (±45°) [(±45°)₁(0°/90°)₁(±45°)₁]. Configuration III had all three plies oriented at (±45°) [(±45°)₃]. The friction velocities were 2.5 m/s and 5 m/s. The humidity was maintained at 37°C during the experiment. Simultaneously, the damaged carbon fiber and the wear of the composites were observed using SEM.

Fig. 2. Curing Conditions for Specimen Preparation

Fig. 3. Effect of Sliding Velocity and Pressure on Friction Coefficient

3. Results and Discussion

3.1. Friction and Wear Behavior

The friction coefficients were compared according to the fiber ply orientation. The changes in the friction coefficient are shown in Fig. 3. As shown in the figure, the friction coefficient did not show a large-scale change according to the sliding distance at a low pressure and speed. However, the friction coefficient was increased and reduced when the pressure and speed increased. The carbon fiber and matrix material had a surface with discontinuity. Preferentially, a crack occurred at the side where these were in contact, and the delamination phenomenon was generated. In other words, the matrix part wore out as the pressure

increased. Thus, it is considered that the fiber received the repeated load. Therefore, it was determined that the pressure and speed had an effect on the friction coefficient. In addition, in the case where the speed was 2.5 m/s, a relatively large friction coefficient was found for configuration I. This appears to be a phenomenon where the bending stress acted on the carbon fiber. However, in a case where the speed was 5 m/s, no definite difference was seen in the friction coefficient according to the carbon fiber ply orientation. Thus, it could be said that the fiber ply orientation was unable to have an effect on the frictional property when the friction velocity was high. Friction tests were carried out to observe the destroyed morphology in the interface between the resin and the fiber, and the friction surface of the specimen was analyzed using an electron microscope.

Fig. 4. SEM Observations

Fig. 4 shows the friction shape for each specimen. In all cases, the debonding of the fiber and PEEK could be confirmed. The carbon fiber was subjected to more repeated loads at high speed. Thus, the debonding seemed to be generated by the degradation of the material.

4. Conclusion

In this study, carbon fiber was used as the reinforcement for composites with PEEK film. The mechanical properties according to the friction and wear were also investigated. In addition, this study analyzed the effect of the friction on the composites according to the fiber ply orientation. The following results were obtained from these data.

(1) The friction coefficient did not show a large-

scale change according to the sliding distance at a low pressure and speed.

(2) The pressure and speed had an effect on the friction coefficient.

(3) No clear difference was found in the friction coefficient according to the carbon fiber ply orientation.

(4) In all cases, the debonding of the fiber and PEEK could be confirmed, and the carbon fiber was subjected to more repeated loads at high speed. Thus, the debonding seemed to be generated by the degradation of the material.

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