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Tribological behaviors of carbon composite grooved surfaces

Seong Su Kim, Hak Gu Lee, Dai Gil Lee *

Department of mechanical Engineering, Korea Advanced Institute of Science and Technology, ME3221, Kusung-dong, Yusong-gu, Taejon 305-701, Republic of Korea

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Abstract

The tribological behavior of carbon epoxy composites whose surfaces have many small grooves of 100 μm width was experimentally investigated with respect to the sliding direction against groove orientation, surface pressure (*P*) and velocity (*V*). The wear mechanism of the composites was observed to calculate the wear volume with the friction coefficient using scanning electron microscopic (SEM). Experimental results show that the abrasive wear is dominant wear mechanism for the grooved composite surface and the friction and wear are greatly reduced when the sliding direction is parallel to the axis of groove because abrasive particles are removed through the grooves effectively.

Keywords: Carbon epoxy composite; Surface grooves; Wear volume; Friction coefficient; Abrasive wear

1. Introduction

Polymers are finding wide acceptance in tribological applications because of their low friction against metal counterparts and the self-lubricating ability. Especially, polymer matrix composites reinforced with fibers have been widely accepted as bearing materials and used in the components supposed to run without any external lubricants [1]. Several investigations have been reported in the past on the tribological characteristics of carbon fiber reinforced polymeric composites. Gopal et al. [2] showed that the specific wear rate carbon fiber epoxy composite per unit load and sliding distance decreased with increasing loads, but increased with increasing drum speed and temperature due to thermal degradation of the resin. Tsukizoe and Ohmae [3] studied wear between unidirectionally oriented fiber-reinforced-plastics and mild steel and found that the wear behavior was greatly influenced by the sliding direction and the mechanical properties of fiber-reinforced-plastics. Sung and Suh [4] found that the wear and friction coefficients were minimum when the orientation of the fibers was normal to the sliding surface.

In order to improve the tribological characteristics of polymer composites, several approaches were made. The deposition of thin (1–10 μm) coatings of low friction material on sliding surfaces has been proved to be an effective way to achieve reduced friction coefficients and wear rates, often without changing the bulk material or using liquid lubricants [5–7]. Several groups of materials are currently used for these coatings: various types of ceramics, solid lubricants, diamond, and diamond-like carbon (DLC). Voevodin et al. [8] studied the development of multilayer coatings for sliding wear applications, from which they suggested that multilayer coatings with Ti20%-DLC and Ti35%-DLC layers were appropriate for low friction coefficients with low wear rates. Zhang et al. [9] studied the friction and wear behavior of metal sulfides or PTFE (Polytetrafluoroethylene) filled with metal sulfides or graphite under both dry and oil-lubricated conditions to get some insight into the friction and wear mechanisms of the PTFE

* Corresponding author. Tel.: +82 42 869 3221; fax: +82 42 869 5221.
E-mail address: dglee@kaist.ac.kr (D.G. Lee).

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composites under oil-lubricated conditions. They found that filling MoS_2, PbS, CuS, or graphite to PTFE can reduce the wear of the PTFE composites by two orders of magnitude compared to that of pure PTFE under dry friction condition.

Among the attempts so far performed, it has been found that tribological characteristics of polymer composites with deposition of thin coatings or mixing with fillers were much better than those of pure polymer composites. However, there have been few investigations on the friction and wear behavior of polymer composites with respect to the shape of sliding surface. In view of the above, it would be interesting to examine the tribological performance of composites that have many small surface grooves fabricated during molding with respect to loading condition and sliding direction.

It was known that the frictional force of metal is originated either or both from plowing the surfaces by particles and asperities, the adhesion between the flat surfaces in contact, and the asperity deformation [10].

The basic mechanisms of sliding friction of polymers are similar. The plowing, adhesion and deformation of asperities are major contributors to friction between polymeric solids and other materials [11]. In the running period, when there was contact between metal and carbon epoxy composite, the surface is sheared and plouged. The shearing and ploughing take place more or less at the same rate. This give rise to loose carbon particles between the mating surfaces, which abrades the surface through shearing and ploughing. These abraded particles produce more loose particles having sharp edges [11]. Accordingly, if these abrasive particles should be removed through many small grooves fabricated on the composite surface, the wear volume and friction coefficient may be decreased much. The frictional heat may be also removed through these grooves which may work as channels for fluid lubrication.

The aim of these investigations is to compare the characteristics of wear and friction of the grooved carbon composite specimen with those of specimen without grooves. Also, the wear mechanism was observed and correlated with the microstructure of the composites.

2. Experimental details

2.1. Material and preparation

The material used for the specimen was carbon fiber epoxy prepreg whose unidirectional properties when cured are listed in Table 1. The fabricating process for the specimens with many small grooves is illustrated in Fig. 1. The mold with many small cavities was fabricated by placing together two different sizes of stainless plates of 100 and 200 μm thicknesses in zig–zag fashion, followed by clamping them using bolts as shown in Fig. 1(a). The composite prepregs were stacked on the mold with applied pressure and vacuum and cured under proper curing cycle (125 °C, 0.6 MPa) as shown in Fig. 1(b). From this process, the composite plate with many small grooves was obtained as shown in Fig. 2. The fibers of prepregs were aligned to the axial direction of grooves during molding.

Table 1
Mechanical properties of unidirectional carbon fiber reinforced epoxy composite

Tensile modulus (GPa)	Longitudinal	130.0
	Transverse	10.0
	Shear	5.1
Tensile strength (MPa)	Longitudinal	2300
	Transverse	56
	Shear	60
Poisson's ratio		0.28
Density (g/cm^3)		1.55

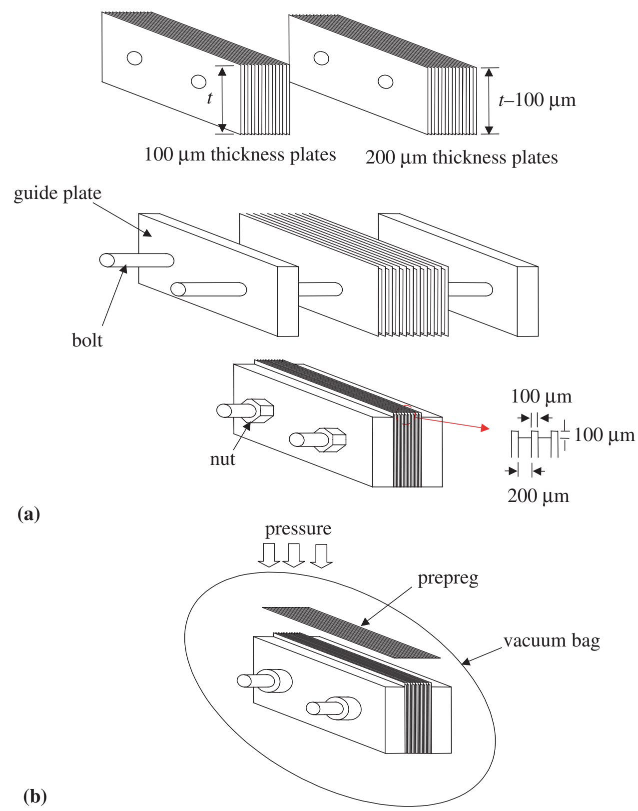

Fig. 1. Fabricating process of the concave mold and specimens (patent pending): (a) mold fabrication method, (b) molding process for the composite with many small grooves.

2.2. Experimental apparatus

The composite plate was cut to the size of 5 mm × 5 mm × 6 mm for the wear test as shown in Fig. 3. The wear tests were performed using a