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Micro CNC surface texturing on polyoxymethylene (POM) and its tribological performance in lubricated sliding

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ABSTRACT

The effect of surface texturing on the friction of polyoxymethylene was investigated in terms of surface texturing density. Surface texture was machined using CNC machining. Five different surface texturing densities were machined and tested in a pin-on-disk sliding configuration. Bearing steel was used as a mating material on polyoxymethylene (POM). Sliding speed and nominal contact pressure were 0.1 m/s and 1.35 MPa, respectively. Sliding distance was 1 km, and the lubricant was SAE 5W-30 oil. The lowest coefficient of friction was obtained with a 10% texturing density, where the reduction in friction was about 50% of that of the non-textured POM.

1. Introduction

It has been shown that the introduction of surface texturing onto a solid material during sliding contact can modify the friction of the mating materials, especially in a hydrodynamic lubrication environment. Surface texturing, mostly in an array of square-patterned dimples or pores, has been reported to lower the coefficient of friction due to lubricant retention. Surface texturing is known to reduce the wear of materials because worn fragments fall into the dimples during sliding, thereby lowering third body abrasion action. Surface texturing is also known to have counterwork due to the hydrodynamic disturbance of lubricant during sliding motions, resulting in an increased coefficient of friction. Therefore, it can be said that the surface texturing density and the shape of a hole based on the aspect ratio play a key role in surface texturing for low-friction materials.

Surface texturing that has a concave shape has been widely studied because the role of surface texturing has been focused on the retention capability of a lubricant. However, surface texturing with a convex shape can be made and used in many areas. For example, surface texturing that has hemispherical pillars has been studied by Ranc et al. [1]. In their study, the silicone pillars were made using a mold technique and were designed to mimic a human tongue with different surface roughness. They reported that the pillar density significantly affected the coefficient of friction in dry as well as lubricated conditions. In particular, they insisted that a minimum of contact angle between a liquid and a pillar structure was a prerequisite for the formation of a lubricating film, thereby contributing to the oral perception of food.

In addition to the geometric characteristics of texturing, the processing method used to produce texturing is important, since each method results in a unique feature of texturing. Mold technique [1], indentation by a hard probe [2], reactive ion etching [3], shot blasting [4], lithography [5], and pulsed air arc treatment [PAAT] [6] are typical ways of creating surface texturing. If a highly precision surface texturing is required, the lithography and the indentation technique would be the best choice, but processing is very costly and time consuming. Meanwhile, other techniques such as the shot blasting technique can be a useful technique for surface texturing. Among them, laser surface texturing (LST) [7–9] is one of the most widely accepted methods due to the distinct characteristics. Laser is known as a highly versatile tool for precision machining, and the most current surface texturing techniques with respect to metallic materials utilize laser over a wide range of wavelengths and pulse energies. However, thermal damage such as the formation of bulges and burrs, a heat-affected zone (HAZ), and debris have been shown to hinder the prompt application of surface texturing. In industry, to get rid of bulges and burrs, for example, lapping and/or polishing work must be performed prior to application, although it is a costly and time-consuming work. Debris also has to be removed from the textured surface in order to keep it from abrading the mating parts during contact.

In this respect, mechanical machining may be preferable to thermal processing, since mechanical machining produces less thermal damage due to the supply of lubricant. This study utilized

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a computer numerical control (CNC) machining technique instead of a laser ablation technique to create surface texturing. Of course, CNC machining has inherent disadvantages in terms of materials selection and texturing dimensions, despite its superior machinability. In other words, if a material is very strong and has a high hardness, texturing via a micro-drill cannot be properly accomplished because of the failure of the micro-drill. Also, the dimensions of the hole and groove are entirely dependent upon the drill's diameter, and thus production of a hole less than 50 μm, the smallest size available, would be technically difficult.

Moreover, most tribological studies of surface texturing have focused on the modification of ceramics [4–5] and metallic materials [7–9], since they are the primary engineering materials. However, a large number of engineering plastics and polymeric composites have replaced metals due to their high specific strength and ease of manufacturability. Therefore, applications of a surface texturing technique for polymeric materials should be investigated. In this work, we first investigated the processibility of laser texturing on polymers. The results were then compared with those from CNC machining. Samples of varying surface texturing densities were prepared using CNC machining in order to study the effect of surface texturing on the coefficient of friction of polyoxymethylene (POM), an important engineering plastic. This study is novel since no previous surface texturing against a polymer was created using computer numerical control (CNC) and no works have yet been reported for surface texturing on a POM surface.

2. Experimental details

2.1. Materials and sample preparation

Polyoxymethylene (POM) was used for surface texturing since it is a widely used engineering polymer due to its low friction characteristic and superior mechanical properties. Prior to surface texturing, POM specimens, 30 mm in diameter and 10 mm in thickness, were prepared by cutting and lathing. The POM surfaces were then further finished by abrasion using SiC abrasive paper of grit number 4000, resulting in a surface roughness of about 0.2 μm Ra (Mitutoyo SJ-201). The POM samples were then mechanically cleaned in an ultrasonic cleaner with acetone for 10 min and dried before machining.

Surface texturing was performed using a small CNC machine (Roland EGX-350), which is used for engraving work. To make an array of holes, a 125 μm micro-drill was used. A hole depth of 125 μm was maintained during machining in order to keep an aspect ratio of 1. Each sample rested on the CNC machine floor, and a zero point on the vertical axis was ensured prior to operation. Using this set-up, the aspect ratio was maintained constant throughout the machining. Chips formed during machining were removed by blowing compressed air. After machining, the samples were cleaned in an ultrasonic bath of acetone. The hole densities over the nominal sample area were 5%, 10%, 20%, and 30%. The maximum texturing density in this study was 30% because a density greater than 30% could make contact area insufficiently small. That is, the sample with a higher texture density, more than 30%, for example, cannot withstand normal or shear loads, since the area of the surface that is not textured decreased substantially as the texturing density increased.

2.2. Sliding test

Sliding tests were performed in a pin-on-disk sliding test configuration (MPW-110, NEOPLUS). In order to increase the contact area between POM surface and a mating disk, a pin and its holder were newly improvised. It has been known that micro-pores/dimples are mainly effective under hydrodynamic lubrication conditions, especially under planar-to-planar contact [4]. However, full contact between two mating solid materials is not easy to achieve. Thus, the original pin jig was slightly modified, as described in Fig. 1. First, a steel bar was cut and machined to produce a steel disk 15 and 7 mm in diameter and thickness, respectively. One side of the disk remained flat, whereas the other side of the steel disk was machined into a large crater-like shape, where the crater was designed to mate with a steel ball 12.7 mm in diameter. The ball installed for the ball-on-disk sliding test was used as an adapter to guide contact between the disk and the POM sample surface, and it is analogous to a ball–socket joint structure. As seen in Fig. 1, the disk was not directly installed into the upper ball holder. Instead, the steel ball was placed between the disk and the ball holder. This structure is believed to compensate for the abrupt off-axis rotational motion of the disk, which maintains better contact between mating parts. The lubricant was applied to the socket surface to reduce friction at the ball–socket interface. Examination of the ball surface after the sliding tests showed neither scratches nor marks, indicating that the ball did not rotate during sliding. In addition, the formation of unidirectional wear marks on the POM and the disk surface indicated that they did not freely rotate during sliding.

Detailed sliding test conditions are listed in Table 1. The diameter and thickness of the steel disk, which was machined for area contact are 6.8 and 1 mm, respectively, as described in Fig. 1. The disk material is a bearing steel, ASTM 52100. It was lapped before the sliding tests, and the roughness of the disk was 0.04 μm Ra. The linear sliding speed was 0.1 m/s and the nominal contact pressure was 1.35 MPa. A sliding distance of 1 km was used for all sliding tests, corresponding to a sliding time of about 2.78 h. The lubricant used in this study was SAE 5W-30 automotive oil (10.13 cSt at 100 °C). The lubricant was spread onto the POM surface and stored in a vacuum chamber to remove entrapped air within the holes. Spreading the lubricant helped it soak into the holes. The samples were then placed on the CNC machine floor. To obtain a uniform lubricant thickness, a windshield wiper blade was cut and installed at the end of a collet of the CNC machine. The height of the windshield blade was kept

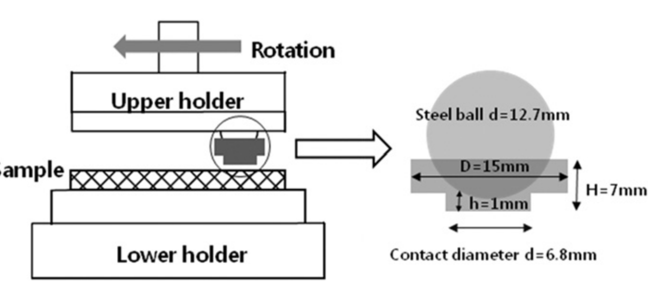

Fig. 1. Schematic diagram of pin-on-disk sliding test configuration used in this study. Dimensions: the ball and the disk contact diameter are 12.7 and 6.8 mm in diameter, respectively. The radius of the wear track is 9.5 mm. Sliding conditions: sliding speed is 0.1 m/s, sliding distance is 1 km, and normal contact pressure is 1.35 MPa.

Table 1
Pin-on-disk sliding test conditions.

Nominal contact pressure (MPa)	1.35
Sliding speed (m/s)	0.1
Sliding distance (km)	1
Sliding time (h)	2.78
Disk material	Bearing steel (ASTM 52100)
Lubricant	SAE 5W-30 (KIXX G1)
Temperature	Room temperature
Wear track radius (mm)	9.5