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Development of the 3D capillary structured bronze by utilizing metal 3D printer

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ABSTRACT – In order to improve the frictional properties, a self-oil-circulating structure, termed a 3D capillary structure, has been proposed. The 3D capillary structure was manufactured by metal 3D printer, because of its complex micro-structure. The bronze was focused as sliding material. In this study, the oil lubricant supplying function and frictional properties of the 3D capillary structured specimen made of bronze were investigated. Experimental results showed that the 3D capillary structured specimen made of bronze had the oil supplying function and lower frictional property than that made of stainless steel.

1. INTRODUCTION

In mechanical parts, it is important to supply an oil lubricant to the sliding surface, because oil starvation causes seizure and eventually a machine failure. Surface texturing is a technique micro-grooves and micro-dimples [1]. It has been reported that surface texturing improves frictional properties by maintaining lubricant on the sliding surface and trapping wear debris [1]. On the other hand, the effect of conventional surface texturing is limited under sever conditions [2]. Therefore, the novel tribo-surface is required to improve frictional properties under severe conditions.

In order to improve the frictional properties, a self-oil-circulating structure, termed a 3D capillary structure, has been proposed. It can collect excessive lubricant from sliding surface and supply it again into sliding interface by utilizing capillary phenomenon. The 3D capillary structure was manufactured by metal 3D printer, because of its complex micro-structure. The 3D capillary structured specimen made of stainless steel had oil supplying function and excellent tribological properties. However, the material used in a metal 3D printer is limited, and it is difficult to manufacture the specimen made of the material with good frictional property.

In this study, bronze is focused as sliding material, and the 3D capillary structured specimen was manufactured by bronze. The oil supplying function and frictional properties of the 3D capillary structured surface were investigated.

2. METHODOLOGY

2.1 Capillary phenomenon

Capillary phenomenon is a phenomenon in which the height of the liquid surface in a tube becomes higher owing to surface tension. The height of the liquid column h is given by

$$h = \frac{2\gamma\cos\theta}{\rho g r} \quad (1)$$

Where γ is the liquid surface tension, θ is the contact angle, ρ is the density of the liquid, g is the gravitational acceleration, and r is the radius of the tube. From Equation (1), it is possible to supply oil lubricant to the sliding surface by reducing radius of the tube.

2.2 Test specimen

The test specimen was manufactured by a metal 3D printer (ProX DMP 200, 3D Systems, USA). The material used for manufacturing was a phosphor bronze powder with an average particle diameter of 31 μm and the chemical composition is shown in Table 1. Figure 1 shows the schematic of 3D capillary structured specimen. The 3D capillary structure has an oil reservoir and three small paths of 0.4 mm in diameter which are connected under the sliding surface. To increase the load capacity, the two dimples of 0.4 mm in diameter were given between the small paths. The depth of small paths was 6.9 mm, and that of dimples was 0.1 mm.

Table 1 Chemical compositions of bronze powder.

Alloying element	Cu	Sn	P	O
wt [%]	BAL	10.1	0.01	0.02

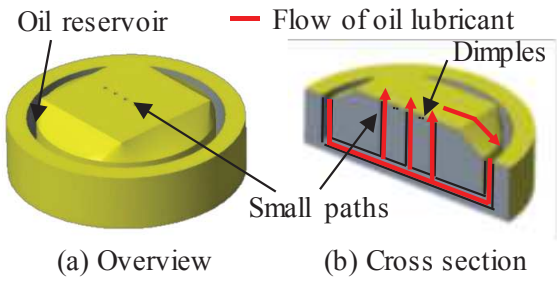

Figure 1 A schematic of the 3D capillary structured specimen.

2.3 The oil supplying function

A sliding test was conducted to confirm whether the 3D capillary structure could effectively supply the oil lubricant. A Bowden-Leben-type cylinder-on-plate friction tester was used. The cylinder (ϕ 6 mm × 8 mm length) was made of AISI 52100. As 300 μL of engine oil (Mobil 1, SAE 0W-20) was injected into the oil reservoir, a sliding test was initiated with a no oil lubricant on the surface. The behavior of the oil lubricant supplied to the

sliding surface was observed by a video camera.

2.4 Friction tests

Friction tests were conducted using a cylinder-on-plate sliding tester (SRV 4, Optimol, GE). The cylinder (ϕ 6 mm × 8 mm length) was made of AISI 52100. The friction test conditions are given in Table 1. A sliding test was initiated after 300 µL of Mobil 1 was injected into the oil reservoir and 50 µL of Mobil 1 was dropped on the surface. To compare the frictional property of a 3D capillary structured specimen made of bronze, a non-textured specimen made of bronze and a 3D capillary structured specimen made of stainless steel were manufactured.

Table 1 Test friction test conditions.

Load	[N]	5
Temperature	[°C]	80
Stroke	[mm]	1.0
Frequency	[Hz]	10

3. RESULTS AND DISCUSSION

3.1 The oil supplying function

Figure 2 shows images of oil lubricant behavior on the sliding surface. Before the sliding test, a meniscus was not formed for Mobil 1 on the surface. However, a meniscus was observed for Mobil 1 between the cylinder and the surface as the sliding test started and the cylinder touched the path. The meniscus was maintained between the cylinder and the surface during the sliding experiment. Therefore, Mobil 1 was supplied to the entire surface by a capillary structure. The experimental results suggested that the 3D capillary structured specimen made of bronze could effectively supply the oil lubricant.

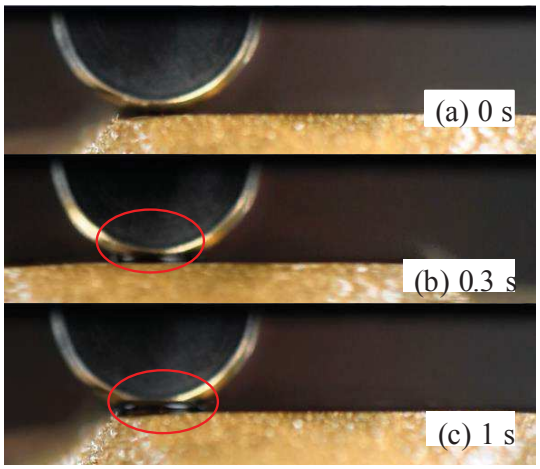

Figure 2 Oil lubricant behavior on the sliding surface.

3.1 Friction tests

Figure 4 shows frictional behaviour of each specimen. The friction coefficient of the non-textured specimen made of bronze, the 3D capillary structured specimen made of stainless steel, and the 3D capillary structured specimen made of bronze was 0.10, 0.07, and 0.02 respectively. From the result of friction test, the friction coefficient for the 3D capillary structured specimen made of bronze was lower than that of non-textured specimen made of bronze and the 3D capillary structured specimen. It was considered that the 3D capillary structure had better frictional property than non-textured specimen and the frictional property of the bronze was better than that of stainless steel.

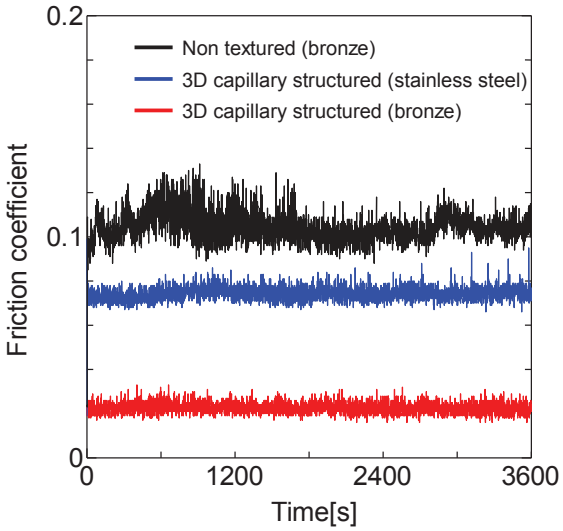

Figure 3 Friction coefficient behavior.

4. CONCLUSIONS

A 3D capillary structured surface was manufactured by metal 3D printer, and its oil supplying function and frictional properties were investigated. The main conclusions drawn are as follows:

(a) The 3D capillary structured specimen made of bronze could effectively supply the oil lubricant.
(b) The friction coefficient for the 3D capillary structured specimen made of bronze showed lowest of all specimens.

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