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Application of Woodceramics to Plain Thrust Bearing

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A plain thrust bearing consisting of four woodceramics pads (MDF-800) was newly designed and manufactured for trial. The tribological property was evaluated under various lubricated conditions. The sliding velocity and the contact pressure were 2.9m/s and 0.4MPa respectively. The mating material was 0.45wt. % carbon steel. The lubrication method was bath lubrication. The friction coefficient under oil and water lubricated conditions was small and in the range of 0.1 to 0.17. The Stribeck's diagram suggested that the woodceramics thrust bearing had a high capacity for maintaining low friction. The specific wear rate was also small and of the order of 10^{-7}(mm^3/Nm) under oil and water lubricated conditions. Thus the woodceramics thrust bearing has a high potential for practical use in oil and water lubricants.

Key words: Woodceramics, Thrust Bearing, Friction and Wear, Tribology, Eco-material

1.INTRODUCTION

A new porous carbon material, "Woodceramics" has been developed (1-2) and its practical use has been expected in the industrial field. It has been reported that the woodceramics has some excellent properties such as thermal resistance, corrosion resistance, oxidation resistance in addition to good shielding effect for electromagnetic waves (3). The woodceramics is composed of two types of carbon materials; a soft graphite and a hard glassy carbon. Since graphite is one of the best solid lubricants along with molybdenum disulfide (MoS_2) and polytetra-fluoroethylene (PTFE), woodceramics would have low friction coefficient and low wear rate. The basic friction and wear behaviour of woodceramics has been studied in details (4-5). However, there are few works about the application of woodceramics to machine elements such as bearing, clutches and so on.

In this study, a woodceramics thrust bearing was newly designed and manufactured for trial. The tribological behaviour was studied under various lubricated conditions.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

Experiments were carried out using a plain thrust bearing tester. The schematic diagram is shown in Fig.1. The upper specimen was driven with a motor and load was applied with a lever loading system. Frictional force was measured using a load cell. The shapes and sizes of specimens are shown in Fig.2. The lower specimen was a woodceramics thrust bearing. It consisted of four woodceramics pads (MDF-800) bonded to steel base with outer and inner diameter of 100mm and 40mm. The woodceramics was produced by carbonizing the medium density fiber board (MDF) impregnated with phenol resin in vacuum furnace at 800℃. The dimensions of pad were 30mm in length, width of 10mm and 10mm of height. The upper specimen was a hollow cylinder made by a carbon steel (S45C). The outer diameter of cylinder was 90mm and inner diameter was 50mm. The apparent contact area was 803mm^2. The surfaces of upper and lower specimens were finished by a surface grinding machine. The properties of specimens are summarized in Table I .

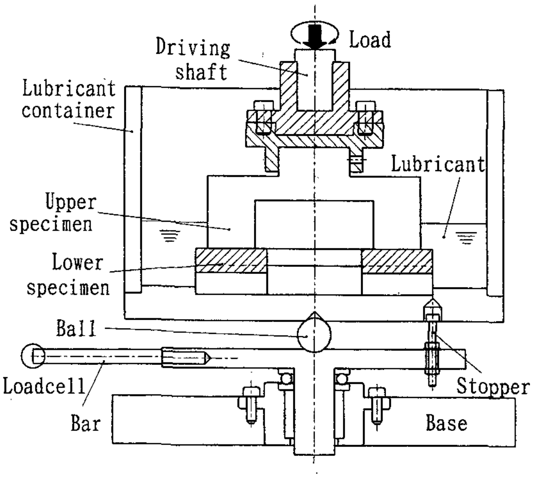
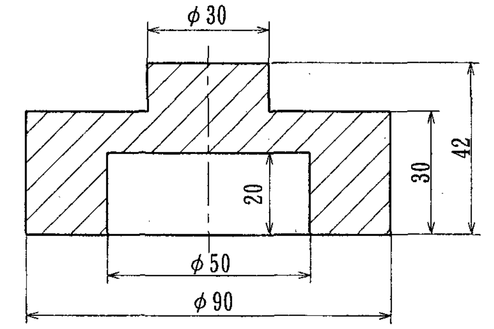
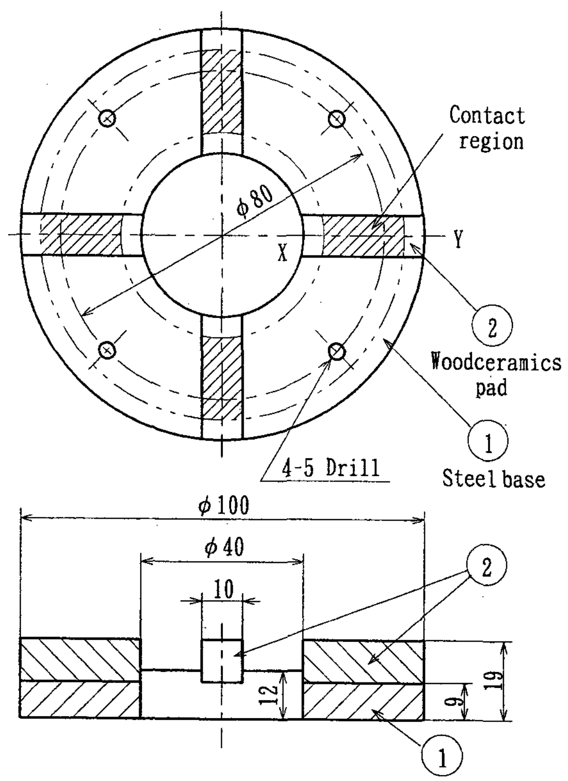


Fig.1. The schematic diagram of wear tester.



(a) Upper specimen



(b) Lower specimen (woodceramics thrust bearing)

Fig.2. The shapes and sizes of upper and lower specimens.

The experimental conditions are summarized in Table II. The experiments were carried out under unlubricated or lubricated conditions. Non-additive turbine oil (ISO VG46) and distilled water were used in this study. The lubrication method was bath lubrication.

The friction coefficient μ was deduced using relation,

$$\mu = F/P \quad (1),$$

$$F = P_L \cdot L/R \quad (2),$$

where F is the friction force, P is the applied load, P_L is the reading of load cell, L is the distance from rotation center (L=120mm) and R is the mean friction radius (R=35mm). Wear scar of each woodceramics pad was measured with a profilometer after the wear test to obtain profile perpendicular to the friction direction. The wear volume of each pad ΔV was derived from the multiplication of the cross section of wear scars measured by a planimeter and the width of the pad (10mm). The specific wear rate Ws was calculated using,

$$Ws = \Sigma \Delta V/(P \cdot S) \quad (3),$$

where $\Sigma \Delta V$ is the total wear volume, P is the applied load and S is the sliding distance.

Table I. Properties of testing materials

	Upper specimen	Lower specimen
Materials	Carbon steel (S45C)	Woodceramics (MDF-800)
Vickers hardness HV (kgf/mm^2)	200	50~179
Surface roughness Rmax (μm)	1.3	33.6

Table II. Experimental conditions

Sliding velocity (m/s)	2.9
Contact pressure (MPa)	0.2, 0.4
Lubricant	(1) Unlubricated (2) Non-additive turbine oil (ISO VG46) (3) Distilled water
Lub. Temp. (℃)	20±3
Lub. Volume (cc)	300

3.RESULTS AND DISCUSSION

3.1 Friction property

Fig.3 shows the relationship between the friction coefficient and the run time under various lubricated conditions. At unlubricated condition, the friction coefficient increases gradually after 20 min. Since the mating steel softens due to the high frictional heat, the contact area increases and wear debris generated from the steel adheres to the woodceramics surface (4). Thus, the friction becomes high at unlubricated condition.

Low and stable friction coefficient of about 0.15 is maintained under oil and water lubricated conditions. The woodceramics has porous structure, so that the lubricant oil does not contribute to reduction of friction due to oil film formation. The oil might be act for cooling the frictional surface and for washing wear debris out from the frictional surface. In fact, the water and oil lubricant temperatures were maintained during the wear test at 50~60℃ and 80~100℃, respectively. Thus, it is considered that water becomes a good lubricant, which has lower viscosity than that of oil.

Consequently, the low friction may be maintained easily in the woodceramics bearing, when the mating material keeps low temperature using a coolant or it is resistant to high temperature, such as stainless steel.

3.2. Stribeck's diagram

Fig.4 shows the relationship between the friction coefficient and the bearing modulus. The bearing modulus is expressed as $\eta\,\omega/Pm$, where η is the viscosity of lubricant (Pa·s), ω is the rotational speed (1/s) and Pm is the contact pressure (Pa). Fig.4 is the Stribeck's diagram which indicates the lubricated condition in the sliding bearing. For the metal bearing, the friction coefficient increases as the bearing modulus decreases because of the decrease of the oil film thickness and direct contact between asperities (6).

The woodceramics bearing maintains low friction coefficient over a wide range of the bearing modulus, as shown in Fig.4. The transition from low friction coefficient to high friction coefficient was not observed in this study. Therefore, it is suggested that the woodceramics has a high capacity for maintaining low friction coefficient at the lubricated conditions or when the operating conditions change suddenly for some reasons.

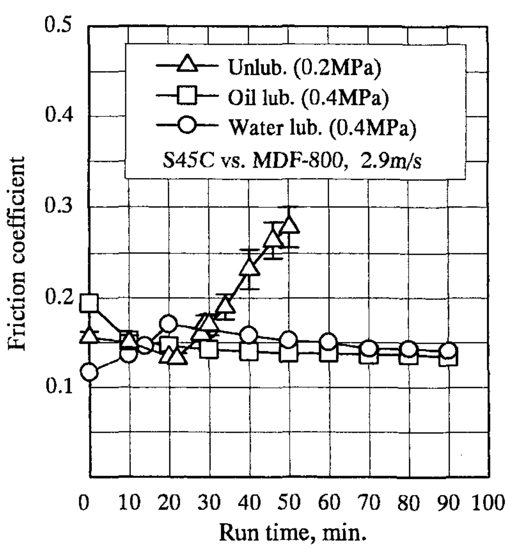


Fig.3. The friction curves under various lubricated conditions.

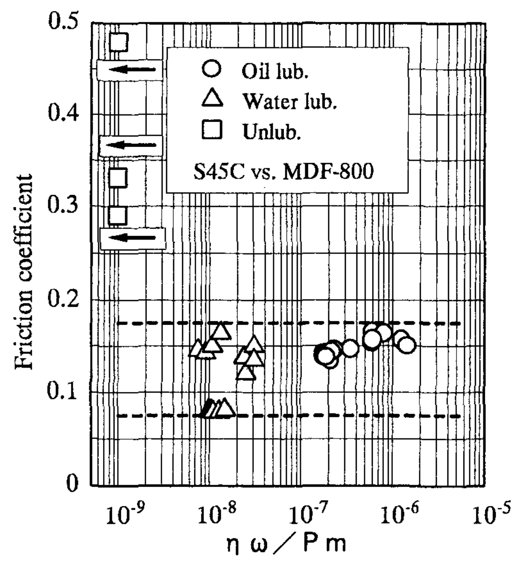


Fig.4. Stribeck's diagram.

3.3 Wear property

Fig.5 shows the specific wear rate of the woodceramics bearing under various lubricated conditions. The specific wear rates are about $2x10^{-6}$ (mm^3/Nm) at 0.2MPa and (4~6) x 10^{-7}(mm^3/Nm) at 0.4MPa. The friction coefficient below 0.3 and the specific wear rate below 10^{-6}(mm^3/Nm) are acceptable for commercial use (7). The woodceramics thrust bearing satisfies these severe demands under oil and water lubricated conditions. The specific wear rate is almost the same under oil and water lubricated conditions. With the increase in the contact pressure, the specific wear rate decreases. The increase in the contact pressure causes the decrease in the porosity near the surfaces, which leads to a decrease in friction coefficient and wear rate due to oil film formation. The similar result has been reported previously (5).

At high contact pressure (0.4MPa) under unlubricated condition, the edge parts of woodceramics were broken by severe vibration induced during the initial stage of friction. Because of its brittleness, severe vibration has to be avoided in a practical situation. In oil and water lubricants, it is expected that the woodceramics is strengthened as the lubricant fills in many pores existing in the woodceramics. Thus, the woodceramics thrust bearing has a high potential for practical use in oil and water lubricants.

There are clear differences between the surface and the inside of woodceramics in friction and wear behaviour. Fig.6 shows the depth profile of the friction coefficient and the specific wear rate of woodceramics.

At shallow region to 2mm, the friction coefficient is relatively high at 0.10~0.15 and the specific wear rate is negligible small. In contrast, at deeper region, friction coefficient becomes smaller and specific wear rate becomes higher. Near the surface, the porosity of the woodceramics is small and the content of hard glassy carbon is high. At the deeper region, the porosity increases and the content of hard glassy carbon decreases. Therefore, it is considered that friction coefficient becomes smaller and specific wear rate becomes higher at the inside of woodceramics. It is concluded that woodceramics maintains stable friction coefficient and low wear rate at shallow region to 2mm from the surface.

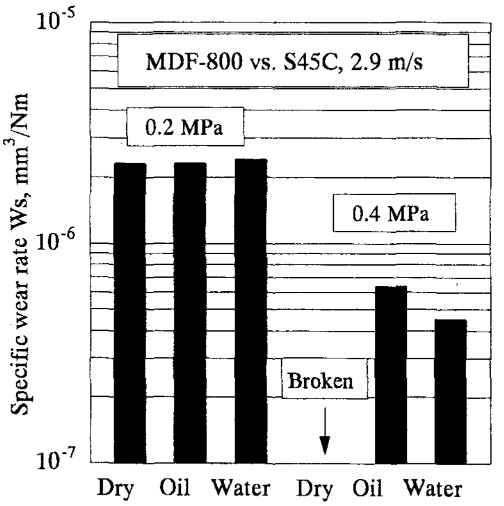


Fig.5. The specific wear rate of the woodceramics thrust bearing under various lubricated conditions.

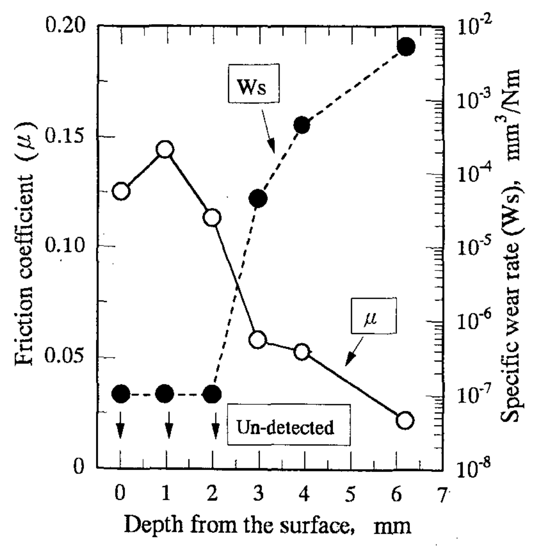


Fig.6. The depth profile of friction coefficient and specific wear rate of the woodceramics.
(MDF-800 vs. MDF-800, 0.5m/s, 0.12MPa, in Water)

After the wear test, wear scars of the woodceramics pads were observed with a scanning electron microscope and an optical microscope. It was confirmed that the porous structure was maintained, although wear scar partially became smooth.

4. CONCLUSIONS

(1) The woodceramics thrust bearing maintained low friction coefficient (0.10~0.17) and low specific wear rate (~10^{-7} mm^3/Nm) under oil and water lubricated conditions. At unlubricated condition, friction coefficient increased gradually after the run time of 20 min.

(2) The Stribek's diagram suggested that low friction coefficient could be maintained over a wide range of the bearing modulus.

(3) The woodceramics maintained stable friction coefficient and low wear rate at shallow region to 2mm from the surface.

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