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Tribological Properties of Woodceramics under Lubricated Sliding Contacts using Mineral Oil, Vegetable Oil and Water

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The effects of lubricants on the friction and wear behaviors of woodceramics were studied under lubricated sliding contact. Four kinds of lubricants such as mineral oil (ISO VG10 and ISO VG46), vegetable oil (rape oil) and distilled water were studied in this study. The experiment was conducted with a block on ring wear tester. The block material was woodceramics (MDF-800). The ring material was forging steel (SF540A). The load was varied in the range of 98N to 294N. The sliding velocity was 10.2m/s. It was concluded that the friction and wear properties of the woodceramics were not dependent on the kinds of lubricants and their kinematic viscosity. For all lubricants, friction coefficient was small and lay in the range 0.08-0.15. The wear rate of the woodceramics was also small and lay in the range 10^{-7}-10^{-8}(mm^3/Nm). Thus it was suggested that woodceramics had a high potential for practical use as sliding bearing.

Key words: Woodceramics, Tribology, Lubricated Wear, Mineral oil, Vegetable Oil, Distilled Water

1.INTRODUCTION

A new porous carbon material, "Woodceramics" has been developed (1) and its practical use has been expected in the industrial field. The woodceramics is an environmentally friendly material, that is, an eco-material (2). It has been reported that woodceramics maintain low friction coefficient and low wear rate under oil and water lubricated conditions at high sliding velocity (3-4). Therefore, the lubrication is indispensable for applying the woodceramics to machine elements operating at high sliding velocity.

In order to enlarge the application fields of woodceramics in practice, it is essential to study the friction and wear behaviors of woodceramics using the various kinds of lubricants. In this paper, the effects of lubricants on the sliding friction and wear behaviors of woodceramics were studied at high sliding velocity.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

Experiments were carried out using a block on ring wear tester. The schematic diagram is shown in Figure 1. The ring material was forging steel (SF540A). The ring had a diameter of 130mm and a thickness of 20mm. The ring surface was finished by cylindrical grinding after turning. The block material was a woodceramics (MDF-800). It was produced by carbonizing the medium density fiber board (MDF) impregnated with phenol resin in vacuum furnace at 800℃. The block was finished by grinding with emery paper (#800) after forming with surface grinding machine. The block had a length of 50mm and a width of 10mm.

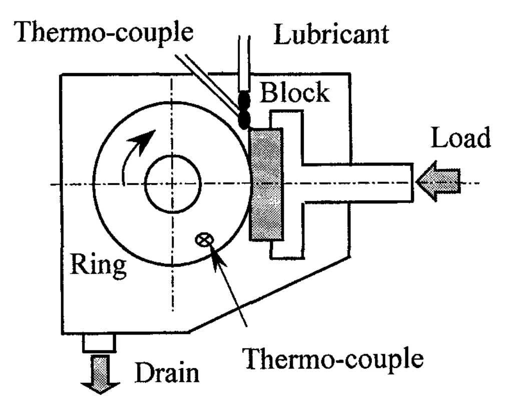


Fig.1 Schematic diagram of experimental apparatus.

The properties of testing materials are summarized in Table I. The experimental conditions are summarized in Table II. Four kinds of lubricants were used; turbine oil (ISO VG10), turbine oil (ISO VG46), vegetable oil (rape oil) and distilled water. The lubricating oil was supplied at a flow rate of 32cc/min using a micro-tube pump. The temperature was kept at 30±3℃ with a controller.

During the test, the frictional torque was measured with a torque meter. The ring temperature was measured with an almel-chromel thermocouple of diameter 0.5mm, which was located at 1mm below the frictional surface. Wear scar of woodceramics was measured with a profilometer after the wear test to obtain profile parallel to the friction direction. The wear volume ΔV was derived from the multiplication of the cross section of the wear scar measured by a planimeter and the width of the block (10mm). The specific wear rate Ws(mm^3/Nm) was calculated using the following formula, $Ws = \Delta V / (P \cdot S)$, where ΔV (mm^3) is the wear volume, P (N) is the applied load and S (m) is the sliding distance. Wear scars of woodceramics were observed with a scanning electron microscopy (SEM) and analyzed with an energy dispersive X-ray spectroscopy (EDS).

Table I . Properties of testing materials

	Materials	Hardness HV (kgf/mm^2)	Roughness Ra (μ m)
Block	MDF-800	~85	3.10±1.10
Ring	SF540A	189±9	0.08±0.04

Table II. Experimental conditions

Sliding velocity (m/s)	10.2
Applied load (N)	98 ~ 294
Lubricant (kinematic viscosity)	(1) Turbine oil: ISO VG10 10cSt at 40℃
	(2) Turbine oil: ISO VG46 46cSt at 40℃
	(3) Vegetable oil (Rape oil) 35cSt at 40℃
	(4) Distilled water
Flow rate of lubricant (cc/min.)	32
Run time (min.)	30
Lubricant temp. (℃)	30±3

3.RESULTS AND DISCUSSION

3.1 Friction property

Figure 2 shows the friction and ring temperature curves under lubrication of the turbine oil and the vegetable oil. The friction coefficient becomes constant at about 0.11-0.13. The ring temperature also tends to become constant at about 100℃. Thus the friction coefficient is not dependent on the kinds of lubricating oils and their kinematic viscosity. Figure 3 shows the friction and ring temperature curves under lubrication of the distilled water. At the flow rate of 32cc/min, the friction coefficient is high and fluctuates largely. This is due to poor lubrication properties of water. At the higher flow rate, it becomes small. Figure 4 shows the relationship between the friction coefficient and the flow rate. As the flow rate increases, the friction coefficient decreases gradually and becomes constant at 0.12. Thus, although the friction coefficient is dependent on the flow rate under the water lubrication, sufficient amount of water leads to low and stable friction coefficient.

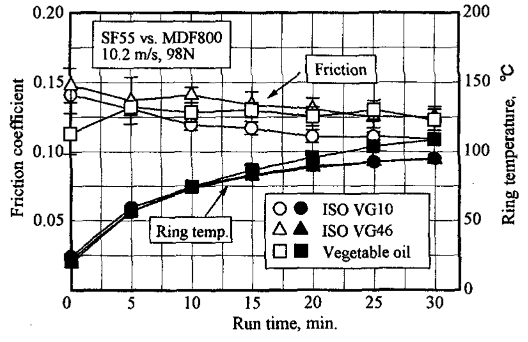


Fig.2 Friction and temperature curves under lubrication of turbine oil and vegetable oil.

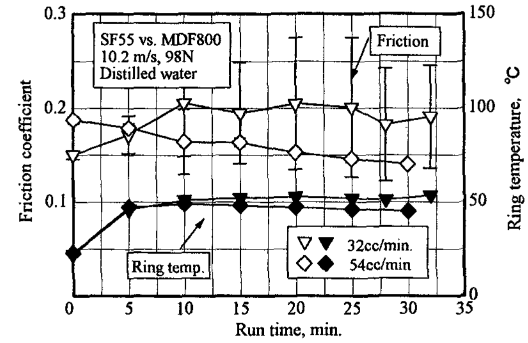


Fig.3 Friction and temperature curves under lubrication of distilled water.

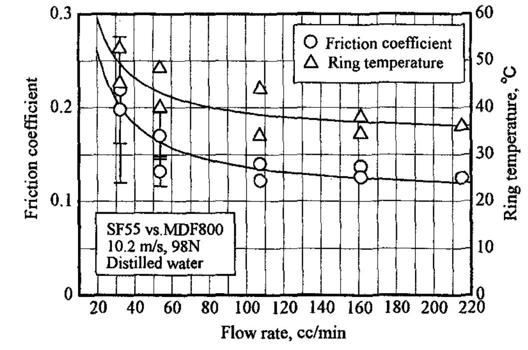


Fig.4 Effects of flow rate of distilled water on friction coefficient and ring temperature.

Figure 5 shows the relationship between the friction coefficient and the load. The friction coefficient decreases gradually with the increase in the load. The friction coefficient at each load is almost the same for all lubricants. The trend is also the same. Thus the lubricants have no obvious effects on the friction coefficient. This is because woodceramics has porous structure and thick oil film is not formed between two frictional surfaces. As the load increases from 98N to 294N, the friction coefficient decreases from about 0.13 to about 0.08. When the contact between the woodceramics block and the steel ring is mainly elastic, the real contact area is proportional to $(\text{load})^{-1/2}$ (5). As the frictional force is proportional to the real contact area, it is clear that the friction coefficient is proportional to $(\text{load})^{-1/2}$. Figure 5 indicates clearly that the contact is elastic. The empirical formula can be expressed as $\mu = 1.4P^{-1/2}$, where μ and P are the friction coefficient and the load respectively.

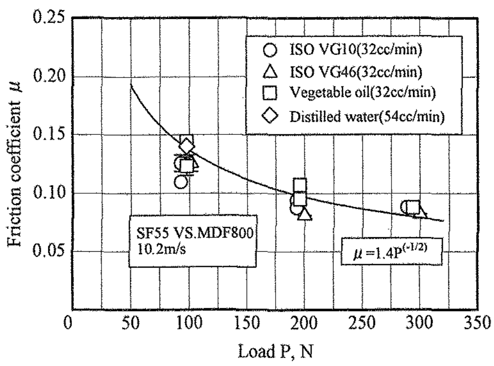


Fig.5 Relationship between friction coefficient and load.

3.2 Wear property

Figure 6 shows the relationship between the specific wear rate of the woodceramics and the load. The specific wear rate of the woodceramics is not dependent on the lubricants and the values for all lubricants are in the range 10^{-8} - 10^{-7} (mm^3/Nm). The friction coefficient and the specific wear rate, which are acceptable in practice, are below about 0.3 and about 10^{-6} respectively. All lubricants satisfy these severe demands.

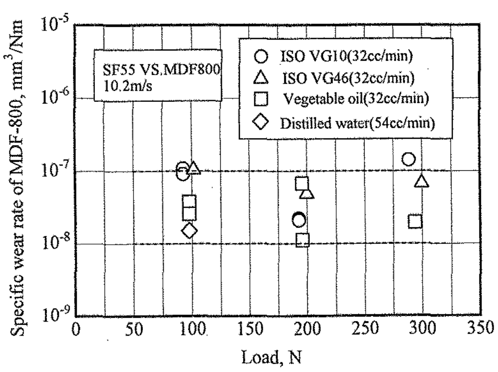


Fig.6 Relationship between specific wear rate of woodceramics and load.

3.3 Temperature increase of ring

Figure 7 shows the relationship between the temperature increase of the ring ΔT and the frictional work μPV, where μ, P and V are the friction coefficient, the load (N) and the sliding velocity (m/s) respectively. There is a good correlation between the temperature increase of the ring and the frictional work. The temperature increase of the ring is found to be directly proportional to the frictional work μPV. The empirical formulas can be expressed as $\Delta T = 0.57\mu PV$ for the turbine oil and the vegetable oil and as $\Delta T = 0.26\mu PV$ for the distilled water. The temperature increase of the ring is not dependent on the kinds of lubricating oils and their kinematic viscosity. This is probably because the heat transfer rate is similar for the lubricating oils. For the distilled water, the temperature increase of the ring is smaller than that of the lubricating oil. This is because the heat transfer rate of the water is larger than that of the lubricating oil. Thus the ring temperature can be roughly estimated using the frictional work μPV.

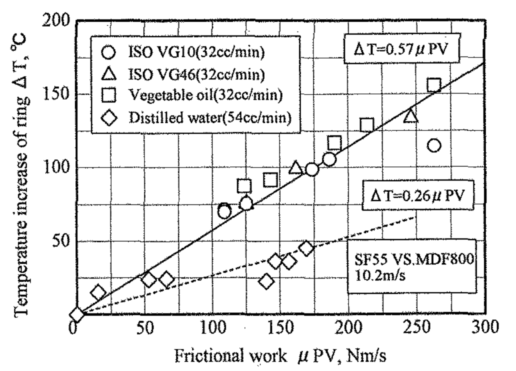
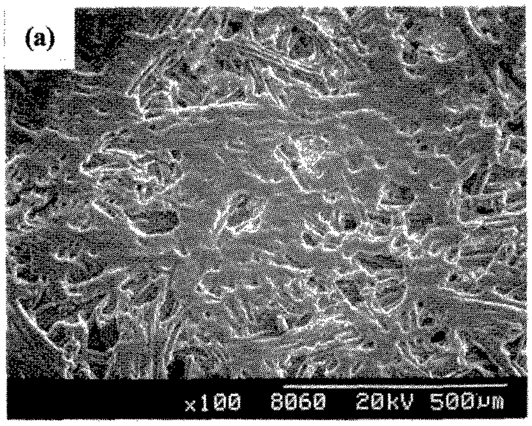
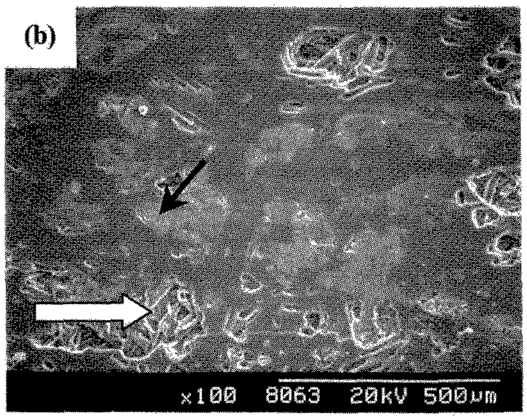


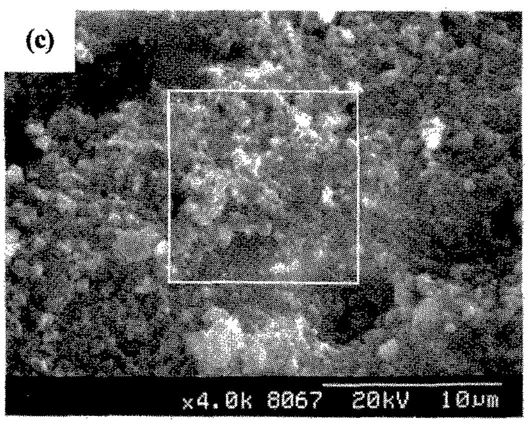
Fig.7 Relationship between temperature increase of ring and frictional work.

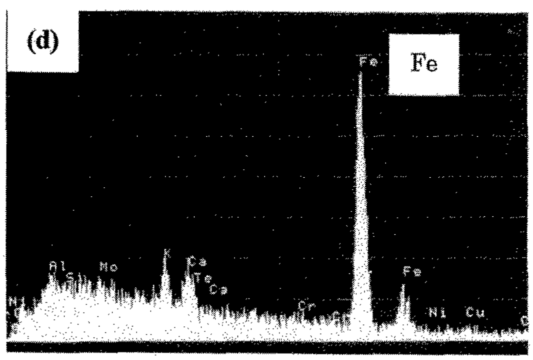
3.4 SEM Observations of wear scars

Figure 8 shows the SEM micrographs of wear scars of woodceramics under the distilled water lubrication. Before friction, the porous structure is common feature, as shown in Figure 8(a). After friction, the surface is polished and a large number of fine wear debris fill in the pores. As the result, the surface becomes smooth, as shown in Figure 8(b). Figure 8(c) is the enlargement of region indicated by black arrow tip in Figure 8(b). Wear debris, which fills in the pores, is very fine less than a few microns in size. Figure 8(d) is the X-ray analysis result of fine wear debris within the region indicated by square in Figure 8(c). Wear debris is rich in the ring material iron. Thus a large number of fine wear debris are generated from the ring under the water lubrication. Figure 8(e) shows the enlargement of smooth surface shown in Figure 8(b). Thus very smooth surface can be obtained in the friction process using the water. Under the turbine oil and the vegetable oil lubrication, the porous structure was persisted after friction.









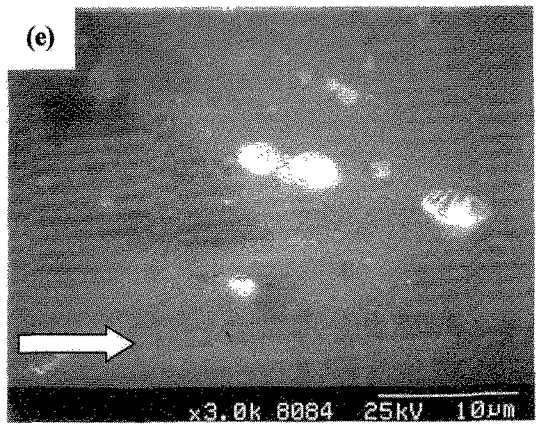


Fig.8 SEM micrographs of wear scars of woodceramics under water lubrication. (a); before friction, (b); after friction, (c); enlargement of (b), (d); X-ray analysis result of (c), (e); enlargement of smooth surface in (b). The white arrow indicates the frictional direction.

4. CONCLUSIONS

(1) The friction coefficient was not dependent on the lubricants. It was in the range 0.08-0.15 for all lubricants.
(2) The specific wear rate of the woodceramics was not dependent on the lubricants. It was in the range 10^{-8} - 10^{-7}(mm^3/Nm) for all lubricants.
(3) The relationship between the temperature increase of the ring ΔT and the frictional work μPV could be expressed empirically as $\Delta T=0.57\mu PV$ for the turbine oil and the vegetable oil and as $\Delta T=0.26\mu PV$ for the water.
(4) As the surface of the woodceramics was polished and fine wear debris consisted of iron filled in the pores in friction process using water, it became very smooth.

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