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Tribological Properties of Woodceramics under Vegetable Oil Lubrication

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Friction and wear properties of woodceramics were evaluated under vegetable oil lubrication. 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 m/s. The vegetable oil tested was rape oil. For a comparison, the mineral oil (ISO VG46) was also tested. The ring temperature was measured using a thermocouple located at 1mm below the frictional surface. It was concluded that the vegetable oil had the excellent tribological properties that were at least equivalent to the mineral oil. Under the vegetable oil lubrication, the friction coefficient was low and stable at about 0.1 over a wide range of load. The specific wear rate of woodceramics was also small and of the order of 10^{-8}(mm^3/Nm). Thus it was suggested that woodceramics had a high potential for practical use as environmentally friendly sliding bearing operating in vegetable oil.

Key words: Woodceramics, Tribology, Vegetable Oil, Rape Oil, Lubricated Wear

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). When the woodceramics slid against metals at high speed, low friction coefficient and low wear rate were maintained under oil and water lubricated conditions (3-4). Therefore, the lubrication is indispensable for applying the woodceramics to machine elements operating at high speed. From the viewpoint of the protection of the environment, the environmentally friendly lubricants such as vegetable or animal oils should be used.

In order to develop the environment friendly sliding bearing made of the woodceramics, it is essential to study the friction and wear behaviors of woodceramics using the environment friendly lubricants. In this paper, sliding friction and wear behaviors of woodceramics were evaluated at high sliding velocity under vegetable oil lubrication.

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

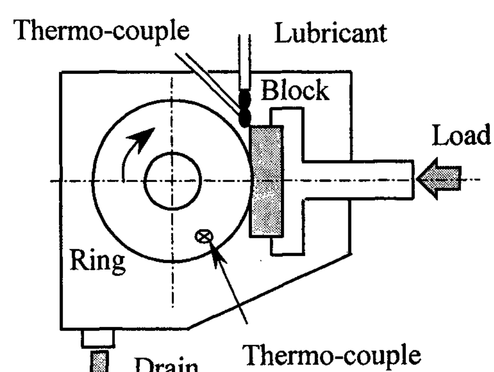

Fig.1 Schematic diagram of experimental apparatus.

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,

$$Ws = \Delta V / (P \cdot S)$$

where ΔV (mm^3) is the wear volume, P (N) is the applied load and S (m) is the sliding distance. The lubricating oil was collected from the drain for the observation of wear debris. Wear debris was separated using a silver filter having a pore diameter of 1 μm. Wear scars of woodceramics and wear debris were observed with optical microscopy and SEM (scanning electron microscopy).

Table I. Properties of testing materials

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

Table II. Experimental conditions

Sliding velocity (m/s)	10.0
Applied load (N)	98 ~ 294
Lubricant	(1) Vegetable oil (Rape oil): 34.9cSt at 40℃ (2) Non additive turbine oil: ISO VG46
Run time (min.)	30
Flow rate of lubricant	30 cc/min.
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 is not dependent on the lubricating oil and becomes constant at about 0.12. The ring temperature also tends to become constant at about 100℃. Thus the vegetable oil maintains the low and stable friction coefficient as well as the turbine oil.

Figure 3 shows the relationship between the friction coefficient and the load. The friction coefficient decreases gradually with the increase in the load. 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 $(load)^{-1/2}$ (5). As the frictional force is proportional to the real contact area, it is clear that the friction coefficient is proportional to $(load)^{-1/2}$. Figure 4 indicates clearly that the contact is elastic. The empirical formula can be expressed as $\mu = 1.3P^{-1/2}$, where μ and P are the friction coefficient and the load respectively. The friction coefficient of the vegetable oil is almost the same as that of the turbine oil over a wide range of the load.

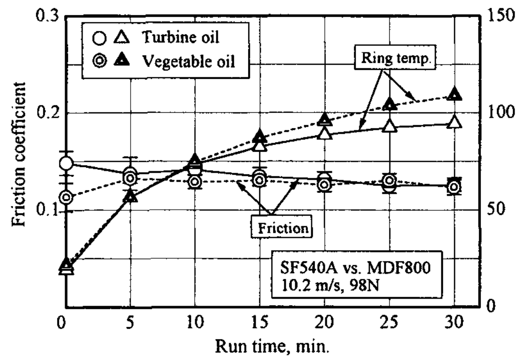

Fig.2 Friction and temperature curves under lubrication of turbine oil and vegetable oil.

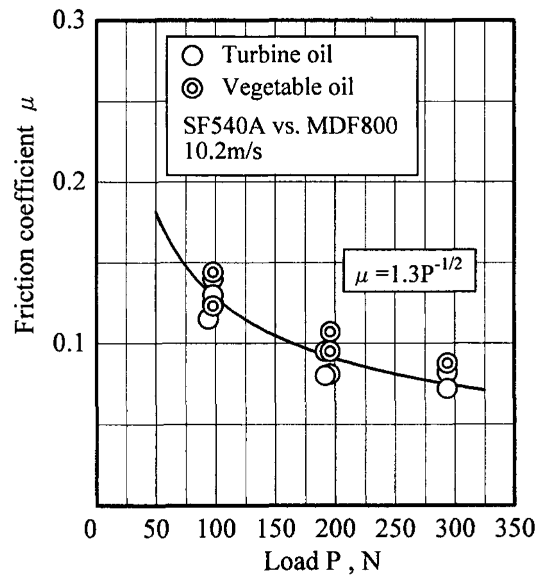

Fig.3 Relationship between friction coefficient and load under lubrication of turbine oil and vegetable oil.

3.2 Wear property

Figure 4 shows the specific wear rate of the woodceramics and the load. The specific wear rate of the woodceramics is not dependent on the lubricating oil and the values lie in the range of 10^{-8} to 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. Both lubricating oils satisfy these severe demands. Thus the vegetable oil has the excellent tribological properties that are at least equivalent to the turbine oil.

3.3 Temperature increase of ring

Figure 5 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). The temperature increase of the ring is found to be directly proportional to the frictional work μPV. There is no difference between the turbine oil and the vegetable oil. The empirical formulas can be expressed as $\Delta T=0.6 \mu PV$, irrespective of the lubricating oil. Thus the ring temperature can be roughly estimated using the frictional work μPV.

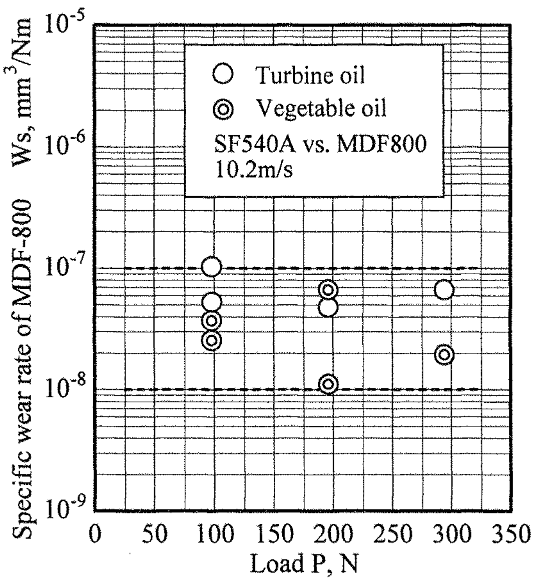

Fig.4 Relationship between specific wear rate of woodceramics and load.

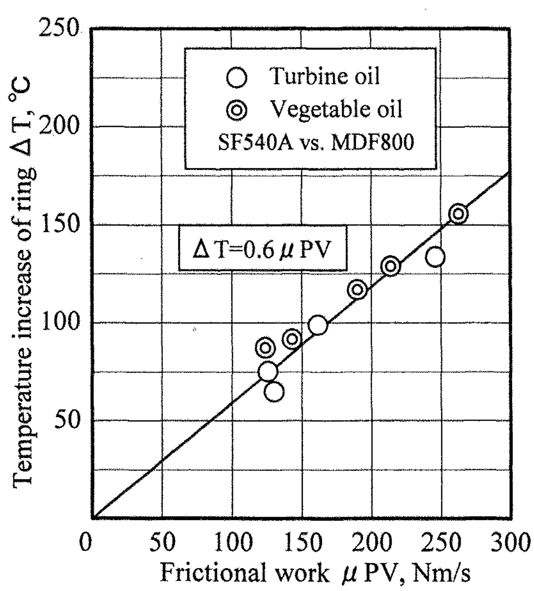

Fig.5 Relationship between temperature increase of ring and frictional work μPV.

3.4 Observations of wear scar and wear debris

Figure 6 shows the optical micrographs of wear scars of woodceramics under the vegetable oil lubrication. Figure 6(a) shows the woodceramics surface before friction. The dark surface and porous structure are common feature. After friction, the surface is polished and becomes very smooth, as shown in Figure 6(b). Severe cracks showing the evidence of brittle fracture are not observed. Metal fragments transferred from the steel ring to the woodceramics block are also not observed. These observation results show that wear condition is normal and acceptable. The wear scars under the turbine oil lubrication was also similar.

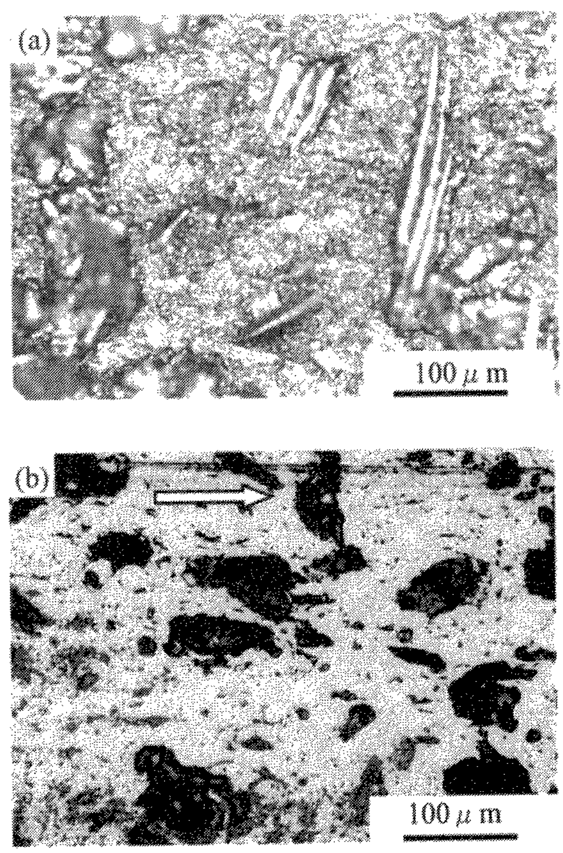

Fig.6 Optical micrographs of wear scars of woodceramics slid against steel ring under the vegetable oil lubrication (10m/s, 98N). (a); before friction, (b); after friction. The arrow indicates the relative direction of motion of counterface.

Figure 7 shows the optical and SEM micrographs of wear debris generated under the vegetable oil lubrication. Figure 7(a) shows the optical micrographs of wear debris collected using a filter. Many wear debris consisting of light and dark debris are observed. Among them, dark wear debris is generated from the woodceramics block.

Light wear debris are generated from the steel ring. Figure 7(b) shows wear debris generated from the woodceramics block. They are plate-like and block-like wear debris and less than about 30 μm in size. It is considered that these wear debris are generated in the process of micro brittle fracture of surface layers of the woodceramics. Figure 7(c) shows wear debris generated from the steel ring. Wear debris is very thin and less than about 20 μm in size. This kind of wear debris is probably generated in the process of abrasive action due to hard glassy carbon. The generation of thin wear debris shows that wear rate of steel is acceptable and lubricated condition is normal (6). Thus hard steel is ground gradually by the woodceramics. Wear debris generated under the turbine oil lubrication was also similar.

4. CONCLUSIONS

(1) Under the vegetable oil lubrication, low friction coefficient (about 0.1) and low wear rate (~ 10^{-8} mm^3/Nm) were maintained.

(2) The vegetable oil had the excellent tribological properties that were at least equivalent to the turbine oil.

(3) The relationship between the temperature increase of the ring ΔT and the frictional work μPV could be expressed empirically as $\Delta T = 0.6 \mu PV$.

(4) Plate-like and block-like wear debris less than about 30 μm in size were generated from the woodceramics. Thin wear debris less than about 20 μm in size was generated from the steel.

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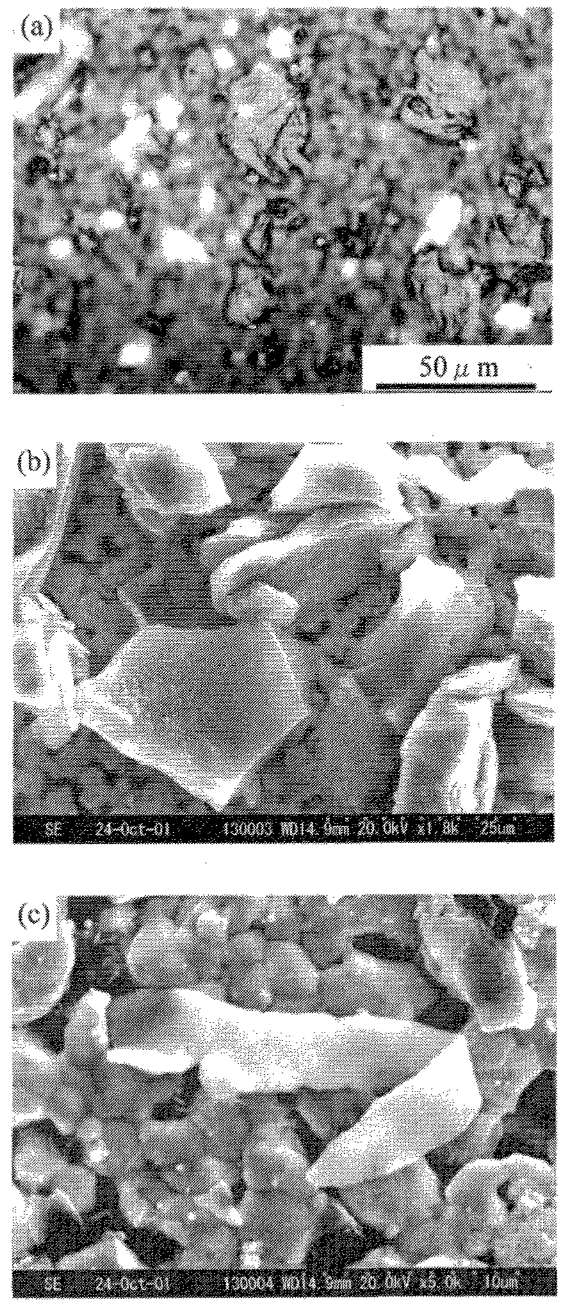

Fig.7 Optical and SEM micrographs of wear debris generated under vegetable oil lubrication (10m/s, 98N). (a); optical micrograph of wear debris collected using a filter, (b); wear debris generated from woodceramics block, (c); wear debris generated from steel ring.

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