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Sliding Wear of Woodceramics under Water Lubrication

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Sliding friction and wear of woodceramics were studied under unlubricated and water-lubricated conditions. The experiment was conducted with a block on ring wear tester. The block material was woodceramics (MDF-800). The ring materials were forging steel (SF55) and stainless steel (SUS304). The sliding velocity was varied in the range of 1.0 to 19.0m/s and the applied load was constant at 98N. When the woodceramics slid against SF55 under water lubrication, the friction coefficient as low as about 0.16 was maintained below about 12m/s. The specific wear rates of woodceramics were also small ranging between 3×10^{-7} and 2×10^{-6} (mm^3/Nm). They increased with increasing sliding velocity above about 12m/s. When the woodceramics slid against SUS304, low friction coefficient was maintained over a wide range of sliding velocity under unlubricated and water-lubricated conditions. The specific wear rates of the woodceramics, however, were higher than those against SF55 and of the order of 10^{-5} (mm^3/Nm).

Key words: Woodceramics, Tribology, Water Lubrication, Sliding Bearing, Friction and Wear

1.INTRODUCTION

A new porous carbon material, "Woodceramics" has been developed (1-2) and its practical use has been expected in the industrial field. The woodceramics is composed of two types of carbon materials; soft graphite and hard glassy carbon. Since graphite is one of the best solid lubricants along with molybdenum disulfide (MoS_2) and polytetrafluoroethylene (PTFE), woodceramics would have low friction coefficient and low wear rate. The basic friction and wear behaviors of woodceramics have been studied in details (3-4). In order to enlarge the application fields of woodceramics in practice, it is essential to study the friction and wear behaviors of woodceramics under various conditions.

In this study, friction and wear behaviors of woodceramics were studied over a wide range of sliding velocity under water lubrication.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

Experiments were carried out using a block on ring wear tester. The schematic diagram is shown in Fig.1. Two kinds of ring materials were used; forging steel (SF55) and stainless steel (SUS304). 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. The sliding velocity was varied in the range of 1.0 to 19.0m/s. The load was 98N. The lubricant was distilled water. It was supplied at a flow rate of 23cm^3/min using a micro-tube pump. The temperature was kept at 30±3℃ with a controller.

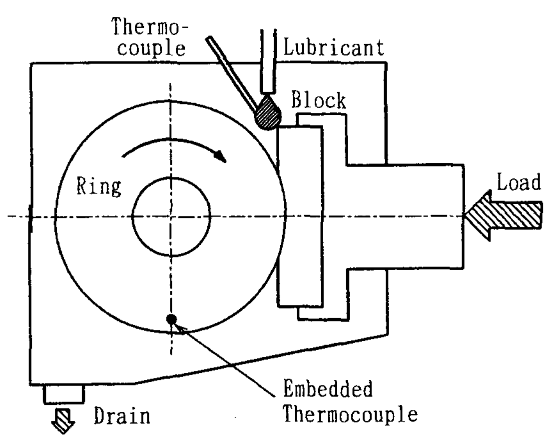

Fig.1 Schematic diagram of experimental apparatus.

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 of the ring. 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. Wear scars of woodceramics were observed with optical microscopy and SEM (scanning electron microscopy).

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	SF55	189±9	0.08±0.04
	SUS304	191±5	0.12±0.01

Table II . Experimental conditions

Sliding velocity (m/s)	1.0 ~ 19.0
Applied load (N)	98
Lubricant	(1) Unlubricated (2) Distilled water
Flow rate of lubricant	23 cc/min.
Lubricant temp. (℃)	30±3

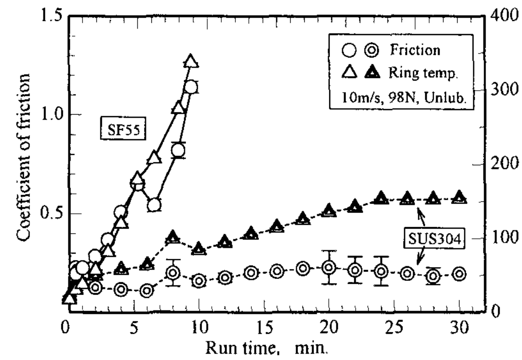

Fig.2 Friction and ring temperature curves under unlubricated condition at 10m/s.

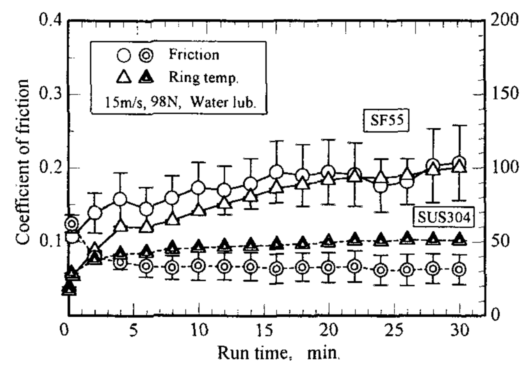

Fig.3 Friction and ring temperature curves under water lubrication at 15m/s.

3.RESULTS AND DISCUSSION

3.1 Friction property

Figure 2 shows the friction and ring temperature curves under unlubricated condition at 10m/s. When the woodceramics slides against SF55 ring, the friction coefficient increases gradually and reaches up to 1.2 after 9min. The ring temperature also increases almost linearly and reaches up to 350℃. Since SF55 ring softens due to the high frictional heat, the contact area increases and wear debris generated from the steel adheres to the woodceramics surface (4). Therefore, the friction coefficient becomes high. When sliding against SUS304 ring, the friction coefficient and the ring temperature become almost constant at 0.2 and 150℃ respectively. Thus low friction coefficient is maintained when the mating material has the superior heat resistance.

Figure 3 shows the friction and ring temperature curves under water lubrication at 15m/s. The friction coefficient and the ring temperature become almost constant. When sliding against SF55 ring, the friction coefficient and the ring temperature are about 0.2 and about 100℃ respectively. When sliding against SUS304 ring, they are 0.07 and about 50℃ respectively.

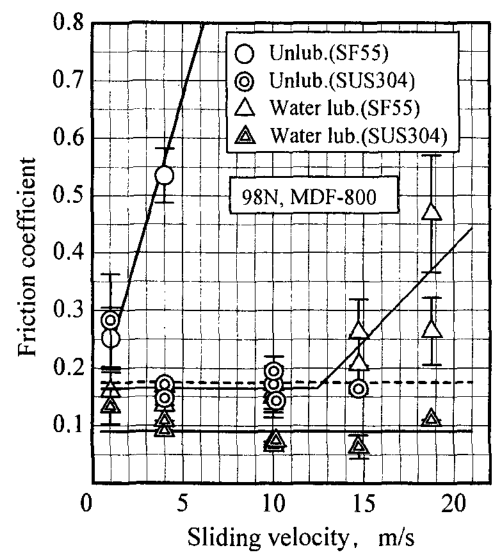

Fig.4 Relationship between friction coefficient and sliding velocity.

Figure 4 shows the relationship between the friction coefficient and the sliding velocity. Figure 5 shows the relationship between the ring temperature and the sliding velocity. The woodceramics sliding against SUS304 ring maintains low friction coefficient over a wide range of the sliding velocity under unlubricated and water-lubricated conditions. The friction coefficients under unlubricated and water-lubricated conditions are about 0.17 and about 0.1, respectively.

When the woodceramics slides against SF55 under unlubricated condition, the friction coefficient increases with the increases in the sliding velocity. Under water lubrication, the woodceramics maintains low friction coefficient (about 0.16) until about 12m/s. Over 12m/s, however, the friction coefficient increases. Over 12m/s, the surface temperature of SF55 ring becomes high and exceeds about 100℃, as shown in Fig.5. At such a high temperature, water can not cool sufficiently the frictional surface. As the result, unlubricated friction becomes predominant and friction coefficient increases. Therefore, it is expected that low friction would persist until much higher sliding velocity, if a sufficient amount of water required for preventing the drying-up is supplied to the frictional surface.

3.2 Wear property

Figure 6 shows the specific wear rate of the woodceramics and the sliding velocity. When the woodceramics slides against SF55 ring, the specific wear rate is about $4x10^{-6}$ (mm^3/Nm) under unlubricated condition. Under water lubrication, it is small and constant at about $3x10^{-7}\sim2x10^{-6}$ (mm^3/Nm) until 12m/s. Over 12m/s, it increases up to $4x10^{-6}\sim10^{-5}$ (mm^3/Nm) at 19m/s. When sliding against SUS304 ring under unlubricated condition, it is the highest at about $7x10^{-5}$ (mm^3/Nm). Under water lubrication, it falls in the range $(1\sim4)x10^{-5}$ (mm^3/Nm). It is concluded that the woodceramics maintains low wear rate when sliding against SF55 ring under water lubrication. When sliding against SUS304 ring, although the friction coefficient is small and constant over a wide range of sliding velocity, the specific wear rate is higher than that against SF55.

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). The temperature increase of the ring is found to be directly proportional to the frictional work μPV. The empirical formulas can be expressed as $\Delta T=0.7\mu PV$ and $\Delta T=0.3\mu PV$ under unlubricated and water-lubricated conditions respectively. The temperature increase of the ring under water lubrication is smaller than that under unlubricated condition. There is no obvious difference between SF55 and SUS304. Thus the ring temperature can be roughly estimated using the frictional work μPV.

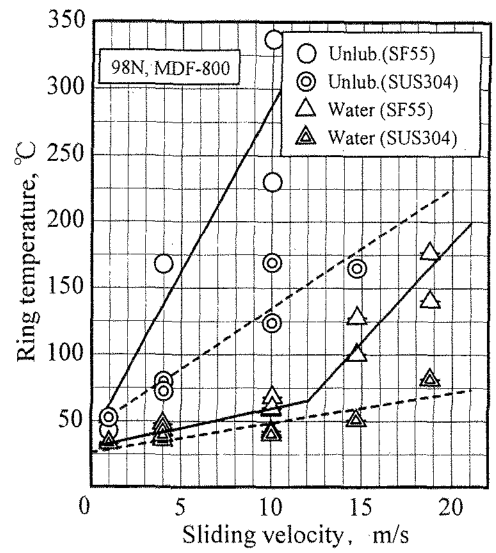

Fig.5 Relationship between ring temperature and sliding velocity.

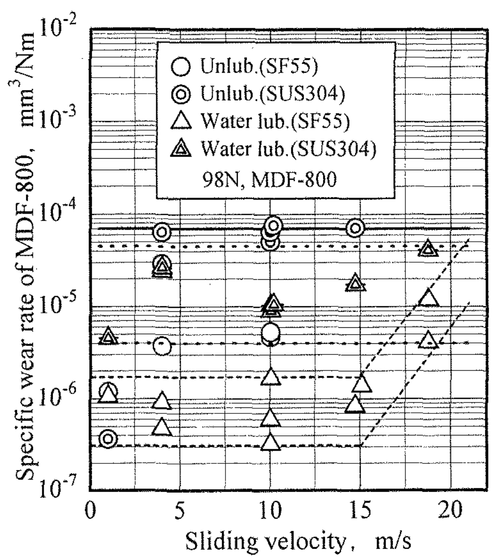

Fig.6 Relationship between specific wear rate of woodceramics and sliding velocity.

3.4 Observation of wear scar of woodceramics

Figure 8 shows the SEM micrographs of wear scars of woodceramics. When the woodceramics slides against SF55 ring under unlubricated condition, some transfer fragments consisting of ring material are commonly observed on the wear scar, as shown in Fig.8(a). When sliding against SUS304 ring under unlubricated condition, severe separation of surface layers occurs and the wear scar is rough, as shown in Fig.8(b). The similar feature was also observed under water lubrication. When sliding

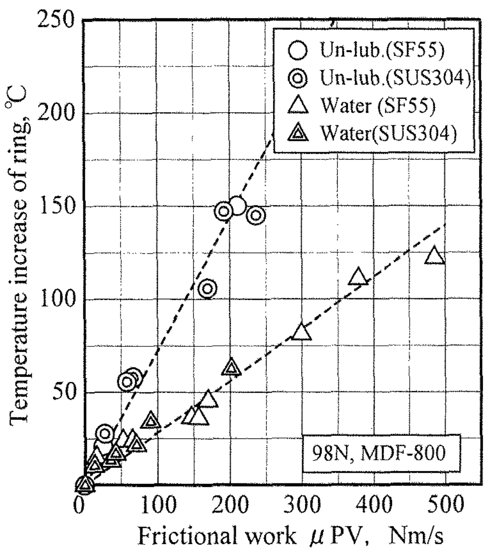

Fig.7 Relationship between temperature increase of ring and frictional work μ PV.

against SF55 ring under water lubrication, the wear scar is smooth, as shown in Fig.8(c). This is because much fine wear debris generated from SF55 ring and the woodceramics block fill in many pores of the wood-ceramics.

4. CONCLUSIONS

(1) When the woodceramics slid against SF55 under water lubrication, low friction coefficient (about 0.16) and low wear rate ($3x10^{-7} \sim 2x10^{-6} mm^3/Nm$) were maintained up to about 12m/s. Above about 12m/s, they increased.

(2) When sliding against SUS304 under water lubrication, low friction coefficient (about 0.1) was maintained over a wide range of sliding velocity. The wear rate fell in the range $(1 \sim 4)x10^{-5}$.

(3) The temperature increase of the ring was directly proportional to the frictional work μ PV, where μ, P and V are the friction coefficient, the load and the sliding velocity, respectively. The empirical formula could be expressed as $\Delta T=0.3 \mu PV$ under water lubrication.

(4) The wear scar of woodceramics sliding against SF55 ring under water lubrication was smooth.

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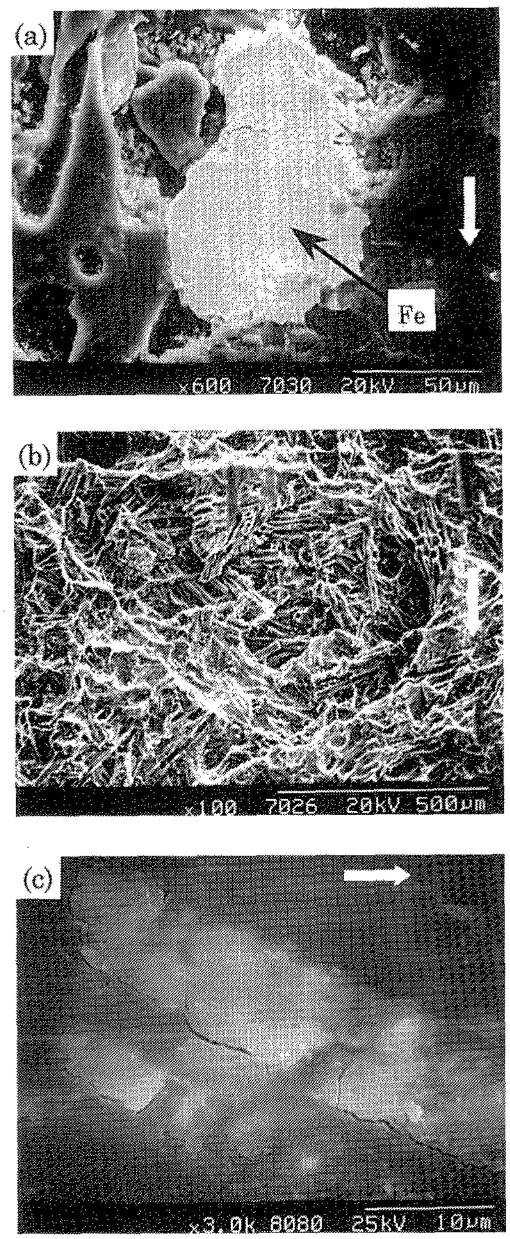

Fig.8 SEM micrographs of wear scars of woodceramics (P=98N, V=10.2m/s). (a) Unlub. (vs. SF55); (b) Unlub. (vs. SUS304); (c) Water lub.(vs. SF55). The white arrow indicates the relative direction of motion of the counterface.

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