TRIBOLOGICAL PROPERTIES OF BIODEGRADABLE LUBRICATING OILS IN FOUR-BALL TEST

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To clarify the tribological properties of biodegradable lubricating oils, the four-ball tests were carried out under dip-feed lubrication using a Soda-type four-ball machine. The test balls were lubricated with soybean oil, rapeseed oil, corn oil and turbine oil. From the tests, the coefficient of friction for all the test balls lubricated with biodegradable lubricating oils was lower than that for the test ball lubricated with turbine oil. Further, from the calculation of the pV value, it was clear that the seizure resistance for all the test balls lubricated with biodegradable lubricating oils was higher than that for the test ball lubricated with turbine oil.

Keywords : Biodegradable Lubricating Oil, Seizure Resistance, Bearing Steel, Four-Ball Test, Dip-Feed Lubrication

1. INTRODUCTION

When the power transmissions are lubricated with a petroleum oil, rivers, seas and lands are polluted due to leakage of a lubricating oil from a bearing. To avoid such soil and water pollution, the biodegradable lubricating oil should be used.

In this report, to clarify the tribological properties of biodegradable lubricating oils, the four-ball tests were carried out under dip-feed lubrication. Further, the test result when lubricated with biodegradable lubricating oils was compared with that when lubricated with turbine oil.

2. EXPERIMENTAL METHOD

The test balls were made of bearing steel SUJ2, and were tempered at 170 ℃ after oil-quenching at 900 ℃. The diameter and the average sphericity of the test balls had 19.05 mm and 0.18 μm, respectively. The surface roughness and Vickers microhardness of the test balls had 0.1 μm R_y and 900 HV, respectively.

The four-ball tests were run under dip-feed lubrication using a Soda-type four-ball machine. The test balls were lubricated with soybean oil, rapeseed oil, corn oil and turbine oil. The normal load was applied by exerting oil pressure on a bowl in the machine. With respect to the measurement of frictional force, the displacement of the plate spring contacting a part of the bowl was detected by a strain gauge.

Table 1 shows the experimental conditions. The normal load per unit ball increased stepwise at the rate of about 40 N during 1 min from 86.3 N until seizure occurred. The sliding velocities at the conjunctional area of the test balls were kept at 0.23 m/s, 0.46 m/s and 0.69 m/s. The tests were run at initial oil temperature in which the kinematic viscosity of the oils were kept at 40 mm²/s due to a electric transformer.

3. TEST RESULTS

As an example, Fig. 1 shows the relationship between the width of wear scar on stationary ball and normal load per unit ball at sliding velocity V = 0.46 m/s. The width of wear scar indicates the its mean value of three stationary balls.

The width of wear scar on stationary ball when lubricated with biodegradable lubricating oils was smaller than that when lubricated with turbine oil. In the case of the biodegradable lubricating oils, the width of wear scar on stationary ball at the normal load per unit ball of less than 500 N was the same as the Hertzian contact zone. However, the width of wear scar on stationary ball significantly increased during 1 and/or 2 test ranges in which the normal load exceeded about 500 N. The above-cited behavior is regarded as the symptom of incipient seizuring that the partially welded junctions occurred in the conjunctional area on the rubbing faces.

In similar, the tests were carried out at the different sliding velocity V = 0.23 m/s and V = 0.69 m/s, and it was found that

Table 1 Experimental conditions in four-ball test

Revolution speed	N	rpm	400	800	1200
Sliding velocity	V	m/s	0.23	0.46	0.69
Normal load per unit ball	P	N	86.3 ~ 1978.0 (48 test ranges)		
Maximum Hertzian contact stress	p	GPa	2.11 ~ 6.00		
Incremental load	P_i	N	40.2		
Running time for each test ranges	t	s	60		

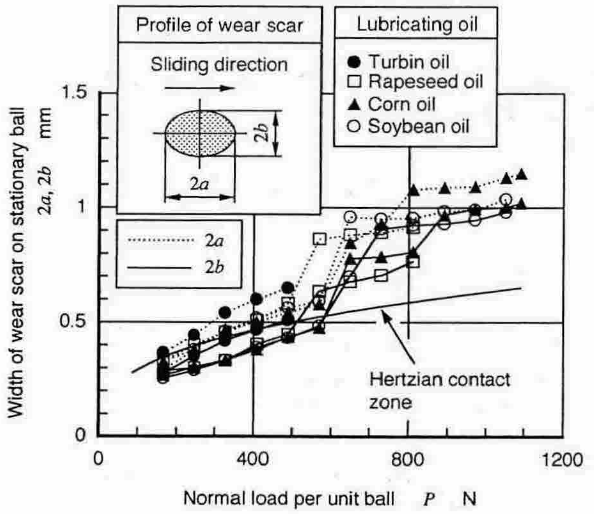

Fig. 1 Relationship between width of wear scar on stationary ball and normal load per unit ball at sliding velocity $V = 0.46$ m/s

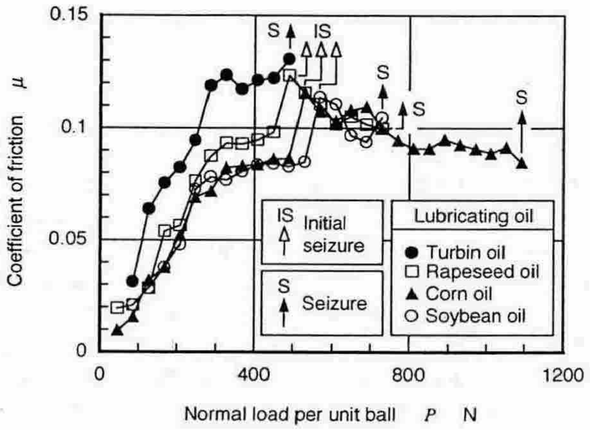

Fig. 2 Variation in coefficient of friction against normal load per unit ball at sliding velocity $V = 0.46$ m/s

the variation in the width of wear scar on stationary ball against normal load per unit ball was the same that observed at the sliding velocity $V = 0.46$ m/s. However, the value of the normal load per unit ball in which the width of wear scar on stationary ball significantly increased decreased with increasing sliding velocity.

As an example, Fig. 2 shows the variation in the coefficient of friction against normal load per unit ball at sliding velocity $V = 0.46$ m/s, where symbol S indicates that seizure occurred at the next test range, and symbol IS indicates the state that the variation in frictional force against normal load was significantly large, though the test could be run.

When the normal load per unit ball was lower than 500 N, the coefficient of friction when lubricated with biodegradable lubricating oils was lower than that when lubricated with turbine oil. In the case of the biodegradable lubricating oils, the coefficient of friction at the incipient stage of seizure was 0.114～0.123. After that, the coefficient of friction decreased

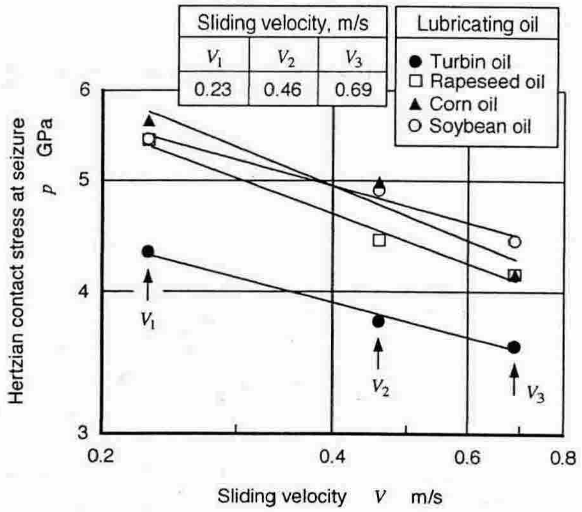

Fig. 3 pV value at seizure in four-ball test

with increasing normal load per unit ball, and was 0.085～0.105 at the final stage of seizure.

Fig. 3 shows the pV value which can be considered to be one of index to judge the risk of seizure, where p is the maximum Hertzian contact stress (GPa) and V is the sliding velocity (m/s).

It can be seen from this figure that the seizure resistance when lubricated with biodegradable lubricating oils was higher than that when lubricated with turbine oil. Further, the seizure resistance of the test balls could be expressed by pV value. The pV values of the test ball lubricated with soybean oil, rapeseed oil, corn oil and turbine oil were $pV^{0.181} = 4.19$, $pV^{0.250} = 3.72$, $pV^{0.270} = 3.86$ and $pV^{0.175} = 3.33$, respectively.

4. CONCLUSION

The seizure resistance lubricated with biodegradable lubricating oils was examined using a Soda-type four-ball machine. From the test results, the following conclusions can be obtained.

Since the seizure resistance when lubricated with biodegradable lubricating oils was higher than that when lubricated with turbine oil, it was clear that the biodegradable lubricating oils had a good tribological properties against seizure, and the seizure resistance of the test balls could be expressed by pV value.

However, the width of wear scar on stationary ball and the coefficient of friction of the test balls significantly increased during 1 and/or 2 test ranges in which the normal load exceeded about 500 N. Therefore, it is necessary to obtain the biodegradable lubricating oils with the high wear resistance due to the additive.

5. ACKNOWLEDGEMENT

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