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Comparison of Rolling Contact Fatigue Life of Bearing Steel Rollers Lubricated with Traction Oil and Mineral Oil Corresponding to ISO VG32

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Using a low viscosity synthetic traction oil and a low viscosity mineral oil with nearly equal viscosity grade of ISO VG 32, the effect of kind of oil on the fatigue life of bearing steel rollers was examined. A pair of rollers finished the contact surfaces to a mirror-like condition were driven under rolling with sliding conditions of s = -3.2% and a maximum Hertzian stress in the range of P_H=2.8GPa~4.0GPa was applied in point contact condition. As a result of experiments, the fatigue life with a mineral oil was longer than that with a traction oil under higher stress conditions above P_H=3.4GPa. Based on the numerical calculation results of the thermal EHL which simulates the present experiment, the authors discuss the reason why such a difference in the fatigue life comes out.

Keywords : Bearing Steel, Rolling Contact Fatigue, Traction Oil, Thermal EHL, Pressure Spike

1. INTRODUCTION

High carbon chromium bearing steel has been widely used as the material of rolling contact elements in traction drive as well as rolling element bearings. Flaking or spalling failure, which occurs on the high hardness contacting surfaces such as rolling elements and bearing races, is generally regarded as a subsurface initiated rolling contact fatigue starting from minute defects like a nonmetallic inclusion, and so far the prolongation of bearing life has been steadily achieved owing to the improvement in the quality of bearing steels. On the other hand, as the fact that the bearing life depends strongly on the film parameter Λ shows, the lubricating condition is another important factor. In addition, in recent works, it is supposed that the rolling contact fatigue is influenced by the property of solidified oil at high pressure as well as the oil film thickness [1-2].

Using a two-roller testing machine, the authors have examined the effect of kind of lubricating oil on the occurrence of rolling contact fatigue of bearing steel rollers with mirror-like smooth surfaces. In the previous investigation, it was found that the fatigue life is longer with a low viscosity mineral oil than with a high viscosity mineral oil or a traction oil [3-4]. In the present investigation, using a low viscosity synthetic traction oil and a low viscosity mineral oil with nearly equal viscosity grade of ISO VG 32, the difference in the fatigue life of bearing steel rollers was examined. Based on the numerical calculation results of the thermal EHL, the authors discuss the mechanism which causes such a difference in the fatigue life.

2. EXPERIMENTAL

Experiments were carried out using a two-roller testing machine having a center distance of 66 mm. A pair of cylindrical D roller and FR roller with crowning of R25 in an axial direction were mated. The outside diameter of both rollers is 66mm and the ellipticity parameter k is about 1.32. In rolling with sliding conditions, both rollers were driven by gears with the gear ratio of 31 / 32 (s = -3.2%). Test rollers were all made of a oil hardened and tempered high carbon chromium bearing steel (SUJ 2 according to JIS G 4805-1990). The contact surfaces of D and FR rollers were finished smooth to a mirror-like condition with a roughness of Ry = 0.02μm (Ry: maximum height of the profile according to ISO 4287-1997 or JIS B0601-1994, sampling length 0.25mm) by precision grinding and subsequent polishing. The surface hardness differed a little with each roller, but a pair of rollers with almost the same hardness were combined. As shown in Table 1, two kinds of lubricating oils with nearly equal viscosity grade but with much different pressure-viscosity coefficient were used. Oil A is a low viscosity synthetic traction oil (ISO VG32 according to ISO 3448-1992). Oil B is a low viscosity paraffinic mineral oil without EP additives (ISO VG32). The oil supplied on the entrance side of the rotating rollers at a flow rate of 15cm^3/s. The temperature of oil supplied was kept at 318K during each running test. The rotational speed of the driving side roller was 3583±10 rpm and the fixed normal load which gives a maximum Hertzian stress in the range of P_H = 2.8GPa ~ 4.0GPa was applied in point contact.

3. RESULTS AND DISCUSSION

Fig.1 shows the map of lubrication regimes [1] for the ellip-

Table 1 Properties of lubricating oils

Oil		Traction oil A (VG32)	Mineral oil B (VG32)
Specific gravity	288/277K	0.902	0.888
Viscosity ν, mm^2/s	at 313K	31.2	29.4
	at 373K	4.47	5.22
Viscosity index	V.I	4	109
Pressure viscosity coefficient α, GPa^{-1}	at 313K	27.9	15.7

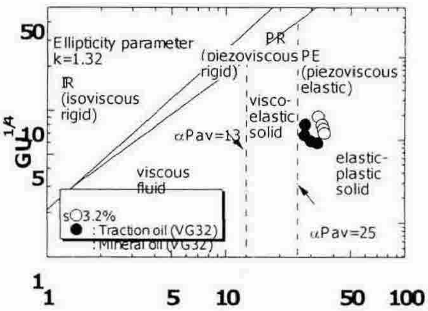

Fig. 1 Map of lubrication regimes for k =1.32

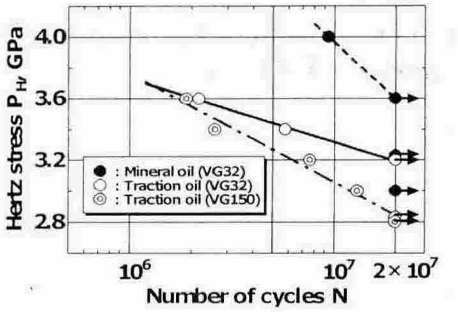

Fig. 2 Effect of lubricating oil on fatigue life (s=-3.2%)

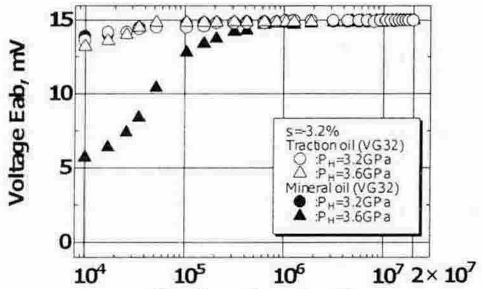

Fig. 3 Changes in voltage between rollers (Eab=0mV:contact, 15mV:separation)

Table 2 Material properties

Density of steel, kg/m^3	7850
Specific heat of lubricant, J/kgK	2000
Specific heat of steel, J/kgK	470
Thermal conductivity of lubricant, W/mK	0.14
Thermal conductivity of steel, W/mK	46

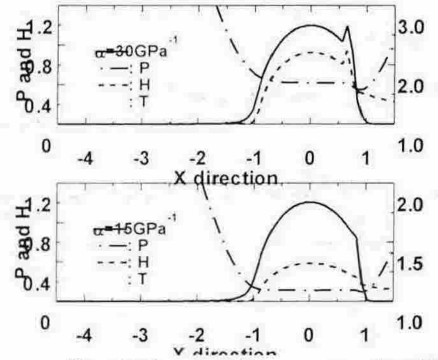

Fig. 4 Pressure, film thickness and temperature in mid-film on the plane of Y=0 (P_H=2.8GPa, W=5.85×10^{-5}, U=2.2×10^{-10})

According to the study by Ohno et al., it is found that the transition form visco-elastic solid to elastic-plastic solid of oil occurs at αPav = 25 (α: pressure-viscosity coefficient GPa^{-1}, Pav: average contact pressure GPa) [1-2]. All the experimental points were included in the elastic-plastic solidifying condition αPav>25 independent of the kind of lubricating oil.

Fig.2 shows the relation between the fatigue life and the lubricating oil. Some results with a high viscosity traction oil of VG150 [3] are also shown in this figure. At a lower stress condition less than maximum Hertzian stress P_H = 3.2GPa, the low viscosity traction oil and the low viscosity mineral oil equally showed a long life beyond $N=2\times10^7$ cycles. On the other hand, the fatigue life with a high viscosity traction oil had tendency to become short compared with a low viscosity traction oil. At a higher stress condition greater than P_H=3.4 GPa, a low viscosity mineral oil showed a extremely long life compared with a low viscosity traction oil.

Fig.3 shows some examples of the progress of oil film formation during operation. When the oil film is developed fully, the voltage Eab recorded on a chart reaches 15mV. In the tests with a low viscosity traction oil, immediately after the start of running, the voltage Eab showed a high value even at a high stress condition of P_H=3.6GPa. On the other hand, in the tests with a low viscosity mineral oil, the voltage showed a lower value at an initial stage owing to the very thin film thickness and then the voltage rose gradually and reached almost full EHL conditions.

In order to discuss such a difference in the fatigue life, numerical calculations based on the thermal EHL problem under rolling/sliding condition were carried out. Table 2 shows the material parameters used in the numerical calculation. The dimensionless load of $W=5.85\times10^{-5}$ (P_H=2.8GPa), the dimensionless speed of $U=2.2\times10^{-10}$ were used as the parameter for the analytical condition. Fig.4 shows the pressure distribution, the film thickness distribution and the temperature distribution in the mid-film on the cross section of Y=0. In the pressure distribution for pressure–viscosity coefficient α=30GPa^{-1}, it is found that the relatively high pressure spike exists. On the other hand, the pressure spike is not recognized in the pressure distribution for α=15GPa^{-1}. H. Sun et al. also analyzed the thermal EHL problem at high speed and extremely heavy load lubricated with a high viscosity traction oil and a extremely low viscosity mineral oil, and discussed the influence of the pressure–viscosity coefficient on the pressure and the film thickness distributions [5]. These theoretical calculations suggest that oils with large pressure-viscosity coefficient shorten the rolling contact fatigue life owing to the thermal effect and the existence of high pressure spike, and agree with the present experimental results.

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