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Mechanism for increase in EHL oil film thickness by formation of sub-micrometer downsteps beside contact point

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ABSTRACT – The mechanism of the increase in oil film thickness with a steel ball with sub-micrometer downsteps beside the contact point on a ball under point-contact elastohydrodynamic lubrication (EHL) condition was investigated. The film thickness was measured using a disk-on-ball friction tester with optical interferometry. The Reynolds equation and finite element method were used to calculate the pressure and deformation distributions, respectively. The analytical results showed that the increase in the oil film thickness was due to the ball and disk taking a unique deformed shape. This restricted oil flow from the contact point, causing the film thickness to increase.

1. INTRODUCTION

Under lubrication conditions, oil films are generally formed between sliding surfaces, which reduces friction and thus reduces wear occurrence. Improving the lubrication conditions is an important topic in tribology, and many techniques for improving them have been investigated. A particularly promising way to improve the tribological conditions is to use surface texturing, which involves the formation of dimples, steps and grooves on the surface. It was recently, reported forming sub-micrometer downsteps beside the contact point of the ball and disk is effective to increase the film thickness under elastohydrodynamic lubrication (EHL) [1]. In this study reported, to we investigated the mechanism of the increase in EHL oil film thickness by using the Reynolds equation and the finite element method (FEM).

2. EXPERIMENT

To determine the effect of sub-micrometer downsteps on EHL film thickness, we used a disk-on-ball friction tester with optical interferometry as shown in Fig. 1. The test samples were SUJ2 balls with curvature R of 20 mm and sapphire glass disks with 15 mm and in diameter ϕ of 180 m. The disks had been coated with a semi-reflective chromium layer.

Illustrations of the prepared balls with sub-micron downsteps are shown in Fig. 2, and their dimensions are listed in Table 1. The sub-micrometer steps were manufactured by femtosecond laser processing. The ball without steps is 'test ball O', the one with 100 nm is 'test ball A' and one with 500 nm-depth downsteps is 'test ball B'.

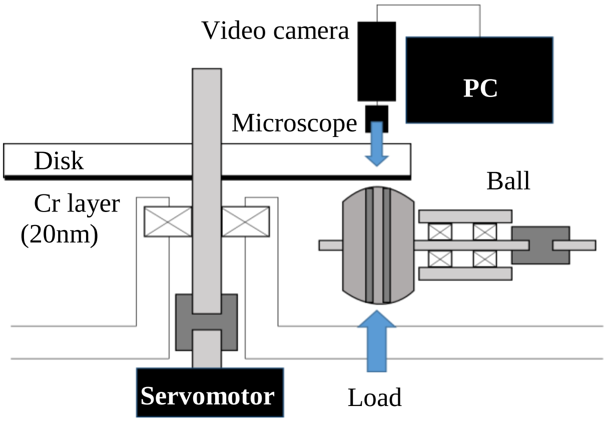
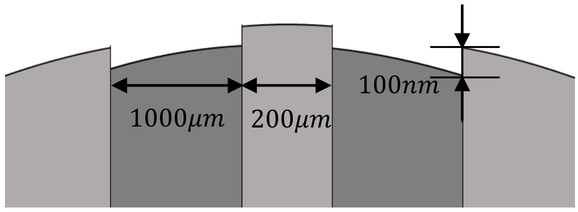
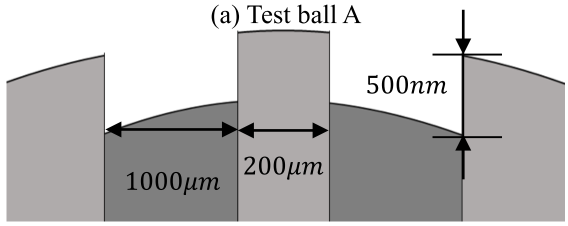


Figure 1 Disk-on-ball friction tester with optical interferometry.



(a) Test ball A



(b) Test ball B

Figure 2 Illustrations of the test balls with downsteps.

Table 1 Dimensions of test balls.

Test ball	Step distance [μm]	Step depth [nm]	Downstep [μm]
O	-	0	-
A	200	100	1000
B	200	500	1000

The experimental conditions are listed in Table 2. The maximum Hertzian pressure and contact diameter under the 20-N load were about 610 MPa and 250 μm, respectively.

Table 2 Experimental conditions.

Disk	Material	Sapphire glass
	Elastic modulus	420 GPa
Ball	Material	SUJ2 steel
	Elastic modulus	208 GPa
Condition	Load	20 N
	Slip ratio	0.1
	Rotational speed	1.0-3.0 m/s
	Lubricant	Turbine oil (26.9 cP@40ºC)
	Temperature	R.T.

As shown in Fig.3, the central EHL fil, thickness at the contact point increased with the rotational speed due to the sub-micrometer downsteps beside the contact point. With the test ball A, the film was the thickest the (almost twice as thick as with the non-step ball). The film shape obtained by the test ball A is shown in Fig. 4. The film shape was a typical horse shoe one.

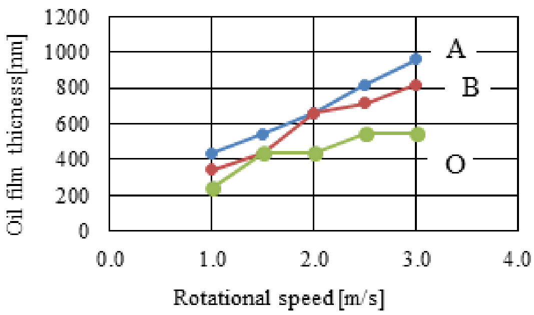


Figure 3 Central EHL film thicknesses at various the rotational speed.

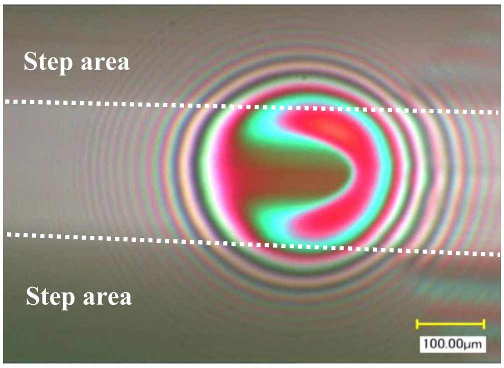


Figure 4 EHL film shape for test ball A at rotational speed of 1.5 m/s.

3. NUMERICAL ANALYSIS

Numerical analysis was used to investigate the mechanism of the increase in film thickness. The Reynolds equation and FEM were used to calculate the pressure and deformation distributions, respectively. First, the pressure distribution was obtained by the Reynolds equation. Second, the deformation distribution was calculated by FEM under the previously obtained pressure distribution. The analytical model for the FEM analysis is shown in Fig. 4. The calculation area was set to 1.0(r)×0.5(θ)×1.0(y) mm. As shown in Fig. 5, both of the ball and disk were deformed by the pressure. The enlarged figure for the clearance distribution between the disk and ball in Fig. 6 show that the distribution took a unique shape and was clearly constricted in the step area. This constriction may have restrict oil leakage from resulting in thicker film.

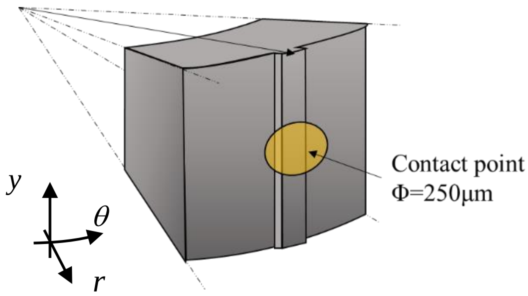


Figure 4 Analytical model for FEM analysis.

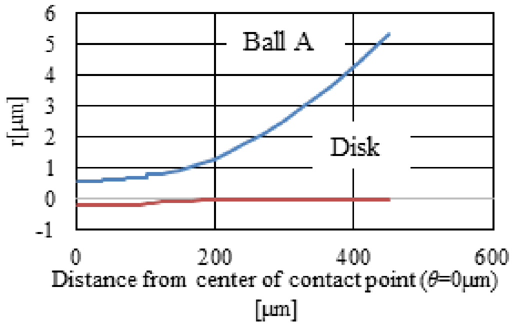


Figure 5 Deformation of disk and ball for pressure distribution calculated using the Reynolds equation.

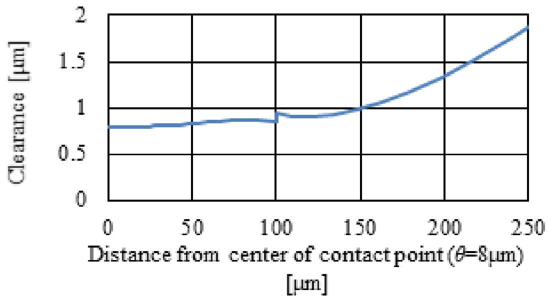


Figure 6 Clearance distribution between disk and ball A calculated from result in Figure 5.

4. CONCLUSION

We experimentally investigated the mechanism of the increase in oil film thickness with sub-micrometer downsteps beside the contact point under point-contact EHL. The analytical result showed that the increase in the oil film thickness was due to the ball and disk taking a unique deformed shape. This restricted oil flow from the contact point, causing the film thickness to increase.

5. ACKNOWLEDGEMENT

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6. REFERENCE

[1] T. Hirayama et al., “Effect of Nano-texturing on Increase in Elasto-hydrodynamic Lubrication Oil Film Thickness,” *J. Tribol.*, 136(3), 031501, 2014.