ASIATRIB 2002 International Conference
JEJU ISLAND, KOREA

In-situ Observations of Lubricant Film Thickness Distribution in Mixed EHD Point Contacts

M. HARTL, I. KŘUPKA and M. LIŠKA

Faculty of Mechanical Engineering, Brno University of Technology,
Technická 2, 616 69 Brno, The Czech Republic

This paper presents an experimental study of the effect of rolling speed and surface roughness on the mixed elastohydrodynamic (EHD) lubrication characteristics for point contact formed between a real, random, rough surface, steel ball and smooth glass disc. The Thin Film Colorimetic Interferometry measurement technique has been extended to give detailed information about in-contact deformation of the microgeometry. It has enabled to derive the amplitude reduction curve that shows progressive recovering of ball roughness features with increasing speed.

Keywords : Elastohydrodynamic lubrication, Mixed lubrication, Interferometry

1. INTRODUCTION

An understanding of mixed lubrication, and in particular mixed lubrication of concentrated contacts sometimes referred as partial elastohydrodynamic (EHD) lubrication, is not only of fundamental interest but also practical importance to design of many machine elements. Considerable progress has been made in numerical simulation of mixed EHD lubrication of real rubbing surfaces. Conversely, only a few experimental studies on this subject can be found in the literature [1].

In this paper the Thin Film Colorimetric Interferometry (TFCI) technique [2] is used for the film thickness mapping in mixed EHD point contact formed between a real, random, rough surface, steel ball and a smooth glass disc. The main aim of the work is to study the effect of rolling speed on the mixed EHD lubrication characteristics such as the average film thickness, lambda ratio, contact area ratio and amplitude reduction.

2. EXPERIMENTAL METHOD AND MATERIALS

The experimental apparatus is a high-pressure ball on disk tribometer equipped with a microscope imagining system and a control unit. The tribometer consists of a steel ball loaded and rotated against a transparent glass disc. The contacting side of the disc is coated with a thin semi-reflective chromium layer that is overlaid by a silicon dioxide "spacer layer". The glass disc is driven, in nominally pure rolling, by the ball that is driven by a servomotor via a planet gearbox. Chromatic interference patterns produced by the contact area are collected by microscope that incorporates a xenon flash lamp and a high-resolution digital camera. Flash discharge is triggered by a signal from the rotary encoder attached to the ball shaft, so that all measurements are carried out at the same ball position.

The experiments reported here make use of the Thin Film Colorimetric Interferometry technique for film thickness measurement. It represents an improvement over conventional chromatic interferometry in which combination of spacer layer and image processing is used. During several last years the accuracy and resolution of this technique has been improved and it is now able to measure film thickness to within 1 nm [3].

Commercially provided 25.4 mm diameter steel balls of two different roughness values designated as "smooth" and "rough" were employed in this study. Their root-mean-square (rms) surface roughnesses were measured by stylus technique and they are 6 nm and 15 nm, respectively.

All experiments were carried out with naphtenic additive-free base oil SUN 500 N. This had a dynamic viscosity of 0.321 Pas and pressure-viscosity coefficient of 31 GPa^{-1}, both at 25°C. The contact load was 29 N, corresponding to a maximum Hertz pressure of 0.5 GPa. The temperature was maintained at 30°C.

3. RESULTS AND DISCUSSION

Figure 1 shows two three-dimensional representations of film thickness for smooth and rough ball at rolling speed of 0.031 ms^{-1}.

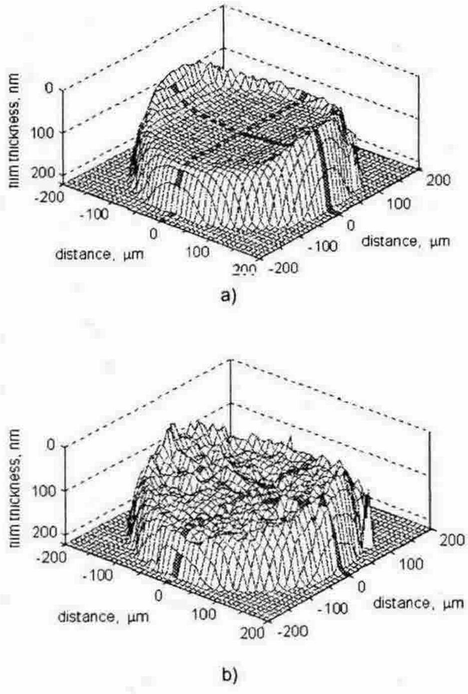

Fig. 1 Three-dimensional representations of film thickness for (a) smooth and (b) rough ball at rolling speed of 0.031 ms^{-1}

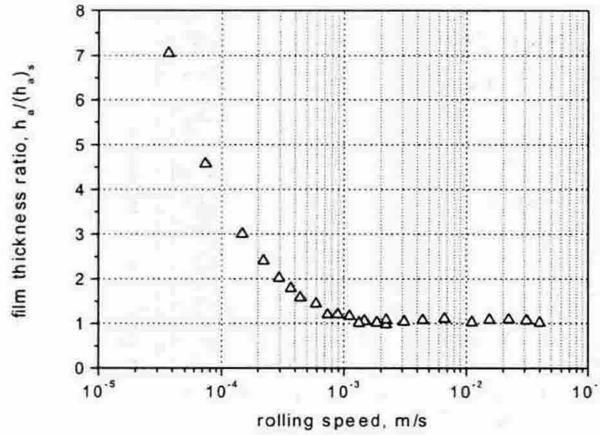

Fig. 2 Ratio of the average film thickness for rough ball to that for smooth ball as a function of the rolling speed

In Fig. 2 the ratio of the average film thickness for the rough ball to that for the smooth ball is plotted against rolling speed. The results show that the effect of surface roughness on the average film thickness do not become significant until rolling speed becomes below approximately 0.001-0.002 m/s. It corresponds to the nominal lambda ratio value around 0.8.

Figure 3 shows the contact area ratio and both lambda ratio and nominal lambda ratio as a function of rolling speed. It is important to see that the curves have the same trends as those obtained from deterministic numerical solutions with measured surface roughness [4]. The contact area ratio decreases as the rolling speed increases, from 35 % at very low speed down to almost zero at higher speeds. Because of the low value of load parameter used in this test, the real contact area is lower than hydrodynamic area for the whole speed range. The reduction of the rolling speed decreased both lambda ratios that are identical down to 0.001 m/s. Below this speed, the lambda ratio is greater than nominal lambda ratio because the roughness makes the film thicker.

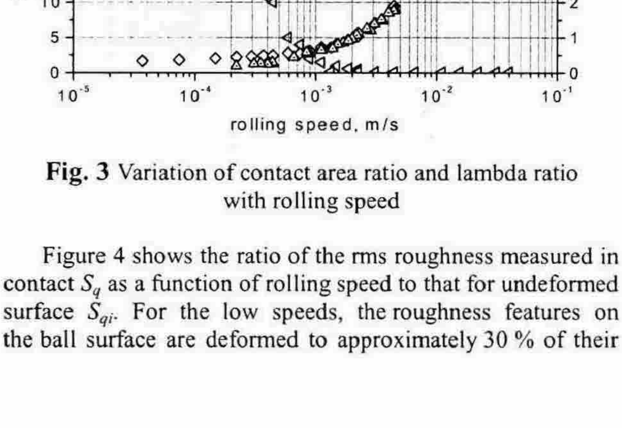

Fig. 3 Variation of contact area ratio and lambda ratio with rolling speed

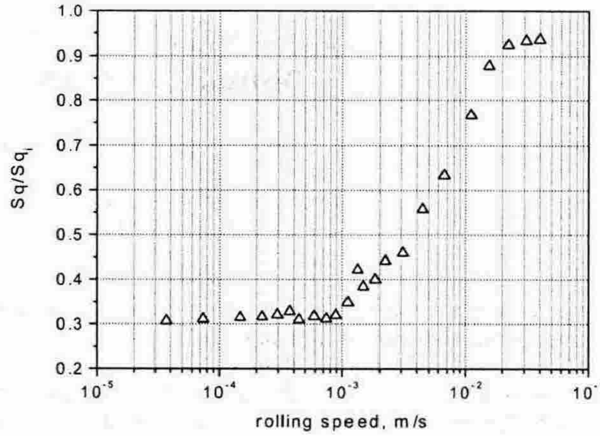

Fig. 4 Variation of contact area ratio and lambda ratio with rolling speed

Figure 4 shows the ratio of the rms roughness measured in contact S_q as a function of rolling speed to that for undeformed surface S_{qi}. For the low speeds, the roughness features on the ball surface are deformed to approximately 30 % of their original height and S_q is close to the value measured in the static contact. As the rolling speed increases the roughness features recover their original form and S_q approaches S_{qi}. Similar effect has been described in numerical studies e.g. [5].

4. ACKNOWLEDGEMENTS

This research was supported by the Grant Agency of the Czech Republic and the Ministry of Education, Youth and Sports of the Czech Republic under grants Nos.101/00/0155 and J22/98:262100002. The test oil was supplied by Sun Oil Company Belgium.

5. REFERENCES

[1] SPIKES, H. A., and OLVER, A. V., Basics of Mixed Lubrication, "Lubricants, Materials, and Lubrication Engineering," Technische Akademie Esslingen, pp. 19-29, 2002.

[2] HARTL, M., KŘUPKA, I., POLIŠČUK, R. and LIŠKA, M., "An Automatic System for Real-Time Evaluation of EHD Film Thickness and Shape based on the Colorimetric Interferometry," Tribology Transactions, Vol. 42, No. 2, pp. 303-309, 1999.

[3] HARTL, M., KŘUPKA, I., and LIŠKA, M., Experimental Study of Boundary Layer Formation in Concentrated Contacts, "Boundary and Mixed Lubrication: Science and Application," Elsevier, pp. 413-421, 2002.

[4] ZHU, D., and HU, Y. Z., "A Computer Package for the Prediction of EHL and Mixed Lubrication Characteristics, Friction, Subsurface Stresses and Flash Temperatures Based on Measured 3-D Surface Roughness," Tribology Transactions, Vol. 44, No. 3, pp. 383-390, 2001.

[5] LUBRECHT, A. A., GRAILLE, D., VENNER, C. H., and GREENWOOD, J. A., "Waviness Amplitude Reduction in EHL Line Contacts Under Rolling-Sliding," Transactions of of the ASME, Journal of Tribology, Vol. 120, No. 4, pp. 705-709, 1998.