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Behavior of thin viscous boundary films in lubricated contacts between micro-textured surfaces

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ABSTRACT

Thin film colorimetric interferometry was used to map changes in film thickness in the vicinity of micro-dents of various depths produced on rubbing surfaces. It has been shown in recent studies that shallow micro-features within concentrated contact can increase mean film thickness by supplying more lubricant to the contact; however, this beneficial effect can also be accompanied by a local film thickness reduction. Nevertheless, these observations were done with mineral base oils that exhibited no boundary films formation. In this study the behavior of micro-textured surfaces are observed using formulated lubricant containing polyalcylmethacrylate (PAMA), viscosity index improver with boundary film forming properties. Obtained results show that an enlarged film thickness due to the presence of viscous boundary films is formed within the whole contact and these boundary films minimize the local film thickness reduction caused by micro-dents and further increase the efficiency of surface texturing within non-conformal contacts. It can be suggested from the obtained results that joint action of both boundary film formation and surface texturing combines both contributions that can help to increase tribological performances in different stages of machine parts operation by increasing lubrication film thickness.

1. Introduction

Design of highly loaded machine components (e.g. rolling bearings, gears and cams and followers) has been all the time accompanied by an effort to reduce friction and wear of rubbing surfaces [1]. It includes many aspects of material sciences, lubricant chemistry, surface topography modifications, etc. This paper focuses on the joint action of two different approaches—the use of very thin viscous boundary films and surface texturing. While the boundary film formation in the concentrated contacts between non-conformal rubbing surfaces has been a subject of numerous studies, the effect of surface texturing on beneficial tribological behavior is still a bit questionable.

In the last decade it has been shown that the presence of thick viscous boundary films formed on rubbing surfaces lubricated with some polymer-containing viscosity index improver (VII) solutions can help to reduce the friction and wear. It was ultrathin film interferometry that enabled to observe the behavior of these boundary films in detail. Smeeth et al. [2,3] described the formation of adsorbed layers on rubbing surfaces with a viscosity much higher than that of the bulk lubricant. They found that some polymer solutions formed highly viscous boundary films of up to 20 nm thickness. These studies have enabled to improve the efficiency of additives through their proper functionalization. Dardin et al. [4] and Müller et al. [5,6] observed that functionalized dispersant polymethacrylates (PMA) significantly reduce friction and wear. Moreover, the beneficial effect of boundary films has been proved in rough surface contacts. Glovnea et al. [7] used dispersant-substituted olefin copolymer and showed that the polymer used as viscosity index improver is able to form a thick boundary film also in rough surface rolling-sliding contact. Very recently, the authors [8] used non-functionalized polyalcylmethacrylate (PAMA) and showed that even very thin boundary film can help to reduce the direct contacts between rubbing surfaces in real rough rolling sliding contact.

While viscous boundary film formation is successfully used to diminish friction and wear of highly loaded machine components, surface texturing has been introduced to improve tribological properties of lubricated contacts between conformal surfaces only [9]. The use of surface texturing within non-conformal contact is accompanied with a significant effect on the local fluctuations in film thickness and pressure. The local changes in film thickness can result in lubrication film breakdown. Besides that, highly localized pressure peaks, in the vicinity of micro-features, increase subsurface stresses that can influence the contact fatigue life. Nevertheless, recent numerical and experimental studies have suggested that surface features introduced to the rubbing surfaces could improve the lubrication capabilities under thin film

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lubrication. Dumont et al. [10] suggested a possible beneficial effect on lubrication in starved conjunction while Zhao and Sadeghi [11] showed that the start-up behavior is determined by the amount of lubricant trapped inside pocket. Recently, Mourier et al. [12] observed strong dependence of lubrication film formation on the depth of the micro-dent. Significant increase in film thickness was observed for a shallow micro-cavity while deep cavities caused a local decrease in film thickness. Through the extrapolation of calculated results they found a threshold value of the micro-dent depth to be around 500 nm. They confirmed these results through the experiments with isolated micro-dents produced on rubbing surface by a femtosecond pulse laser. Ren et al. [13] numerically observed changes in film thickness caused by micro-features of various shapes and depths for both negative and positive slide-to-roll ratio conditions and found that the benefits in film thickness are more obvious for shallower micro-features. Hsu [14] used lithographic electrochemical etching technique to fabricate simple surface features on metal surfaces

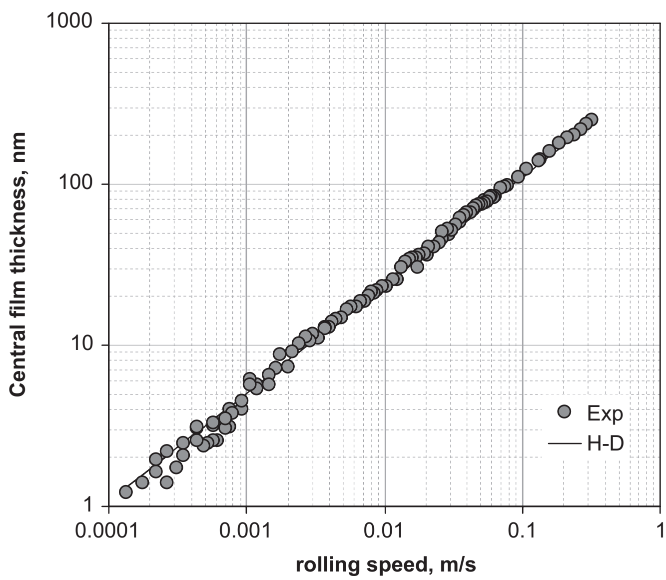

Fig. 1. Central film thickness vs. rolling speed for paraffinic base oil SR 600.

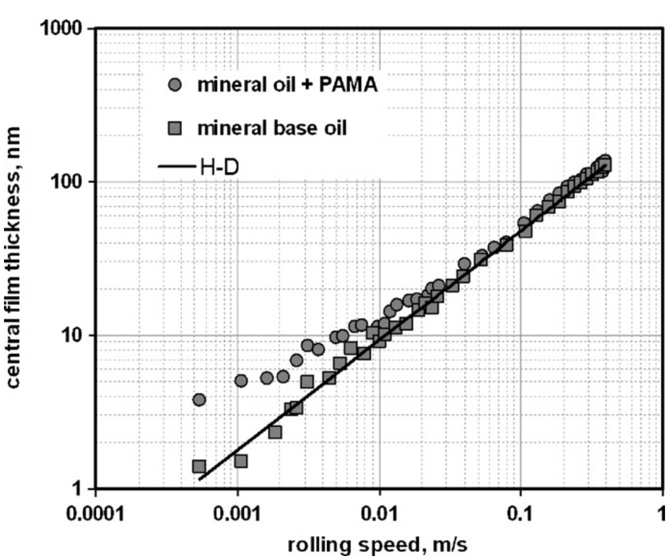

Fig. 2. Central film thickness vs. rolling speed for mineral base oil and mineral oil formulated with PAMA.

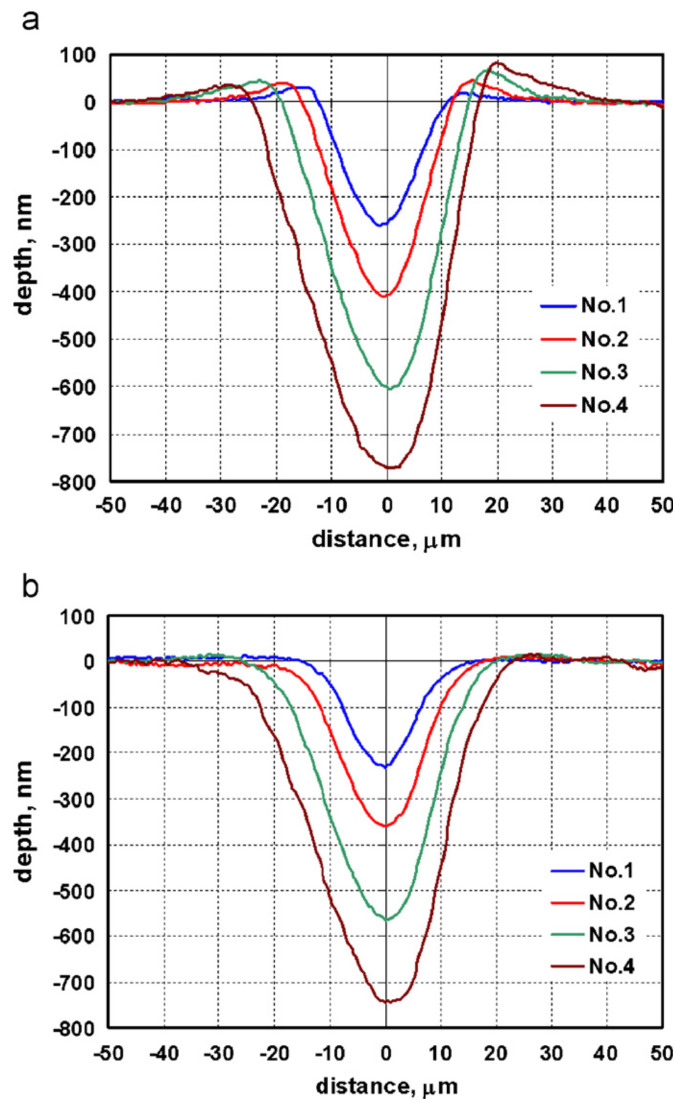

Fig. 3. Dents of various depths produced on the ball surface before (a) and after (b) surface polishing.

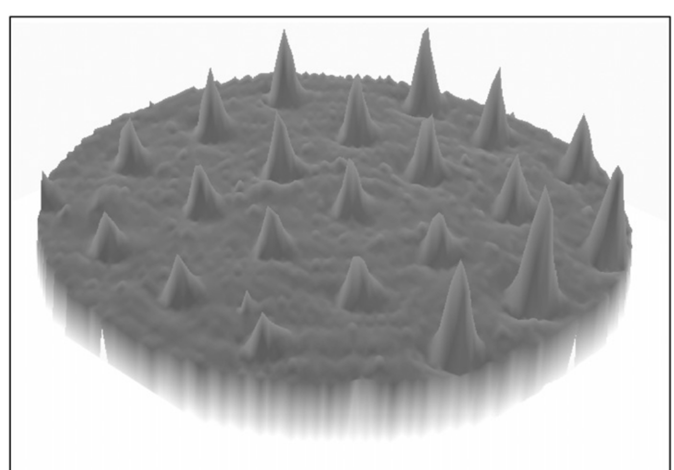

Fig. 4. Surface image of a ''negative'' replica of an array of micro-dents obtained with 3D profilometer.