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STUDY OF THE CHANGE OF STEEL SURFACE TOPOGRAPHY ON A BOUNDARY LUBRICATED RECIPROCATING SLIDING CONTACT

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ABSTRACT

Experiments on ball-on-plate steel under boundary lubricated reciprocating sliding contact were performed to study the change of the surface topography. The surface characteristics were measured by an optical profilometer: Micromap 512. In order to get more detailed information about the surfaces before and after the experiment the Matching and Stitching method was employed. The profile evolutions of the surface for a certain number of running-in cycles were presented. Analysis of roughness was done to get the important information of the surface topography change. Results show that the surface changes more in the running direction than in the traverse direction.

Keywords: *surface topography, boundary lubrication, sliding contact.*

INTRODUCTION

When two surfaces are sliding against each other, the way lubrication takes place between these interacting surfaces is of particular interest for understanding their contact behaviour. If the lubrication regime can be effectively determined, it would help the maintenance of machine parts and to predict the performance of the machine. The lubrication regimes determine the effectiveness of fluid film formation, and hence, surface separation. The Stribeck curve was first recognised by Stribeck [1] in 1902 to study the regimes of journal bearing lubrication. The work was continued by Hersey [2] in 1915 by observing the variation of sliding friction using the number $\eta N/p$, where η is the lubricant viscosity, N the angular velocity and p the average contact pressure. The Stribeck curve divides lubrication into three regimes: thick film, thin film and boundary lubrication.

Boundary lubrication usually occurs under high-load and low-speed conditions. Under these conditions, the lubricant viscosity is relatively unimportant and the physical and chemical interaction of the lubricant with the solid bodies controls friction and wear. Metallic contact occurs at the asperities of both surfaces. Rapid deformation and crushing of the tips of individual asperities occur during the initial operation until they are run-in and producing an increase in real contact area. Within lubricated wear, most wear occurs under boundary lubrication. In this regime, the coefficient of friction is usually insensitive to the load. The load is totally supported by the asperity contacts which are protected by layers at the surfaces (chemical interaction between the lubricant and the surface). Based on this phenomena, a study to determine the microscopically change in the asperity-asperity contact level of surface was done in a boundary lubricated ball-on-plate reciprocating sliding experiment. By doing experiments for various number of cycles or sliding distances, the results can be used to verify the contact and wear model.

EXPERIMENTAL APPARATUS

S-Tribometer

Friction and wear tests were carried out on the S-tribometer as is schematically shown in Fig. 1. The apparatus executes a sinusiodal reciprocating motion of a hemispherical specimen on the stationary counterface with amplitude of 46 mm. The hemispherical specimen is fixed in a holder, held in a loading arm, connected to the slider/support. The pivot of this loading arm lies in the plane of the sliding contact. The slider/support is driven by a gear mechanism connected by a chain transmission to a motor with a continuously variable speed. The maximum velocity is $2\mu Af$, where A is the amplitude and f the frequency of the moving supports. The specimen is loaded through a short spindle by a pressurized air bellow fixed on top of the support. The support moves in a plane parallel to the counterface through a system of four roll blocks guiding two cylindrical bars fixed to the support. The counterface is held in an aluminium holder which is fixed to the heat exchanger. The heat exchanger is connected to a thermostatically controlled oil bath and is supported by two steel blade springs fixed to the frame of the tribometer. These springs only allow movement parallel to the direction of sliding. This movement is restricted by a piezoelectric force transducer fixed between the heat exchanger and the frame of the tribometer. A modification of the tribometer was made in order to unload the contact at and near the ends of travel by using a lift system. Omitting the lift system contact between pin and plate at the ends of travel exists. The frictional force is measured at the maximum velocity.

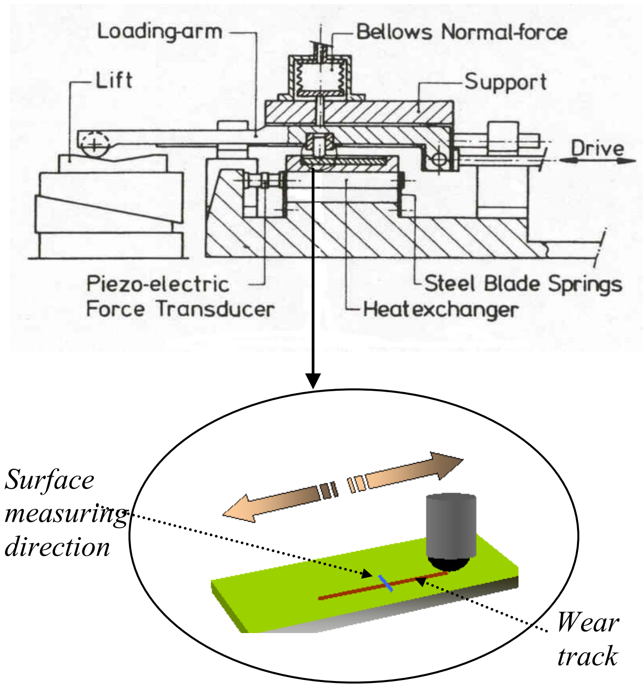


Fig 1. General layout of S-Tribometer.

Micromap

There are many methods to determine and/or calculate surface roughness parameters (R_a, R_q, S_k, K_u, and R_t) such as mechanical stylus, optical, scanning probe microscopy, fluid, electrical, and electron microscopy. The optical method is a non-contact means of accurately measuring surface profiles-heights in 3 dimensions. The output is very similar to a standard geographical contour map where any given surface and individual bands of (false) colour represent area of equal height. Unfortunately at this level the styli of profilometers can behave like ploughshares and may destroy many of the features we would like to look at. The optical profilometry Micromap 512 was used to measure the surface topography parameters in these experiments. The Micromap 512 has the the following characteristics:

- High resolution of approximately 1 nm
- Size of the measured area 110x85 μm up to 4.42x3.45 mm
- 304x228 pixels, at very smooth surfaces 640x478 pixels (phase mode)

EXPERIMENTAL PROCEDURES

Testing conditions

Three hardened steel AISI 52100 plates and three SKF Standard Balls with the diameter of 20 mm were used as samples. Each pair of Ball and Plate was run under conditions as indicated in Table 1.

Table 1

Experimental conditions

Parameters	Value(s)
Sliding velocity (m/s)	**0.01**
Applied load (N)	**100**
Ambient temperature (°C)	**25**
Initial roughness value R_a of the ball (nm)	**8.5**
Initial roughness value R_a of the plate (nm)	**40**
Number of cycles	**1, 3 and 5**

Shell Tellus R5 was used as lubricant in this experiment which has the property of viscosity η = 5.43 mPas at $T \approx 25^{o}$C. In order to run in the boundary lubrication regime, the parameter of Schipper [3] was used for determining the sliding velocity as shown in Fig. 2. Since the lubricant viscosity η Ball roughness R_{ab}, and Plate roughness R_{ap}, are known the boundary lubrication sliding velocity V is easily determined where the combined surface roughness R_{at} = $(R_{ap}^{2}+R_{ab}^{2})^{0.5}$.

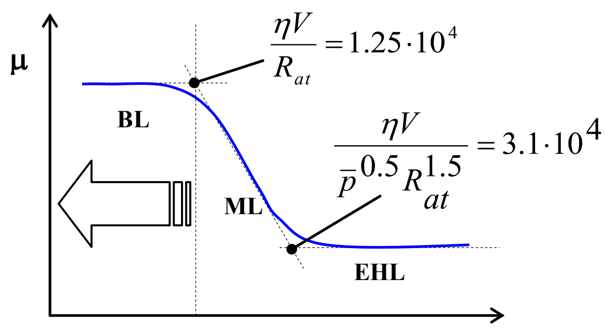


Fig. 2 Range of sliding velocity on the boundary lubrication regime.

Surface Roughness Measurements

The Micromap 512 interferometer was employed to measure the surface topography using the available highest magnification, 40X, in order to get more details in surface topography data. The 40X magnification has the property of 110 X 85 μm area with 304 X 228 data points. A single 40X magnification measurement of the Ball surface by Micromap 512 is shown in Fig. 3. To predict how many surface images should be measured as input for the stitching process, the Hertzian contact area was calculated. Since the minimum track width is 374 μm, by using 40X magnification and a two-third overlapping area, 11 Ball surface images in the running direction and 19 Plate surface images perpendicular to the running direction were measured. These images will be used for the Matching and Stitching code for further surface analysis.

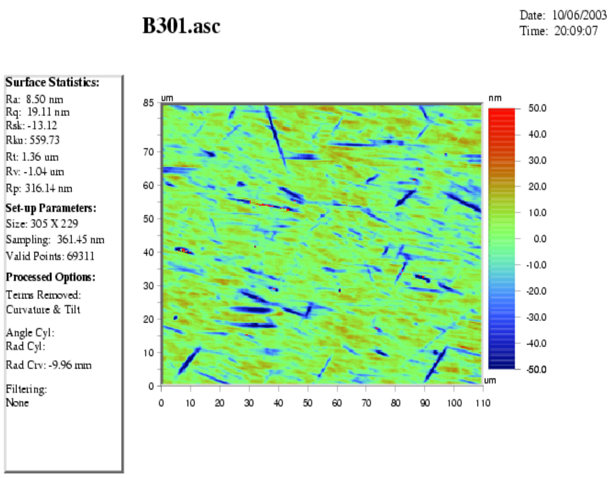
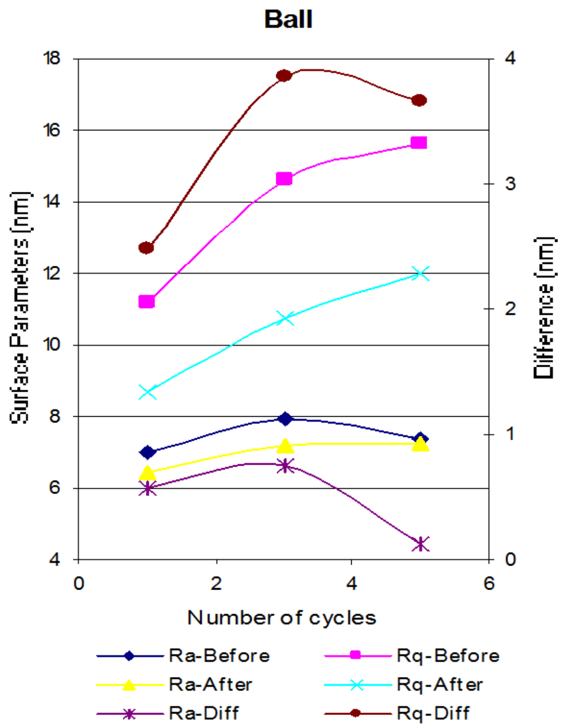


Fig. 3 Single measurement image result of the Ball by Micromap 512.

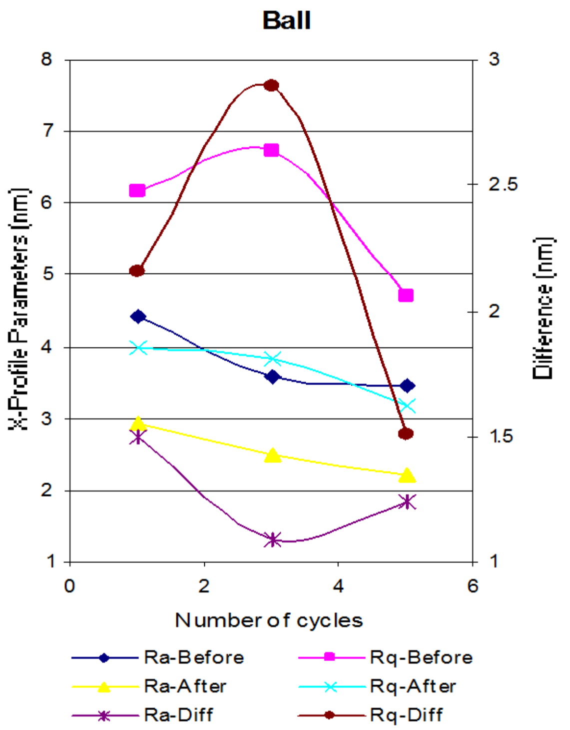
RESULTS AND DISCUSSIONS

To determine small local surface changes or micro-geometry change in surface topography, a Matching and Stitching method can be used even when the roughness parameters do not change much. In these experiments, the surface parameters change significantly though, so therefore the surface roughness analysis is done as well. Under boundary condition, contact occurs at the asperities of both surfaces because of the rupture of oil films so rapid deformation and crushing of the tips of individual asperities occur during the contact operation. The significant change of the asperities contributes a lot of the surface parameters values.

The R_a and R_q surface parameters were used to analyse the change of the surface topography. R_a or roughness average is the mean height as calculated over the entire measured length/area and R_q is the root means square (rms) average between the height deviations and the mean line/surface, taken over the evaluation length/area. The R_a and R_q for the surface, x-profile and y-profile of the Ball and Plate as a function of number of cycle are presented in Fig. 4 and 5, respectively. The roughness parameters of the surfaces were taken by selecting a certain part, 100 x 100 μm for the Plate and 70 x 70 μm for the Ball, of the stitched images at exactly the same position before and after the experiment. The surface and average profile parameters were taken from the selected images. Results show that the values of the roughness parameters of the surfaces were dominated by the roughness data of the x-profile or in the running direction. It means that the surface change more in the running direction than that in the traverse direction.



(a)



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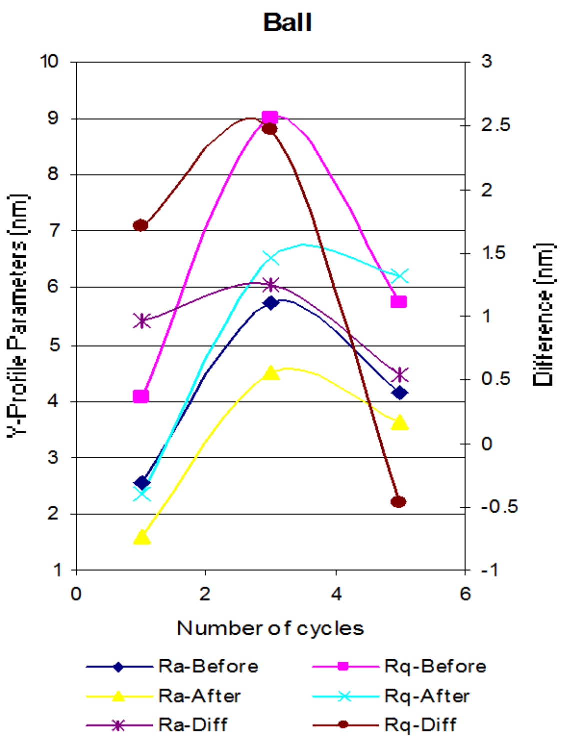
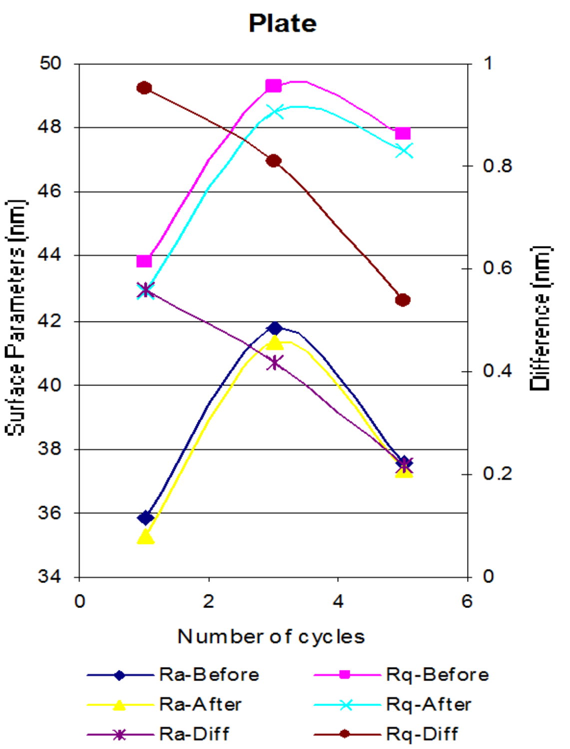


(c)

Fig. 4 The change in surface roughness parameters of the Ball: (a) Surface, (b) X-profile and (c) Y-profile.



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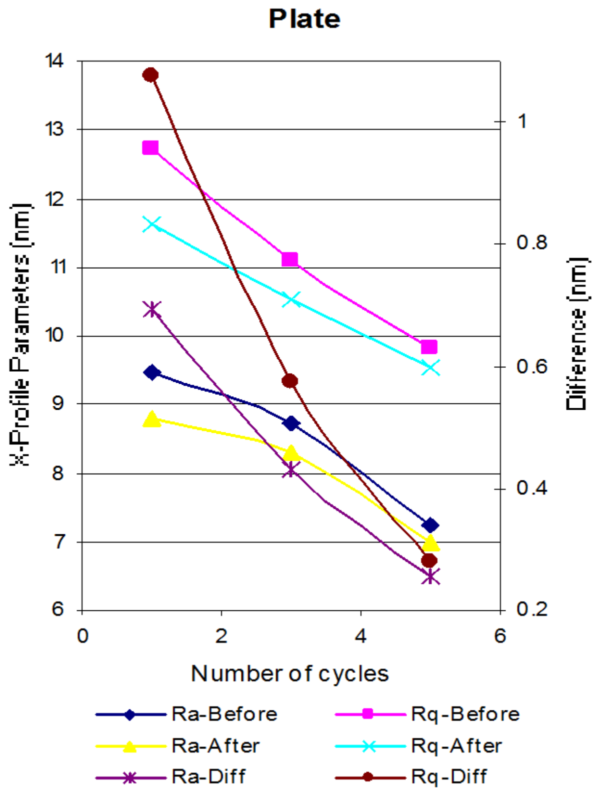

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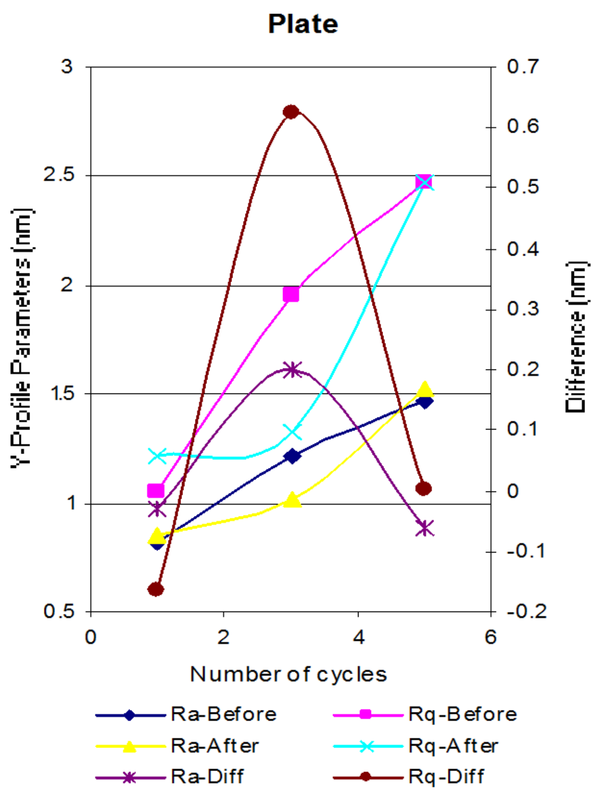

(c)

Fig. 5 The change in surface roughness parameters of the Plate: (a) Surface, (b) X-profile and (c) Y-profile.

CONCLUSIONS

The Matching and Stitching method is applicable to the experiments on ball-on-plate steel under boundary lubricated reciprocating sliding contact. To get important information of the surface micro-geometry change, analysis of roughness can be done accurately with the Matching and Stitching method. Results show that the surface changes more in the running direction than in the traverse direction. This information is very important to study further on the running-in of surfaces [4].

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