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Plastic deformation in running-in of rolling contact

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ABSTRACT – The aim of this study is to understand the surface deformation during the first phase of rolling contact cycles. Quantification of surface characteristic at micro-geometry scale is crucial for wear and fatigue prediction. In this study, a new test rig is developed to measure the progressive surface deformation. The online measurement of surface deformation is evaluated periodically using infinite focus microscope (IFM). This is the first time the surface deformation is monitored online by using IFM.

1. INTRODUCTION

Running-in is the first phase of the lifetime in rolling or sliding contact. At this period, the asperity peak of original surface finish is reduced by plastic deformation and the valley is filled. Plastic deformation (a permanent deformation or change in shape of a solid body in response to applied forces) and wear (removal of material during contact of surfaces) are the main critical mechanisms observed in the contacting surface that may lead to failure. Plastic deformation of cyclically loaded structure at the first application of load which occurs until elastic steady cyclic state achieved is known as 'shakedown'[1]. The elastic shakedown can be seen after a number of cyclic plastic deformations. The evolution of surface roughness during running-in has been carried out extensively experimentally and numerically [2,3]. However, few works have looked at the surface deformation at micro-geometry/asperity levels [4,5]. The measurement of progression in localized surface deformation requires a very precise positioning method. In this study an online surface monitoring system is developed to quantify surface deformation and wear without dismounting the sample. The progress of the surface geometry over the rolling cycle is important in order to get a better understanding of the plastic deformation and wear mechanism in rolling motion.

2. METHODOLOGY

2.1 Experiment Set Up

The experimental setup consists of a new developed test rig and infinite focus microscope (IFM) as shown in Figure 1. This microscopy device is selected due to ability to measure roughness in two dimensional (2D) and three dimensional (3D). In addition, there are few software enhancement which permit further surface analysis, which is not available in traditional microscope. The rig is designed to be small enough to fit into the IFM and consists of two rollers, linear guide, load flange and stepper motor. The roller samples are maintained at a relative consistent contact for accurate measurement of surface deformation.

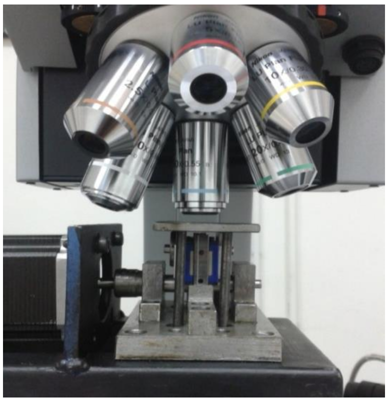

Figure 1 Experimental setup

The experiment details are shown in Table 1.

Table 1 Experimental setup.

Parameter	Value
Roller diameters	20 mm
Surface roughness	Upper roller : 0. 7 µm Lower roller : 0.01 µm
Rotation speed	1 rpm
Load	50 N

2.2 Development of Finite Element Model

The scanned surface is used in the modeling of rough surface for finite element analysis as shown in Figure 2. The advantage of this method is the real surface distribution is obtained. Previous work considered elastic–plastic solid with a sinusoidal profile brought normally into contact with a rigid plane [6,7] where the first body is treated as rigid, smooth and perfectly flat while the second is a surface with profiles.

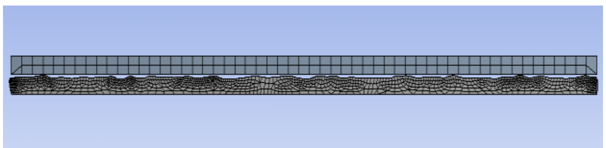

Figure 2 2D finite element model of rough surface in contact with flat surface.

3. RESULTS AND DISCUSSION

Figure 2 shows the surface deformation for the first ten cycles. The y-axis represents asperity height while x-axis is a measurement length. The profiles acquired by interrupting the test every one cycle for surface scanning by IFM. The surface is scanned with 20x magnification and the roughness filter is applied to the primary profile. The figure shows that the system has a capability to quantify surface change up to nano-scale range, an indication that experimental rig can measure surface deformation in micro-asperity level.

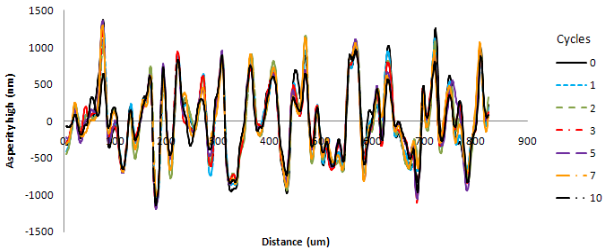

Figure 3 Surface asperity evolution for the first 10 cycles.

The different phases of surface deformation are exhibited in Figure 3. The phases are evaluated by the measured average roughness (Ra) of the surface asperity. From the graph, an elastic shakedown is achieved at 1300 cycles (running-in phase). This is a turning point for a steady state of rolling contact. At the first phase (running-in), the average roughness is reduced by 31.7% while after shake down, the roughness level is maintained with a percentage of changing rate at 6 %. With the high reduction in phase I, it can be concluded that plastic deformation is active until elastic shake down is achieved. After that, the roughness is maintained due to elastic behavior of material.

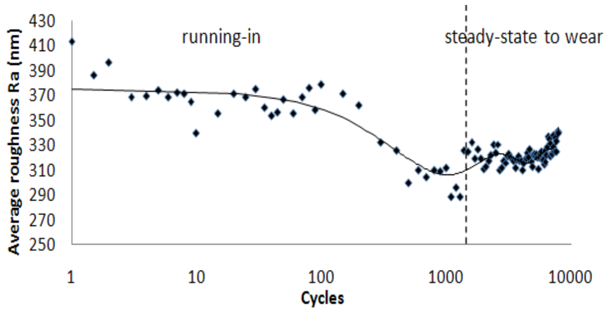

Figure 4 Surface deformation regimes from running-in to steady state.

Figure 4 shows how the asperities deform during plastic deformation. There are reductions of asperity peaks while the valleys are maintained at the same level.

The stress distributions on the asperity peaks after plastic deformation are shown in Figure 5. The blunted asperities cause the increase of the area of contact, therefore resulting in a reduction of the contact stress.

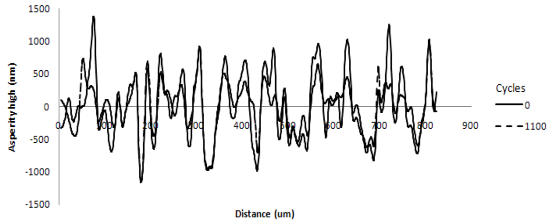

Figure 5 Surface asperity profiles before and after running-in.

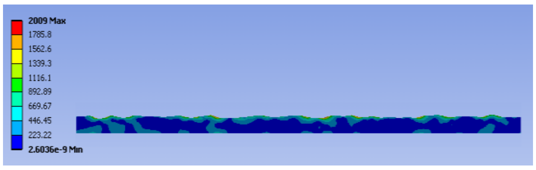

Figure 6 Finite element results on the stress distribution on the asperity peaks.

4. CONCLUSIONS

A plastic deformation mechanism during running-in of rolling contact is understood. The test rig able to measure the small changes in the surface geometry indicates that a high precision system has been developed. This is the first time the surface deformation is monitored periodically under IFM. This improves the current method available in wear measurement hence open an opportunity for a further assessment of surface deformation and wear mechanism.

5. REFERENCES

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