Proceedings of Asia International Conference on Tribology 2018, pp. 109-110, September 2018

A new ball-on-disk vacuum tribometer with in situ measurement of the wear track by digital holographic microscopy

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Keywords: Ball-on-disk tribometer; digital holographic microscopy; in situ & real time measurement

ABSTRACT – This contribution presents a new ball-on-disk vacuum tribometer with in situ and real time measurement of the wear track by digital holographic microscopy (DHM). The new instrument was tested and validated by taking DHM images during wear test at room temperature and in vacuum at 2.10^{-6} mbar on polished 100Cr6 disks. 3D wear track evolution can be analyzed by this new technique in real time without removing the sample. An excellent correlation was found between images taken on the same sample by in situ, real time DHM, and by traditional scanning electron microscopy and confocal microscopy.

1. INTRODUCTION

Friction and wear are the main characteristics of a tribo-system. Friction force can normally be measured easily with load sensors. The measure of wear, however, is not trivial and is usually determined by *ex situ* and *post mortem* measurements. It is well known that any slight changes in the position of the sample could lead to unpredictable local change of test conditions. To overcome these limitations, in situ measurement of wear is the only solution. Various methods have been studied by different researchers. Yagi et al. [1] have taken advantage of using a transparent sample to observe the wear surface. Radionuclide technique (RNT) method was used to measure the radiation concentration in the debris produced by the wear on sample [2, 3] in order to deduce the wear rate. Korres et al. [4] presented a novel method for in situ measurements of the sample surface topography inside a tribometer by a microscope using the digital holography principle. Since then, only few other studies have taken advantage of this method.

In this study, we designed and validated an environment controllable tribometer in combination with digital holographic microscopy.

2. EXPERIMENTAL SETUP

The base of the instrument is a ball-on-disk high vacuum, high temperature tribometer from Anton Paar TriTec SA (Switzerland). This instrument has a normal force range of 20 N, lateral force range of 10 N, max rotation speed of 500 rpm, and sample temperature up to 800 °C. The whole tribometer is enclosed in a vacuum chamber with top view option to accommodate a 3rd party observation tool, in this study a digital holographic microscopy (DHM) from Lyncee Tec SA in Switzerland. The DHM has two high power laser diode modules at 415 and 485 nm, which together define a synthetic wavelength of 2.87 µm and a combined vertical resolution of 4 nm. The holograms acquisition is performed by a 1.4 Mpix CMOS camera with a shutter time of 0.1 ms. The imaging is synchronized with the tribometer rotation speed to ensure the successive the measurement at exactly the same location on the wear track. Figure 1 shows a photo of the instrument setup.

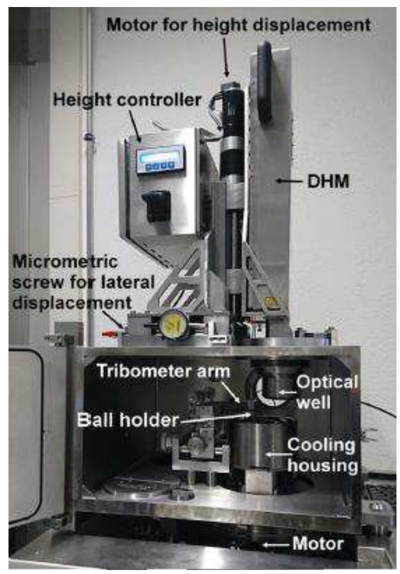

Figure 1 Picture of the high temperature, high vacuum tribometer, combined with a digital holographic microscopy (DHM).

3. RESULTS AND DISCUSSION

To determine the evolution of wear, it is necessary to observe the changes in surface topography during the tribology test. Figure 2 shows the images taken in real time and always on the same wear location. Figure 3 presents the evolution of coefficient of friction, the wear track volume and the ridge volume versus the lap number.

The evolution of the wear can be clearly divided into 3 stages, delimited around the 80^{th} lap and 350^{th} laps. The wear mechanisms changed from gentle plastic deformation in the initial stage to more severe abrasive wear in the end, due to the gradual formation of 3^{rd} body debris at the contact interface.

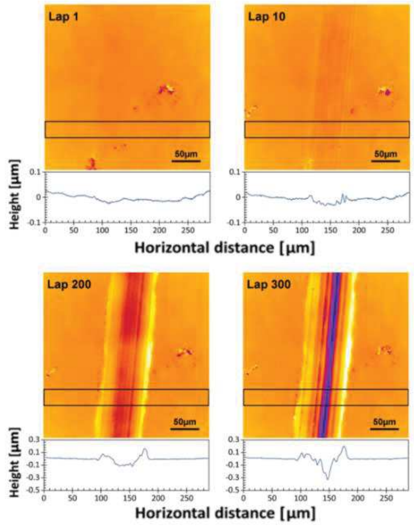

Figure 2 Evolution of wear track at a fix location for various numbers of laps (1, 10, 200, 300 laps).

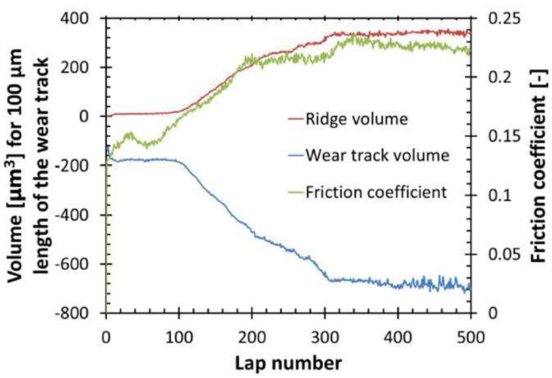

Figure 3 Friction coefficient, ridge volume and wear track volume versus lap number.

The wear track cross section along a lap is often assumed to be constant. Unfortunately, this is rarely the reality and can often lead to an erroneous calculation on wear rate. A panorama image can be taken on the track by combining several DHM images along the rotation direction during measurement. Figure 4 shows the combined image on a wear track length of 2.5 mm, and 4 extracted profiles indeed show that the wear are not exactly the same along the track.

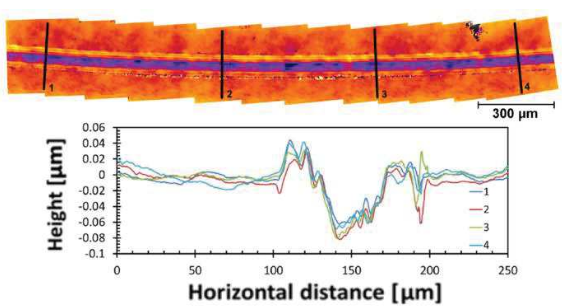

Figure 4 Panorama view of the wear track on a length of 2.5 mm taken by DHM and four selected profiles.

In order to validate the in situ wear track measurement, we compared the images taken by DHM, confocal microscopy and scanning electron microscopy. Figure 5 is an example of the comparison. It shows that indeed the image taken by DHM is in excellent correlation with other more mature imaging techniques.

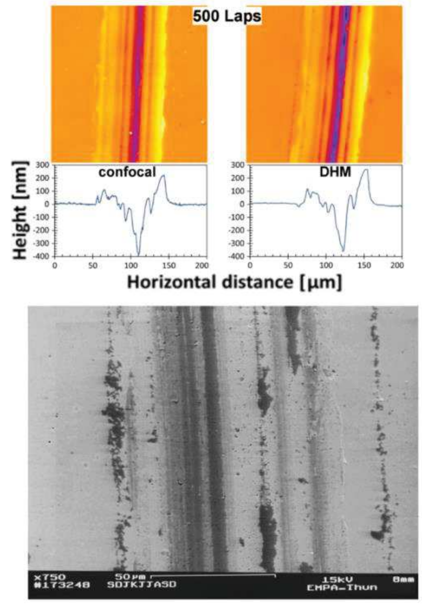

Figure 5 Sample wear images at 500 laps with DHM (top right), confocal (top left) and SEM techniques (bottom) showed that DHM is in good correlation with other imaging techniques.

4. CONCLUSION

A new high vacuum, high temperature ball-on-disk tribometer with in situ measurement of the wear track by digital holographic microscopy is presented. This instrument is able to measure wear evolution during continuous tribology measurement without removal of sample. It is capable of assembling a panoramic image along the wear track. It can perform measurement and imaging under various vacuum, gas, and temperature conditions. This instrument is validated by comparison with mature imaging techniques such as confocal and scanning electron microscopy.

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