

Optical evaluation of wear volumes

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Abstract

This paper describes recent progress in the use of 3D optical microscopy for the evaluation of wear volumes. The instrument presented in this paper uses the variation in intensity of light as the objective is moved in a vertical plane through the focal point to generate height information pixel by pixel for the image area being analysed. The vertical resolution of these instruments can be as good as ~10 nm, depending on instrumental parameters and choice of objective lens.

The advantages and potential drawbacks of these instruments for the evaluation of wear volumes is outlined, and the utility of the instruments is shown by the application to a case study on microscale abrasion of coated samples.

Keywords: Optical evaluation, wear, coatings

1. Introduction

An integral part of any well designed wear experiment is the examination of the damage that has been made to the samples by the wear process [1].

This is done for two reasons. Firstly, an evaluation needs to be made of the magnitude of wear that has occurred. This is often carried out by mass loss measurements, but in many cases other techniques are also used. Secondly, information is often required on the mechanisms of wear that have occurred so that a better understanding of wear in the materials under test can be obtained.

Examination of wear damage is often carried out after a wear test has been performed, or can be performed forensically on worn components received from applications where wear has occurred. To examine the magnitude of wear that has occurred, contact profilometry can be used where in the simplest case the cross sectional area of a wear track or scar is measured and knowledge of the likely form of the damage is used to calculate a wear volume. Direct evaluation of the wear volume can also be made by 3D scanning profilometry.

Recent developments in optical microscopy [4,5] have provided major improvements in the evaluation of worn surfaces. Two types of instrument are considered in this paper. These are confocal optical microscopes and focus variation instruments. They both rely on the physics of how the intensity of reflected light varies as the focal position with an object is reached. A key characteristic of these systems is that it does not only deliver topographical information but also an optical colour image of the surface that is perfectly registered to the height data.

2 Optical Measurement System

The instrument used in this study was an Alicona InfiniteFocus focus variation microscope [5]. This uses a motorized stage to move from the lowest to the highest focal plane in the surface while continually acquiring information. By analyzing how the focus changes during movement, the system is able to accurately determine the height of each object point.

3 Case Study on Micro-scale Abrasion

Micro-scale abrasion tests have become very popular recently as they are particularly suited for evaluating the wear of coatings, or for samples where the amount of material that is available is very small. They can be used for various types of coatings including metallic coatings, polymeric films, thin hard ceramic coatings and thick thermally sprayed coatings [7]. A review of different types of micro-scale abrasion tests is provided in [8]. The basic principle is demonstrated in Fig 2a. A rotating ball, typically of bearing steel, is pressed against the test sample in the presence of an abrasive slurry. By measuring the worn material of the coating and the underlying substrate important information on the wear resistance is obtained. A typical crater formed by this process is shown in Figure 2b.

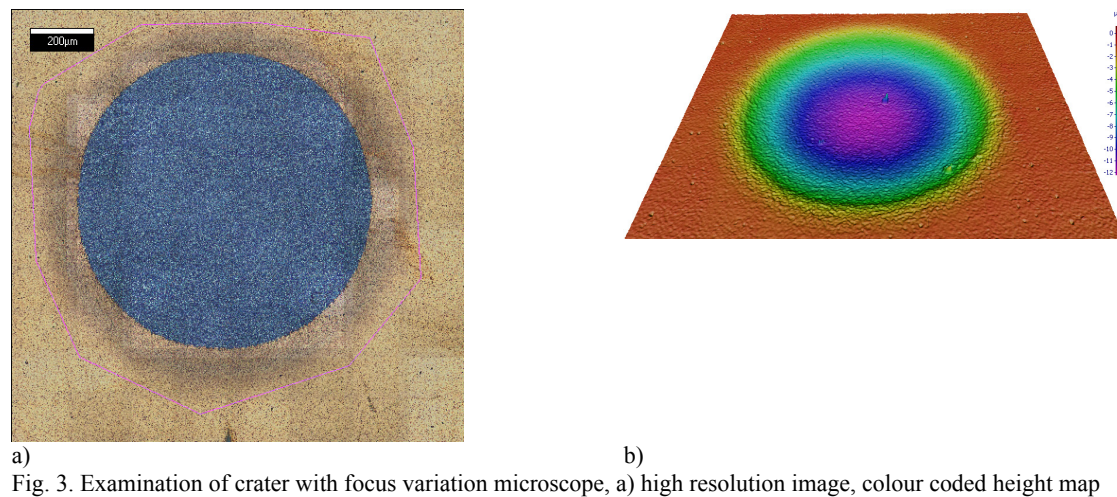
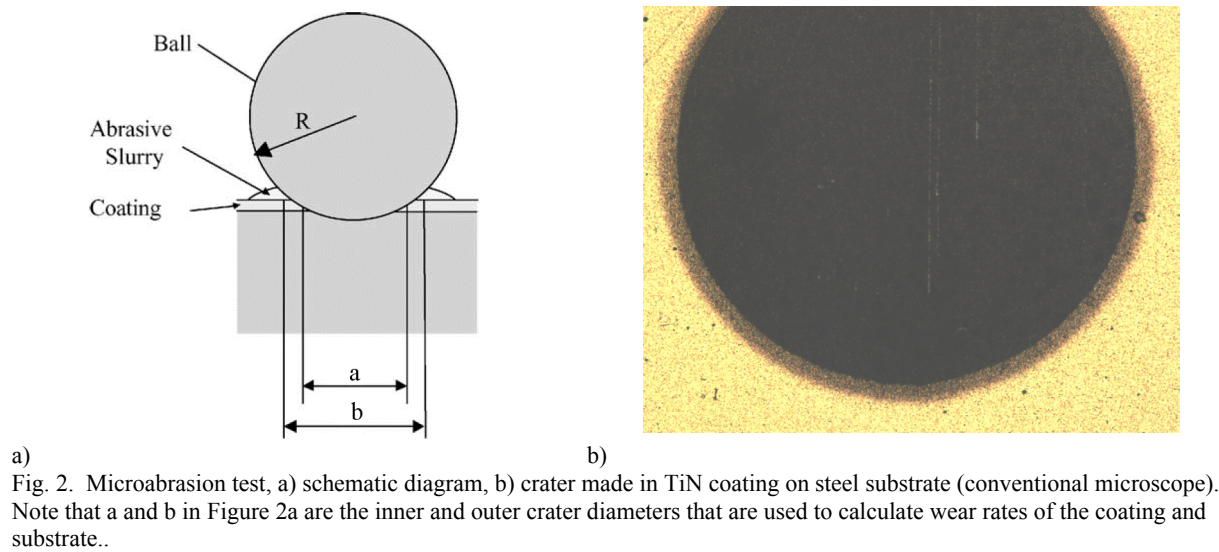
When the crater is examined in the focus variation microscope, the microscope settings can be adjusted so that both the steel in the substrate and the TiN coating are in good contrast. This is achieved by scanning the gain of the CCD camera for every pixel so that the information with the best contrast can be obtained for every point in the image.

Although this might seem to give a less visually appealing micrograph, the ability to see detail on both surfaces is very valuable (compare Figures 2b and 3a; note that the crater in Figure 2b is very much larger than the one in Figure 3a). Thus some faint scratching is visible on the substrate in Figure 3a that would not be easy to see with conventional microscopy.

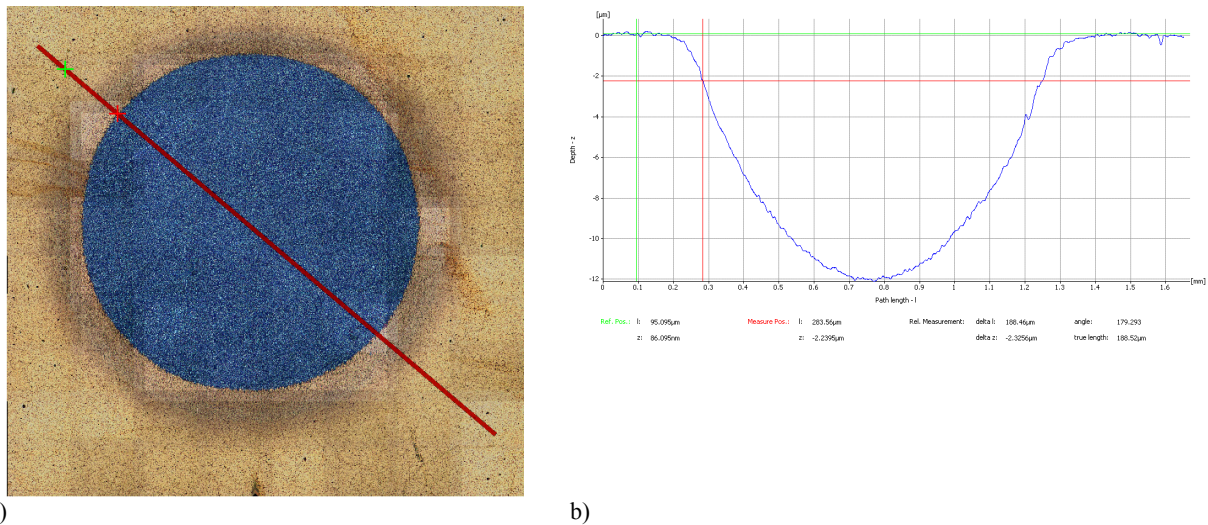
Figure 3b shows a 3D view of the crater, with the height information colour coded for height. A 3D view of the surface can also be formed where every pixel in the height map is overlaid with the colour and intensity of the same point in the image. This yields a 3D simulacra of the surface under examination that can be rotated in any plane interactively. The real-time manipulation of this simulacra is an extremely valuable facility, as it enables the user to gain a real feel for the 3D shape of features on the surface, and their relationship to features in the image.

The combination of the 3D height information and the images can be explored in many other ways. The extraction of profiles from the 3D height data can be used to clarify the position of the crater edge. This is important because the test relies on the accurate assessment of the position of the crater edge [8]. In a similar way, this type of analysis gives an accurate measure of coating thickness (Figures 4a and 4b).

The volume of both the volume of the crater in the substrate and the total crater volume can both be calculated accurately. These results can be used in the calculation of wear rates for both the coating and the substrate materials [8].



The extraction of profiles also provides useful information on the formation and shape of craters. When the coating was much harder than the substrate, it was found that there was less wear to the coating than in the substrate so that the portion of the crater in the coating was proud of the crater in the substrate. For a soft coating on a hard substrate the opposite was true with the portion of the crater in the coating depressed relative to the remains of the crater. For a coating with similar hardness to the substrate depression or elevation of the crater in the coating did not occur, but there was some rounding at the edge of the crater.



a) b)
Fig. 4. Detection of crater edges, a) image showing edges of crater (marked by red and green crosses) detected in b) profile from image enabling unambiguous thickness measurement to be made.

4 Discussion

The results presented in this paper show that modern optical microscopy systems based on focus variation or confocal principles can be used very effectively to measure wear. A major advantage of these systems is that height information is acquired simultaneously with a high resolution optical image. The importance of this cannot be overemphasised, as the correlation of the height information with microstructural information provides an important route towards developing a better understanding of the mechanisms of wear.

A key factor that has made this type of instrument effective has been the development in computing power and ease of use. Confocal optical microscopy has been in existence for many years [9]. The factor that has transformed these instruments is the availability of fast, powerful PCs that have functionality that was not available even a few years ago. Together with good software design, this has enabled the type of measurements that have been presented in this paper.

This is particularly important for features where digital image correlation is used to match datasets that are acquired before and after wear of a sample or component to determine wear volumes directly. This is also important to achieve good accuracy in the stitching together of overlapping datasets, because high resolution height information can only be achieved when a high magnification objective lens is used, so that large fields of view are only achievable if a relatively large number of individual areas are analysed and joined together.

Although this paper shows that these instruments can be used to aid in the interpretation of the results of wear tests, some care is needed with regard to some aspects of measurement using these instruments. Recent work has shown that artefacts can be introduced in measurements with optical based surface form measurement instruments [10,11]. This puts some uncertainty into the use of these instruments, particularly for quantitative analysis. These errors arise because of interference between light reflected at different angles from different parts of the surface.

It should be noted, however, that these errors are particularly prevalent for smooth surfaces and for low variation in heights. Most of the surfaces that are generated in wear are too rough to give the specular reflections that generate these errors.

Further work is required to pin down the uncertainties that these errors give in the application of these optical measurement techniques to the evaluation of wear damage.

5 Conclusions

This paper has shown that modern optical microscopy now has the capability not only to provide very high resolution optical micrographs that can provide information on the structure of a material or surface features, but can also be used to provide quantitative height information.

These new capabilities are illustrated by application to micro-scale abrasion where much more detail is provided on the form of craters that are produced during the test, together with a much more accurate evaluation of wear volume.

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