

Measurement Note

DEPC (MN) 045

Measurement of Wear With a Chromatic Aberration Probe

Summary

This measurement describes experiments to explore the use of a chromatic aberration probe for real time in-situ measurement of the wear to one component of a wear couple in sliding wear experiments.

The chromatic aberration probe was shown to provide useful measurements of wear to the disc in the pin-on-disc experiments. When coupled to a careful examination of the wear surfaces with 3D optical microscopy, a better understanding of the processes of wear that occurred was obtained.

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Introduction

Pin on disc testing of a wear couple commonly measures the movement of the arm holding the pin to determine the removal of material during the test. Thus movement of the arm towards the disc can indicate removal of material from either or both of the pin or disc. The wear of only one sample is therefore impossible to monitor as the test proceeds so that the proportion of wear that has taken place to just one sample can only be evaluated post test by techniques such as mass changes, dimensional measurements, or by profilometry. If reactions occur at the interface or debris builds up, this can cause difficulties with the interpretation of these measurements.

In this work measurement of wear from the disc alone has been attempted using a chromatic aberration probe fixed to the system frame. The chromatic aberration probe measures displacement of a surface by focussing polychromatic white light on to the surface. By using the chromatic aberration of the lens system to disperse the continuous range of wavelengths, only one particular wavelength will be exactly in focus at the surface and a detector within the lens system determines this wavelength when reflected back into the probe. From knowledge of this wavelength the probe-surface separation is determined.

By measuring the wear of the disc in this way it is also possible to deconvolute some of the combined information available from the standard arm displacement sensor in combination with examination of the wear surfaces after the test.

Experimental

The wear couple examined in these tests comprised low carbon steel discs of 145 mm diameter by 8 mm thick as a bearing surface to 6 mm diameter alumina (99.99 %) pins with a 5 mm radius end in contact with the steel. A load of 10 N was

applied between the pin and disc. The wear track diameter was adjusted to 90 mm and the disc rotated to give a relative speed of 0.1 m s^{-1} at this diameter.

Test System

The test system that was used is shown schematically in Figure 1. The disc is driven through a toothed belt by a variable frequency drive. The system is fitted with an LVDT to measure conventionally the displacement of the pin as a result of the combined wear of pin and disc by sensing the movement of the loading arm during a test. The disc table was adjusted to give a runout of $<100 \text{ }\mu\text{m}$ at the 90 mm wear track diameter

To measure wear of the steel alone, a chromatic aberration probe was fixed by an extension arm to the load cell support arm (D in Figure 1) and its height and lateral position adjusted to focus the probe spot on the centre of the wear track. The sampling rate and spectral averaging functions were adjusted to enable a good output from both the highly reflective plate before wear and the rough wear track. The probe output was set to give a 0 to 10 V output for a $500 \text{ }\mu\text{m}$ deflection and this output calibrated with a drum micrometer.

Friction force was measured by a load cell clamped to the friction load arm C; this load arm is connected through the loading arm bearings to the main loading arm so that a frictional force on the pin pushes the load cell against the load cell support D. (Rigid connection of the load cell to the load cell support was not employed because thermal expansion of the test system was found to cause drift and thus a lower apparent friction).

The data from the tests was captured using a National Instruments DAQ card and a Labview program.

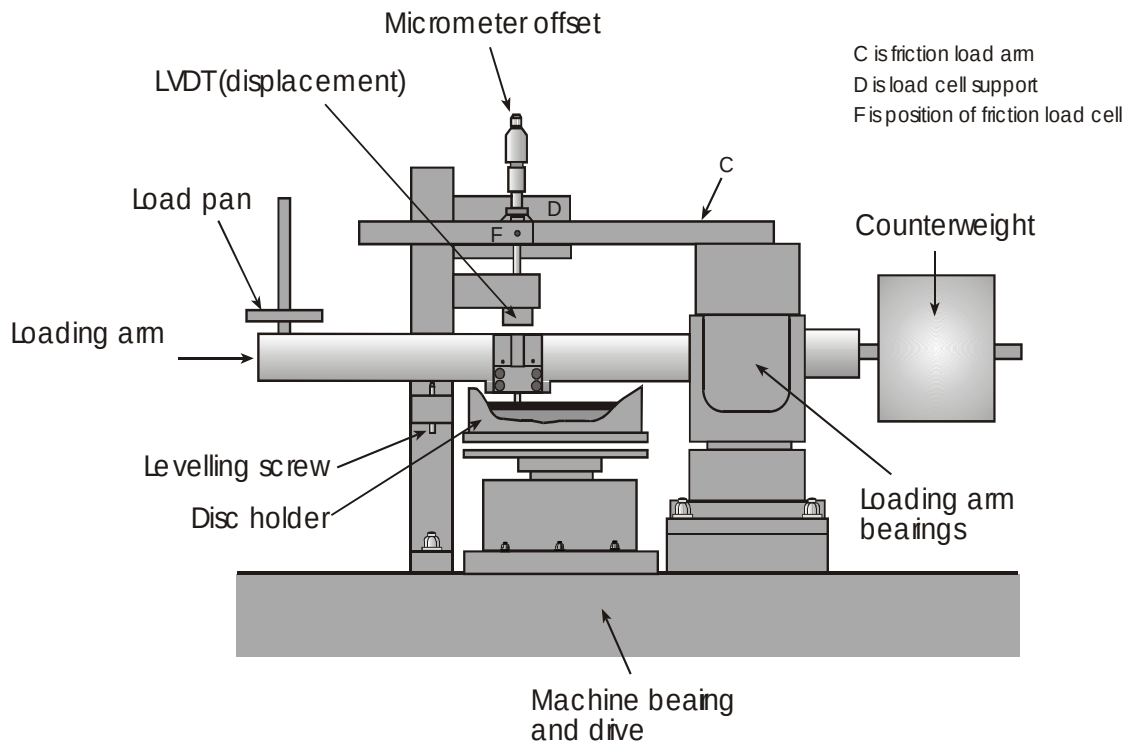


Figure 1. Schematic diagram of pin-on-disc wear testing system.

An initial run was carried out to establish the probe position and settings and then three further runs were made with only minor positional adjustment during the first revolution of the disc. Tests were carried out for 3600 seconds at the load of 10 N at a speed of 0.1 m s^{-1} . Pin and disc were weighed before and after the test and also examined before and after with an Alicona Infinite Focus optical microscope to generate 3-d images of the wear surfaces.

Test measurement results

Figures 2a, 2b and 2c plot respectively for the tests 2, 3 and 4, both the measured friction coefficient and the output of the optical probe against time for the entire test duration of 3600 seconds. Figures 3a, 3b and 3c show both the optical probe data from figure 1 plotted alongside the arm displacement. Figure 4 combines all 3 sets of information for just the first 1000

seconds with the probe output converted to micrometres using the calibration determined from the NPL calibrated drum micrometer.

In general the three measured parameters behaved very consistently across all 3 recorded tests. Most significant changes occurred within the first 600 seconds for all 3 and the general trends can be summarised as:

- Friction peaks at between 0.73 and 0.83 within the first 400 seconds of the test, falling by approximately 30% within the next 200 seconds and then slowly rising over the remainder of the test.
- The optical probe shows a very brief period at the start of the test with no movement followed by a rapid increase indicating the development of a wear scar eroding into the plate. The increase

plateaus by 600 seconds and then changes by $<0.25\ \mu\text{m}$ for the remainder of the test.

- The arm displacement measures changes of similar magnitude to the optical probe, with the increasing displacement indicating overall a wearing away of material. After an initial large movement within the first 600 seconds there is a gradual very steady wear of the pin by about $3\ \mu\text{m}$ over the remainder of the test.

Looking at figures 3-4 in more detail, tests 2 and 4 are very similar; the optical probe indicates the rapid wear of a groove of about $2\ \mu\text{m}$ after an initial plateau, followed by a further gradual increase in groove depth of about $1.5\ \mu\text{m}$ completed by the time the friction has flattened out after 600 seconds. In the same timescale the arm displacement suggests a quick build up beneath the pin, lifting it by $7\text{--}8\ \mu\text{m}$ from the original surface, followed by a wearing away of this build up over 600 seconds and in the case of test 2 only, some additional wear of the pin of up to $8\ \mu\text{m}$.

Test 3 differs slightly from the other 2 tests in that the groove wear in the plate recorded by the optical probe takes longer to start and then occurs gradually, indicating a total groove depth of $5\ \mu\text{m}$ after 600 seconds. The pin/arm movement also shows no initial build up, but rapid wear of approximately $12\ \mu\text{m}$ with a small interruption between 300 and 400 seconds suggesting some build up before this is worn away again.

The initial plateau with no wear of the plate as seen by the optical probe is initially matched in all three tests by a period of low friction <0.3 , before the rapid rise to the peak of >0.7 , although the precise time at which both wear and friction curves rise rapidly do not coincide exactly.

It was noted during the tests that after a short interval of 30-60 seconds that pin/disc couple began to produce an audible “grating” noise which gradually increased in intensity over the subsequent 100-200 seconds before declining again to a lower pitch level.

Post wear test inspection of components

Figure 5a and 5c show Alicona IF images of the wear track from test 3 taken at points 180° apart, and figures 5b and d, vertical sections taken from these images. Maximum wear depths below the average surface level are approximately 6 and $8\ \mu\text{m}$ in localised off-centre grooves; if however the depth is taken as that of an average arc drawn from edge to edge of the track (total width $\approx 700\ \mu\text{m}$), the depth would be about $3\ \mu\text{m}$. Equivalent images of the wear track from test 4 are shown in figures 6a-d; Figure 6a and b show a groove of maximum depth $6\ \mu\text{m}$ but 6c and d just a general track of about $2.5\ \mu\text{m}$ depth similar to that of the average of 5a-c.

Figure 7a and b show 3d views of the tip of the pin from test 3 with a 90° degree rotation between the two views; figure 7c a 2d view of the same area and figure 7d a vertical section along the line drawn in figure 7c. Wear to the alumina pin surface is visible, particularly as the groove in figure 7a and the flattened grey area in figure 7b. The difference between the predicted tip radius and the actual flattened area suggests up to $10\ \mu\text{m}$ of removal from the tip. The diameter of this wear scar on the pin tip is approximately $700\ \mu\text{m}$, very similar to the width of the scar on the disc. Build up, on top of the alumina, of a rust coloured material is also clearly seen; this is predominant on one side of the pin, forming “cliffs” at right angles to the grooves in the alumina with a plateau flattened by contact with the steel disc in the same way as with the alumina.

Wear of the alumina pin itself from test 4, shown in Figure 8a-e is less obvious than

that of test 3 because of extensive build up of material from the wear test on the surface of the pin; figure 8c shows one region indicated by an arrow that may be a worn surface of alumina. A surprising feature of the images is the occurrence of two regions showing wear marks in directions approximately 60° to each other. The vertical section of figure 8f suggests wear of the alumina pin of about $15\text{ }\mu\text{m}$, almost exactly balanced by build up similar to that of the previous test.

Summary and Conclusions

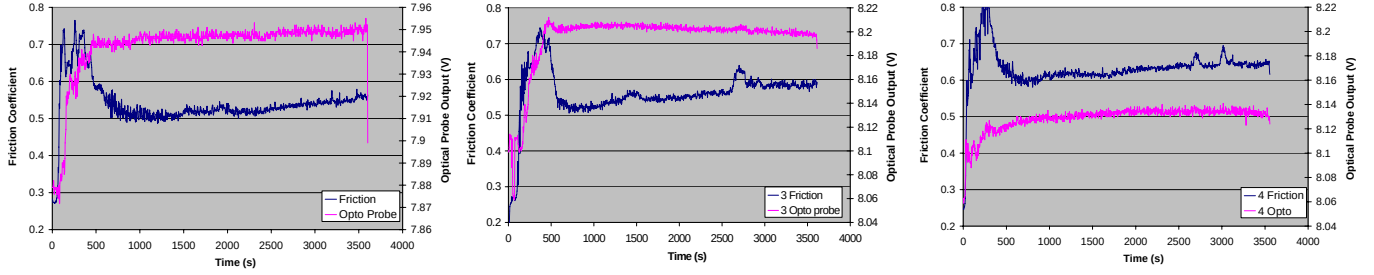
The use of the Chromatic aberration probe appears to give sensible measurements of the wear of the steel disc independent of the wear to the pin, with very similar magnitude depth changes being recorded by the probe as by the final wear track. A couple of issues could bear further investigation:

- i) shorter term tests to confirm that the changes in reflectivity in the early stage of the test do not influence the measurement and calibration of the chromatic aberration probe.
- ii) investigation of the spot size relative to the wear track size to better understand the effects of sampling and position on the measured results

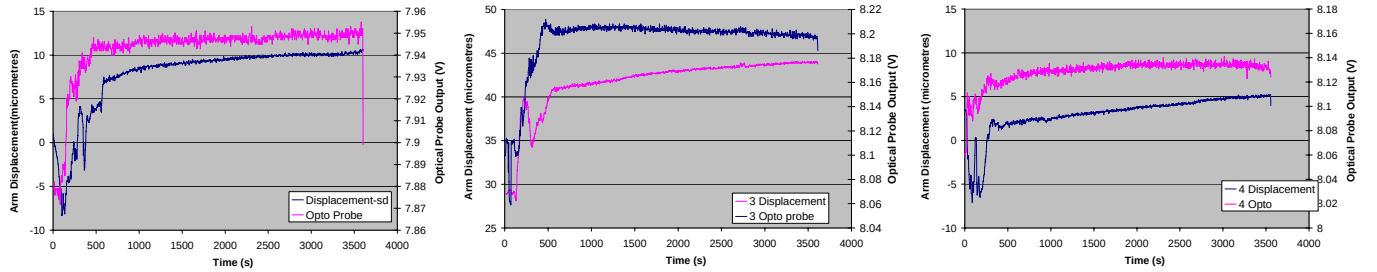
When the aberration probe results are combined with the mechanical displacement measurement and examination of the final worn surfaces with the Alicona microscope a clearer picture can be built up of the sequence of events during the tests. It is surmised that the initial wear of the disc under a high pressure from the radiused pin tip occurs in the first 60 seconds or less and that this generates debris of very fine iron particles which then oxidise, some forming rust coloured agglomerates. These particles of iron or rust build up between pin and disc, causing a rapid rise in friction as more particles adhere to the build up. This agglomeration between pin and disc is itself worn away rapidly and a debris-agglomerate-alumina pin composite surface makes contact with the steel disc. This composite surface wears away with a gradual reduction in friction. The transfer of wear from steel disc to alumina/debris pin may be as a result of work hardening of the steel. The increased contact area may also reduce the pressure and lead to the plateau in wear behaviour after approximately 600 seconds.

Acknowledgements

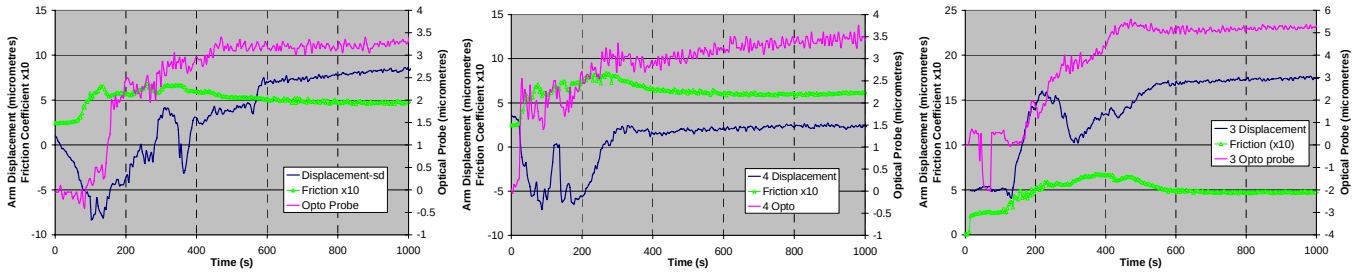
The authors would like to thank DTI for funding under the Materials Measurement Programme



a) b) c)
Figure 2, Friction coefficient and chromatic aberration probe output for a) test 2, b) test 3 and c) test 4



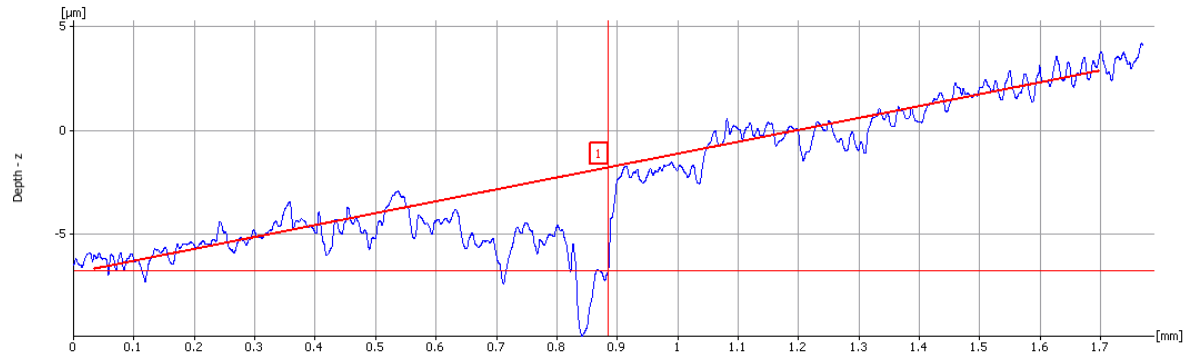
a) b) c)
Figure 3, Load Arm displacement and chromatic aberration probe output for a) test 2, b) test 3 and c) test 4



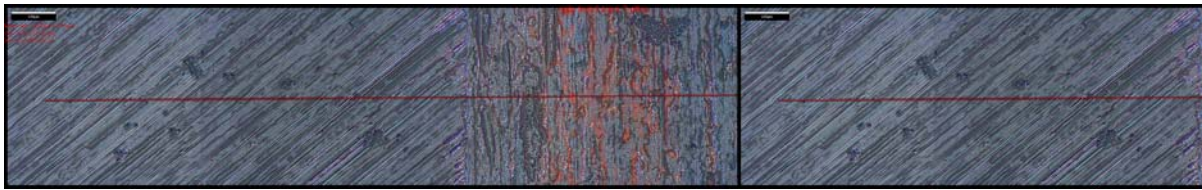
a) b) c)
Figure 4, Load arm displacement, friction coefficient and chromatic aberration probe output (converted to μm) for the first 1000 seconds for a) test 2, b) test 3 and c) test 4



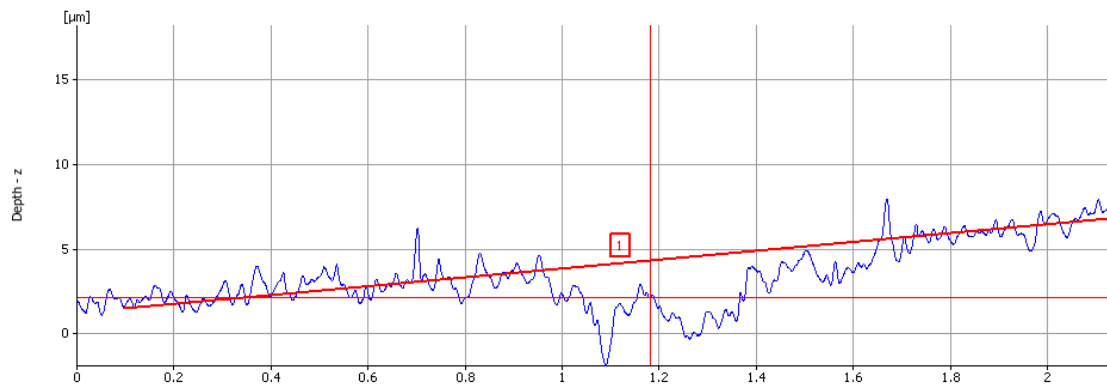
Figure 5a



b) cross section depth profile at position of red line in Figure 5a

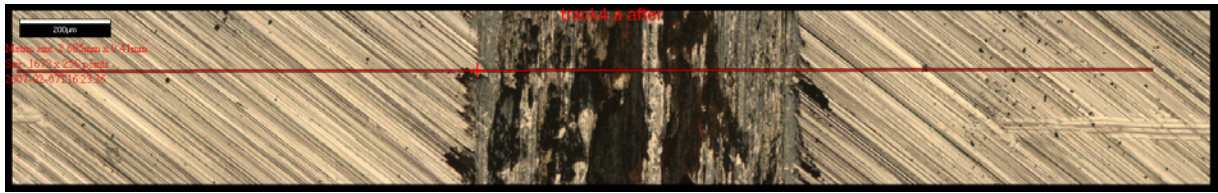


c)

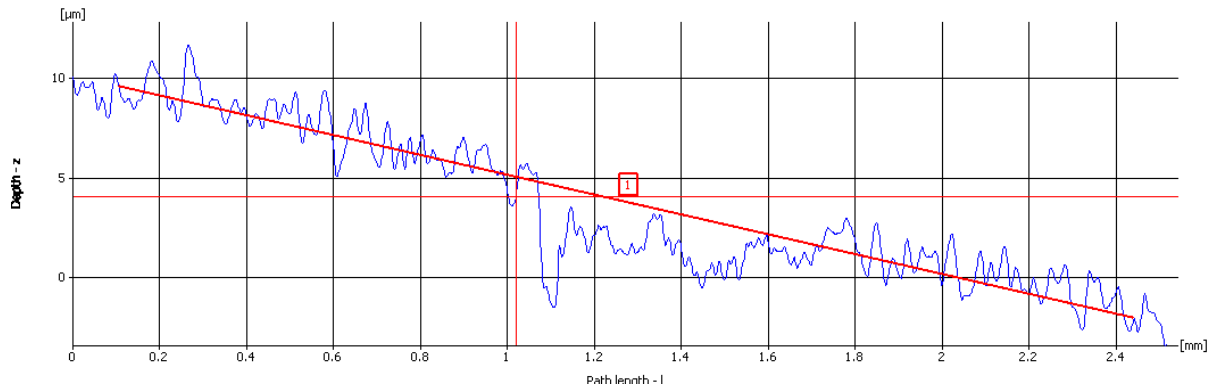


d)

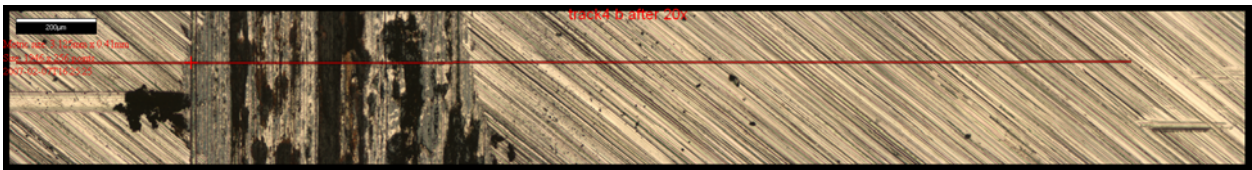
Figure 5, 3D optical microscope measurements of a) planar (2-d) view of wear track from test 3, b) cross section depth profile at position of red line in Figure 5a, c) planar (2-d) view of wear track from test 4 at point 180° apart from Figure 5a, d) cross section depth profile at position of red line in Figure 5c



a)



b)



c)

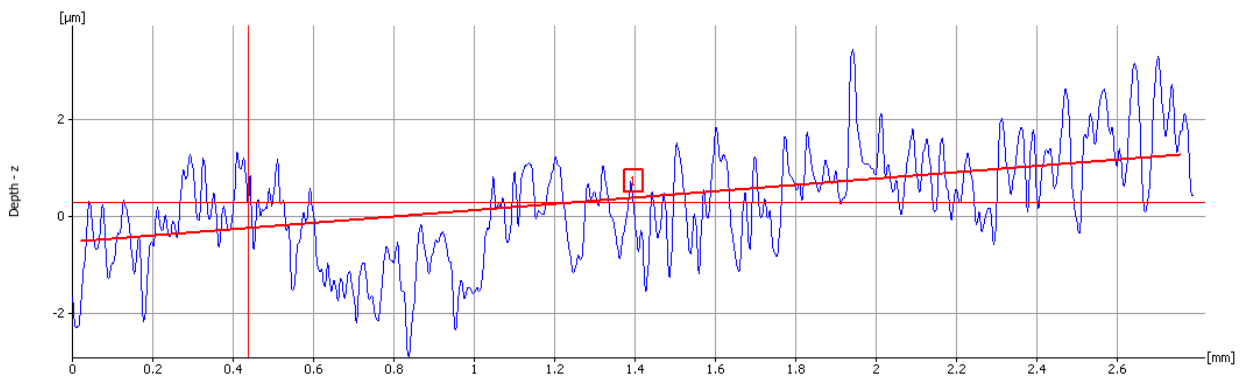
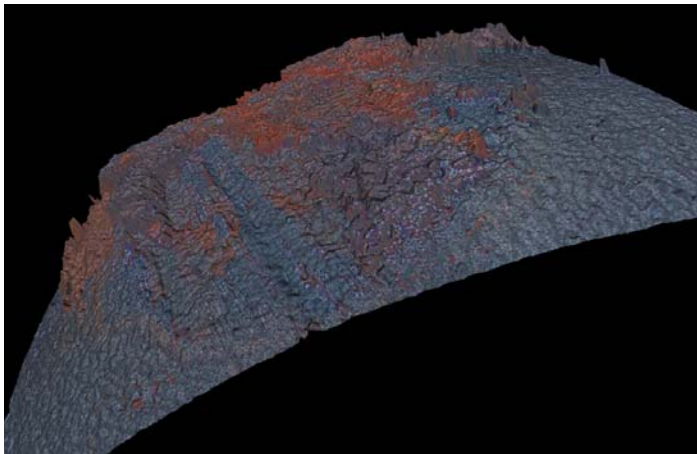
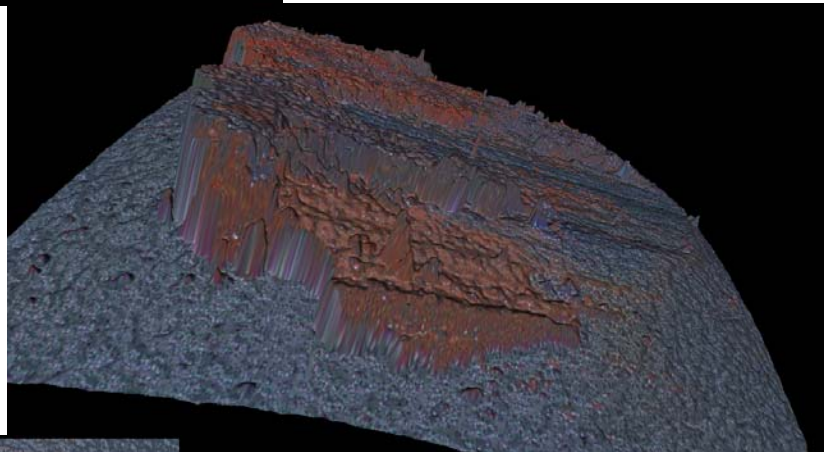


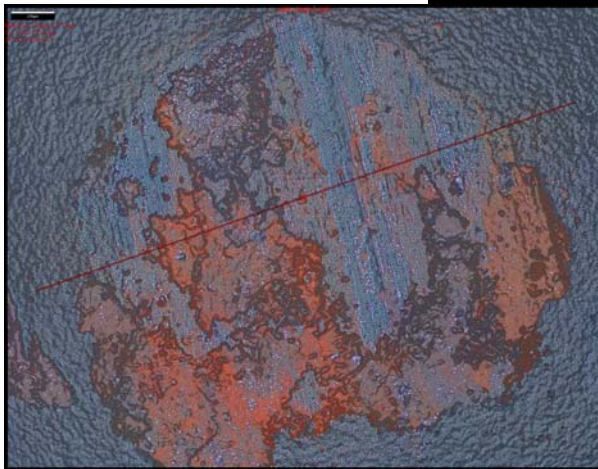
Figure 6, 3D optical microscope measurements of a) planar (2-d) view taken of wear track from test 4, b) cross section depth profile at position of red line in Figure 6a, c) planar (2-d) view taken of wear track from test 4 at point 180° apart from Figure 6a, d) cross section depth profile at position of red line in Figure 6c



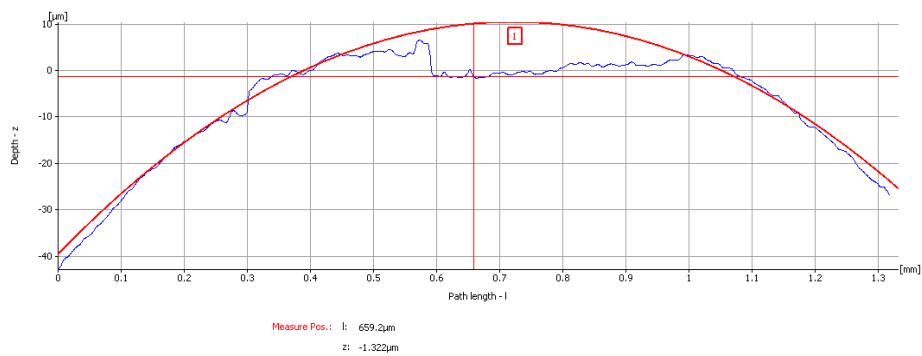
a)



b)

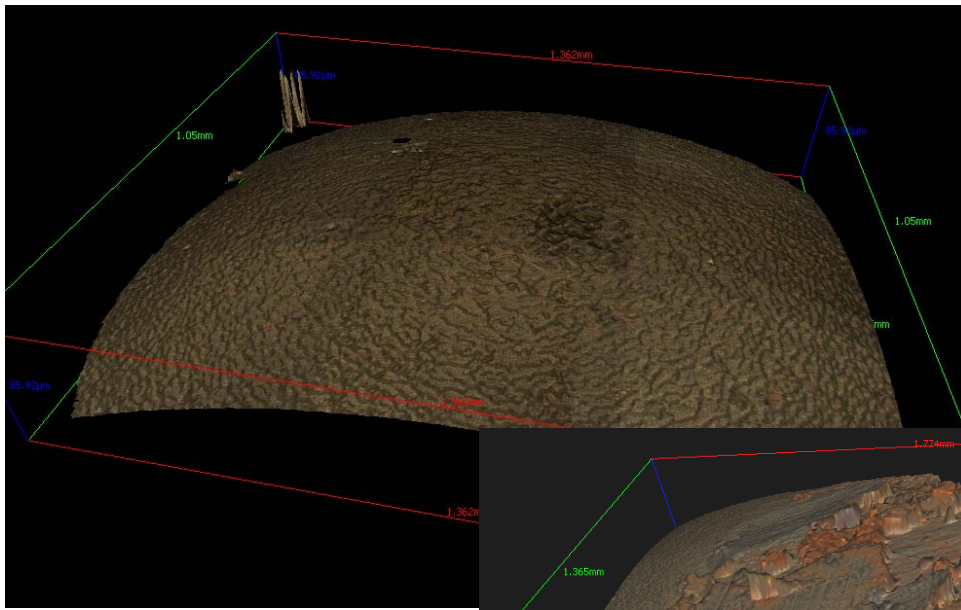


c)

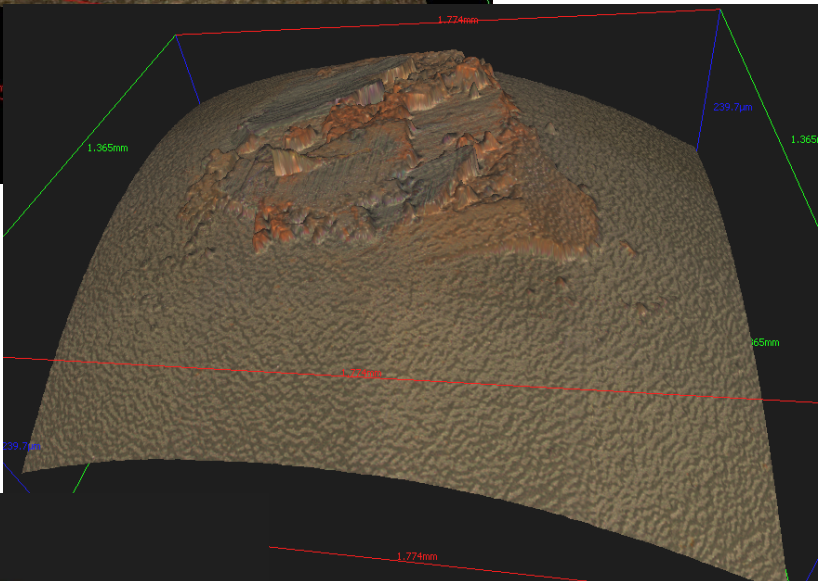


d)

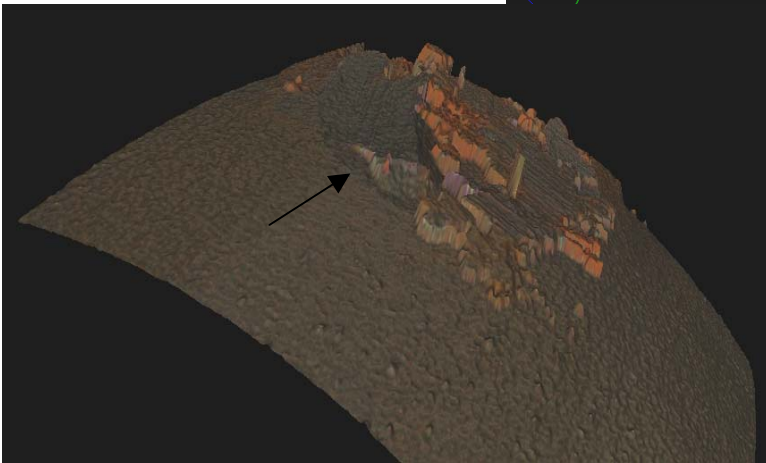
Figure 7, 3D optical measurements of end of pin from test 3, a) and b), 3D views of pin end, c) image, d) profile along red line in 7c.



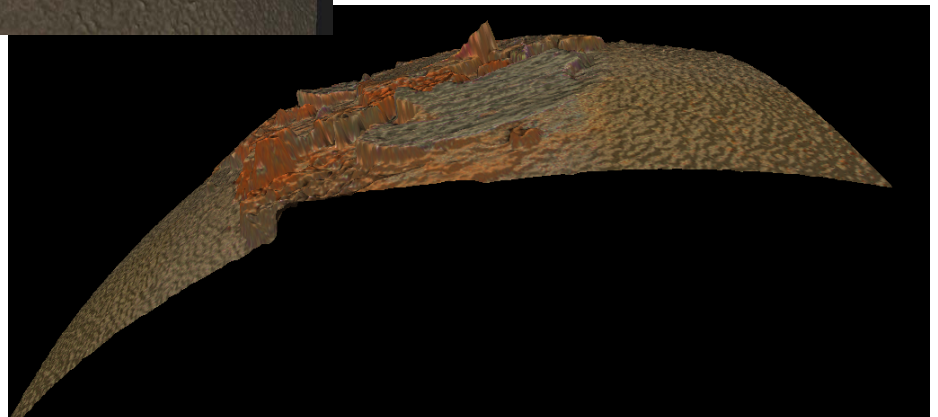
a)



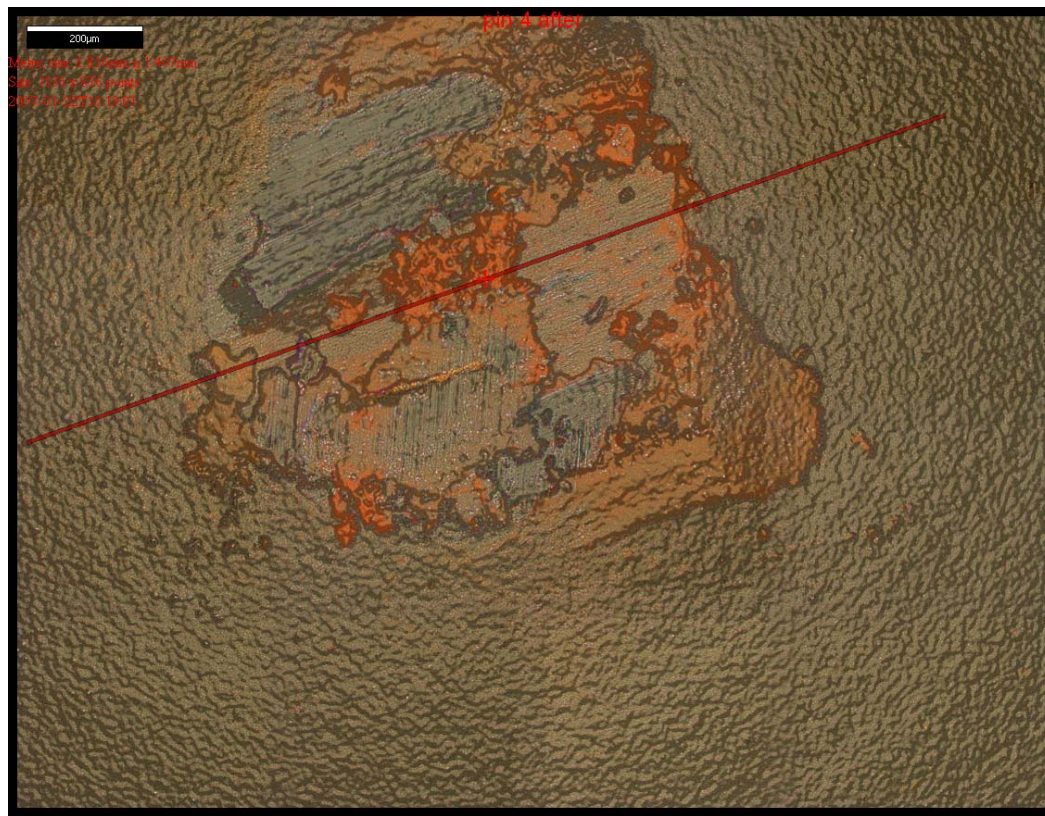
b)



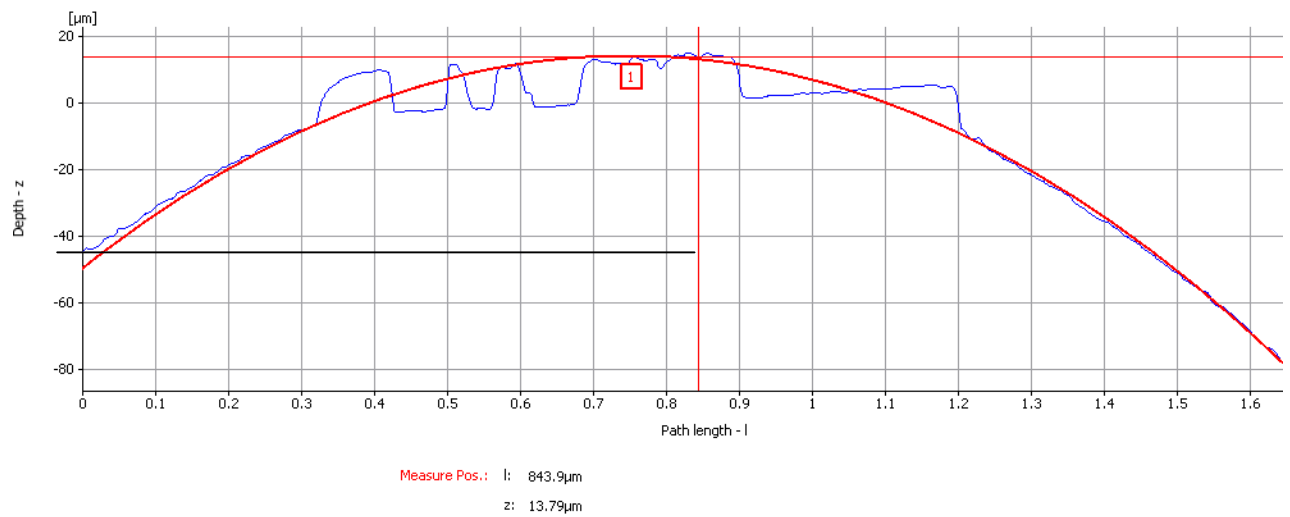
c)



d)



e)



f)

Figure 8, 3D optical measurements of end of pin from test 4, a) 3D view of unworn pin, b), c) and d) 3D views of pin end, e) image, f) profile along red line in 8e.