TRIBOLOGY AND CORROSION EVALUATION USING WHITE-LIGHT INTERFEROMETRY

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INTRODUCTION

Interference microscopes remain one of the most accurate, repeatable, and versatile metrology systems for precision surface measurements. Such systems successfully measure material in both research labs and production lines in the micro-optics, MEMS, data storage, medical device, and precision machining industries to sub-nanometer vertical resolution. Increasingly, however, these systems are finding uses outside of traditional surface-measurement applications, including film thickness determination, environmental responses of material, and determination of behavior under actuation.

Most recently, these systems are enabling users to examine behavior of materials over varying time-scales as they are used in cutting, grinding, or other high-stress environments. In particular, quantification of wear of surfaces with varying coatings and under different conditions is of increasing value as tolerances decrease and consistency in final products is more valuable. Also, response of materials to corrosive environments allows users to quantify the gains of varying surface treatments against the cost of those treatments. Such quantification requires novel hardware and software for the system to ensure results are fast, accurate, and relevant.

In this paper we explore three typical applications in tribology and corrosion. First, deterioration of the cutting surfaces on several multi-blade razors is explored, with quantification of key surface features, under different use conditions. Next, corrosion of several metal surfaces is analyzed. The surfaces are analyzed for rate of deterioration over time and to examine how initial surface conditions affect corrosion. Pitting, roughness changes, and other surface parameters are evaluated and their rates of change during the corrosion process are plotted. Finally, wear of multiple drill bits of different materials and coatings is quantified.

BACKGROUND

White-light optical interferometry has been one of the preferred methods of nondestructive, precision surface characterization for more than fifteen years. This non-contact, three-dimensional metrology provides vertical ranges of up to 10mm, vertical scan speeds of over 100 µm/sec and single fields of view from 60 µm to over 10mm makes this one of the fastest and most versatile techniques available. Lateral resolution is sub-µm and vertical resolution is sub-nm. Further, these instruments are available in configurations which support any environment from the research laboratory to the production floor.

For this paper measurements were performed using a Wyko NT9800 optical profiler. Vertical calibration of the instrument is via an internal HeNe reference laser which monitors the scan rather than against discrete step heights, giving the system enhanced accuracy over large ranges. Lateral calibration of the instrument is via a certified pitch standard used to calibrate each objective. Measurement times ranged from approximately 4 seconds to 20 seconds on the samples studied. All analyses were performed by the Veeco’s Vision software which controls the instrument. The paper is designed to illustrate key analyses and considerations used by industry when quantifying changes over time. In these studies, for each surface measurement typically twenty to forty different surface parameters were logged of the several thousand available in the software. Only a few of key results are presented in this abstract.

CUTTING SURFACE METROLOGY

Among the more common types of machined components examined in tribological studies are blades, other cutting surfaces and grinding components. Critical parameters include the roughness, width, height, and alignment variations within each surface and between them. All of these help characterize the quality
of the cutting surface and changes in these parameters with time can identify key failure points and areas for process improvement.

For this study several commercial multi-blade manual razors were examined in their new state and again over time under two conditions: in a true use case (parts used for shaving), and in a more controlled setting where they were used to shave a fibrous material over a set distance a set number of times. Low magnification measurements were first taken to examine the relative geometry between the blades in a single field of view.

Automatic region finding analysis was used to examine the relative geometries of the surface designed to contact the skin, with the right of the two blade surfaces used as the reference. In Figure 1, the left contact surface is nearly 520µm higher and tilted at an angle of 30mrad with respect to the other. Relative angles and heights between the surfaces did varied by up to 50mdeg and 200 microns.

High magnification measurements were then taken to characterize both the skin-contacting surface and the actual cutting surface at high resolutions. Figure 2 below shows the surface new and after 100 and 200 cycles of use. Surface roughness of the contacting surface increases by nearly a factor of three; the process is also nonlinear, with dramatic degradation between 100 and 200 cycles. For this study no lubrication was used with the blade. There was no statistically significant surface degradation for surfaces at different angles or vertical heights with respect to one another on the four separate blades examined.

Figure 1: Roughness, height, and relative tilt information of two skin-contacting surfaces of a razor blade.

Figure 2: Skin-contacting surface measured new (left) after 100 wear cycles (center) and after 200 wear cycles (right).

The cutting surfaces of the blades were also measured throughout the study. Key measures were surface roughness, the width of the cutting surface and its variation. Significant roll-off of the worn cutting blade, and increase in the variation of the width of the cutting surface was observed.

CORROSION MEASUREMENTS

Yet another area where optical profilers are commonly used to study dynamic processes involves the study of corrosion. Often different materials and coatings are studied to determine if they are more or less resistant to degradation in a given environment. Optical profilers have been used to study corrosion processes associated with medical implants, wires and other electronics, metals, and glass. In some cases surface wear is studied in conjunction with corrosion to determine how different frictive processes affect the tendency of the surface to degrade. The effect of surface finish parameters on the durability of a given material is also of high interest. It is this aspect of corrosion that will be studied below. Key parameters involving corrosion when examining a single surface include surface roughness, number of pits, their volumes, and the spatial distribution of surface features.

In this study a microfinish comparator strip from Gar Electroforming was corroded using a mildly acidic solution. The comparator strip is nickel, but had different processes used to create surface finish and different target roughnesses (lapped, ground, and milled surfaces examined here) in different regions. The goal was to examine the corrosion process for each region,
to see if there were preferential areas for the start of corrosion and how surface finish affected the overall result.

Figure 5 below shows a sub-region of a high magnification measurement of the 8G surface throughout the corrosion process. Even visually the changes in surface finish are notable. Figure 6 plots the power spectral density (PSD) of this surface against time in the corrosive environment, showing an increase in higher spatial frequency content.

![Figure 5: 50X subregions of the 8G region of the comparator strip uncorroded (left) and after 7, 14, and 21 hours in the corrosive liquid.](image)

![Figure 6: Power spectral density plot for the surfaces of Figure 5.](image)

Another highly useful tool for examining surface corrosion is to directly compare the differences in surfaces across time. Through use of fiducial alignment capability in the software one is able to subtract two datasets even with translation or rotation between them. Figure 7 below shows the subtraction of the uncorroded 8G surface from the same surface after corrosion for 7 and 14 hours. One can readily see the spread and deepening of the corrosion on the left portion of the image, while the rest of the image remains fairly random in its appearance.

![Figure 7: 8G seven hour corroded (left) and fourteen hour corroded (right) surface subtracted from the original uncorroded surface.](image)

**DRILL BIT METROLOGY**

The last application examined here is tribology associated with various drill bits. Such measurements are becoming increasingly common as process control moves earlier into the machining cycle. Rather than continuous testing of final machined parts, many manufacturers are testing the tooling used for part creation. This can save significant costs as often the tooling can be replaced before many, if any, bad parts are produced.

Four ¼” drill bits were purchased and used to drill holes in a 10mm anodized aluminum plate. One bit was solid high speed stainless steel, one was solid SiC, one was TiN coated steel and the last was TiCN coated steel. After some initial studies to determine at what point noticeable wear could be observed, 10 holes each were drilled in the material. Measurements were performed on the head of the drill bit, along the inside of the bit, and along the leading edge of the bit, as illustrated by the boxes in Figure 8 below. The bits were fixtured such that measurements were performed on the same areas of the bit each time. Ultimately 30 holes drilled with each bit was shown to achieve significant changes in topology, which was noticeable as well in the ability of the bits to drill into the aluminum surface.

![Figure 8: Drill bit showing boxes around the areas for measurement: head (left), inside surface (center) and leading edge (right).](image)

As the drilling process progresses large peaks and valleys become evident as seen in Figure 9. Results from five separate locations were used to create a stable set of data for analysis; results
varied too much across the surface to employ a single location.

**Figure 9:** High speed steel inside surface measured for 0, 10, 20, and 30 times drilled and reflecting the changes in surface structure.

The S Parameter functions and bearing ratio proved most capable of quantifying the surface feature variations. These variations are obvious to the eye but often do not reflect themselves in many common analyses, particularly in areas such as average surface roughness and peak-to-valley calculations. The S parameter analyses are a set of analyses developed to characterize three dimensional surfaces. In Figure 10 below the Str parameter, which is the length of fastest decay of the autocorrelation function of a surface divided by the length of slowest decay, shows the dramatic increase in randomness of the surface as drilling progresses. The other parameter plotted is the height between the 10% and 90% points of the bearing ratio curve, showing that the surface is greatly varying from uniform as the drilling progresses.

**Figure 11:** Str and Bearing ratio of drill bit surface.

**CONCLUSIONS**

White light optical profilers provide highly accurate, non-destructive metrology for precision machined surfaces. Such surface characterizations are increasingly being performed over time and under a variety of stress conditions on the sample being measured. The ability to both rapidly measure such surface and analyze them for changes with time across a large number of potential metrics enables timely and accurate feedback into the processes being examined. Increasingly metrology is moving away from the produced parts and into the tooling which makes them. Metrology needs for tribology and corrosion will continue to drive different mechanical fixturing capability, software analyses, and the ability to measure components in situ in interference microscopy so that it can remain the most versatile instrumentation for such measurements.

**REFERENCES**


