CSM Instruments
Advanced Mechanical Surface Testing

APPLICATIONS BULLETIN

Applications of the ConScan Surface Profilometer

//// Introduction

In the study of the surface mechanical properties of any material, the topography can be of significant importance in understanding the behavior of the material. Therefore it is a crucial step to be able to accurately characterize the topography of the surface prior to mechanical analysis, as well as the deformation, degradation and changes induced by the analysis. In this vein, the use of a raster scanning, confocal white light profilometer to build a three dimensional representation of the surface topography (CSM Instruments ConScan) is an ideal tool to characterize the test surface on a variety of sample types.

The concept behind confocal profilometry involves the use of the chromatic aberration (CA) principle. By directing a white light source through a filtering optical component towards a sample surface it is possible to use the chromatic aberration to separate the light with a dispersive lens into its component wavelengths, each of which corresponds to a different z-coordinate in the optical axis. Therefore the visible light spectrum is now encoded with z-coordinate data as a function of varying focal distance from the end of the lens.

As the focus point of each wavelength is represented at a different distance from the lens, the returning light waves will be different according to the height characteristics of a specific region of the sample. Therefore the returning spectrum at any given point can be regarded as the spectrophotometric signature of z-height, where strong spectral response is indicative of a defined distance away from the lens at a given focal point. By raster scanning the sample underneath a stationary lens it is possible to define a scan area which is only limited by the size and accuracy of the automated tables and the 'spot' size of the focal point. In practice, this allows for the creation of an overall large image (cm x cm) with single micron (µm) lateral resolution and nanometer (nm) scale vertical resolution (Fig.1).

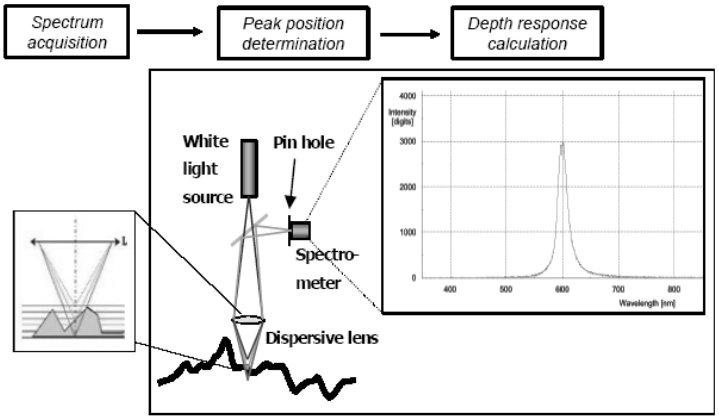


Fig. 1 - A white light source is dispersed into the chromatic spectrum with each color at a different focal distance away from the lens.

The techniques described here will effectively demonstrate the use of a ConScan white light optical profilometer to characterize the surface morphology of several different types of sample materials.

//// Plastic Deformation Analysis of Polymer panels using the Conscan

Plastic deformation of a surface can be defined as the permanent scarring, marring or residual indentation which remains after the interaction between a loaded indenter and a material. Elastic recovery is defined as the difference between the deformation of the sample under load and the permanent plastic deformation once this load has been removed.

In scratch testing, three passes are made over the same surface in order to accurately record the penetration and residual depth of the scratch. The first pass, called the prescan, records the profile of the sample. The second pass is a progressively increasing load during which the penetration depth (Pd) of the scratch is recorded; this is called the loading scan. The third pass records the residual depth (Rd) of the resultant scratch; this is called the post scan. The prescan and the postscan are done with a very low contact force and can be viewed as profilometry. The Rd can be defined as the plastic deformation of the sample surface and the elastic recovery can be determined by measuring the difference between the Pd and the Rd (Fig.2). Typically when making measurements on hard samples such as metals or ceramics, the aforementioned method of analysis is sufficient to produce accurate deformation and recovery data. However, when the desired samples are soft, such as the scratch test analysis of polymers or gels, the act of profiling the surface for residual depth measurements with a nominal load induces a measurable distortion of the surface which can significantly affect the Rd results.

One application of the ConScan is to analyze the sample surface after performing a scratch test to determine the true plastic deformation and elastic recovery of the sample. In this example, a flat polyurethane panel was scratch tested with a CSM Instruments Micro Scratch Tester (MST) by progressively increasing the load from 0 to 1000 mN over 3 mm with a 200 µm radius Rockwell C diamond indenter. As is standard practice using the MST, a prescan, a progressive scratch test and post scan were performed. The scanning load of this experiment was 30 mN. An image of this same scratch was then created using the ConScan. As can be seen in Fig. 3, the ConScan image is the same size and dimension as the panorama photo of the scratch taken at 200X magnification.

In this particular experiment, a critical load was defined at a force of 854 mN to denote the visual change in the scratch where tearing began to occur. It is at this critical point (Lc1), denoted by a vertical line in all figures of this section, that depth measurements will be compared for this experiment.

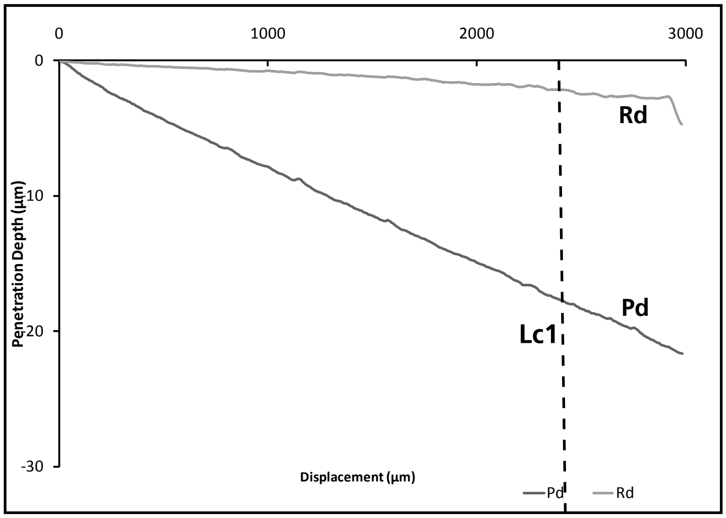
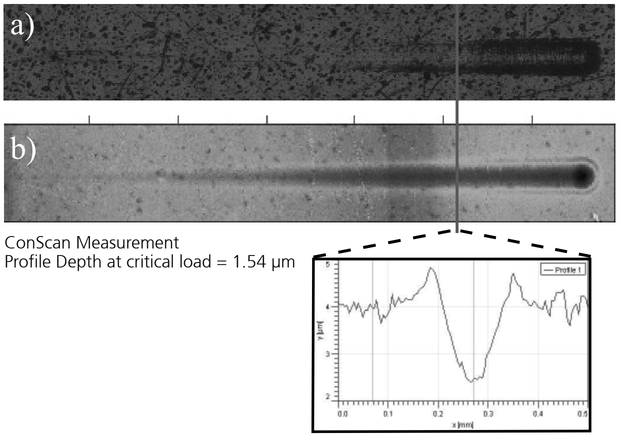


Fig. 2 - The penetration depth, Pd (Blue), and residual depth, Rd (Green), measurements on a polyurethane test panel as tested by a CSM Instruments MST. Please note the Pd and Rd at the vertical line denoting the Lc of this sample are ~ 19 and 3 µm respectively.

MST Measurement
Residual Depth at critical load = 2.43 µm



ConScan Measurement
Profile Depth at critical load = 1.54 µm

Fig. 3 - Comparison of a panorama photo of the scratch test (a) to a 2D false color representation of the scratch produced by the ConScan (b) with a profile extracted at the critical load for depth comparison.

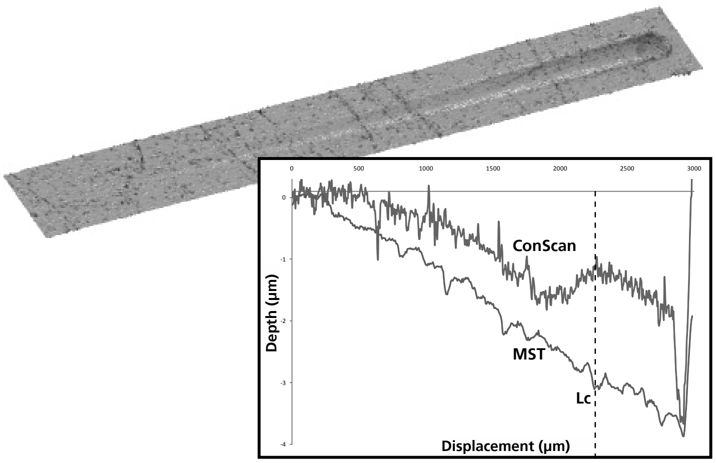


Fig. 4 - Comparison of the measured residual depth obtained by the post scan of the scratch test (Red) to the true residual depth (Blue) of the scratch as measured by the ConScan.

As can be seen in Figs. 3 and 4 there is a significant difference in the measured plastic deformation of a scratch test depending upon whether the depth is measured via the MST Rd or a ConScan profile. The MST-recorded Pd of the sample at Lc1 is 18.70 µm. The MST Rd measurement at Lc1 is 2.43 µm whereas the ConScan measured depth of the plastic deformation at Lc1 of the scratch is 1.54 µm. This means there is a 0.89 µm increase in the depth of the scratch which is caused by the 30 mN scanning load used during the residual depth measurement. This also means that there is a 0.89 µm difference in the measured elastic recovery of the polymer sample. This is equivalent to nearly a 6% error in the measurement of elastic recovery, 16.27 µm in the case of the post scan MST measured depth and 17.16 µm as measured by the ConScan.

As stated above, such discrepancies in the deformation measurement are a function of the measurement method. Contact profilometry (MST Rd measurement) will deform the surface being analyzed by a function of the contact load whereas the ConScan passive measurement will more accurately reflect the plastic deformation induced during the test.

//// Using ConScan to measure wear track properties after Tribometer analysis

The ConScan can be used to make high quality surface topography images of tribometer wear tracks.

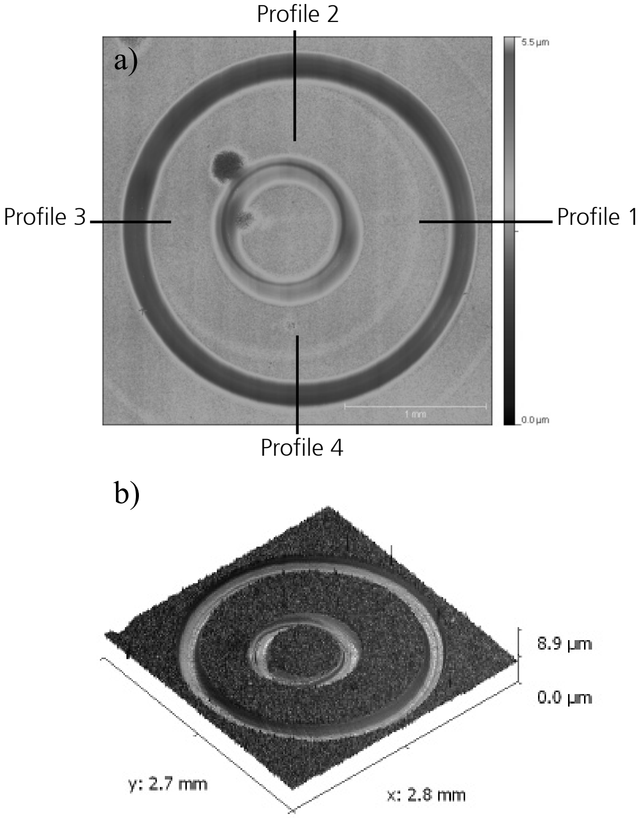


Fig. 5 - 2D representation (a) of the topography of two tribometer wear tracks in a TiN coated steel. A 3D representation of the same wear tracks is shown in (b).

A CSM Instruments Pin-on-Disk Tribometer was used to create the wear tracks on the sample. The outer wear track was created using a 7.0 N normal load rotated for 20,000 laps at a linear speed of 7 cm/s. The outer track has a diameter of 2.8 mm. The inner wear track was also created using a 7.0 N normal load rotated for 20,000 laps, however the linear speed was reduced to 3.5 cm/s. The inner wear track has a diameter of 1.5 mm. Both wear tracks were made using a 6 mm diameter alumina (Al_2O_3) spherical static contact partner.

As seen in Fig. 6, profiles were drawn across the larger diameter wear track to compare the depth as a function of orientation around the circle. It was relevant to check the wear rates at various locations as there are statistically significant wear rate differences depending on which location was chosen around the circumference of the wear track. This was confirmed by the slightly different profile shapes found at the various different locations around the circle. This was interesting to note as typical wear track analysis may be done using a single profile extrapolating the volume of material for the entire wear track. With the use of 3D topography it is possible to extract a more accurate representation of the true wear track volume by taking profiles at multiple locations.

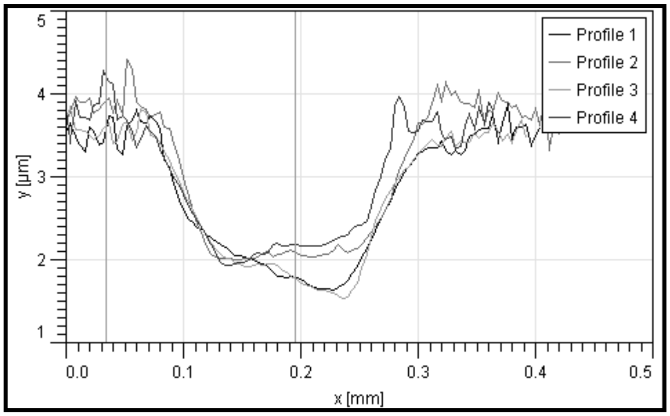


Fig. 6 - Curves of the 4 profiles taken across the 3 mm (outer) wear track superimposed.

Table 1 - Properties of the 4 profiles taken across the 3 mm (outer) wear track shown in Fig. 5.

	Depth of Track (µm)	Area of Wear Track (µm²)	Wear Rate (µm³/N/m)
1	1.80	298.00	2128
2	1.84	309.62	2211
3	1.85	312.90	2235
4	2.03	366.24	2616
Average:	***1.88***	***321.69***	***2298***

//// Measuring the surface roughness of a polished concrete sample

Using the ConScan it is also possible to measure and map the surface roughness of any material. In this example, images were made of the surface topography of two polished concrete samples, A and B, and from these images the surface roughness was calculated. Such analysis can be important in order to know the approximate roughness of the sample surface for subsequent indentation measurements. If the surface of the sample is excessively rough, the true contact area of the indenter for a given depth will not match the modeled contact area required for the instrumented indentation to report accurate results (as addressed in CSM Instruments Applications Bulletin 23, March 2007 – The influence of surface roughness on Instrumented Indentation Testing).

Table 2 - This table illustrates the difference in surface roughness between concrete samples A and B.

	Sample A	Sample B
Ra (µm)	1.48	3.10
Rms (µm)	1.85	6.20
Projected Surface Area (mm²)	9.03	9.03
Measured Surface Area (mm²)	9.06	9.38

As can be seen in Fig.8, sample A had already been analyzed using microhardness testing. There were four indentation measurements made in total, two with a 5 N maximum load and two with a 1.5 N maximum load. The average hardness of the 5 N indents was 380 ±13 MPa whereas the average hardness of the 1.5 N indents was 282 ±19 MPa. Comparing the location of the indents to the approximate surface roughness it is possible to see that the large indents (5 N in this case) were less influenced by the surface roughness than the smaller (1.5 N) indents. The higher value of the standard deviation for the 1.5 N load was a direct result of the increase in surface roughness compared to the relative size of the indent. This was confirmed when comparing the 3D surface rendering of the roughness of sample A to the relative size of the indentation imprints. There were no indents made within the surface of sample B.

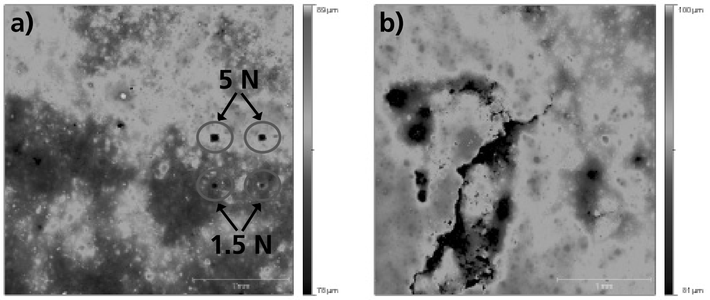


Fig. 8 - Two dimensional topographical surface scans of sample A (a) and sample B (b). The color range indicates z-height over a distance of 20 µm from highest value, white, to lowest value black. It is clear from a qualitative comparison that sample B has a much higher surface roughness than sample A. This is confirmed by quantitative analysis in Table 2.

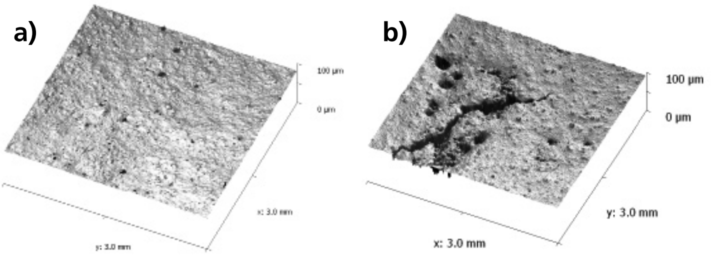


Fig. 9 - Three dimensional surface rendering of sample A (a) and sample B (b).

Note the presence of the 4 residual indentation imprints on sample A. The 5 N indents are much larger than the 1.5 N indents.

One additional feature of the ConScan which is especially useful on samples with heterogeneous composition is the ability to compare the z-height axis to the albedo, or the extent which a surface diffusely reflects light from a given source. This is done by recording the surface profile image (z-height of the sample) and the intensity of the signal simultaneously using the spectrophotometric detector at the time of measurement. As can be seen in Fig. 10, the 2D topographic surface image displays only the height information of sample A. This information was used to determine if the sample was well polished for analysis. However, the topographic information reveals nothing about the underlying grain structure of the concrete.The intensity measurement can be used to show the underlying grain structure of the concrete regardless of the z-height as a function of increased or decreased reflectivity of the sample surface.

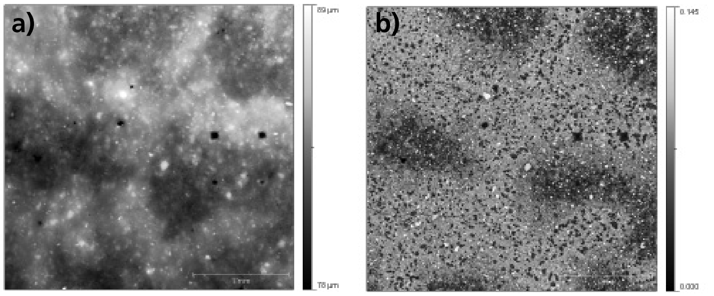


Fig. 10 - Comparison of the topographic information (a) to the intensity of the signal (b) recorded at the time of measurement of Sample A. Using the intensity signal, it is possible to highlight the underlying grain structure of a sample independent of topography.

//// Three dimensional metrology with ConScan

The ConScan can be used to perform routine metrology to determine the dimensions of a patterned sample. As can be seen Fig.11, a polycarbonate sample with a microfluidic pathway was imaged using the ConScan. By extracting the profiles it was possible to measure the depth of each channel.

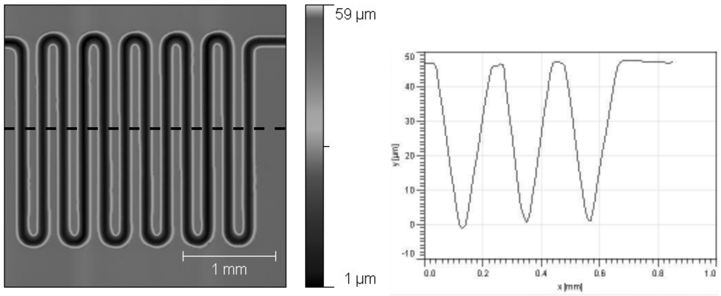
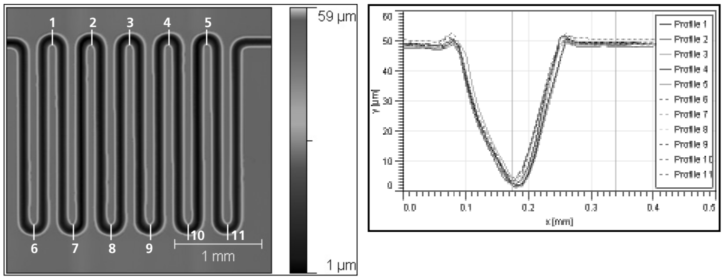


Fig. 11 - A two-dimensional representation of the microfluidic device, together with a cross-sectional profile.

The advantage of using the Conscan to measure metrological data from a given surface is that once the image is acquired, unlimited profiles can be extracted in many locations and directions. In other words, this is an "image once, measure many" type of instrument. As can be seen in Fig. 12, the acquired image was profiled in 11 locations to verify quality of the microfluidic pathway.



Profile	1	2	3	4	5	6	7	8	9	10	11	**Mean**	**Std. Dev.**
Depth (µm)	46.81	45.98	46.19	45.63	44.17	46.26	46.18	46.16	45.88	45.89	45.97	**45.92**	**0.65**

Fig.12 - Comparing the depth of each turn in this microfluidic pathway allows for quick verification of manufacturing tolerences.

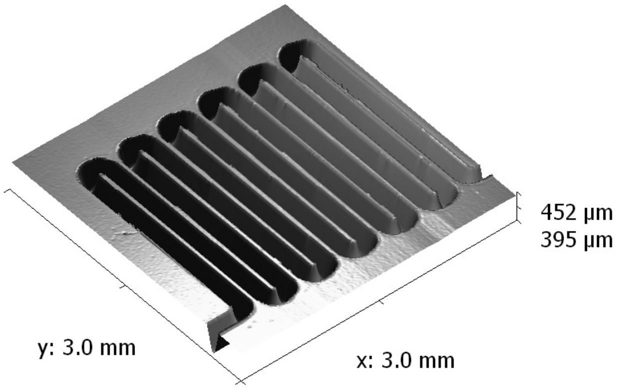


Fig.13 - 3D representation of the 2D image in Fig. 12.

As can be seen in Fig. 12 it is also possible to compare the tight, U-shaped turns in this particular device, which has an average depth of channel of 45.92 µm. In fact, it is possible to place profiles across any dimension of the acquired image to extract measurement data about a given sample without the need to make additional measurements. This is a tremendous advantage over traditional profilometry devices which will require a physical sample to be analyzed prior to the generation of any additional measurements.

CSM Instruments

This Applications Bulletin is published quarterly and features interesting studies, new developments and other applications for our full range of mechanical surface testing instruments.

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