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A Better Measure.

CORROSION SURFACE ANALYSIS USING 3D PROFILOMETRY

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INTRO

Corrosion of materials is the most important and common failure mechanisms in industry, from infrastructure and transportation to production and manufacturing. According to a breakthrough 2-year study entitled "Corrosion Costs and Preventive Strategies in the United States"[i] released by NACE International and the U.S. Federal Highway Administration, the total annual estimated direct cost of corrosion in the U.S. is a staggering $276 billion—approximately 3.1% of the nation's Gross Domestic Product (GDP). Therefore, corrosion inspection and monitoring becomes critical for implementing optimal corrosion control practices to improve lifecycle and asset management.

IMPORTANCE OF 3D PROFILOMETRY FOR CORROSION ANALYSIS

Electrochemical oxidation of metals is the most common form of corrosion. Oxide(s) or salt(s) grow on the metal surface as the metals are exposed to moisture in air. Corrosion can either take place locally to form a pit or crack, or it can extend uniformly across a wide surface. As a result, proper surface analysis of the corroded sample is vital in evaluation of corrosion characteristics and mechanism, so as to select the best material, protective coatings and corrosion control measures for targeted application. Unlike other techniques such as touch probes, the Nanovea 3D Non-Contact Profilometer measures the surface features without touching the sample. This avoids the risk of removing important loose corrosion product and allows preserving the true surface feature. Moreover, the portable model JR25 enables corrosion inspection on site.

MEASUREMENT OBJECTIVE

In this application the Nanovea PS50 Profilometer is used to analyze the surface morphology of the samples after service in corrosive environment. Surface roughness, materials loss and pits on the sample surface are measured to provide more insight in the corrosion mechanism.

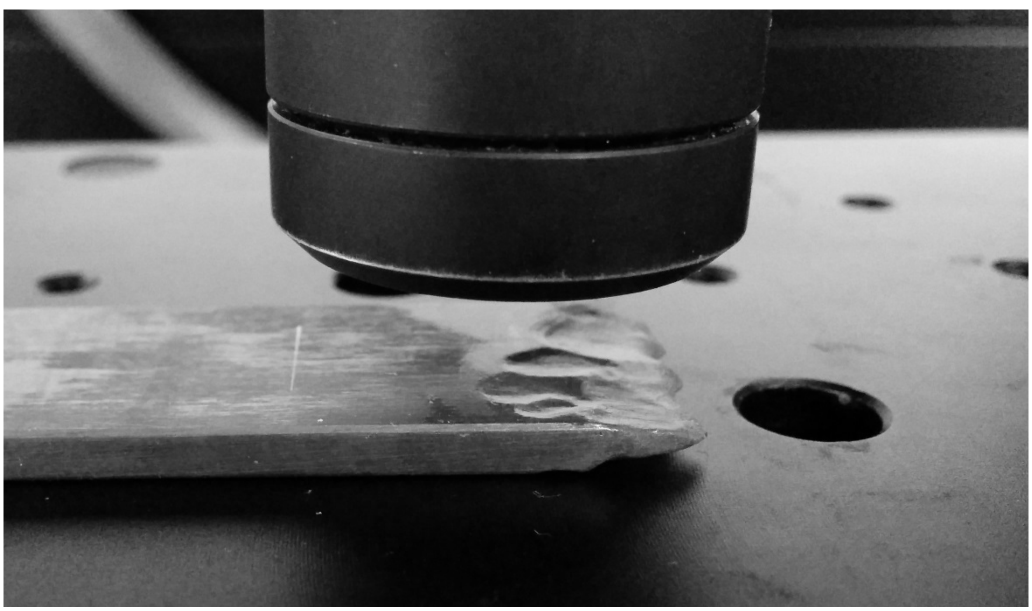


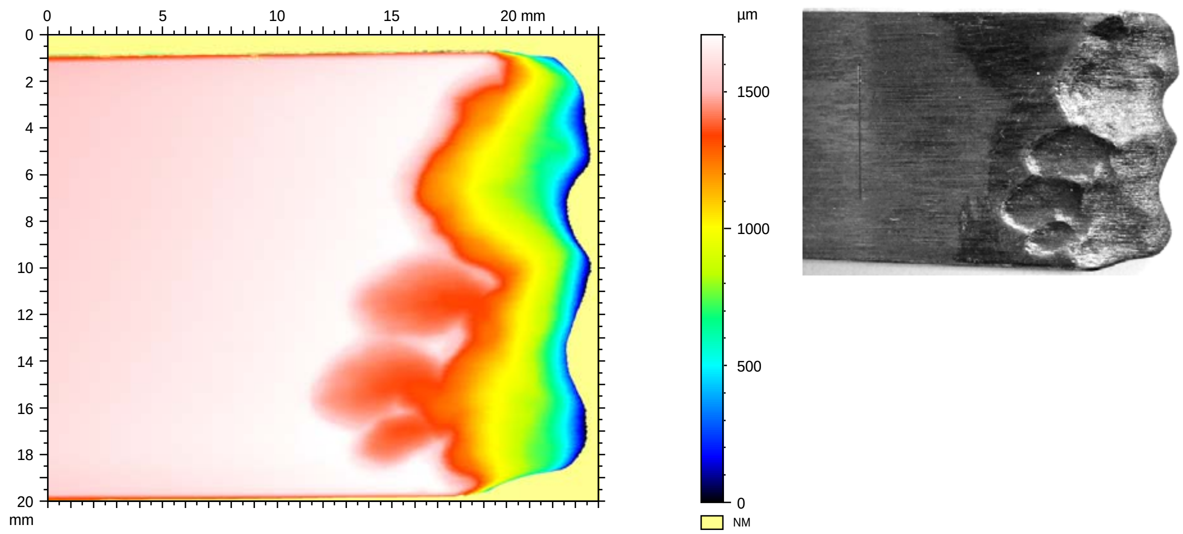
Figure 1: Non-contact optical pen scanning on the corroded sample.

RESULTS AND DISCUSSION

Sample A after corrosion & erosion attack

The False Color View and 3D View provide users a straightforward tool to directly observe the morphology of the surface from different angles. Figure 2 shows that Sample A has been severely attack by corrosion and erosion at the edge.

(a)



(b)

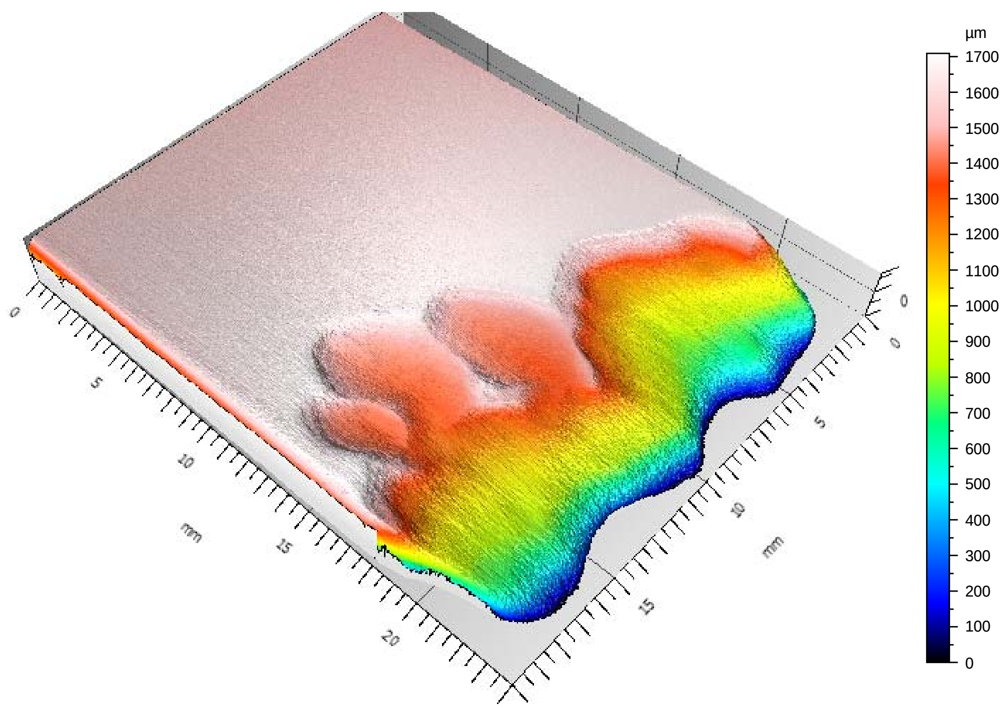
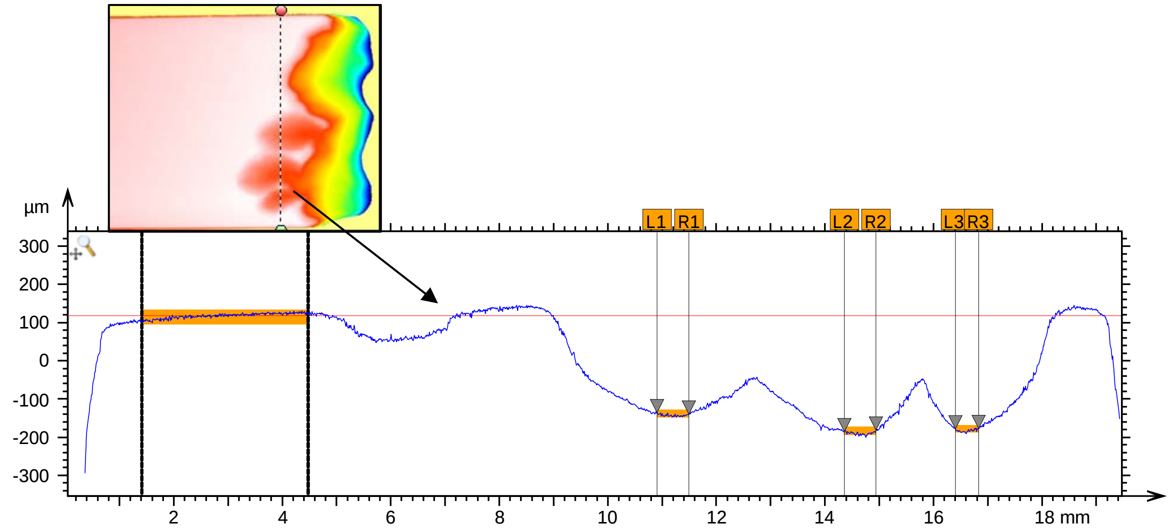
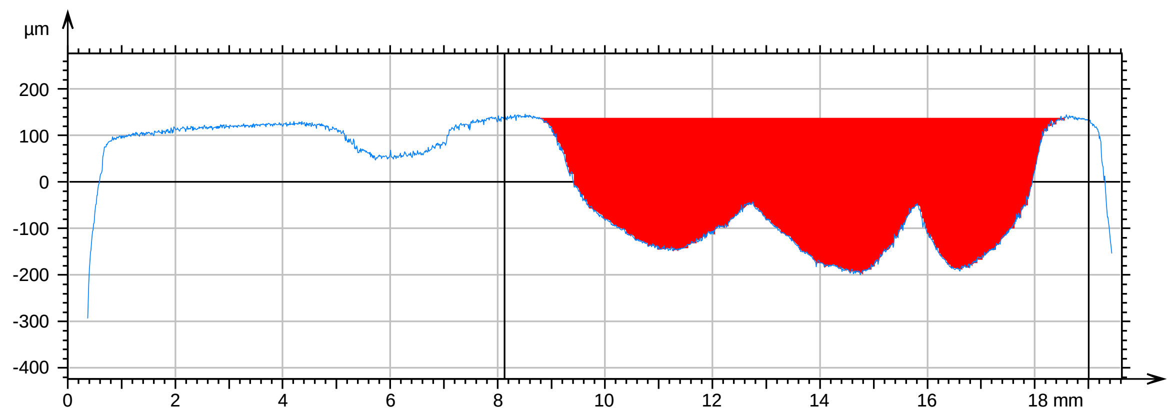


Figure 2: (a) False color view and (b) 3D view for Sample A.

Figure 3 shows an example of 2D profile analysis on the valleys created during the corrosion and erosion attack. The adjacent three valleys possess depths of 265, 318 and 309 µm, respectively, and the total area of the hole is ~2.3 mm^2. Such 2D profile analysis is helpful in providing more precise measurement of the shape of the sample.



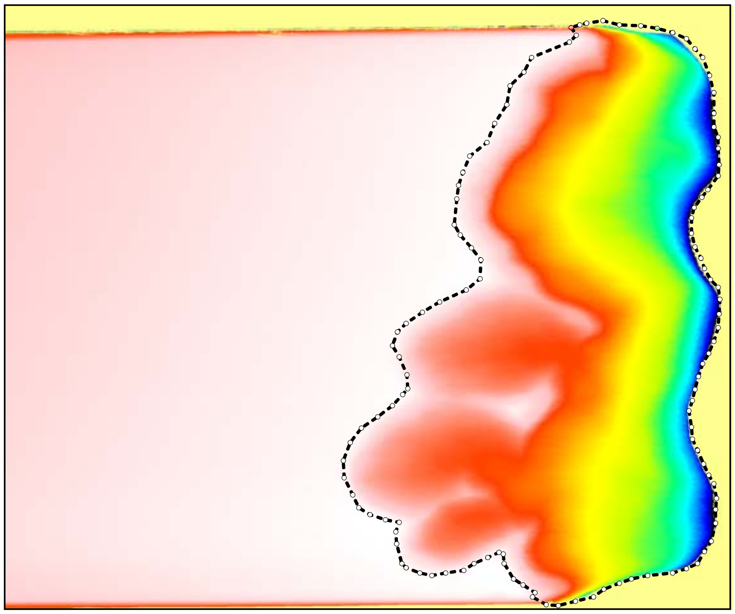
Parameters	Unit	Step 1	Step 2	Step 3
Maximum height	µm	265	318	309
Mean height	µm	260	308	301



Parameters	Value	Unit
Maximum depth	345	µm
Area of the hole	2340713	µm²

Figure 3: Step height and area of the valleys on Sample A.

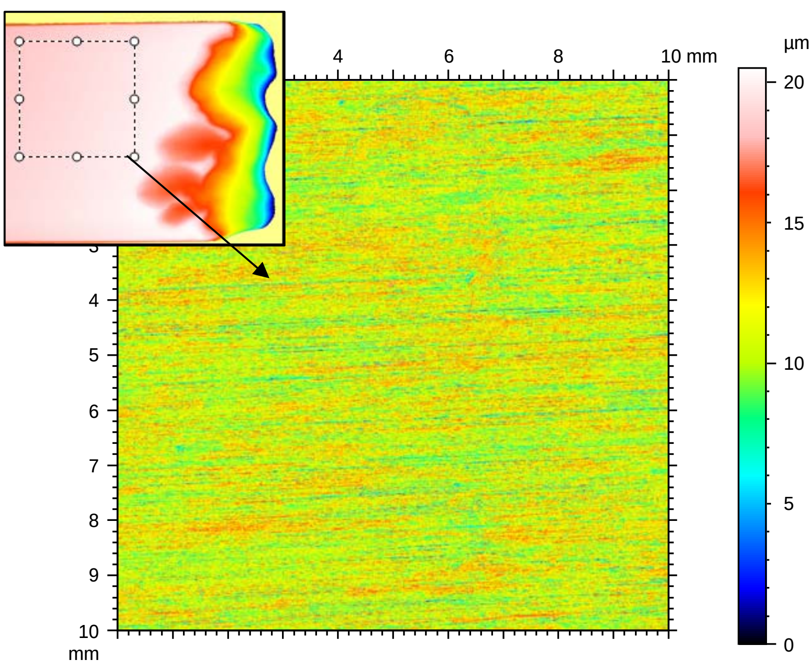
The volume loss of Sample A is analyzed in Figure 4, where the severely attacked area was selected and measured. The total material loss in the selected area is 89 mm^3 as calculated by the software. This information is important in the process of selecting the best material candidate with the lowest corrosion rate.



Parameters	Unit	Hole	
Surface	mm²	158	
Volume	µm³	8.928684324e+010	
Max. depth/height	µm	1749	
Mean depth/height	µm	566	

Figure 4: Volume loss for Sample A.

Figure 5 measures the average roughness of the less attacked area of Sample A. The roughness S_a in this region is 1.73 µm.



ISO 25178		
Height Parameters		
Sa	1.73	µm
Sq	2.20	µm
Sp	9.22	µm
Sv	11.3	µm
Sz	20.5	µm
Ssk	-0.223	
Sku	3.50	
Other 3D Parameters		
Miscellaneous		
Spar	100	mm²
Sdar	105	mm²

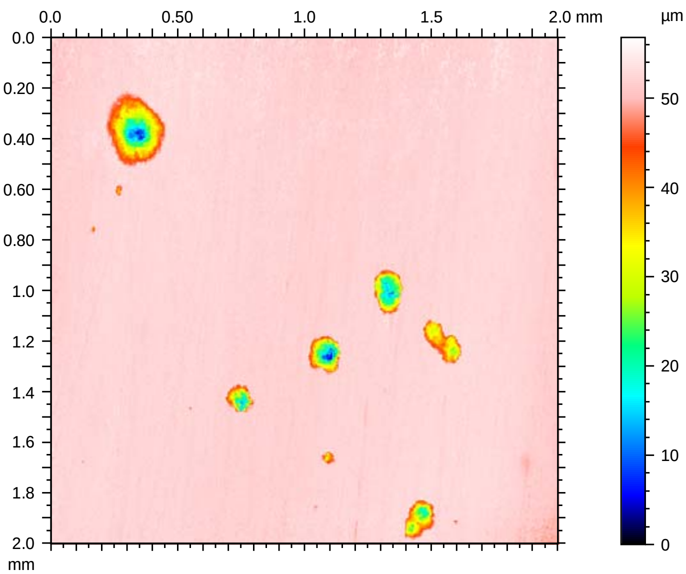
Figure 5: False color view and roughness parameters for Sample A.

Sample B after pitting corrosion

Pitting corrosion is a localized form of corrosion which leads to generation of cavities in the material. Pitting is more difficult to detect, predict and design against, and thus more dangerous than uniform corrosion damage. Therefore, a reliable tool for pitting detection and analysis is critical to prevent catastrophic failures that pitting may provoke.

Figure 8 shows the false color view and 3D view for Sample B after pitting corrosion attack. Eight pits of different sizes distribute on the measured surface, while the other areas remain intact, reflecting the extremely localized nature of pitting corrosion.

(a)



ISO 25178		
Height Parameters		
Sa	1.13	µm
Sq	3.49	µm
Sp	5.55	µm
Sv	51.3	µm
Sz	56.8	µm
Ssk	-7.43	
Sku	65.2	
Other 3D Parameters		
Miscellaneous		
Spar	4.00	mm²
Sdar	4.24	mm²

(b)

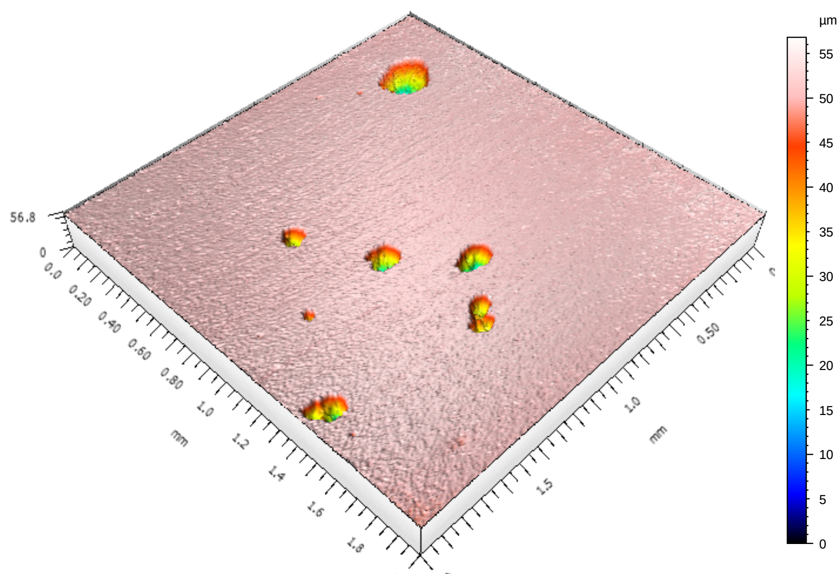
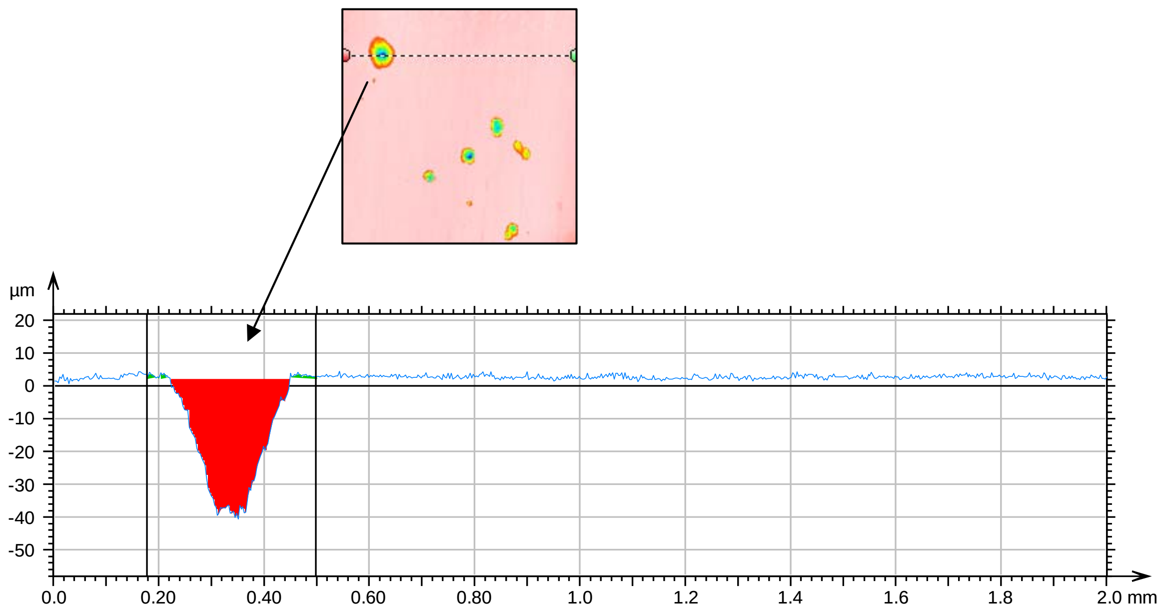


Figure 6: (a) False color view and (b) 3D view for Sample B.

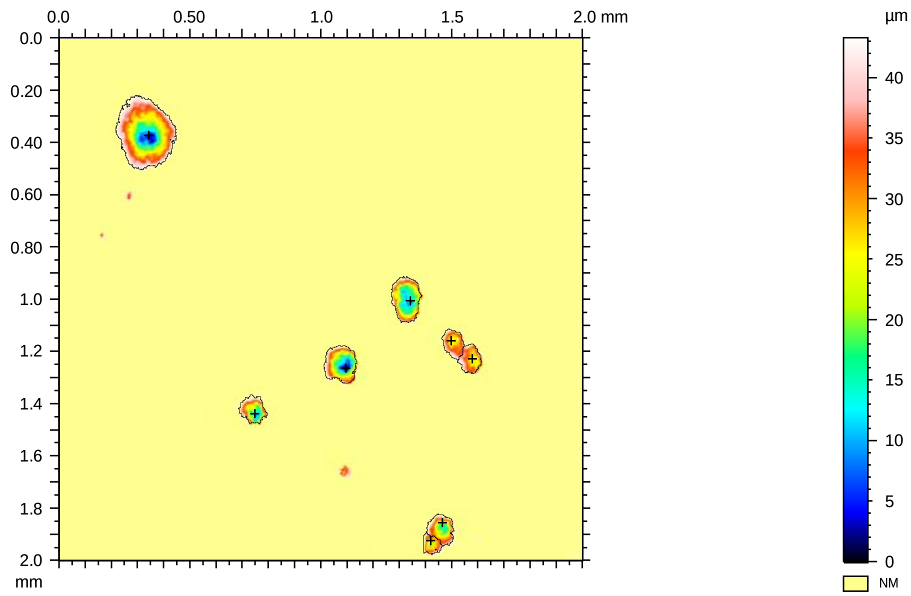
Pitting can be initiated by several factors, such as localized chemical or mechanical damage to the protective oxide film or the protective coating, as well as the presence of non-uniformities in the metal structure.[ii] Figure 7 exhibits the 2D profile analysis on one of the pits as an example. The measured pit has a "cone" shape with a maximum depth of 43 µm and area of 5513 µm^2. Such information is critical in analyzing the corrosion mechanism and development stage of pitting.



Parameters	Value	Unit
Maximum depth	43.3	µm
Area of the hole	5513	µm²

Figure 7: Area of 2D pitting profile analysis for Sample B.

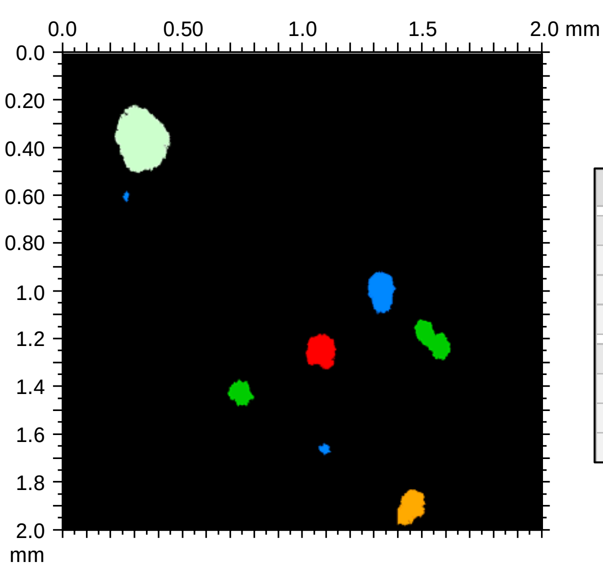
Figure 8 and Figure 9 analyze the individual and overall pits on the sample surface, respectively. From Figure 8 we can easily measure the depth, size, volume and diameter of each pit, while in Figure 9 the statistics of all the pits are evaluated. This in-depth information of the pits enables users to precisely assess the severity of the pitting corrosion of the test sample, so as to make an informed decision in the implementation of optimal corrosion control practices.



Number of motifs	8

Parameters	Unit	Grain #1	Grain #2	Grain #3	Grain #4	Grain #5	Grain #6	Grain #7	Grain #8
Height	µm	42.4	33.3	35.8	15.9	16.4	10.9	13.4	11.6
Area	mm²	0.0457	0.0138	0.0147	0.00774	0.00851	0.00406	0.00686	0.00678
Volume	µm³	605311	142235	285814	20214	27666	6528	25825	19489
Mean diameter	mm	0.236	0.129	0.131	0.0955	0.0997	0.0682	0.0894	0.0889
Roundness		0.726	0.742	0.590	0.743	0.704	0.662	0.659	0.559

Figure 1: Pitting analysis on individual pits of Sample B.



Statistics over all grains - Sorted grains (0.000...			
Global information	**Value**		
Number of grains	8		
Total area occupied by the...	0.105 mm² (2.63%)		
Density of grains	2.00 Grains/mm²		
Grain parameters	**Unit**	**Mean**	**Std d...**
Area	mm²	0.01...	0.0128
Perimeter	mm	0.508	0.292
Mean diameter	mm	0.112	0.0603

Figure 2: Overall pitting analysis for Sample B.

CONCLUSION

In this application, we have shown how the Nanovea 3D Non-Contact Profilometer evaluates different forms of corrosion, including erosion and pitting corrosion. The axial chromatism technique allows measuring the corroded surface without touching, preserving all the details of the surface feature. The analysis software provides measurements such as roughness, volume loss, as well as pit distribution, depth, size and volume, enabling users to obtain more insight in the corrosion characteristics and mechanism.

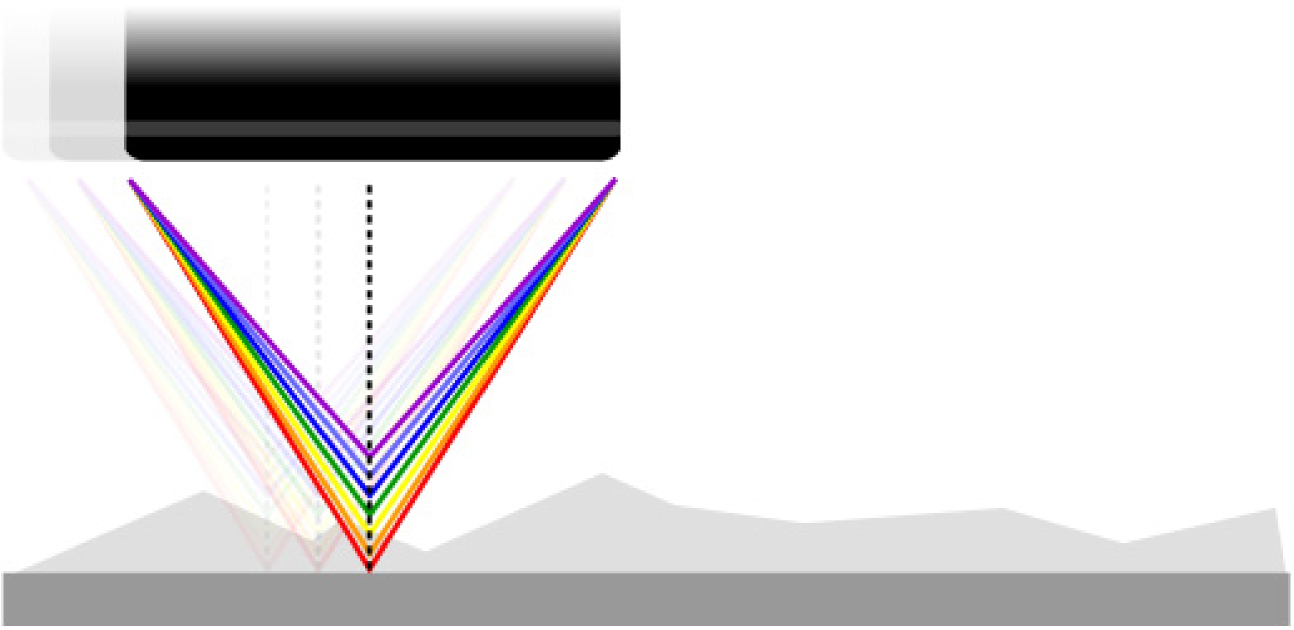
The data shown here represents only a portion of the calculations available in the analysis software. Nanovea Profilometers measure virtually any surface in fields including Semiconductor, Microelectronics, Solar, Fiber Optics, Automotive, Aerospace, Metallurgy, Machining, Coatings, Pharmaceutical, Biomedical, Environmental and many others.

Learn more about the Nanovea Profilometer or Lab Services

[i] http://www.nace.org/uploadedFiles/Publications/ccsupp.pdf
[ii] http://www.nace.org/Pitting-Corrosion/

MEASUREMENT PRINCIPLE:

The Chromatic Confocal technique uses a white light source, where light passes through an objective lens with a high degree of chromatic aberration. The refractive index of the objective lens will vary in relation to the wavelength of the light. In effect, each separate wavelength of the incident white light will re-focus at a different distance from the lens (different height). When the measured sample is within the range of possible heights, a single monochromatic point will be focalized to form the image. Due to the confocal configuration of the system, only the focused wavelength will pass through the spatial filter with high efficiency, thus causing all other wavelengths to be out of focus. The spectral analysis is done using a diffraction grating. This technique deviates each wavelength at a different position, intercepting a line of CCD, which in turn indicates the position of the maximum intensity and allows direct correspondence to the Z height position.



Unlike the errors caused by probe contact or the manipulative Interferometry technique, Chromatic Confocal technology measures height directly from the detection of the wavelength that hits the surface of the sample in focus. It is a direct measurement with no mathematical software manipulation. This provides unmatched accuracy on the surface measured because a data point is either measured accurately without software interpretation or not at all. The software completes the unmeasured point but the user is fully aware of it and can have confidence that there are no hidden artifacts created by software guessing.

Nanovea optical pens have zero influence from sample reflectivity or absorption. Variations require no sample preparation and have advanced ability to measure high surface angles. Capable of large Z measurement ranges. Measure any material: transparent or opaque, specular or diffusive, polished or rough. Measurement includes: Profile Dimension, Roughness Finish Texture, Shape Form Topography, Flatness Warpage Planarity, Volume Area, Step-Height Depth Thickness and many others.

DEFINITION OF HEIGHT PARAMETERS

	Height Parameter	Definition
Sa	Arithmetical Mean Height	Mean surface roughness. $$Sa = \frac{1}{A}\iint_A \lvert z(x,y)\rvert dxdy$$
Sq	Root Mean Square Height	Standard deviation of the height distribution, or RMS surface roughness. $$Sq = \sqrt{\frac{1}{A}\iint_A z^2(x,y)dxdy}$$ Computes the standard deviation for the amplitudes of the surface (RMS).
Sp	Maximum Peak Height	Height between the highest peak and the mean plane.
Sv	Maximum Pit Height	Depth between the mean plane and the deepest valley.
Sz	Maximum Height	Height between the highest peak and the deepest valley.
Ssk	Skewness	Skewness of the height distribution. $$Ssk = \frac{1}{Sq^3}\left[\frac{1}{A}\iint_A z^3(x,y)dxdy\right]$$ Skewness qualifies the symmetry of the height distribution. A negative Ssk indicates that the surface is composed of mainly one plateau and deep and fine valleys. In this case, the distribution is sloping to the top. A positive Ssk indicates a surface with a lot of peaks on a plane. Therefore, the distribution is sloping to the bottom. Due to the large exponent used, this parameter is very sensitive to the sampling and noise of the measurement.
Sku	Kurtosis	Kurtosis of the height distribution. $$Sku = \frac{1}{Sq^4}\left[\frac{1}{A}\iint_A z^4(x,y)dxdy\right]$$ Kurtosis qualifies the flatness of the height distribution. Due to the large exponent used, this parameter is very sensitive to the sampling and noise of the measurement.
Spar	Projected Area	Projected surface area.
Sdar	Developed Area	Developed surface area.