REPLICA MOLDING OF INNER PIPE CORROSION USING 3D PROFILOMETRY

Prepared by
Duanjie Li, PhD & Ali Mansouri

6 Morgan, Ste156, Irvine CA 92618 · P: 949.461.9292 · F: 949.461.9232 · nanovea.com

INTRODUCTION

Corrosion causes an annual estimated direct loss of $276 billion in the U.S. — approximately 3.1% of the nation's Gross Domestic Product (GDP) according to a breakthrough 2-year study entitled "Corrosion Costs and Preventive Strategies in the United States"[i]. Metal pipe corrosion is a major cause of the pipe failure. It is a continuous and variable process determined by various environmental conditions, including by not limited to the water properties, the soil surrounding the pipe and stray electric currents[ii].

IMPORTANCE OF SURFACE ANALYSIS ON CORRODED PIPE

Surface finish of the metal pipe is critical for its product quality and performance. Rust progressively builds up and pits initiate and grow on the metal surface as corrosion process takes place, resulting in roughening of the pipe surface. The differential galvanic properties between metals, the ionic influences of solutions as well as the solution pH may all play roles in the pipe corrosion process, leading to corroded metal with different surface features. An accurate surface roughness and texture measurement of the corroded surface provides insight in the mechanisms involved in a specific corrosion process. Conventional profilometers have difficulty in reaching in and measuring the corroded inner pipe wall. Replica molding provides a solution by replicating the inner surface features in a non-destructive way. It can easily be applied on the inner wall of the corroded pipe and sets in 15 min. We scan the replicated surface of the replica molding to obtain the surface morphology of the inner pipe wall.

MEASUREMENT OBJECTIVE

In this application, we show that Nanovea ST400 optical profilometer in combination with the replica molding provides a convenient surface analysis tool for measuring the inner surface morphology of a corroded pipe.

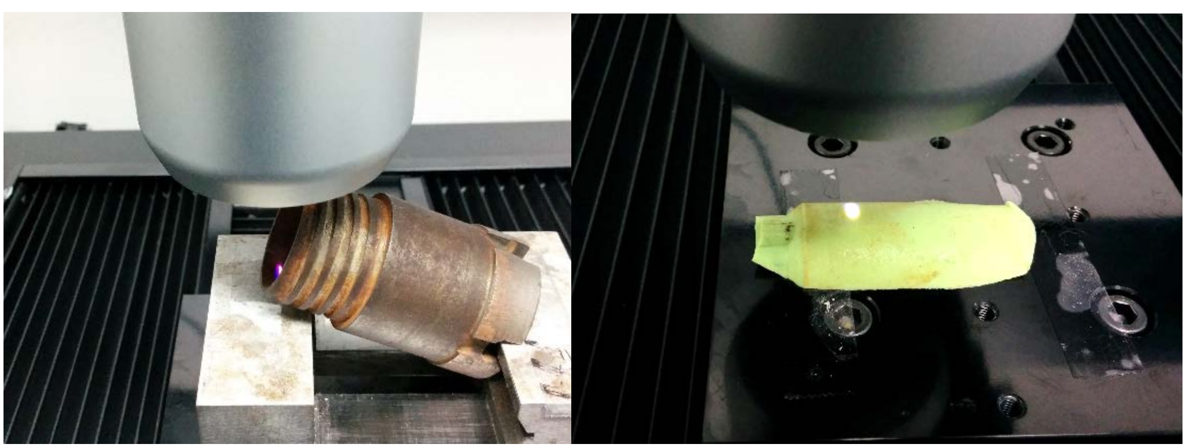


Fig. 1: Optical line sensor scanning on the inner surface of the corroded pipe and its replica molding.

RESULTS AND DISCUSSION

The replica molding was applied in the inner surface of the corroded pipe as shown in Fig. 2 and set in 15 min. It was then easily removed from the pipe, with one face replicaed with the 3D inner surface morphology of the corroded pipe. This method significantly facilitates measurement of the inner surface features of the pipes, such as roughness, pits and others. Such information is usually difficult to obtain using conventional profilometer measurement directly on the inner surface, due to the restricted space in the small pipe.

(a) (b)

Fig. 2: Replica molding and the corroded pipe.

The 3D view of the replica molding is displayed in Fig. 3, which provides users a useful tool to directly observe the surface morphology from different angles in detail. No evident pitting is observed on the replica molding of the pipe.

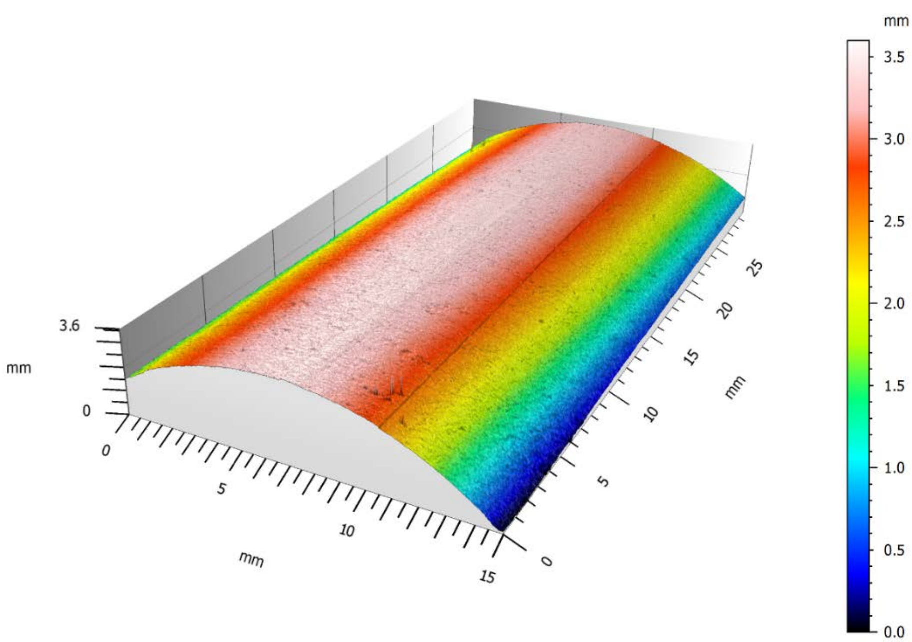
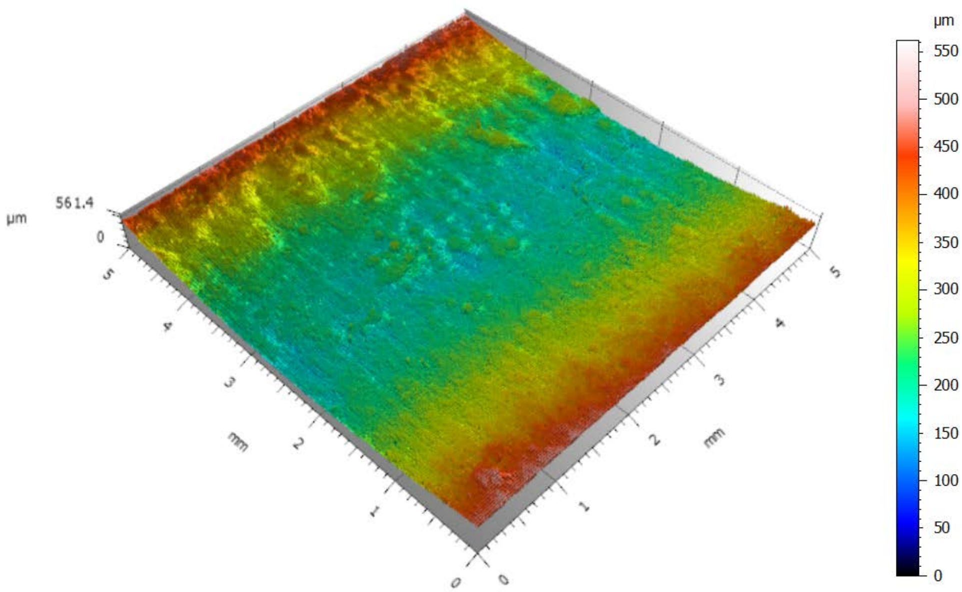


Fig. 3: The 3D view of the full scan of the replica molding.

Fig. 4 shows the 3D View of the inner surface measured directly and the replica molding of the corroded pipe at a larger magnification, in order to further evaluate and compare the shape and roughness of the inner pipe surface and the replica molding. The surface morphology of the inner pipe surface and the replica molding after removing the cylinder form is compared in Fig. 5, revealing more detailed rough surface features. The direct inner surface and the replica molding of the corroded pipe match well in terms of shape and roughness. As summarized in Table 1, they possess comparable average roughness S_a of ~8.7 µm. Such a roughened metal surface is caused by rusting -- a common form of corrosion which includes galvanic corrosion, pitting corrosion, and crevice corrosion. Rust usually creates red or brown flaking or pitting on the metal surface[iii].

(a) The inner-surface of the corroded pipe:



(b) The surface of the replica molding:

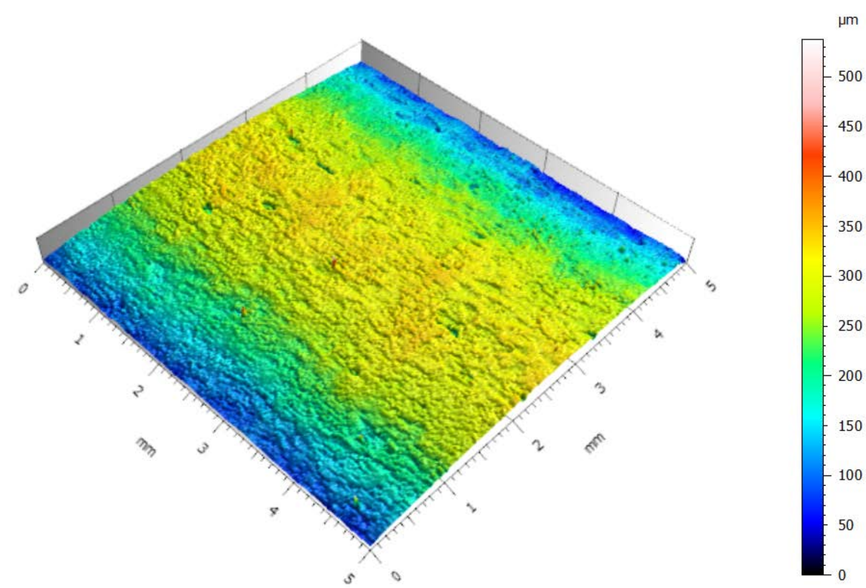
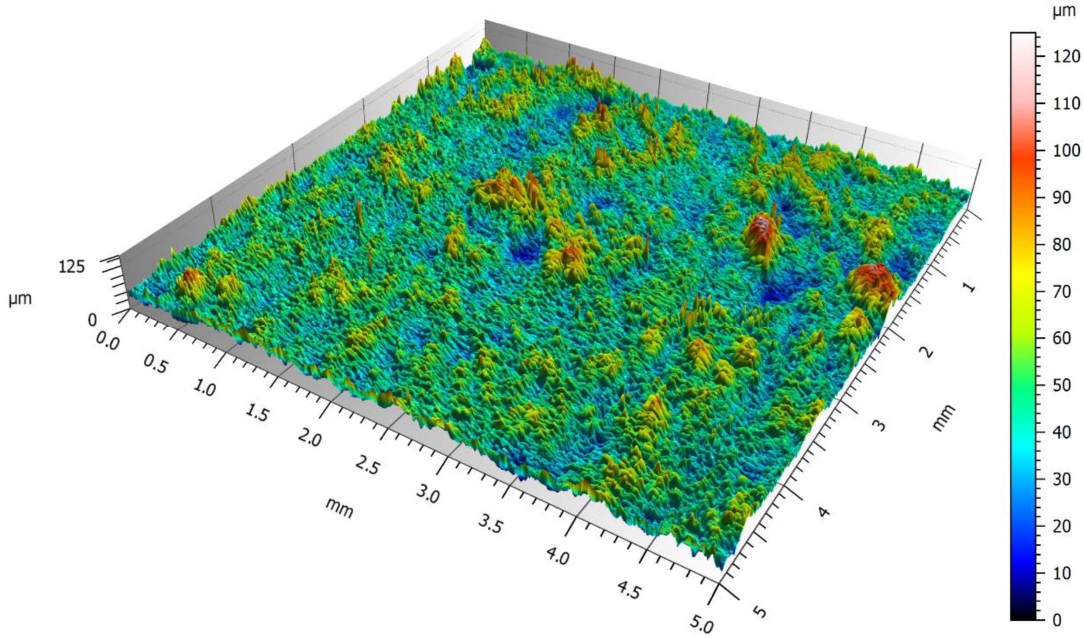


Fig. 4: 3D views of the inner-surface of the corroded pipe and the replica molding.

(a) The inner-surface of the corroded pipe after form removal:



(b) The surface of the replica molding after form removal:

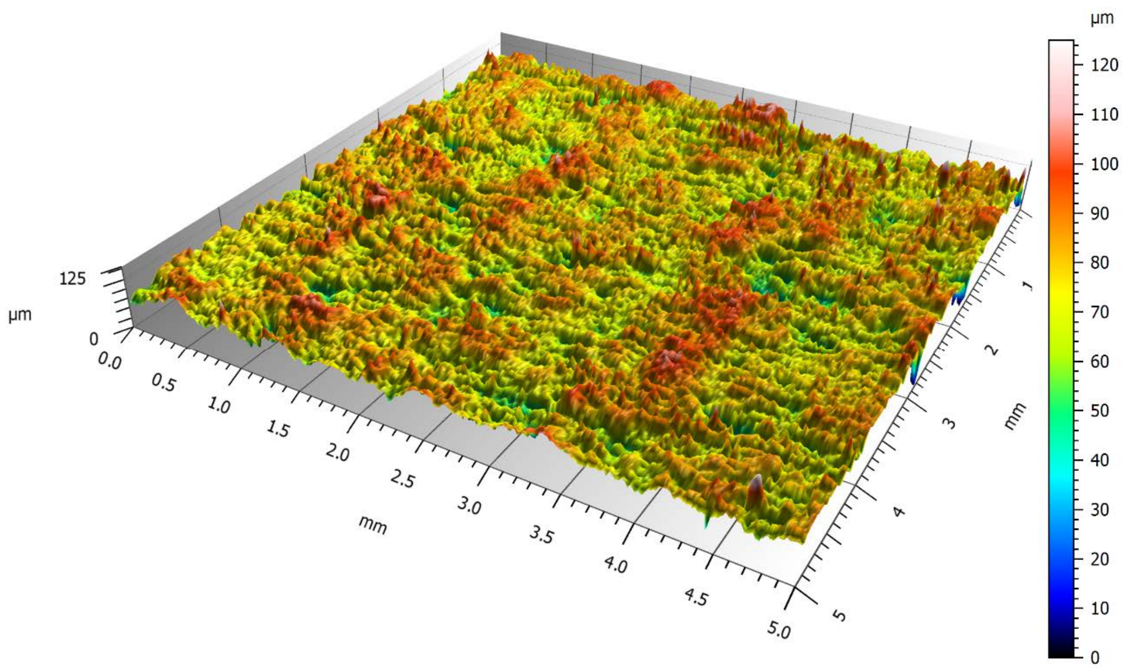


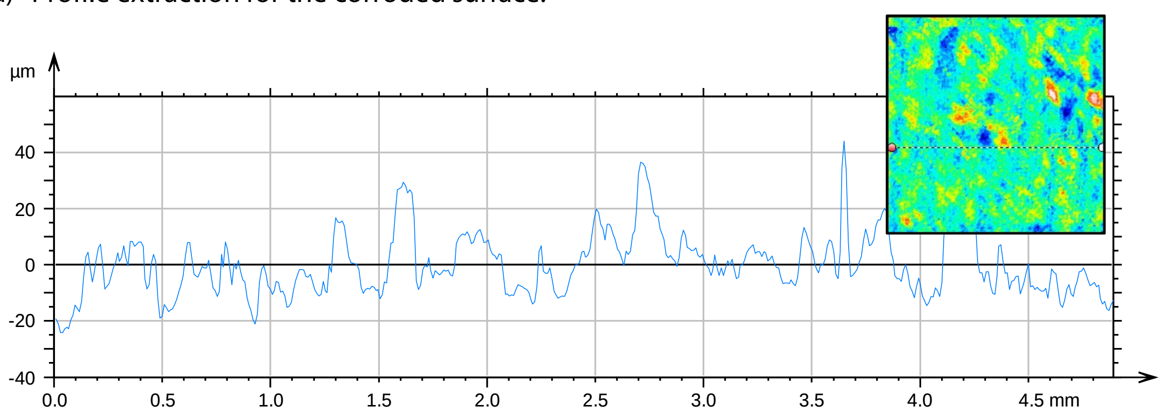
Fig. 5: The inner-surface of the corroded pipe and the replica molding after form removal.

		Corroded pipe	Replica Molding	Note
Sq	µm	11.57	11.58	Root-mean-square height
Ssk		0.8656	-0.7357	Skewness
Sku		5.357	5.940	Kurtosis
Sp	µm	66.62	54.17	Maximum peak height
Sv	µm	39.07	74.51	Maximum pit height
Sz	µm	105.7	128.7	Maximum height
Sa	µm	8.726	8.725	Arithmetic mean height

Table 1: Comparison of surface roughness of the corroded pipe and the replica molding.

The 2D profiles across the 3D morphology are shown in Fig. 6, allowing us to directly measure the shape and texture of the surface profile at different locations and detect possible corrosion pits with different depth, size, volume and diameter.

(a) Profile extraction for the corroded surface:



(b) Profile extraction for the replica molding:

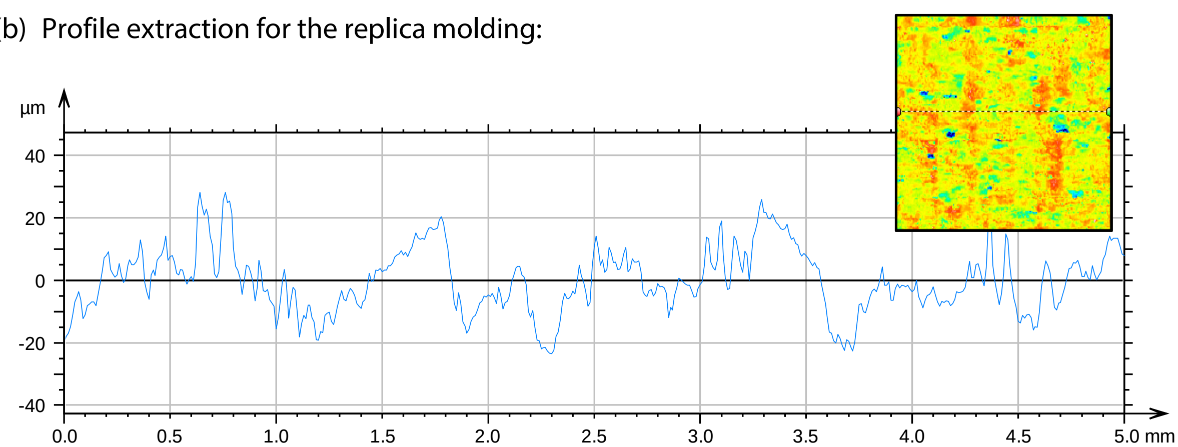


Fig. 6: 2D profiles of the corroded pipe and the replica molding after form removal.

CONCLUSION

In this application, we have showcased that the Nanovea ST400 non-contact profilometer in combination with the replica molding is a useful and convenient tool to evaluate the morphology and roughness of the inner surface of a corroded pipe. The measured 3D profile and roughness of the replica molding is in agreement with the values measured directly on the inner surface of the corroded pipe. The software provides various analysis tools such as roughness and peak and valley profile, enabling users to have a comprehensive understanding of the corroded surface, which was difficult to measure using direct profilometer measurement.

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

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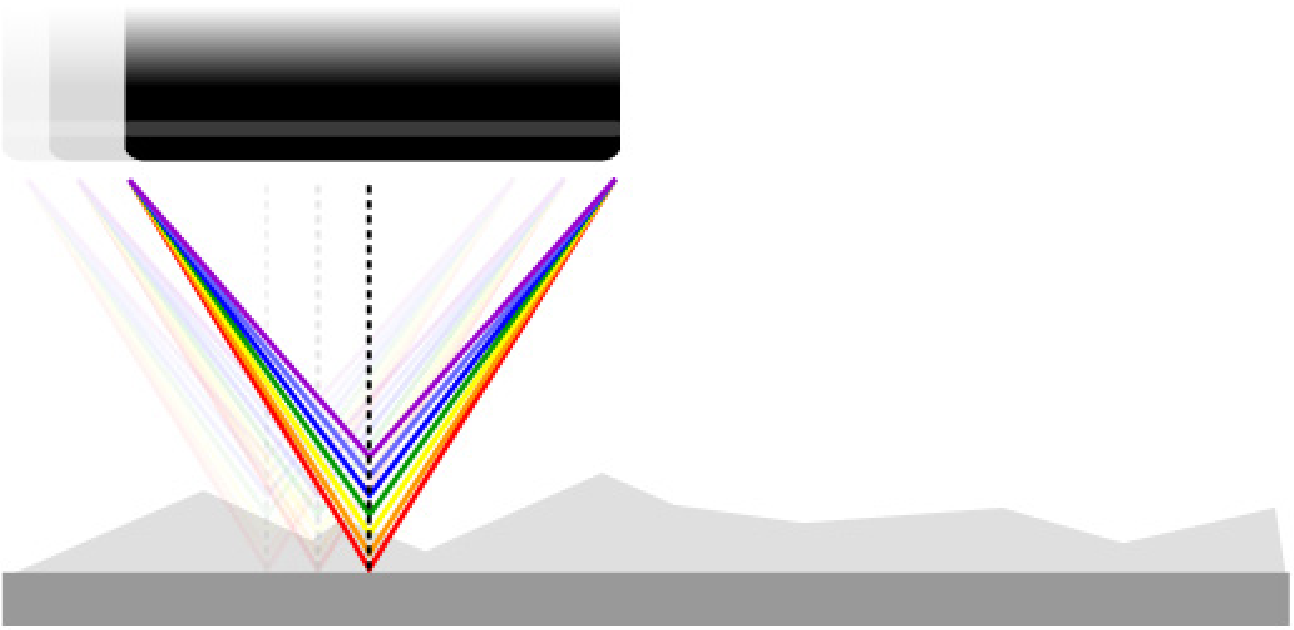
[i] http://www.nace.org/uploadedFiles/Publications/ccsupp.pdf
[ii] http://www.cdc.gov/fluoridation/factsheets/engineering/corrosion.htm
[iii] https://www.nachi.org/rust-inspection-prevention.htm?loadbetadesign=0

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.