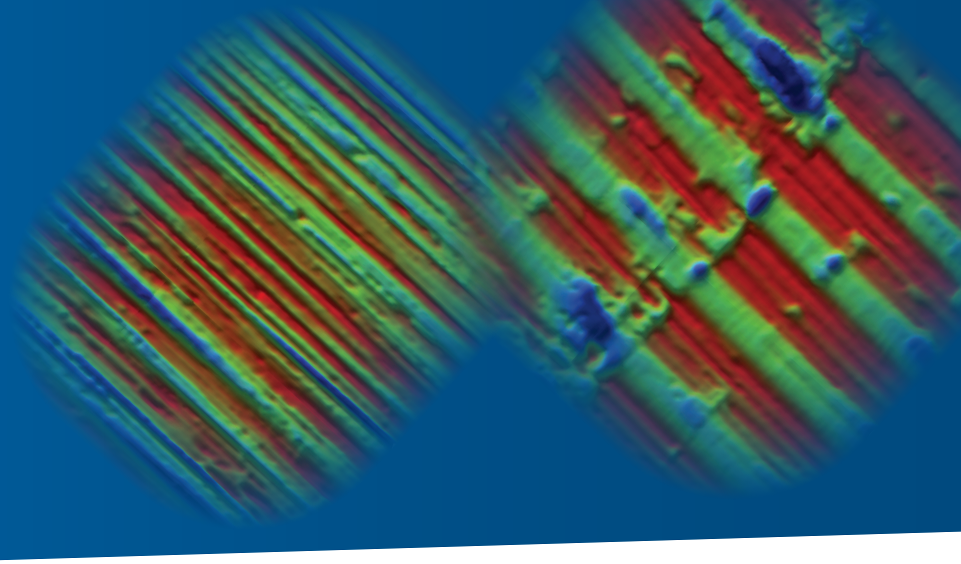

Application Note

#582

Characterizing Surface Quality: Why Average Roughness (*Ra*) Is Not Enough

Quantification of surface finish is both complex and necessary. Despite surface topography being three-dimensional, the most established surface measurement parameter is average roughness (*Ra*), a two-dimensional parameter. *Ra* is easy to measure and can be compared with historical data, but does nothing to describe a surface's nuances or potential functionality. This application note explores the impacts of using 3D parameters to provide greater insight into surface finish and performance, including two case studies where the use of 3D parameters guided the design and development of high-performance surfaces.

Evolution from R Parameters to S Parameters

Stylus-based techniques for measuring surface finish were developed in the 1930s. For stylus measurements, a sharp or rounded tip is traced along the surface with its vertical deflection correlating to sample heights. Data from stylus measurements was quantified using R parameters, 2D descriptors including *Ra*, *Rp* (maximum peak height), *Rv* (maximum valley depth), *Rt* (total height), *Rq* (root-mean-square roughness), *Rz* (average of maximum peaks and minimum valleys), and others.

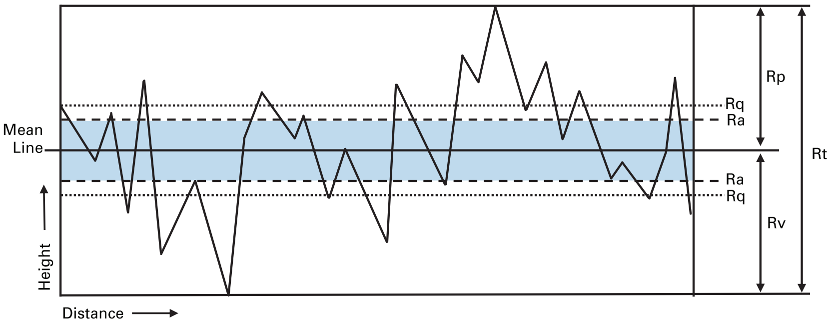

FIGURE 1.

Some of the parameters used to describe surfaces in 2D.

In the late 1900s, the 3D surface measurement technique optical profiling was developed and refined, enabling fast, large-area topographical analysis via areal data collection and multi-frame stitching. These 3D datasets revealed much more about surface texture than a 2D trace, and *Ra* became an insufficient quantitative descriptor. Initially, *Ra* was just modified to be the equivalent in 3D, average surface roughness (*Sa*), but this neglected the rich information regarding surface height variation details and texture specifics that is stored in 3D datasets.

Amplitude parameters (based on overall height)	
Sa	Average roughness over entire 3D area
Sp	Maximum peak
Sv	Minimum valley
Sq	The root-mean-square deviation (RMS of height distribution)
Ssk	Skewness, degree of asymmetry of a surface height distribution
Sku	Kurtosis, degree of peakedness of a surface height distribution
Sz	Total surface peak-to-valley (Sp + Sv)
Spatial parameters (based on frequencies of features)	
Str	Texture aspect ratio
Sal	Fastest decay autocorrelation length
Std	Texture direction of surface
ACF	Autocorrelation Function
Hybrid parameters (based on a combination of height and frequency)	
Sds	Density of summits
Sdq	Root-mean-square surface slope
Ssc	Mean summit curvature
Sdr	Developed surface area ratio
Functional parameters (based on function applicability)	
Sk	Kernel roughness depth (core)
Spk	Reduced peak height (roughness of peaks)
Svk	Reduced valley height (roughness of valleys)

TABLE 1.

Some of the many parameters used to describe surfaces in 3D.

The S parameters (Table 1) were devised in the 1990s, and are grouped into four initial general categories: amplitude, spatial, hybrid, and functional. These parameters describe a surface more completely than 2D parameters, painting a quantitative picture of waviness, micro-roughness, wearability, lubricant retention capability, texture direction, and much more. Using the S parameters, engineers and process designers can understand their surfaces in greater detail and can design surfaces with a focus on functionality.

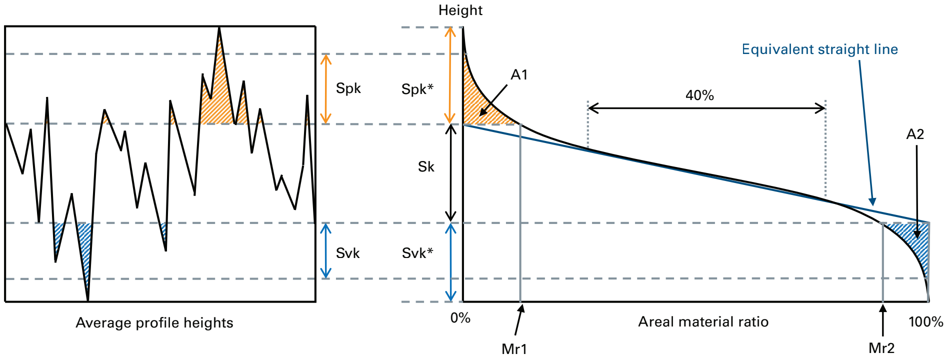

FIGURE 2.

Bearing area curve, with *Spk**–peak height, *Svk**–valley depth, *A1*–peak cross-sectional area, *A2*–valley cross-sectional area, *Mr1*–material ratio 1, and *Mr2*–material ratio 2

Another way to understand and represent surface texture is the bearing area curve (BAC, also known as a bearing ratio curve or an Abbott-Firestone curve). The BAC, shown in Figure 2, is the cumulative probability density function of height for a surface profile line. That profile can come from either a single trace (for 2D data) or an average over multiple traces (for 3D data). This Abbott curve is also used for the evolution of the 3D volume parameters for fluid characterization, such as *Sci* (core fluid retention index) and *Svi* (valley retention index).

Persistence and Weaknesses of *Ra*

Surface finish is still often described using only an *Ra* value, despite its inability to capture the nuance of real surfaces. This lingering attachment to *Ra* is due to two main factors: ease of low-cost 2D measurements with a stylus profilometer, and the existence of historical data for *Ra*. While it does remain useful as a general surface texture guideline, *Ra* is too general to describe a surface's real variations or functional nature.

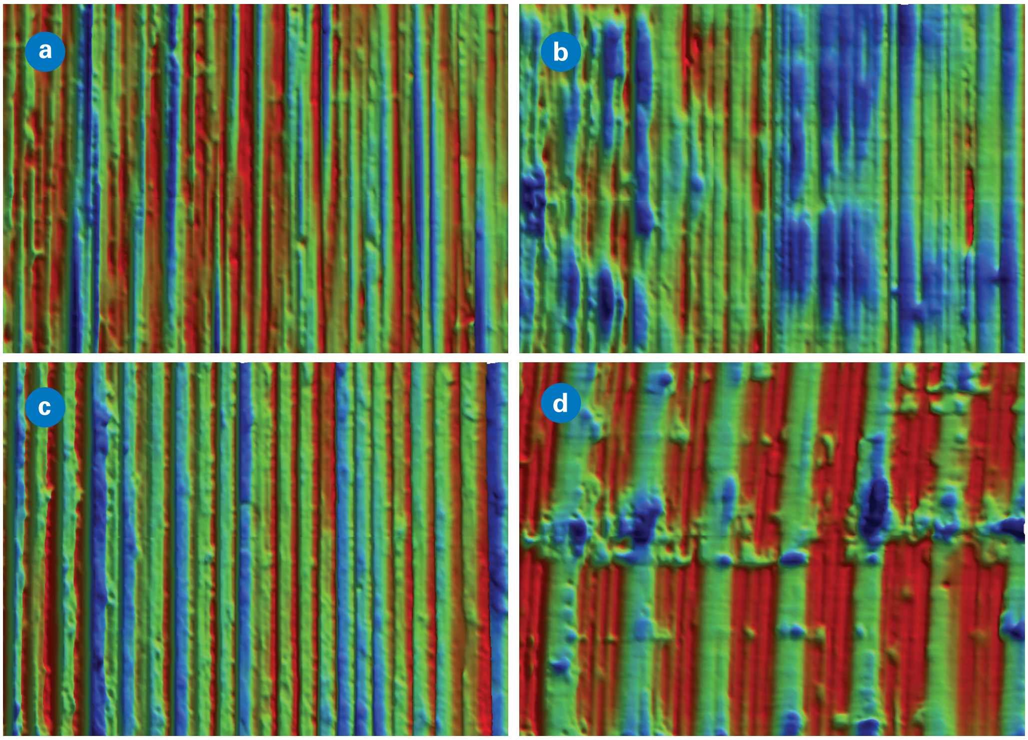

FIGURE 3.

Four very different surfaces all with *Ra* = 0.4 µm (16 µin), finished by (a) grinding, (b) horizontal milling, (c) reaming, and (d) vertical milling.

A surface with sharp spikes and deep pits or one with general isotropy may yield the same *Ra* value. Figure 3 shows four surfaces with the same *Ra* for different finishing steps, producing visually distinct surfaces that would functionally perform very differently from each other. *Ra* calculated from a single trace (or even several) cannot distinguish these surfaces and cannot provide information about their functionality, while S parameters can do both.

The surfaces from Figure 3 were evaluated using (1) several stylus-collected *Ra* measurements, and (2) Bruker's white-light interferometry (WLI) to calculate S parameters and perform a stylus analysis that correlates back to stylus measurements. *Ra* and S-parameter results are plotted in Figure 4. With guidelines connecting the same parameter across samples on the plot, it is clear that the advertised and included certified values of *Ra* are very close for all four fingernail standard samples (nearly horizontal lines at *Ra* = 400 µm). All other measurements deviate from these provided values of *Ra*, though. An independent certification and WLI stylus analysis–calculated *Ra* values (which are based on an average over an area) show great correlation with each other, only deviating for the vertical milling sample where the stylus measurement location was unknown. For more information on these measurements and how Bruker's Vision64® software can facilitate stylus analysis of WLI areal data, refer to Bruker Application Note 558, "Correlating Advanced 3D Optical Profiling Surface Measurements to Traceable Standards".

The two plotted S parameters from WLI measurements (summit density *Sds* and structure angle *Std*) in Figure 4 show different distinctions between the samples than *Ra* does. In particular, vertical milling had a much higher *Std* (due to the angle of the dominant surface structure) and lower *Sds* (due to the lower summits per unit area) than the other three finishing steps. It is obvious that single- or multiple-trace *Ra* does not provide a complete picture of the differences between these surfaces. Averaging *Ra* over a larger area begins to clarify variations, and adding an analysis of S parameters furthers understanding both of differences and of what those differences could functionally mean.

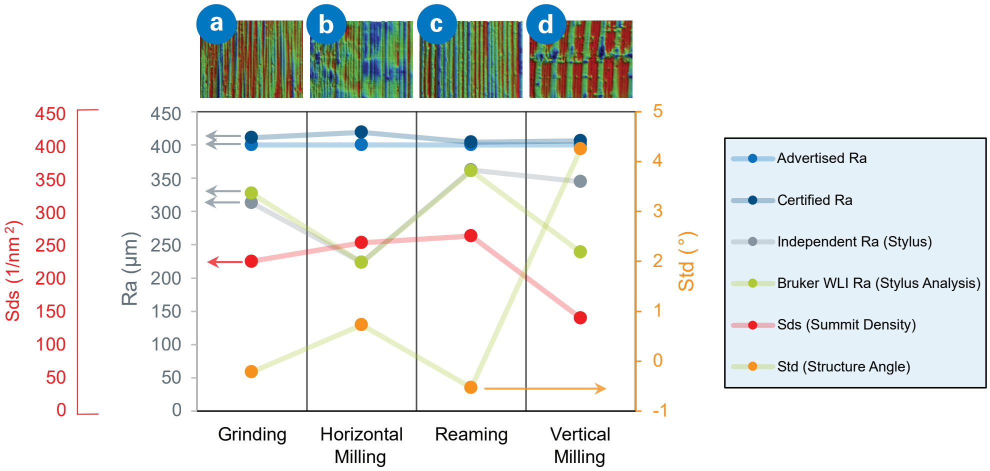

FIGURE 4.

Plot showing *Ra*, *Sds*, and *Std* for the four samples in Figure 2. There were four variants of *Ra*: as-advertised, as-certified, independently-verified, and WLI data–calculated. Connecting lines are simply a guide for the eye, following the same parameter across samples.

Case Study 1: Determining a Source of Corrosion

Ra is not necessarily an effective quality screen or an adequate measure for development and problem solving. At Masco Corporation, Research & Development, incoming ASTM 366 coil steel stock was conforming to an average roughness specification of 20 to 70 microinches, but a significant portion of the stock had corroded after a series of cold working and surface treatment processes.

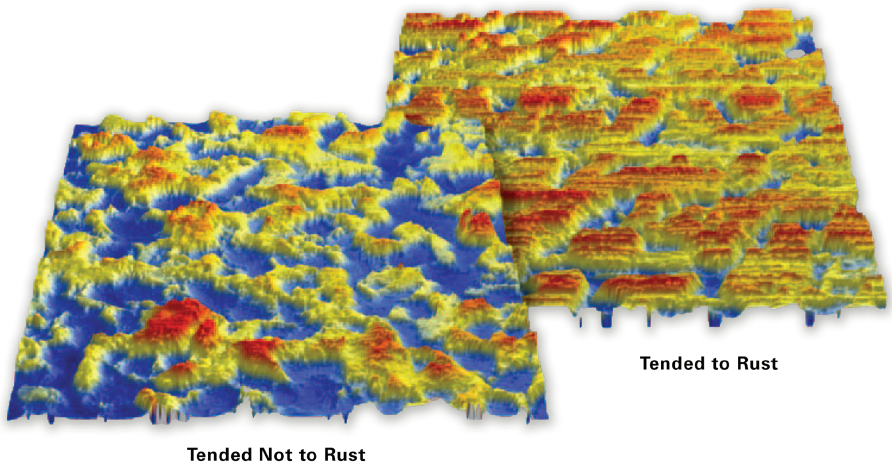

FIGURE 5.

Surfaces of ASTM 366 coil steel stock that either tended to rust (right) or not to rust (left). Courtesy of John Finch, Terry Chuhran, and Daryl Wilusz, Masco Corporation.

To determine the source of the rust, surface analysis was performed on the incoming stock. Figure 5 shows 3D optical profiler plots of the different stock surfaces that resulted in either acceptable or rust-prone final parts. Many deep valleys can be seen on the rust-prone stock, whereas the acceptable stock is more isotropic. Of the S parameters, skewness (*Ssk*) and valley depth (*Sv*) were found to correlate well with the tendency towards corrosion.

In Figure 6, a BAC was plotted for both types of stock, indicating the percentage of the surface that falls above or below a certain depth. These curves quantified the percentage of valley area that tended to lead to corrosion. From this data, it was determined that the deeper valley structure tended to hold processing solutions and did not rinse or dry properly, allowing flash rusting to occur. A ratio of parameters derived from the bearing area analysis was an excellent indicator of the incoming stock's tendency to corrode.

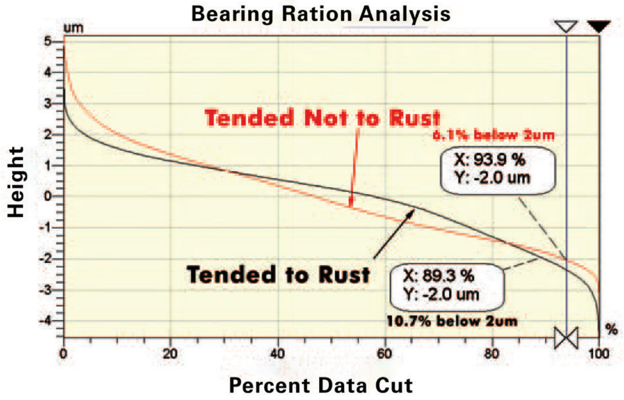

FIGURE 6.

Bearing ratio analysis of the two surfaces in Figure 5. The stock that eventually corroded showed a greater percentage of valleys deeper than 2 µm.

Case Study 2: Using 3D Parameters to Engineer a Surface

The engineering of a surface for a new part requires more than just an *Ra* value. A new clutch plate design at Steel Parts needed to have the best friction and wear performance. After several plate designs with known performance characteristics had been evaluated (Figure 7), it was determined that skewness and kurtosis correlated well with wear and friction, as did several other combinatorial parameters. These parameters were used to successfully develop and control a novel manufacturing process that ensured consistent part performance.

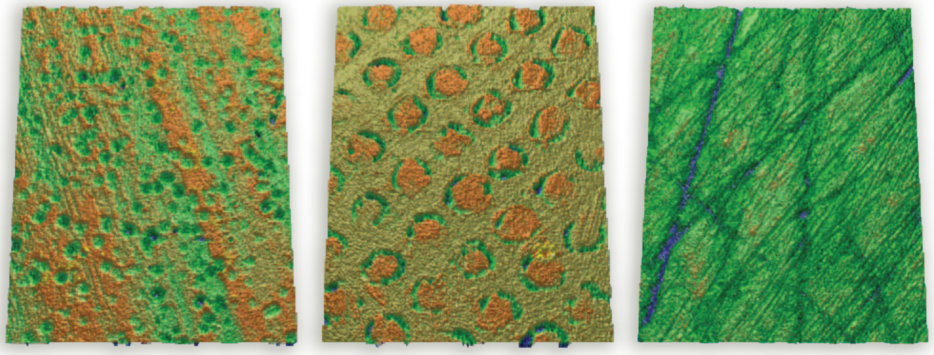

FIGURE 7.

Experimental clutch plate designs whose performances were connected to certain S parameters. Courtesy of John Riggle, Steel Parts.

Conclusion

Advances in 3D measurement techniques such as optical profiling have given engineers, process designers, and quality control professionals a significantly improved toolkit for describing surfaces. 3D parameters uniquely differentiate not only surface shape but functionality as well. A careful surface design study results in a better understanding of functional characteristics, a more controllable process and, ultimately, better surface performance. For more definitions and usage guidelines for surface parameters, see the standards listed in Table 2.

TABLE 2.

Standards with definitions and usage guidelines for surface parameters.

Standard Number	Title	Publisher	Year
ISO 13565-1	Geometrical Product Specifications (GPS)—Surface texture: Profile method; Surfaces having stratified functional properties—Part 1: Filtering and general measurement conditions	International Organization for Standardization	2021
ISO 14406:2010	Geometrical Product Specifications (GPS)—Extraction		2010
ISO 16610-1:2015	Geometrical Product Specifications (GPS)—Filtration—Part 1: Overview and basic concepts		2015
ISO 16610-61:2015	Geometrical Product Specifications (GPS)—Filtration—Part 61: Linear areal filters		2015
ISO 16610-61:2014	Geometrical Product Specifications (GPS)—Filtration—Part 71: Robust areal filters: Gaussian regression filters		2014
ISO 17450-2:2012	Geometrical Product Specifications (GPS)—General Concepts—Part 2: Basic tenets, specifications, operators, uncertainties and ambiguities		2012
ISO 21920-1:2021	Geometrical product specifications (GPS)—Surface texture: Profile—Part 1: Indication of surface texture		2021
ISO 21920-2:2021	Geometrical product specifications (GPS)—Surface texture: Profile—Part 2: Terms, definitions and surface texture parameters		2021
ISO 25178-1:2016	Geometrical product specifications (GPS)—Surface texture: Areal—Part 1: Indication of surface texture		2016
ISO 25178-2:2021	Geometrical product specifications (GPS)—Surface texture: Areal—Part 2: Terms, definitions and surface texture parameters		2021
ASME B46.1-2019	Surface Texture (Surface Roughness, Waviness, and Lay)	The American Society of Mechanical Engineers	2019
ASME Y14.36-2018	Surface Texture Symbols		2018

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