Characterizing Surface Quality:
Why Average Roughness is Not Enough

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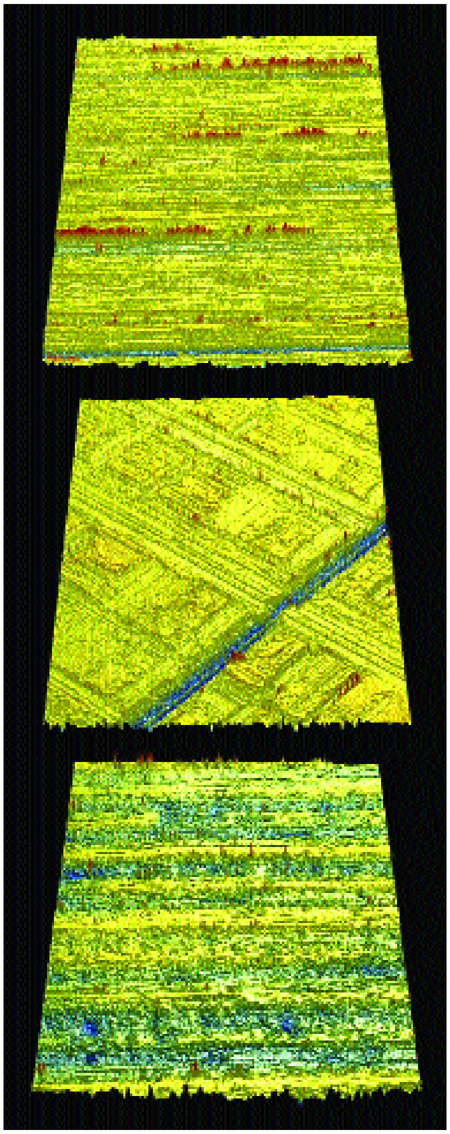

Figure 1. Optical profiler images of three very different surfaces indistinguishable by Ra.

Introduction

Three dimensional surface measurement techniques and parameters are well understood and widely adopted for characterizing surface finish and performance. Nevertheless, in many applications 2D parameters, chiefly average roughness (Ra), are the only parameters specified for controlling surface quality. In this article we will explore why 2D parameters continue to be used and, more importantly, how 3D parameters can be employed to provide greater insight into surface finish and performance. We will examine two cases in which 3D parameters have helped in the design and development of high-performance surfaces.

Surface Parameter History

Modern surface finish measurement traces back to stylus techniques developed in the 1930s. In a stylus measurement, a small tip is moved across a surface while its vertical deflection is recorded. This technique has been refined and is in widespread use today.

A series of parameters were devised to quantify the information from stylus measurement data. These parameters include Ra, Rq (root mean square roughness), Rz (an average of the maximum peaks and minimum valleys), and more than 100 other parameters.

To address a need for fast, large-area measurements, 3D techniques were developed which could accommodate both smooth and rough surfaces. Chief among these methods is optical profiling, in which the interference of two beams from a white light source is used to measure surface features. A white light optical profiler can characterize an area over 50 square millimeters in a single measurement. A considerably larger area can be measured by "stitching" multiple measurements into one larger dataset. Features from 0.1nm roughness to 8mm step heights can be resolved, in seconds.

3D data can highlight large data trends, such as waviness or lay, and features, such as a predominance of ridges or scratches, that a 2D trace cannot show. Initially, 2D parameters such as Ra were modified to explain these 3D data trends. More recently, "purebred" 3D parameters, such as the S Parameter set, have been implemented and are currently being standardized. With these new parameters, engineers and process designers are not only able to view their surfaces in much greater detail: they're also able to design and test surfaces with an eye toward functionality.

The Shortcomings of Ra

Despite the breadth of available 3D parameters, quality professionals continue to specify surface finish based solely on the value of Ra. There are several reasons for this tendency: average roughness is easy to measure; it is well-established and understood; literature and standards are available to explain its parameters; and, perhaps most importantly, historical part data is based upon it. Process engineers know that they can specify Ra and finish a surface within that specification.

While Ra remains useful as a general guideline of surface texture, it typically proves too general to describe the surface's functional nature. A surface with sharp spikes, deep pits, or general isotropy may all yield the same average roughness value. Ra makes no distinction between peaks and valleys, nor does it provide information about spatial structure.

Figure 1 shows three surfaces from a surface comparator strip (courtesy of GAR Electroforming), generated by grinding, Blanchard grinding, and shape turning. All three surfaces were measured on a Wyko® NT Series optical profiler (Veeco Instruments, Inc.) and found to have approximately the same Ra value (680-750nm). Yet the functional traits of these very different surfaces are indistinguishable by Ra. Which surface will wear well? Which will retain fluid? Which will survive a bearing load, or which is susceptible to stress cracking along machining marks? Ra provides no information of this type.

3D Parameters Offer More Detail

3D surface parameters, readily calculated from 3D topographical measurement data, highlight a surface's waviness, microroughness, wear ability and lubricant retention, as well as the angular direction of residual machining marks, and much more. In the last ten years significant effort has been directed toward developing standard, worldwide 3D parameters. Much of this work has been completed by a European consortium, the result of which is a set of standard "S Parameters" in four general categories: amplitude, spatial, hybrid and functional.[1]

Amplitude parameters

(based on overall heights):

Sq: The Root-mean-square deviation (RMS of height distribution)

Ssk: Skewness, the degree of asymmetry of a surface height distribution

Sku: Kurtosis, the degree of peakedness of a surface height distribution

Sz: Average of ten highest and lowest points

Spatial Parameters

(based on frequencies of features):

Sds: Density of Summits

Str: Texture Aspect Ratio

Sal: Fastest Decay Autocorrelation Length

Std: Texture Direction of Surface

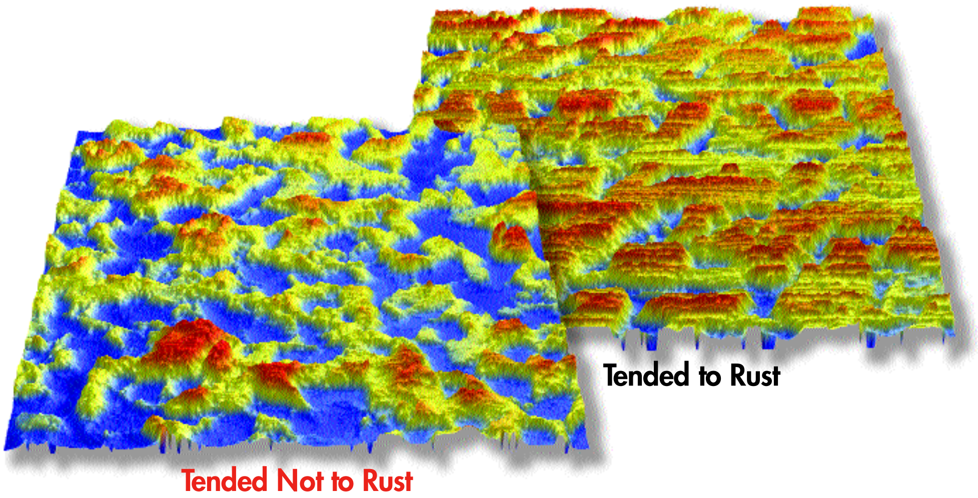

Figure 2. Stock either maintained an acceptable surface finish (left image) or corroded (right image) following processing. 3D parameters helped trace the difference to a predominance of deep valleys which Ra did not discern.

Hybrid Parameters

(based on a combination of height and frequency):

SDq: Root-Mean-Square Surface Slope

Ssc: Mean Summit Curvature

Sdr: Developed Surface Area Ratio

Functional Parameters

(based on applicability for particular functions):

Sbi: Surface Bearing Index

Sci: Core Fluid Retention Index

Svi: Valley Fluid Retention Index

This 3D parameter set greatly extends the degree to which surface analysis can uniquely characterize both sample shape and function.

The following case studies illustrate how 3D parameters have been used to determine the sources of process deviation and to develop a controllable process from the start.

Function	Amplitude	Spatial	Hybrid	Functional
Bearings	▲	▲	■	▲
Seals	▲	■	▲	▲
Friction	▲	▲	▲	▲
Joint Stiffness	▲	■	■	▲
Slideways	▲	▲	■	▲
Electrical/Thermal Contacts	▲	▲	▲	▲
Wear	▲	▲	▲	▲
Galling	▲	●	▲	▲
Bonding & Adhesion	▲	●	■	▲
Painting & Plating	▲	■	■	▲
Forming & Drawing	▲	▲	■	▲
Fatigue	▲		●	▲
Stress & Fracture	▲		■	▲
Reflectivity	▲	■	▲	▲
Hygiene	▲		■	▲

▲ = Much evidence ■ = Some evidence ● = Little or circumstantial evidence

Table 1. Typical applications for various 3D parameters.[1].

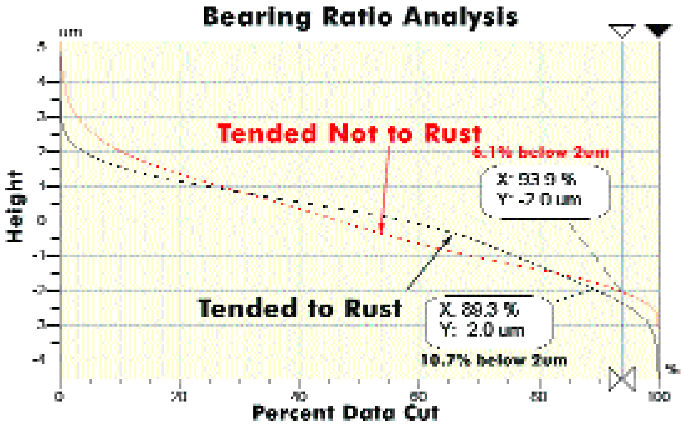

Figure 3. Bearing ratio analysis of the two surfaces in Figure 2. The stock which eventually corroded showed a greater percentage of valleys deeper than 2 microns.

Case Study 1:
Determining a Source of Corrosion

Masco Corporation, Research & Development, a manufacturer of brand-name consumer products, discovered that Ra is not necessarily an effective quality screen or an adequate measure for development and problem solving. As Terry Chuhran, Metallurgist, and John Finch, Materials Development Project Leader at Masco explained, incoming ASTM 366 coil steel stock was conforming to an average roughness specification of 20-70 micro-inches. Yet a significant portion of the stock was found to corrode following a series of cold working and surface treatment processes.

To determine the source of the rust, chemical and surface analyses were performed on the incoming stock. Figure 2 shows 3D optical profiler plots of the stock which resulted in acceptable and rust-prone final parts. A predominance of deep valleys is visible on the rust-prone stock, whereas the acceptable stock is essentially isotropic.

A bearing ratio analysis was performed on both types of stock (Figure 3). A bearing ratio curve indicates the percentage of a surface that falls above/below a particular 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.

The final task, then, was to develop a method to correlate initial surface finish to final corrosion resistance. Several variables, chiefly skewness and valley depth, were found to correlate well with the tendency toward corrosion. Furthermore, a ratio of parameters derived from the bearing area analysis proved an excellent indicator of the incoming stock's tendency to corrode.

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

When designing or redesigning a part's surface, engineers often start from an experimentally or historically accepted average roughness value. They then attempt to develop a process which yields the proper Ra value and the correct functional characteristics. It is almost as if achieving Ra and functionality are two separate goals.

John Riggle, Advanced Product Engineering Manager of Steel Parts, took a different approach. Setting out to truly engineer the surface for a new clutch plate design, Riggle's team's goal was to develop a surface that would produce the best friction and wear performance. They would determine parameters that could uniquely describe the functional characteristics of the surface, then develop a process to hold tolerances on those parameters.

The team's first step was to examine a number of plate designs with known performance characteristics. Figure 4 shows the surfaces of several such designs. From correlation studies it was determined that skewness and kurtosis correlated well with wear and friction, as did several combinational parameters. Armed with these parameters, the team was able to develop, and control, a novel manufacturing process that ensured consisted part performance.

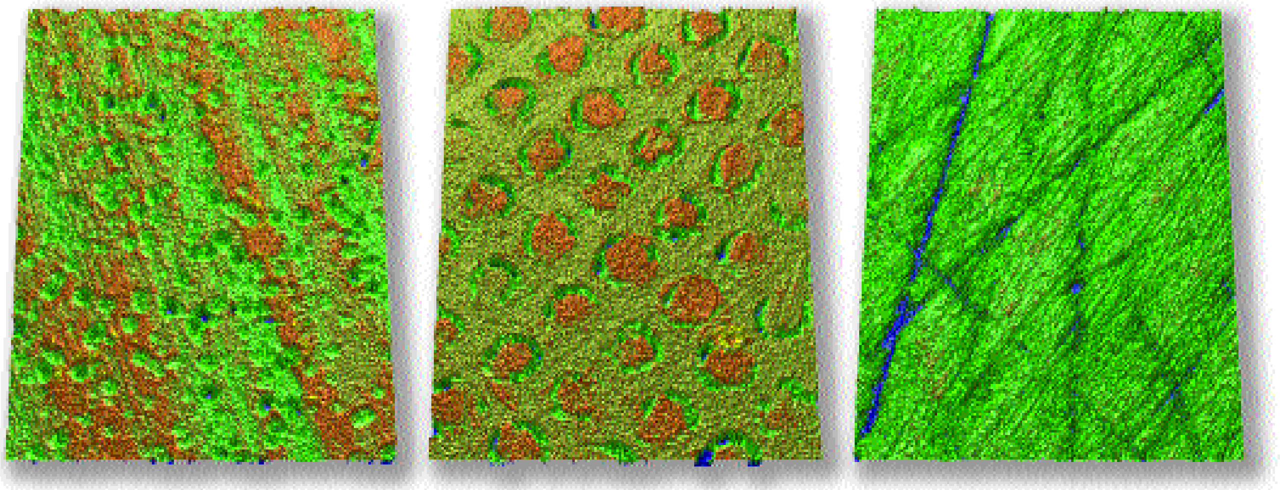

Figure 4. Experimental clutch plate designs. 3D parameters that describe and distinguish between these surfaces were used to drive process development.

Making the Move from Ra

While an engineering team may decide to use detailed 3D parameters to designate an acceptable surface, they may face obstacles from quality control and suppliers. "There is still some resistance to these techniques," says Don Cohen of Michigan Metrology, whose contract metrology and consultation services are often employed by engineering teams. "We find that R&D engineers take the time to fully understand a surface finish, yet the resultant product drawings only call out an average roughness tolerance. This is due, in part, to limited understanding of 3D parameters at the quality lab and process control level. But the advantages of 3D analysis compel engineers to employ it. So we are seeing a shift—these parameters are now making their way onto drawings, and suppliers are being held to these specifications. 3D parameters improve communication and hold a process in control in ways that Ra simply cannot."

Cohen added that the ISO community is currently working to establish standards for S parameters. The ISO/TC213 committee offers a number of useful information and links on the subject.

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 better understanding of functional characteristics, a more controllable process, and, ultimately, better surface performance.

■

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Footnote:

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