Photo: Pamela Simmons

REPLICA TAPE

Unlocking Hidden Information

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Steel surfaces are frequently cleaned by abrasive impact or by power tools prior to the application of protective coatings. This process removes previous coatings, mill scale, rust and contaminants. It also roughens the surface to improve coating adhesion.

The resultant surface profile, or anchor pattern, is composed of a complex pattern of peaks and valleys which must be accurately assessed to ensure compliance with job or contract specifications and ensure a successful coating project. It is generally accepted that the nature of these surfaces is predictive of long-term coating performance. Characteristics of a blasted surface include peak height, peak density, developed surface area, angularity, sharpness and shape.

Today, only peak height (H) is commonly measured. If this height is insufficient, paint will not adhere. If too great, more paint is required to fill the "valleys" and the high peaks may protrude through the paint to become foci for corrosion.

While the importance of measuring peak height is undeniable, one parameter alone does not fully describe the dynamics of a coating/substrate relationship. Peak density (P_d) is also an important indicator of performance and can now be measured thanks to recent developments in field instrumentation.

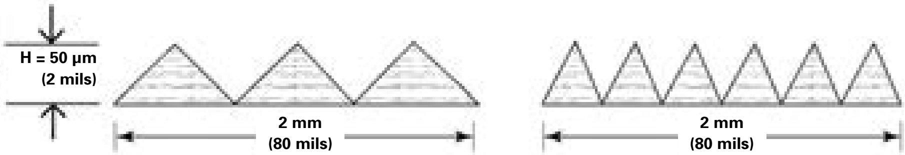


Fig. 1: Both surfaces have the same measured peak-to-valley height. A second important measurable parameter, peak density, helps explain why coatings bond differently to each surface.

Counting Peaks

In 1974, J.D. Kean, J.A. Bruno and R.E.F. Weaver wrote in an article titled, “Surface Profile for Anti-Corrosion Paints,” that a surface prepared for painting via blast cleaning could not be completely described by measuring peak-to-valley distance (H) alone. Their paper supported field experience which suggested that there was another important parameter besides H, namely, the number of peaks per unit length or peak count (P_c), or peaks per unit area or P_d. Besides increasing the bonding surface area, their paper explained that increasing the number of peaks in a defined area increased the angularity of that area. That put more shear adhesion stress on the coating rather than tension (pull-off) stress. This increased coating bond strength for the applied coating as shear values are always higher than tensile values. The applied coating, of course, must wet out 100 percent of the surface (“wet out” meaning wet the surface thoroughly).

Figure 1 is a simplified example of why both peak height and peak density are important in understanding coating performance. The two surfaces have different geometries yet their height measurements are the same. To get a clearer picture of the surface available for bonding, peak count measurements must also be obtained. Furthermore, both measured values make it possible to investigate the increase in surface area resulting from the abrasive blasting process.

There is little doubt that peak density measurements are important to the corrosion industry, but the problem until now is that peak counts have not been easy to determine.

In June of 2005, *JPCL* published a significant paper by Hugh J. Roper, Weaver and Joseph H. Brandon titled “The Effect of Peak Count on Surface Roughness on Coating Performance,” which reported that peak counts could be controlled and, like peak height, could affect coating performance. Their work resulted in the creation of ASTM D7127, “Standard Test Method for Measurement of Surface Roughness of Abrasive Blast Cleaned Metal Surfaces Using a Portable Stylus Instrument.”

In a follow-up article they concluded that “the optimum steel profiles for a wide range of standard industrial coatings that will completely wet the surfaces are a 2 to 3 mil (50 to 75 micron) profile height and a peak count between 110 and 150 peaks per inch (40 and 60 peaks per centimeter)”. The authors recommended that stylus roughness instruments, the best field instrument available at the time, be used in the corrosion industry to provide both critical pieces of profile information — peak height and peak density.

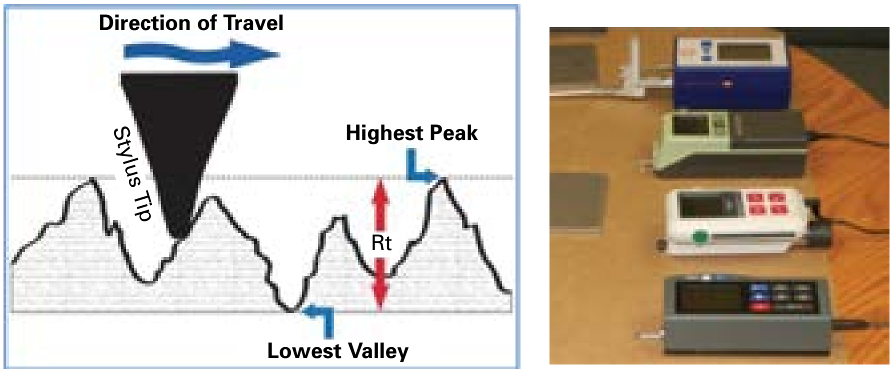


Fig. 2: Stylus roughness instruments.

Stylus Profilometers

Stylus roughness instruments record the up and down movements of an external stylus traversing across a surface (Fig. 2). They measure a height parameter called R_t in compliance with ISO 4287, “Geometrical Product Specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters,” which yields the vertical distance between the highest peak and lowest valley within any given evaluation length of 0.5 inches (12.5 mm). Five traces are made and R_t values averaged to obtain the average of the maximum peak-to-valley distances.

In 2011, an ASTM round-robin study (Research Report RR:D01-1169) determined peak-to-valley height R_t as measured by stylus roughness instruments related closely to H as measured by both depth micrometers and replica tape. But if

Fig. 3: Burnishing replica tape.

stylus roughness instruments could generate measurements of both peak height and the number of peaks encountered along a sampling length, why has the corrosion industry been slow to adopt them?

Likely this reluctance is based on economic and practical reasons. Stylus profilometers are fragile in nature since they depend on a precisely calibrated stylus that often extends a distance from the body of the device itself. They can be complex to set up and to operate and they report a number of roughness parameters that are of limited interest to the coatings industry. All these factors likely dissuade potential users.

A lesser known fact is that stylus-based roughness testers, although popular in metal machining industries, are challenged by the complex patterns generated by surface-cleaning operations. They measure only a single line on a roughened surface and most of the features recorded as peaks are actually peak "shoulders" where the stylus traced over the side of the peak rather than over the top of the peak.

What other measuring solutions are available? It is anecdotally believed within the corrosion industry that definitive measurement devices must use laboratory methods such as white light interferometry, focus variation microscopy, confocal laser microscopy or atomic force microscopy. But these powerful devices are also challenged when measuring complex blasted surfaces. They are costly to purchase, do not operate in the field, and require extensive training to set-up myriad test parameters for topographic analysis.

It is therefore desirable to have one affordable, robust field instrument designed specifically for the corrosion industry that can provide both H and P_d measurements to give inspectors a more meaningful and functionally correlative prediction of coating performance during surface preparation. The solution lies with replica tape.

Measuring Peak Density: A New Solution

Replica tape has been used to characterize surfaces since the late 1960s (Fig. 3). It is simple, relatively inexpensive and is particularly useful on curved surfaces. Its operation is described in a number of international standards including ASTM D4417, "Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel"; ISO 8503-5, "Preparation of steel substrates before application of paints and related products — Surface roughness characteristics of blast-cleaned steel substrates — Part 5: Replica tape method for the determination of the surface profile" and NACE RP0287, "Field Measurement of Surface Profile of Abrasive Blast-Cleaned Steel Surfaces Using a Replica Tape." Compared to other methods, it has the advantages of ruggedness, relatively low start-up cost, good repeatability and the ability to retain a physical replica of the surface being evaluated.

Replica tape is made of a layer of compressible foam affixed to an incompressible polyester substrate of a highly uniform thickness. When pressed against a roughened steel surface the foam collapses and forms an impression of the surface. Placing the compressed tape between the anvils of a micrometer thickness gage and subtracting the contribution of the incompressible substrate, 2 mils or 50.8 microns, gives a measure of surface profile height.

Accessing New Information

As common as this product is, it is not widely known that these surface replicas contain far more information than just peak height as measured by a micrometer. Significant data is available through digital imaging.

A new measurement approach is to use a property of the tape that is related to, but different from, its capacity to replicate surfaces; that is, the tape's increase in transparency where it is compressed. Using this principle, a three-dimensional map of the surface can be generated from an optical scan of the burnished replica tape. Peak counts can be determined by simply counting bright spots on the image taken by a digital image sensor.

A photograph of a back-lit piece of tape reveals light areas of higher compression (peaks) and dark areas of lower compression (valleys) (Fig. 4, p. 57). A portable instrument can identify peaks and determine areal peak density, that is, how many peaks are present per square millimeter, or P_d, as defined by ASME B46.1, "Surface Texture (Surface Roughness, Waviness, and Lay)."

3-D Surface Mapping

Going a step further, additional surface parameters can be extracted once the thickness/transparency relationship has been applied to the intensity image using 3-D rendering software. The result is a 3-D map of the blasted steel surface at a cost far less than interferometric or confocal profiling devices. An example of how the process works is shown in Figure 5 (p. 57) and Figure 7 (p. 59).

Correlating Replica Tape Measurements to Established Measurement Technique

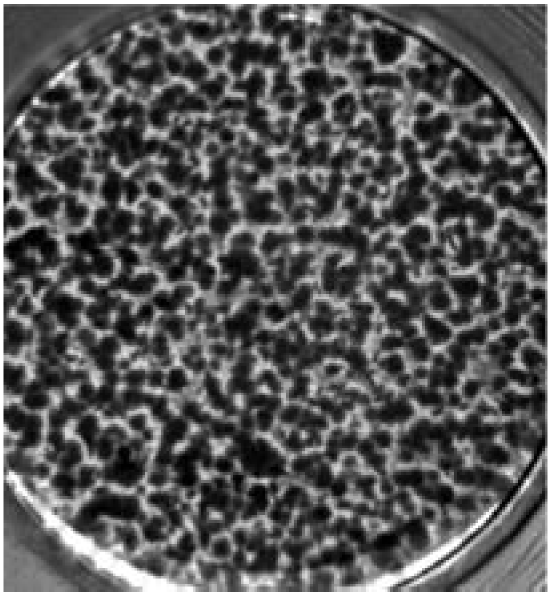
To validate 3-D replica tape measurements, the parameter measurements obtained from the tape (H and P_d) were compared to two established surface roughness measurement methods: confocal microscopy and stylus profilometry.

The first step taken was to confirm that light intensity imaging of replica tape yielded values comparable to those obtained using known laboratory methods. A study was carried out using three steel panels blasted with grit 50, garnet coarse, and shot 230/grit 40 media. The panels were sent to a university lab along with three sets of burnished replica tape for measurement with a confocal microscope. The 3-D replica tape measurements were found to closely correlate with the laboratory methods (Table 1, p. 58)

To compare measurements from 3-D replica tape images with those determined from stylus roughness instruments, measurements of peak density were taken on the five panels used in the 2011 ASTM round-robin study. Two-dimensional stylus profilometer measurements are not directly comparable with the 3-D optical replica tape measurements. However, a direct correlation was observed.

Adhesion Testing

Given the previous research by Roper and others on the correlation between adhesion and both H and P_d, an adhesion study was carried out to determine if 3-D replica tape imaging methods gave similar results. Twenty-five steel samples were prepared using a variety of blast media and measurements were performed with the 3-D replica tape imager. The samples were then sprayed with three coatings: an epoxy, a two-component acrylic and a polymer composite coating, and allowed to cure. Three pull-off adhesion tests were then performed on each sample following the test method described in ASTM D4541, "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers" using a Type V hydraulic pull-off adhesion tester described in Annex A4 (Test Method E) of that standard.



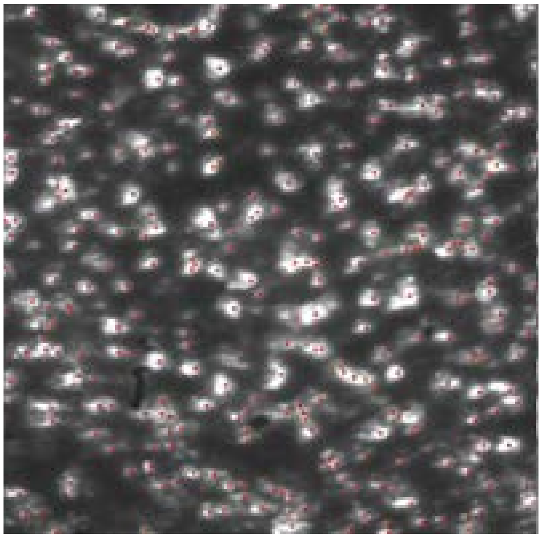


Fig. 4: This figure depicts a 2-D image derived from replica tape (above) and digitally counting bright spots or peaks (right).

Correlation of Adhesion with Surface Profile Height

In the 2006 Roper et al. paper, it was theorized that "the optimum steel profiles for a wide range of standard industrial coatings that will completely

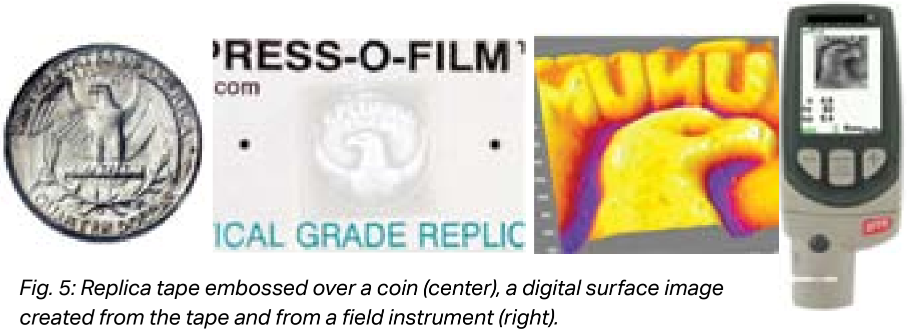


Fig. 5: Replica tape embossed over a coin (center), a digital surface image created from the tape and from a field instrument (right).

wet the surfaces are a 2- to 3-mil (50- to 75-micron) profile height". The highest adhesion strengths were observed in the 2 to 3 mil range with adhesion values decreasing as profile heights increased above 3 mils, likely because the coating failed to fully wet the substrate. The observations in this study appear to affirm this hypothesis although no samples were taken with profile heights below 2 mils. It is theorized that adhesion levels would begin to decrease below this figure because of insufficient profile to anchor the coating. A hypothetical trend line, with P_d held constant, is overlaid on this study's data in Figure 6.

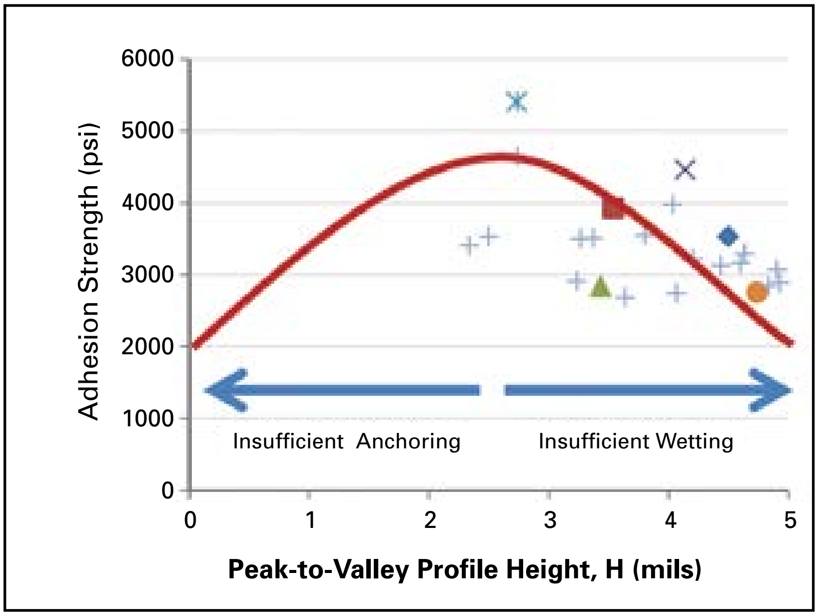


Fig. 6: Observed peak-to-valley profile height versus adhesion strength for various blast media types with hypothesized trend and justification.

Table: 1: Comparison of Peak Density (P_d) Calculations Between a Field and a Lab Instument

Sample	Field Instrument RTR-P (peaks/mm^2)	Lab @ 1000 µm^2 (peaks/mm^2)
G50	25	34
Garnet Coarse	11.8	13.8
S230/G40	8.3	7.6

Correlation of Adhesion with Peak Density (P_d)

There appears be a strong positive correlation between peak density and adhesion, reinforcing Roper's hypothesis that peak count is relevant to coating performance. Their paper asserted "the optimum steel profiles for a wide range of standard industrial coatings that will completely wet the surfaces are … a peak count between 110 and 150 peaks/in (40 and 60 peaks/cm)."

As stated earlier, a stylus profilometer counts the number of peaks in a straight line (expressed in millimeters) whereas a replica tape reader counts peaks in a unit of area (expressed in square millimeters). Since those authors used a stylus profilometer in their research, their numbers are not directly comparable to the data in this

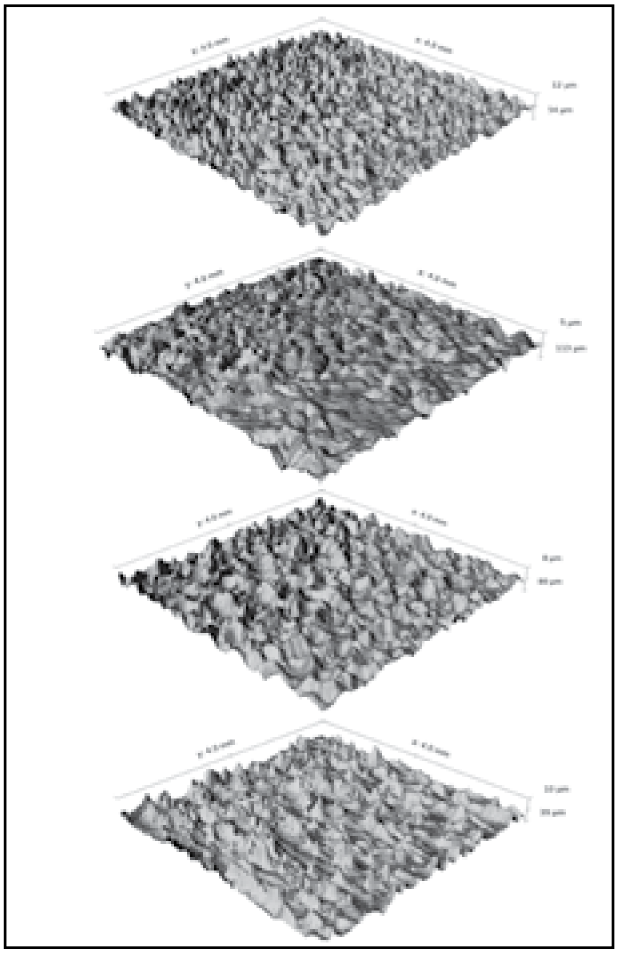


Fig. 7: 3-D images of blasted surfaces derived from replica tape using a field instrument. In order from top: G50, Garnet, S230/G40 and hand-held bristle blasting tool. (Z-axis enhanced for clarity.)

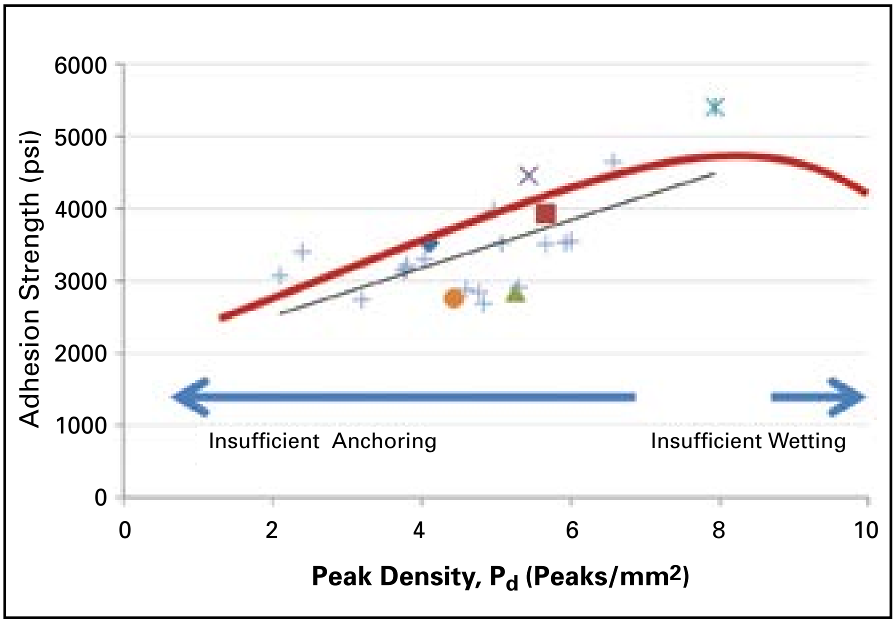


Fig. 8: Observed peak density versus adhesion strength with hypothesized trend and justification.

study. However, based on our study, an optimal 3-D peak density of around 8 peaks per square millimeter was observed. It is hypothesized that the observed positive relationship between adhesion strength and peak density would not persist at peak densities greater than those observed in this study. This theorized relationship between adhesion and P_d with H held constant is shown in Figure 8.

Conclusion

It is generally accepted that the nature of abrasive blast cleaned steel surfaces is predictive of long-term coating performance. The corrosion industry does not fully understand the dynamics of this complex problem but it has several measurable parameters available to it, including peak height, peak density, surface area, angularity, sharpness and shape. Commonly held industry beliefs would suggest that increasing several of these parameters will improve long term coating performance. Empirical data suggests it is not that simple.

The most important of these parameters, H, is commonly measured today and is usually the only parameter reported. While its importance is undeniable, one parameter alone does not fully describe the dynamics of a coating/substrate relationship.

P_d is also an important indicator of performance. While it also cannot be a sole measure like H has been for several decades, together with H it provides a better prediction of long-term coating performance as measured by pull-off adhesion testing.

$$A = f(H, P_d)$$

This relationship helps to explain why H measurements alone have not always been a reliable method for predicting performance for all coating types. A coating may bond to a surface with low H and high P_d just as well as to one with high H and low P_d. For this reason the corrosion industry should report both values so that customers can determine the best ratio for their particular coating application. Both parameters are controlled with the proper selection of abrasive material type and size. Perhaps a hybrid parameter will be specified in the future.

About the Author

David Beamish is the president of DeFelsko Corporation, a manufacturer of hand-held coating test instruments sold globally. He has a degree in civil engineering and more than 27 years of experience in the design, manufacture and marketing of these instruments in a variety of international industries including industrial painting, quality inspection, and manufacturing. Beamish conducts training seminars and is an active member of various organizations including SSPC, NACE, ASTM and ISO. ***JPCL***