

Effect of Steel Surface Profile Peak Density on Rust Creepage

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ABSTRACT

Rust creepage or undercutting from a discontinuity in a coating film, such as scribe or holiday, is an important mode of coating degradation on steel substrates. The mechanism of rust creepage is attributed to cathodic disbondment. This paper describes an experimental study of the influence of steel substrate topography, measured with a digital replica tape reader, on rust creepage. For the two coating systems that were studied, it was found that rust creepage was strongly inversely correlated with substrate peak density.

Key words: profile, profilometer, roughness, rugosity, tortuosity, topography, adhesion, cathodic disbondment, coating, replica tape, peak count, peak density, delamination

Definitions

The following terms used in this paper are defined as follows:

Disbondment: The loss of adhesion between a coating and the substrate.

Rust Creepage (Undercutting): The spread of corrosion or disbondment from a scribe or holiday in a coating film.

INTRODUCTION

The spread of disbondment or corrosion from a scribe or holiday in a coating film, for which the terms rust creepage or undercutting are used in this paper is an important mechanism of coating degradation. The mechanism of rust creepage has been well studied by several authors who concur that the

mechanism is driven by electrochemical reactions¹⁵. The reactions occurring at the discontinuity in the coating (scribe or holiday) involve an anodic reaction in which iron is dissolved. Adjacent to the anodic region, under the coating, a cathodic reaction occurs in which oxygen is reduced to hydroxyl ions. The negatively charged hydroxyl ions formed underneath the coating attract cations to the cathodic areas. It is thought that the combined destructive effect of an alkaline environment, peroxides, and free radicals weakens the bond between the coating and the substrate. This causes a 'cathodic disbondment' front to advance from the discontinuity into the intact coating regions which undercut the coating. As well as undercutting, blistering may also occur near the discontinuity. The term 'cathodic disbondment' is also used to describe the similarly electrochemically driven disbondment that occurs at a discontinuity ('holiday') in a coating under applied cathodic protection.

Background

It is well understood that surface profile height is important to achieve adequate coating adhesion. In a 2006 study by Roper et al.⁸, it was theorized 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". Surface profile height specifications typically fall within this range.

While nearly any blasting process can yield surface profile heights in the 2 to 3 mil (50 to 75 micron) range, they often produce very different surface geometries. Intuitively, a coating on a surface with few peaks will have weaker adhesion strength than one on a surface with many peaks, despite the profile heights being identical. The normal industry practice of measuring only profile height leaves the applicator unaware of this variance. For example, the two idealized surface profile cross-sections shown in Figure 1 would yield the same peak height measurements, despite the significant difference in the nature of their surfaces.

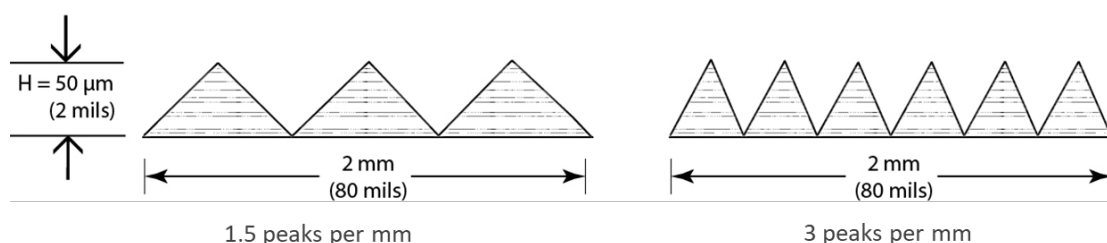


Figure 1: An example of two surface profile cross-sections that would provide identical peak height measurements

Coating product data sheets and job specifications usually require the surface profile to be "angular" or "jagged". In these documents, guidance is rarely provided regarding how to determine if the profile or abrasive operating mix is sufficiently "angular".

It is clear that while surface profile height is an important variable, more parameters are needed to characterize a surface and predict adhesion. Peak count (Rpc) is defined as "The number of peak/valley pairs per unit distance". Roper et al.⁸ experimentally studied the effect of peak count on coating performance. They prepared three sets of steel panels using three different steel grit operating mixes while holding peak height constant so that each of the sets of the panels had a different peak count but the same peak height. The panels were coated with six types of coating and exposed for 5,000 hours in two accelerated salt fog test environments as listed in Table 1.

Table 1: Coating Types and Test Exposures⁸

Label	Coating Type	Thickness (μm)	Test Environment
A	Polyurethane hybrid	500	ASTM B117
B	Polyurethane	500	ASTM B117
C	Polyurethane modified	500	ASTM B117
D	Epoxy	175	ASTM B117
E	Phenolic high-temperature immersion grade	375	ASTM D 5894
F	Phenolic	325	ASTM B117

The rust creepage data that Roper⁸ originally published in tabular format in 2005 were re-examined at the start of this study to investigate the relationship between peak count and rust creepage. These data are represented graphically in Figure 2 below to illustrate the correlation.

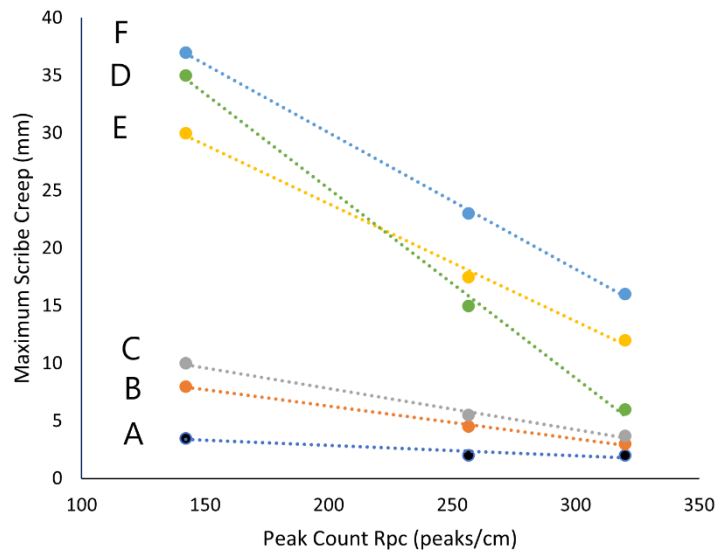
**Figure 2: Plot showing the influence of peak count on rust creepage⁸**

Figure 2 clearly shows that for all six coating types in Roper's experiment, in which all variables except peak count were held constant, rust creepage was almost perfectly inversely correlated with peak count ($r^2 > 0.99$). Other data in the study also show a positive correlation between peak count and pull-off adhesion strength. The Roper paper also noted that for some coatings, the pull-off strength weakened at high peak count values. The authors theorized this was due to insufficient wetting of the substrate. It was theorized that, much like for peak height, the greatest pull-off adhesion strengths occurred in the intermediate peak counts range, and that higher peak counts are not necessarily better. The usefulness of the Roper study to the industry when it was published was limited by the fact that no field-ready instrument was then available to measure peak counts. The stylus profilometer-type instruments, like those that were used in Roper's study, are relatively fragile and require a complex setup.

Several subsequent papers have reinforced Roper's findings. In 2015, Beamish⁹ found that pull-off adhesion strengths were greatest in the 2 to 3 mil profile height range cited in the Roper paper, and also observed a clear positive correlation between pull-off adhesion strength and peak count. This paper used a new, field-ready instrument capable of measuring peak count that had become available after the publication of the Roper study. The instrument was a digital replica tape reader.

A 2011 study of a liquid applied epoxy coating applied on blasted steel by Weinel et al.⁷ demonstrated that the rate of cathodic disbondment was strongly correlated with the substrate tortuosity. In 2016, Hagen et al.¹² published a study in which it was found that cathodic disbondment decreased as blasted surface

interfacial area (Sdr) increased. In the Hagen study, a stylus profilometer was used for the measurement of surface topography. In 2018 Draper et al.¹⁰ published a study in which it was also found that fusion bonded epoxy coating cathodic disbondment decreased with increased Sdr. A digital replica tape reader was used for surface topography measurements in the latter study.

Measuring Surface Topography

Replica tape is a layer of crushable plastic micro-foam coated onto an incompressible polyester substrate of even thickness. Different grades of replica tape are available for different ranges of profile height. 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, often termed 'Profile'. This method is widely used in the coating industry and standardized in NACE SP0287⁴ and ASTM D4417³ Method C.

A new measurement approach is to use a property of the replica 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.



Figure 3: Photograph of a digital replica tape reader

By passing a beam of light through an optical grade replica tape, a digital tape reader, like that in Figure 3, can capture a digital image of the surface. The tape reader uses an algorithm that converts light intensity to height, thus generating a 3D map of the surface. From this map, surface roughness parameters can be extracted, including 2D 'R' parameters equivalent to those measured by a drag stylus instrument and 3D 'S' parameters equivalent to those measured by optical imaging techniques. These parameters are defined in the digital replica tape reader documentation and standards such as ISO 25178⁵. A brief guide to the parameters is provided in Table 2 below.

Digital imaging, while an established non-destructive examination method in some industries, has not been standardized for inspection of steel surfaces by the coating industry. The digital replica tape imaging measurements have been validated against measurements obtained using confocal microscopy, the industry-standard laboratory technique for surface imaging.