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# **Thermal Spray Coatings – Effect of Selected Coating Parameters on Corrosion Resistance**

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## **Abstract**

Thermal Spray coatings have long been adopted as a surface modification technique. Unique in their ability to mechanically bond to the surface of most substrate materials, the Thermal Spray coatings offer a generic solution to improving mechanical, corrosion or tribo-corrosion properties of the affected substrate material. Of the available systems, Flame Spray techniques offer the simplest and most cost-effective method of applying these coatings. In the current study, an investigation was conducted into the comparative performance of a selection of these coating systems – a polymer coating, with various coating thicknesses, and a metallic coating - in a number of Corrosion Test environments, when applied to a Mild Steel Alloy. The effect of chlorides on the life-to-failure of these systems is predicted and reviewed. Electrochemical Impedance Spectroscopy and Immersion Testing were carried out, in conjunction with microscopic and metallographic studies. Using these combined methodologies, it has been shown that the efficacy of the Thermal Spray coatings reviewed is dependent on both the inherent nature of the coating material and the coating thickness.

## **Introduction**

Development in surface engineering processes has resulted in the growth of new technologies for increase of wear resistance, corrosion resistance and for aesthetic function. Besides the traditional processes – surface hardening, carburising, nitriding etc, a number of advanced physical technologies have been developed and are being increasingly used, like the laser and plasma assisted processes. For engineers – especially in design and in definition of production processes - the right choice of appropriate surface treatment is a very important task. Indeed, the development of new coatings and application processes is generally accompanied, or even preceded by, the introduction of newer environments which are more aggressive and provide more stringent tests. Nowadays in this field, a lack of adequately prepared guidance and expert proposals is evident.

The two most aggressive forms of material loss are Corrosion and Wear but, in applications where these two elements work in tandem, the results can be catastrophic. It is impossible to deduce the environmentally influenced mechanical behaviour of a system from its behaviour in separate corrosion and erosion experiments<sup>i</sup> as corrosion, which can be either “synergistic” or “additive”<sup>ii</sup>, may have only minimal impact on certain systems, such as aerospace coatings, but, when incorporated into a mechanical abrasive test, can lead catastrophic failure. Likewise, the wear characteristics of an engineered surface may have exemplary resistance to deterioration but the introduction of a corrosive element may ultimately lead to the untimely and premature failure of the system. The dynamic nature of these aggressive systems has compelled both industry and academia to address the short-comings of the traditional surface modification techniques.

Engineering Coating Development can be loosely categorised under the following headings:

- Organic Coatings, including systems embedded into an organic matrix
- Thermal Spray Coatings
- Vapour Deposition Coatings
- Chemical/Electrodeposition Coatings

One of the most aggressive forms of mechanical and chemical attack on a surface, leading to extensive material loss, is termed Tribocorrosion. This is a complex degradation process, affecting surface and near-surface material, which results from the combined effects of mechanical loading and environmental influences and many aspects of the phenomenon remain to be elucidated. In terms of the magnitude of the material loss, the effect of corrosion on erosion (often referred to as synergy) is a much more prominent feature for both materials.<sup>iii</sup> The areas of tribocorrosion under consideration are erosion-corrosion, abrasion-corrosion, cavitation-corrosion and flow-induced corrosion<sup>iv</sup>. Although its cost to the industrialised world has not yet been fully quantified, the cost of corrosion to national GNPs runs between 3% and 5%<sup>v</sup>.

## **Experimental**

### ***Test Panels***

- Mild Steel was chosen as the substrate material, due to its widespread use in industry.
- The Test Panels were machined from flat plate, to a size of 100mm x 130mm.

- A total of 30 test panels were produced.

### ***Pre-Treatment***

#### *Cleaning and de-greasing*

Prior to the coating treatment, the panels were Grit Blast, using a 60/40 Fe<sub>2</sub>O<sub>3</sub>/Al<sub>2</sub>O<sub>3</sub> Grit Blend.

### ***Coating Application***

Two distinct coating types were applied to different test panels. A polymer coating, in the EverTuff range, and an Inconel 625 coating; both supplied by Castolin Eutectic. Coating application is described below:

#### EverTuff ET 11:

- Was applied using a TeroDyn System 3500(Figure 1), produced and supplied by Castolin Eutectic
- Coatings were applied at two thicknesses - ~100µm and ~350µm



Figure 1 TeroDyn System 3500

#### Inconel 625

- Was applied with the CDS 8000 system(Figure 2), produced and supplied by Castolin Eutectic
- Coating thickness were to be 90-110µm



Figure 2 CDS 8000 Flame Spray gun

### ***Sample Preparation – Cross Sections***

- Cross Sections(CS), taken from an untested panel of each coating, were mounted in an epoxy resin (Sampl-Kwick fast cure acrylic resin, produced by Buehler).
- The CS samples were then ground to a 1200 SiC grit finish, followed by polishing in successively finer grades of diamond paste (Buehler Sample Preparation system) to a 0.05 micron finish.
- Samples were then etched for 5 minutes in a 2% Nital solution.

### ***Hardness Testing***

CS Samples for each coating system were Hardness Tested, using the Buehler Micromet II Microhardness Indentor, as outlined in ASTM E384-99e1 : Standard Test Method for Microindentation Hardness of Materials.

### ***Coating Thickness Measurements***

Coating Thicknesses were measured on CS samples of each coating system using optical microscopy and PC-based image capturing software.

### ***Corrosion Testing***

#### ***EIS Testing***

Short-Term Corrosion Testing was carried out using EIS (Electrochemical Impedance Spectroscopy) and was performed for 4 wks. The solution was chosen on the basis of the Long Term Test regimes:

- 0.5M NaCl

#### ***Immersion Testing***

A single panel , per coating, was tested in each environment. The Immersion Testing was performed for 6 weeks in three separate environments:

<b>Test</b>	<b>Environment</b>
pH 3	Acetic Acid [CH <sub>3</sub> OOH]
pH 7	NH <sub>4</sub> CL
pH 12	Na OH

**Table 1** : The Immersion (Corrosion) Test Environments

## **Results and Discussion**

Micrographic examination results are displayed in Figure 3. It can be noted from these images that while the polymer coating (i and ii) has good interfacial integrity and no apparent porosity, the Inconel 625 coating has extensive porosity and does not adhere well to the surface of the substrate. This is typical of this process and has been found by numerous other authors<sup>viii</sup>. The implication of this is that these coatings tend to have poor corrosion

resistance<sup>viii</sup>. A number of methods are used to overcome this issue. With metallic coatings it is possible to fuse the coating, post application. This involves re-heating the coating to plastic region of the material, thus allowing flow in the coating, causing voids and pores to close and providing a better interfacial bond with the substrate. An alternative method is to

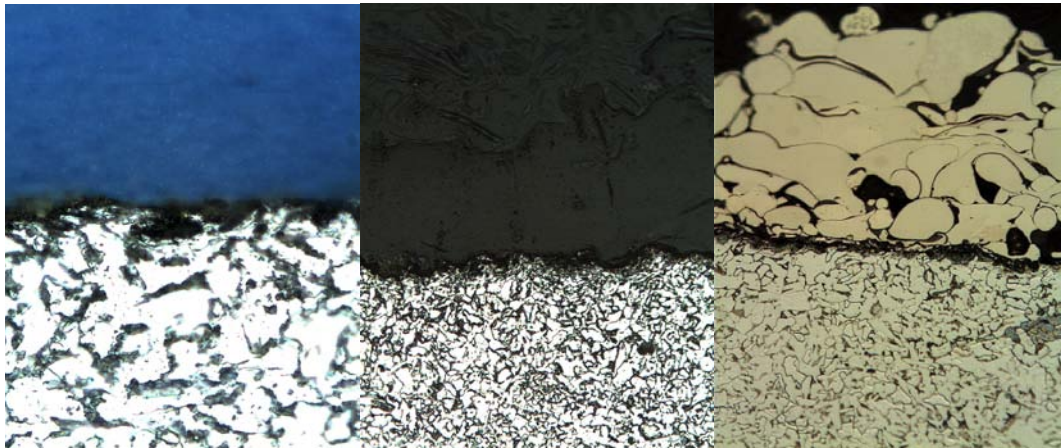


Figure 3 Micrographs showing Polymer Coating (i) 350m[500x] (ii) 100m[200x] and (iii) Inconel 625[200x]

use self-fluxing powders, which are a type of thermal spraying material, having functions of self-deoxidization and self-slag formation when melting.

The EIS testing was carried out in a typically marine environment (0.5M NaCl). Whilst this is a very aggressive environment, it can be seen (Figure 4) that the thick(>300µm) polymer

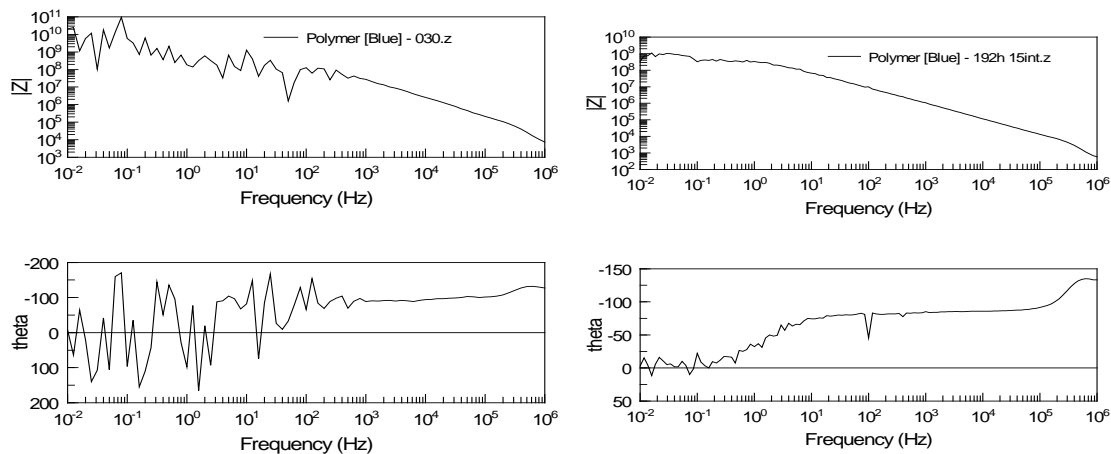


Figure 4 EIS Results for Polymer Coating (>300m) (i) 30 hr (ii) 192 hr

coating maintained elevated resistance to the corrosive environments ( $10^{-9}\Omega\text{cm}^{-2}$ ) over the duration of the test). The noise at the lower frequencies is typical of coatings with very high impedance readings. The reason for this high level of resistance is associated with the high level of integrity in the coating, along with the greater thickness. For the thinner coating (100µm), initial resistance to degradation was high but this began to drop after 96 hrs in

solution. It is suggested that the thinner coatings suffer from a greater occurrence of through-defects, resulting in a greater propensity to attack in aggressive environments. This can also be seen with the Inconel 625 samples (Figure 5), where coating thickness was also in the

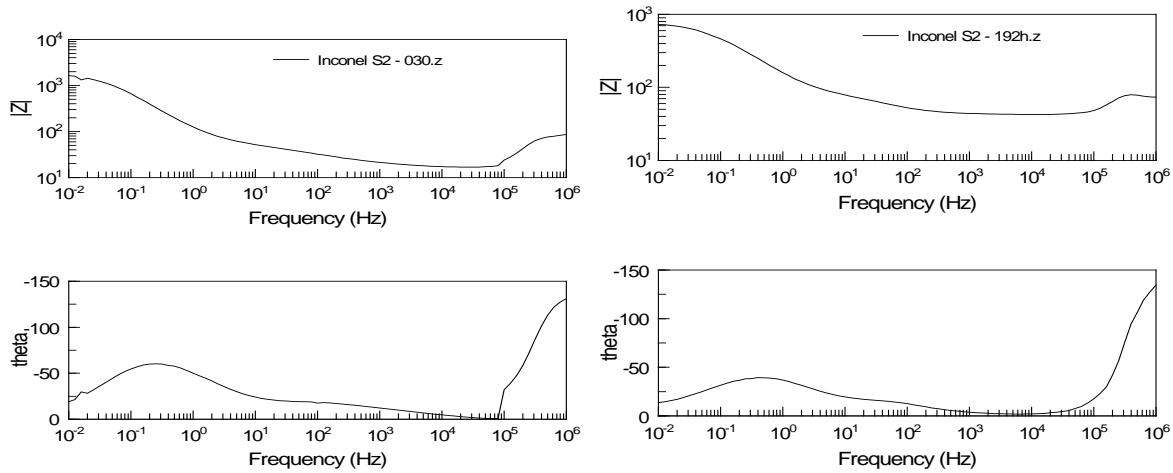


Figure 5 EIS Results for Inconel 625 Coating after (i) 30 hours (ii) 192 hours

region of 100µm, with obvious inhomogeneities occurring in the coatings, such as porosity

Reading	Inconel 625	EverTuff ET 11
1	87.2	1.85
2	81.4	2.06
3	120.6	2.13
4	93.5	1.95
5	59.1	1.68
Average	88.36	1.54

Table 2 Table showing microhardness results for the coatings.

through the coating and interfacial anomalies suggesting poor adhesion, resulting in through-coating defects and limited or no resistance to chemical attack, with an initial impedance value of  $10^{-3} \Omega \text{cm}^{-2}$ . It was initially assumed that the organic

(polymer) coatings would have superior corrosion resistance, though it can be seen from these results that the integrity of the coating is very dependent on the thickness.

Microhardness results are shown in Table 2. This is an important property and has been related back to coating integrity by some authors<sup>ix</sup>. The disparity between the metallic and polymer coatings is as expected and needs no further analysis. Attempts to quantify the adhesion properties of the coatings, using the Dolly Pull Test (ASTM D4541) produced unquantifiable results, as all of the failure occurred at the adhesive/dolly interface between, and are therefore not reported here.



## Conclusions

The work detailed in this paper looked at the effect of coating type and coating thickness on the corrosion behaviour of selected Flame Spray coating materials. An organic and a metallic coating were chosen for the analysis.

It was found that the coating thickness for polymer had a dramatic effect, resulting in the initialisation of corrosion failure in the thinner coating after 96 hrs. It was also found that the use on non-self-fluxing metallic coatings (Inconel 625) resulted in a coating with a large degree of porosity and interfacial inhomogeneties.

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