Influence of thermal spraying parameters on the corrosion resistance of aluminium oxide coatings deposited on steel 1020

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Abstract. Parameters required for the preparation of coatings of aluminium oxide deposited on AISI 1020 steels were determined according to their thickness and type of flame to differentiate their behaviour against corrosion. Commercial powders were used by the method of thermal spraying deposition. The coatings were analysed by OM (optical microscopy), the thickness was measured by means of a coating thickness gauge and electrochemical techniques variables measured was the Linear Polarization Resistance (LPR) and approximation Tafel potentiodynamic curves. The corrosion current for steel 1020 with Na₂SO₄ electrolyte of 3.5% is of the order of hundreds of $\frac{A}{cm^2}$ and coated steel given in the order of $\frac{A}{cm^2}$, which leads to think that the projection produces coatings uniform low closed porosity, although techniques DC indicate a significant porosity as is observable current response to the potentiodynamic curve. The observed thicknesses fall into the hundreds of microns and little uniformity was noted in this coatings. The coatings deposited by oxidizing flame was better performance in corrosion than the coating deposited by neutral flame.

1. Introduction
An Alumina coatings improve the tribological properties of the substrates where it is deposited and increasing the corrosion resistance of metallic materials that are subject to aggressive environments [1].

Thermal spraying is an effective method to obtain coatings of aluminium oxide as it is conducted at temperatures which allow melt the alumina in powder form, producing coatings with good adhesion and uniform porosity that allows its use in applications of thermal barrier with a very good mechanical performance and outstanding corrosion resistance [2].

Alumina based coatings have been described as uneven in their thickness and with remarkable levels of porosity, as well as excellent mechanical performance but with a bond to the anchoring layer (nickel-based) that can present problems [2].

The purpose of this work is to characterize the corrosion behaviour of Al₂O₃ coatings on 1020 steel using potentiodynamic curves and linear polarization resistance measures, which give us evidence of coating performance in aggressive media, in addition to observing the effect of thickness on electrochemical measurements.

2. Methodology
1020 steel coupons, 1 inch in diameter and 1 cm high, were used. This was surface prepared with sandblasting, so as to have a surface free of impurities and adequate roughness allowing better adherence.
Preheating the substrate to a temperature of 130°C was made, thereby eliminating moisture and improve adhesion. A first thermal spray coating is made, Ultrabond 50000, a Ni-based alloy [3], over which a layer of Al₂O₃ is deposited using two different flame conditions (neutral and oxidizing flame).

To the coated specimens were performed thickness measurements and electrochemical tests in order to find correlation between thicknesses (given by the number of layers) and type of flame (see Table 1).

### 2.1. Experimental design

The average coating thickness was calculated over multiples measurements using a magnetic thickness gauge following SSPC PA_2, dry thickness magnetic gages.

Table 1. The flame was characterized by means of gases fluxes and the rate of powder.

| Flame          | Neutral | Oxidizing |
|----------------|---------|-----------|
| Powder Flux    | 40 g/min| 40 g/min  |
| Argon Pressure | 20 psi  | 12 psi    |
| Argon Flux     | 15 L/min| 8 L/min   |
| O₂ Pressure    | 60 psi  | 100 psi   |
| O₂ Flux        | 6 L/min | 11 L/min  |
| C₂H₂ Pressure  | 5 psi   | 5 psi     |
| C₂H₂ Flux      | 10 L/min| 10 L/min  |

The experimental matrix considered two factors (Table 2), type of flame, with two levels, neutral and oxidizing flame; and thickness average, with three levels, 2 layers, 4 layers and 6 layers (determinates for the number of pass of the deposition mechanism).

Table 2. Experimental Matrix.

| Anchoring mechanism | Flame | Layers | Average thickness (m) |
|---------------------|-------|--------|-----------------------|
|                     | UltraBond50000 | 100 m aprox. |
| UltraBond50000      | Neutral | 2      | 46,32                 |
|                     | Neutral | 4      | 106,53                |
|                     | Neutral | 6      | 134,33                |
|                     | Oxidizing | 2      | 46,32                 |
|                     | Oxidizing | 4      | 106,53                |
|                     | Oxidizing | 6      | 134,33                |

### 2.2. Materials and methods

For the electrochemical test was used Na₂SO₄ electrolyte of 3.5%, a scan rate of 2mV/s, an exposed area of 0,93cm² with a sweep from -500mV to +500mV with respect to Ecorr. The steel was previously characterized by means of arc spectroscopy and other experimental details are summarized immediately.

#### 2.2.1. Thermal spray process

In this process the powder on oxyfuel flame (oxy-acetylene), where it is melted and led by a jet of air and the flame to the workpiece, is fed. The particle velocity is relatively low (<100m/s) and the adhesion force of the deposits is generally less than faster processes. The porosity may be high and the cohesive force is generally lower. The deposition rate is 0.5 to 9kg/hour while materials with low melting point can be sprayed at higher deposition rates. The substrate temperature can be quite high [4].

#### 2.2.2. Experimental equipment

2.2.2.1. Thermal spray equipment. The equipment, located in the laboratories of Metallurgy Engineering (UPTC, Tunja, Colombia), consists of a closed chamber, a gun CastoDyn DS 8000™ with a programmable mechanism through LabView™ that automates the process of spraying.
2.2.2. Electrochemical equipment. The Gamry G-750 Potentiostan-Galvanostats, an electrode Ag/AgCl and a flat electrochemical cell was used for generate the potentiodynamics and LPR curves and is located in the Materials Lab of the Universidad Antonio Nariño, Tunja, Colombia.

2.2.2.3. Magnetic thickness gauge. Al₂O₃ coating Thickness can be measured on magnetic 1020 steel surfaces using a digital Elcometer™ coating thickness gauge. The principle of electromagnetic induction is used for non-magnetic coatings, like Al₂O₃, on magnetic substrates such as steel + Ultrabond 50000.

3. Results
The obtained results were resume in the next potentiodynamics graphics and in the Table 3. In the potentiodynamics graphics, the x axis is the base 10 logarithm of current (Amperes) and the y axis is the Potential E in Volts (see Figure 1).

3.1. Potentiodynamics curves
The potentiodynamics curves have different behaviour depending on the type of flame deposition. Likewise it shows its variation depending on the number of deposited layers.

![Figure 1](image1.png)

(a) (b)

*Figure 1*. Curves for Neutral (a) and Oxidizing flame (b) for the different number of layers.

3.2. Resume for experimental data obtained
The main response variables for each experiment were the corrosion and current potential, anodic and cathodic pending by means of Tafel approximation and LPR, obtained by linear regression.

| Flame   | Layers | Ecorr (mV) | Icorr (A/cm²) | a (mV/dec) | c (mV/dec) | CR (mm/y) | LPR (*cm²) |
|---------|--------|------------|---------------|------------|------------|------------|------------|
| Neutral | 2      | -666,61    | 69,85         | 184,5      | -612,0     | 0,8132     | 177,28     |
| Neutral | 4      | -622,48    | 51,48         | 336,2      | -185,0     | 0,5993     | 229,89     |
| Neutral | 6      | -536,48    | 15,34         | 237,4      | -302,5     | 0,1785     | 345,49     |
| Oxidizing | 2   | -627,98    | 29,00         | 168,2      | -326,8     | 0,3376     | 286,19     |
| Oxidizing | 4   | -539,12    | 11,42         | 317,4      | -651,7     | 0,1330     | 360,92     |
| Oxidizing | 6   | -496,62    | 3,25          | 251,5      | -572,7     | 0,0378     | 440,97     |
4. Discussion
Comparisons for each factor are made in the graphs below. The scale for each plot is particular, but it indicates the change in the response variable for each of the considered factors. 

In the Figure 2 it is compared the corrosion current for the two types of flame. It shows that as the number of layers decreases, current value is increased.

The best performance of coatings applied with oxidizing flame is evident if is considered a constant thickness. It follows that the oxidizing flames generate less porous coatings respect to neutral flame, which contributes to better sealing and therefore the barrier effect is better, reducing the redox processes of the steel substrate (see Figure 3).

5. Conclusions
Given that the thermal spraying is a method that generates coatings whose purpose is to reduce wear [2], it is also true that they have remarkable porosity and corrosion performance is improved if the number of layers is increased as it improves the sealing of the film. The porosity thus decreases.

The anchoring layer based on nickel and deposited with oxidizing flame [2], has better compatibility with oxidizing flame deposition. This indicates that the additional oxygen in the deposition inhibits chemically reacts with the electrolyte.

By increasing the number of layers, therefore the thickness, the corrosion potential tends to passive states, that is, its value decreases in magnitude in both types of flame.

The thickness has an ohmic behaviour when considering that as the number of layers increases, the corrosion current decreases and the lineal polarization resistance increases.

References
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