Evaluation of tribological wear and corrosion in coatings of diamalloy 4060NS deposited by thermal spray

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Abstract. Surface engineering seeks the development of new techniques to improve the performance and life of components of machines or industrial facilities, always looking for low costs and the least possible environmental damage. Thermal projection is one of the techniques that is based on the projection of particles of compounds and alloys on properly prepared and heated substrates, these particles are driven by a stream of air passing through an oxyacetylene flame which gives the energy to the process; These coatings give the possibility to improve the properties of the materials or the maintenance of components to maximize the availability of service. In order to reduce the damage caused by wear and corrosion of a low carbon AISI 1020 steel, they were coated with a metal based alloy, studying the effect of the cobalt-chromium-silicon-tungsten carbide alloy coating (DIAMALLOY 4060 NS). The coating was deposited with two different pressures in the gases supplied to the torch, obtaining two flames and working three thicknesses of coating that oscillate between 100-500μm, according to the number of deposited layers, making use of a projection gun Castolin Eutectic. Powder and substrate characterization was performed using X-Ray Diffraction (XRD) techniques, X-Ray Fluorescence (XRF), Scanning Electron Microscopy (SEM), spark emission spectroscopy and metallographic analysis. The results confirm the chemical nature and structure of the powder of the alloy and the substrate to be used, in addition, the thermal stability of the system was verified. The evaluation of the adhesion of the deposited layers was carried out by the implementation of pull-off tests according to ASTM D4541, in order to determine the type of failure that is presented. Mechanical wear was determined using a MT/60/NI microtest tribometer while electrochemical tests were performed using a suitable experimental unit for this purpose, confirming that the substrate exhibits lower wear levels when coated with Layers between 300-400μm, demonstrating that the implemented methodology allows to reduce the process of wear of mechanical parts subjected to aggressive operating conditions.

1. Introduction
Thermal spray coatings are widely used throughout the world; however, Colombian industry has not adopted this technique yet, as a common method to combat corrosion, wear and thermal fatigue. This is due to the lack of knowledge regarding the benefits of thermal projection. Another reason is that the medium and small metallurgical companies consider that this technique is expensive and opt for other alternatives less expensive, like paintings of high performance. Although the costs of these coatings are apparently high, the increase in efficiency is approximately 1.5 times higher than in high-performance paint systems [1].

In order to extend and improve the properties of an AISI 1020 steel, the projection parameters of the cobalt-chromium-silicon-tungsten carbide alloy (DIAMALLOY 4060 NS) were determined and
deposited with two gas pressures supplied to the torch, obtaining two flames with three coating thicknesses ranging from 100-500μm, depending on the number of deposited layers (2.4 and 6 layers). This is about the way to determine the best performance regarding wearing and corrosion in a saturated salt medium.

2. Experimental procedure
The coatings were made in a chamber systematized with a Castolin Eutectic 8000 spray gun, where the parameters and variables with which the coatings were made were fixed (Figure 1).

Figure 1. Thermal projection equipment. UPTC.

2.1. Material
The material used in the development of the tests corresponds to an AISI 1020 steel, 2cm in diameter and 1cm thick.

2.2. Terms
The samples used were sandblasting or sandblasting surface preparation achieving an average Ra roughness of 8.79μm in order to create a surface that allows a good adhesion between the coating and the substrate. The cleaning was done in a bath with isopropyl alcohol in an ultrasonic cleaner Brason-2510, during 20min.

The Diamalloy 4060NS powder was baked at 100°C to remove the existing moisture and then fed to the dispenser with a speed of 2.5rpm and a nitrogen pressure of 20psi and a flow rate of 5l/min.

The samples of AISI 1020 steel were heated before starting the projection with a temperature of approximately 160°C.

2.3. Settings
A projection distance of 150 mm between the substrate and the gun was used, a torch advance speed of 3.2mm/s, speed of rotation of the sample holder 63rpm, 4 heating passes, and two types of flame were obtained with oxygen pressures of 60psi and acetylene of 10psi, flame 1 with a flow of 4l/min of oxygen and 7.2l/min of acetylene and flame 2 with a flow of 4l/min of oxygen and 9.1l/min of acetylene. Obtaining a relation of the flame 1=1:3.27 and calls 2=1:5.75 respectively O2:C2H2. See Table 1.
Table 1. Projection parameters.

| Thermal Spray Equipment Parameters          |
|---------------------------------------------|
| Projection distance                         | 150mm                        |
| Dosing plate speed                          | 2.5rpm                       |
| Thickness per coat                          | 40-60μm                      |
| Speed feed rate                             | 3.2mm/s                      |
| Turning speed of the sample holder           | 63rpm                        |
| Preheating layers                           | 4                            |
| Preheating temperature                      | 140°C                        |
| Oxygen pressure                             | 60psi                        |
| Flame 1 oxygen flow                         | 4l/min                       |
| Flame 2 oxygen flow                         | 10psi                        |
| Acetylene pressure                          | 10psi                        |
| Flow of acetylene flame 1                   | 7.2l/min                     |
| Flow of acetylene flame 2                   | 9.1l/min                     |
| Nitrogen Pressure                           | 20psi                        |
| Flow of Nitrogen                            | 5l/min                       |

3. Results and discussion

3.1. Characterization of steel
The roughness Ra obtained for the flame 1 had an average of 12.0354μm and the flame 2=12.7642μm obtaining a rougher surface with respect to that of the bare steel. Figure 2 shows the microstructure of the steel, in which the phases of ferrite (light zone) and perlite (dark zone) are observed, which correspond to AISI/SAE 1020 steel.

Figure 2. Microstructure Steel 1020 to 700X.

The chemical composition according to the results obtained in the optical emission spectroscopy with spark source corresponds to AISI/SAE 1020 Steel, with a difference in Mn of 0.16; With respect to the norm that is of 0.3-0.6% Mn (Table 2).
Table 2. Chemical composition of 1020 steel.

| Element | Al | C  | Cr | Cu | Fe  | Mn | Ni | P   | S   | Si  | Sn | Ti | W   |
|---------|----|----|----|----|-----|----|----|-----|-----|-----|----|----|-----|
| %       |    |    |    |    |     |    |    |     |     |     |    |    |     |
|         | 1.01 | 0.15 | 0.05 | 0.13 | 98.1 | 0.76 | 0.04 | 0.02 | 0.05 | 0.16 | 0.03 | 0.01 | 0.02 |

3.2. Morphology and dust characterization Diamalloy 4060NS

3.2.1. Morphology obtained by SEM. Figure 3 shows the shape of the powder particles which are totally spherical due to their method of manufacture by atomized gas with average sizes of 11.53, 29.1, and 44μm.

![Figure 3](image)

Figure 3. (a) Morphology of the powder at 5000X. (b) Morphology of the powder at 700X.

3.2.2. Characterization made using DRX and FRX. Analyses were performed in order to corroborate the information obtained by the manufacturer of the Diamalloy 4060NS powder and confirm the chemical composition. Figure 4 and Table 3 shows the results obtained from the analysis of XRD and FRX to the powder, (a) the presence of Co, Cr and other elements in proportions very similar to those reported by the manufacturer is reported. (b) Presence of Co and Cr is confirmed as the elements in greater proportion with small traces of the other elements, Co and Cr peaks are present in the same crystallographic planes because they are in the same cubic crystalline system centred in The FCC faces.

![Figure 4](image)

Figure 4. Characterization of the Diamalloy 4060NS powder.
Table 3. Characterization of the Diamalloy 4060NS powder.

| Casa Fabric | Element | Co  | Cr  | Si  | W  |
|-------------|---------|-----|-----|-----|----|
|             | %       |     |     |     |    |
| FRX         | 67.5    | 27.3| 1.31| 3.8 |

3.3. Characterization of coatings

3.3.1. Pull-off Test. According to the results we can say that the flame 2 has a better adhesion behaviour to the flame 1 with increases as the thickness of the coating grows. Table 4.

Table 4. Pull-off test results.

| Flame     | Type of fault | Adhesion value (psi) | N° Layers |
|-----------|---------------|----------------------|-----------|
| Flame 1   | adhesive      | 424                  | 2         |
|           | glue          | 877                  | 4         |
|           | cohesive      | 1557                 | 6         |
| Flame 2   | cohesive      | 898                  | 2         |
|           | adhesive      | 972                  | 4         |
|           | glue          | 1124                 | 6         |

3.3.2. Thickness using SEM. The coatings with the highest thickness reported were those that were worked with the flame 2, in all common characteristics were observed such as lamellae, non-melted particles, voids, starters, pores. Figure 5. (a) flame 1 and 2 layers: thickness of 146.5μm, (b) flame 2 and 2 layers: thickness of 186.3μm, (c) flame 1 with 4 layers: a detachment between coating and (D) flame 2 with 4 layers: thicknesses of 383.8μm, (e) flame1 with 6 layers: thicknesses of 379.9μm, (f) flame 2 with 6 layers. Layers: a slight detachment between the substrate and the coating with greater voids is observed unlike the others, thicknesses of 410.2μm.
3.3.3. Wear evaluation (Pin on disk). The wear coefficient was determined with a load of 5N, footprint of 6 mm of radius, distance of travel of 500m, speed of wear of 100rpm and an ambient temperature of 19 to 21°C. The coatings that presented the least wear were those of flame 1 with a thickness of approximately 300μm. Figure 6.

3.3.4. Corrosion evaluation (electrochemical cell). The corrosion rate was determined by means of an electrochemical cell, using as reference electrode: Pt / ClPt and as counter electrode: platinum wire; In 1% NaCl salt saturated with CO2. The effectiveness of the flame 2 with respect to the flame 1 is evident, but considering that both protect the steel against the phenomenon of corrosion. For the flame 1 decreases as the thickness increases and in the flame 2 the opposite happens totally as the thickness increases the corrosion increases. Figure 7.
4. Conclusions
The tribological wear of the steel improves when a flame 1 is obtained with a flow of 4l/min O2 and 7.2l/min C2H2 with thicknesses around 400μm obtained an approximate coefficient of wear of 1.17E-13m3/Nm , with a flame ratio of 3.27:1. Unlike flame 2, as the thickness increases, the coefficient of wear increases proportionately; thus the flame 2 with a flow of 4l/min O2 and 9.1l/min C2H2 reports an increase in the adhesion with respect to the flame 1, as its number of layers increased, the particles had greater adhesion between them and the substrate, compared with the electrochemical tests was determined that this is inversely proportional, that is to say; as the thickness of the coating increases, the wear increases but the corrosion decreases, which agrees since as the particles are better adhered and melted in the coating the better their resistance to corrosion and wear; since the particles are more united causing less abrasion and not allowing the passage of substance to the substrate.

In scanning electron microscopy both types of flames presented lamellae, unmelted particles, voids, pores and starts with a significant increase between layers, noting that flame 2 has an increase in thickness percentage with respect to flame 1, increase of thickness is due to the fact that the particles melted or semi-melted in a better way, being able to be located forming more bonded and resistant layers giving the coating better adhesion between layers and the substrate as less porosity.

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