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STUDYING ADHESION PROPERTIES AND MICROSTRUCTURE OF FeCoCr ALLOY COATINGS

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Abstract. *Thermal spraying processes were developed on the last years and they are a very suitable method to obtain layers with high hardness for protecting or repairing the base component. This work has as main objective the evaluation of properties of coatings formed by the spray of alloys onto the surface of carbon steel substrate. The process used was thermal spray by electric arc of metallic coatings. An assessment of the microstructural morphology by optical microscope (OM) and scanning electron microscope (SEM) was made, and also evaluation of the coatings proprieties by microhardness measurement, salt spray test and porosity quantification. The results obtained by OM and SEM indicated that the coatings showed uniformity throughout the deposited layer and low amount of oxides and porosities. It can be concluded that in the salt spray corrosion test, the superficial corrosion products can be adherent and act as additional protection barrier. Based on the performed characterizations, the ýndings suggested that the CoCrB deposition, with an epoxy sealing, is suitable to be used as an efýcient coating of carbon steel in aggressive marine environments.*
Keywords: *Thermal spraying, metallization; metallic coatings; characterization*

1. INTRODUCTION

Thermal spraying processes are a very suitable method to obtain layers with high hardness for protecting or repairing the base component. Currently, the application of TS technique has been increasing due to companyôs concern, mainly in the oil and gas sector, in extending the life of the materials exposed to the harsh marine environment. In addition, the guidance which guides the production and services of every company that is "better, faster, cheaper", since the demand for production and services is always increasing. Employing these processes it is possible to overlay metallic substrates with polymers, metals and ceramics. All these techniques permit the deposition of coating materials, generally ductile, with self-lubricating properties and improved corrosion and wear resistance. The impact against the substrate surface flats the particles and produces adhesion to the substrate in a direction parallel to it by the interlocking of the molten or semi-molten, according to Braday *et al.* (2008) and Sampson (1997)

To resist increases in thermal and mechanical stress is required of science professionals materials to develop specific alloys withstand the most varying conditions of service. In addition to the improvement of processes, properties such as porosity and oxide content is controlled during the process, resulting in improved coating quality. This study aims to evaluate the properties of different materials formed by deposition of coatings alloys for thermal spray electric arc process in carbon steel substrate SAE 1020, previously prepared by abrasive blasting, to two conditions: pipe and plate. The microhardness and quantification porosity properties were evaluated. Characteristics microstructural was made by optical microscopy (OM) and scanning electron microscopy (SEM), Antunes *et al.* (2015) and .

2. METHODOLOGY

The steel samples were cut to form approximately 100 mm x 150 mm x 4,5 mm sized specimens and resin was used to protect the edges. Tubes with diameter of 65,5 mm and wall thickness of 5 mm, no machined and machined , also were used. Table 1 depicts the chemical composition of the three wires used in preparation of coatings and Tab. 2, the combinations of wire used to form the coatings. An intermediate alloy was initially applied which has the function of increase coating adhesion.

The process of thermal spray was done with the following parameters: voltage about 40 V, current about 100 A and deposition rate of 3,24 kg/h. The equipment has two entrances for the reels with wire of 1.6 mm in diameter to be deposited.

Table 1. Chemical composition of wire used to form the coating. Values below 0.01% are not presented in the table.

Wire	Fe (%)	Co (%)	Cr (%)	Ni (%)	B (%)	Mn (%)	W (%)	Mo (%)	C (%)	Si (%)
I	66,1		27		3,5	1,8				1,6
II	65,7		25,7	2,9		1,9		0,8	1,6	1,4
III	3,6	58,4	28,8	1,9		0,9	4,9	0,02	1,1	0,3

Table 2. Detail of the studied combinations

Combination	Coating: Combination of two wires
1	I+ III
2	I + II

Microhardness testing was performed using a Vickers microhardness tester (Wilson Instruments, model 422MVD) with a load of 300 gf. Microhardeness analysis were made from the surface of the coating to the substrate.

An assessment of the microstructural morphology by optical microscope (OM) and scanning electron microscope (SEM) coupled with an X-ray energy dispersive spectroscopy (EDS) was made and compared with microhardness. Vickers (HV 500) test and porosity quantification. The samples for microscopic examination were prepared by standard metallographic techniques.

The coating porosity was determined by quantitative image analysis on the basis of optical micrographs taken from cross sections at magnifications of 500x, Vreijling (1998) .

The resistance to corrosion was analysed in salt spray during 40 hours, Fig. 1, according to ASTM B 117.

Table 3 shows the six conditions studied:

Table 3 ï Conditions, combination of wires and intermediate bonds.

Condition	Combination of wires	Intermediate bond	Type of sample
1	a + c	95Ni-5Al	plate
2	a + b	95Ni-5Al	plate
3	a + c	95Ni-5Al	Tube (machined)
4	a + b	95Ni-5Al	Tube (machined)
5	a + c	95Ni-5Al	Tube (no machined)
6	a + b	95Ni-5Al	Tube (no machined)

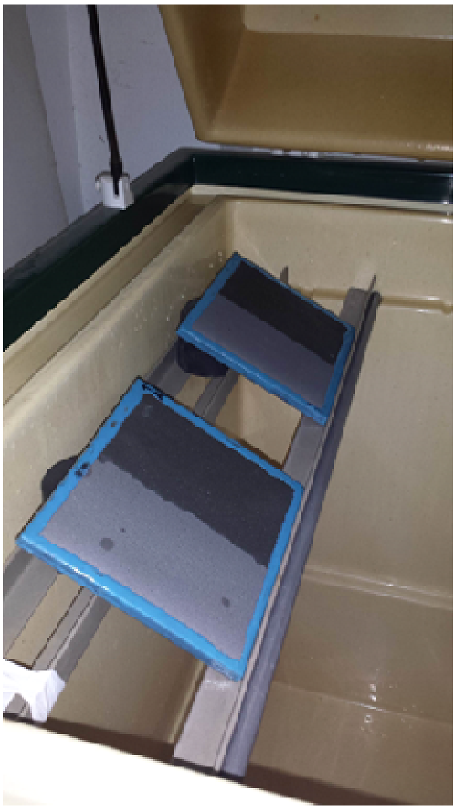


Figure 1. Detail of specimen position in salt spray chamber.

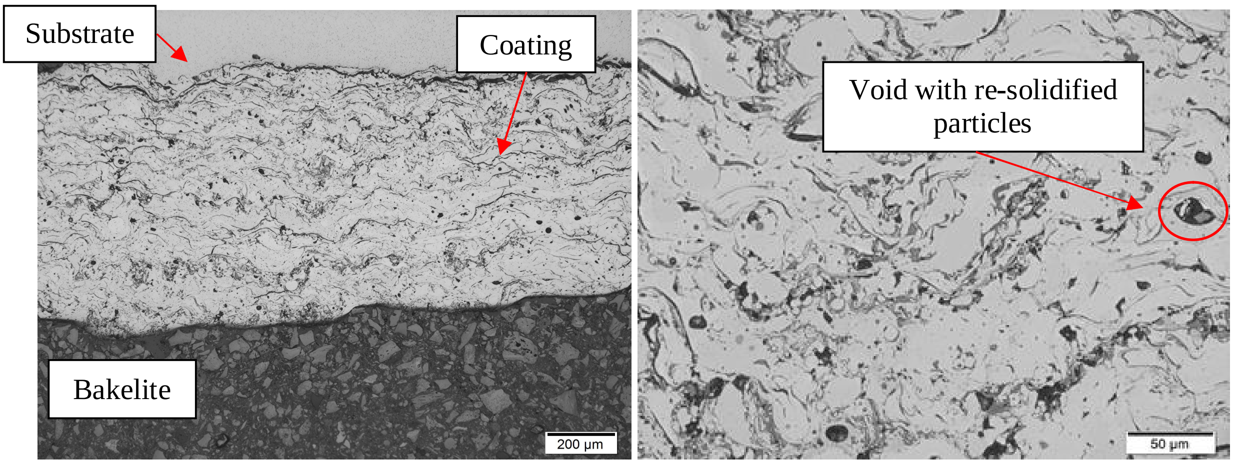
3. RESULTS

Optical micrographs of coating are shown in Fig. 2 (plate specimen) and Fig. 3 (tube specimen).The morphology of coatings exhibit characteristics of lamellar microstructures with the long axis of impacted splats oriented along the substrate surface. Incompletely melted particles with a distribution of similarly oriented oxides were observed for the two coating types. Oxides are hard particles and increase coating hardness. Conversely, abundant and continuous oxide networks can lead to cohesive failure of coating and contribute to excessive wear debris of bearings. Consequently, it is important that the oxide content of coatings be limited. The darker surfaces of micrographs are empty and gray surfaces are oxides formed by contact with oxygen in the air during the deposition process, such as chromium oxides, manganese and silicon, Antunes *et al.* (2015).

Coatings applied on plates specimens had a better uniformity and less variation in thickness when compared to pipe specimen.

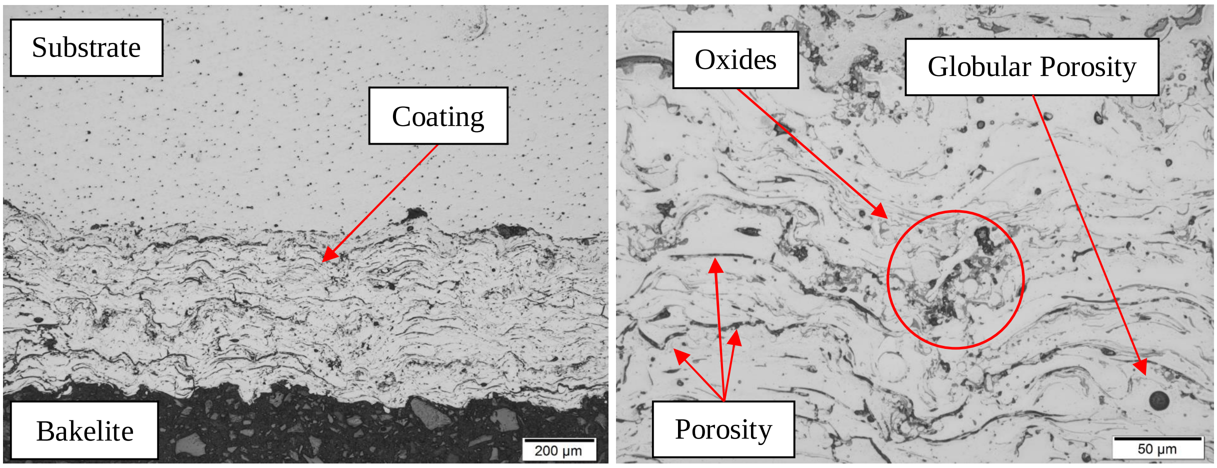
In relation to the rectified samples there was no detachment of the coating surface, due to the action of the cutting tool. The final thickness after the machining process has been satisfactory and preserved the function of protecting the substrate.

Excessive and continuous oxide can lead to cohesive failure of a coating and contribute to excessive wear resistance. Due to that, it is important to control oxide content, when selecting materials, coating processes, and processing parameters.



(a) Specimen: Increase of 100x (b) Coating: Increase of 500x

Figure 2. Condition 1 - Plane specimen micrographic.



(a) Specimen: Increase of 100x (b) Coating: Increase of 500x

Figure 3. Condition 4 - Pipe specimen micrographic.

The occurrence of porosity was very low for conditions without epoxy sealant, reaching a maximum of 12,5% in condition 5 and a minimum of 7,25% in condition 4, see Tab. 4.

Basically, two main parameters influenced the porosity (Sampson, 1997): particle velocity and temperature. Increasing the flow rate leads to an increase in the particle velocity and a decrease, simultaneously, in the diameter of the particle. Consequently, smaller and faster spray particles are produced forming a denser structure. At the same time, higher oxide content can be observed (Cortés, 1998).

Table 4: Area percentage of porosity of the conditions.

Condition	Porosity Area (%)
1	8,25
2	9,75
3	9,5
4	7,25
5	12,5
6	10,5

The results presented in Figure 4 depicted the decreasing trend of coating microhardness with machined specimens (condition 5 and 6). These microhardness values lie between 425 and 555 (top of machined coating) HV.

The higher hardness of these two coatings can be attributed to the fine microstructure of individual lamellae and the inclusions of iron oxide. According to the literature, Paredes *et al.* (2003) and Antunes *et al.* (2015), hard coating shows an improvement in wear resistance. The results of microhardness are depicted in Fig 4..

Experimental results showed that the measured data of microhardness of the coatings exhibited high scattering and this behaviour may be explained by the through-thickness hardness variation and the microstructure of the coating with high inhomogeneity.

It was possible to identify a major difference between the average hardness of the substrate (132.8 HV) and the average hardness of the coatings. This difference shows the efficiency of thermally sprayed metallic coatings on carbon steel substrates, for applications in environments that require high mechanical hardness.

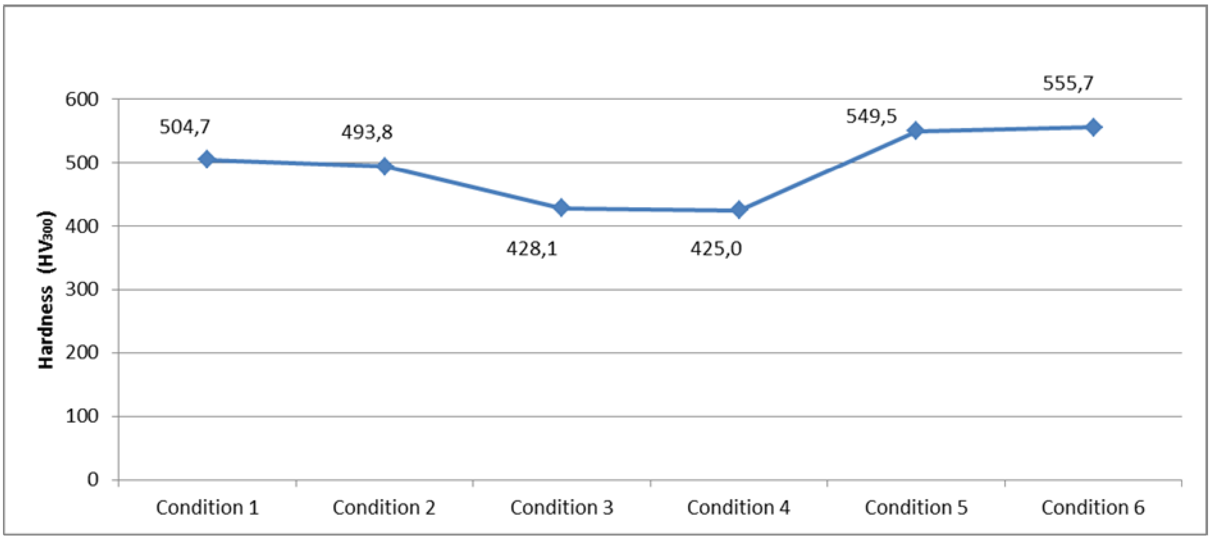
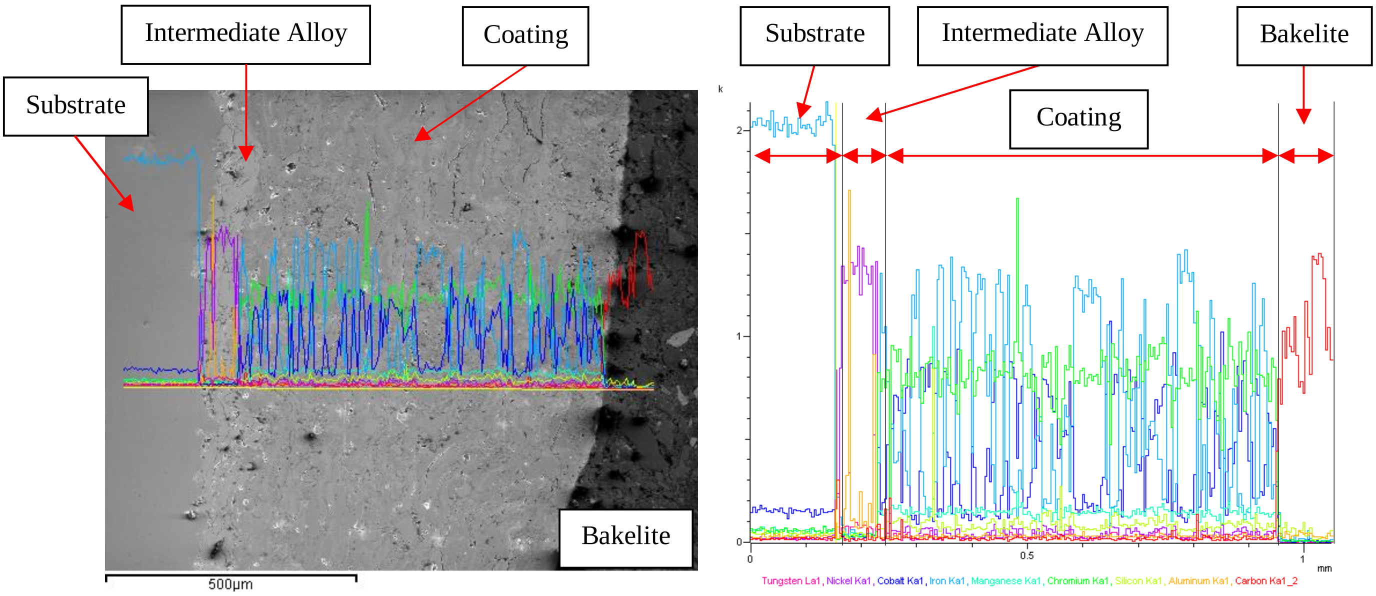


Figure 4. Global microhardness of the specimens studied.

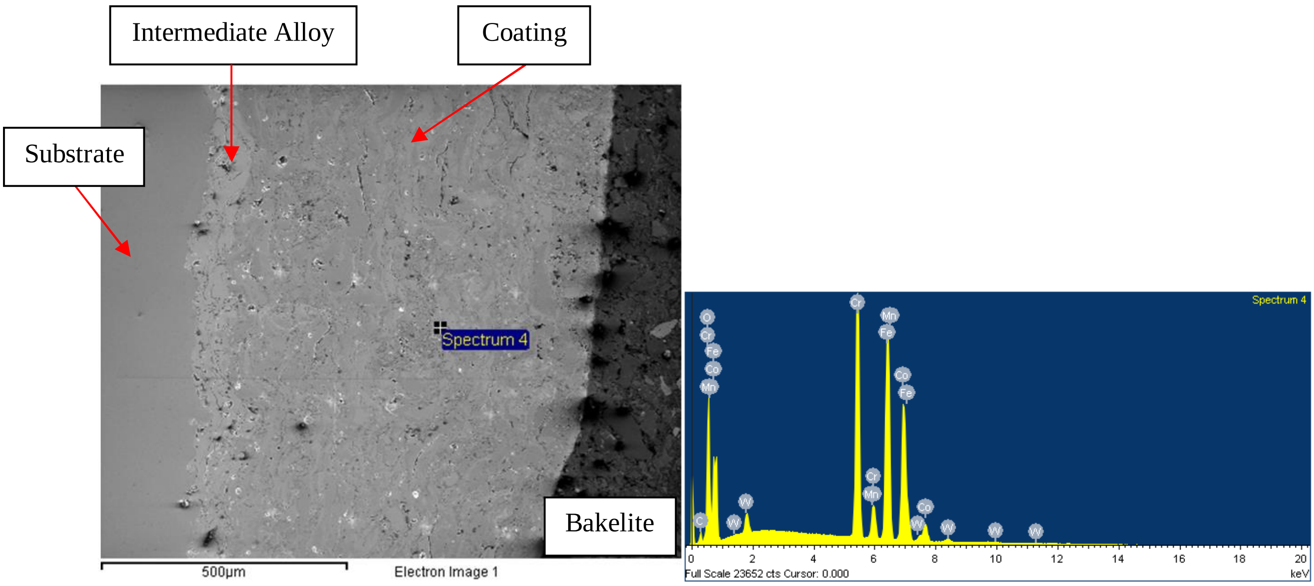
EDS measurement results of SEM facilities show agreement between phase compositions of substrate (see Figures 5, 6) for all conditions. Line analysis shows the distributions of elements between the substrate and coating. The observed variation in the alloying content can be ascribed to the non-uniform cooling conditions of individual

The retention of some unmelted and/or resolidified particles can produce deposits with low cohesive strength, especially in the case of ὓas-sprayedὔ materials without post-deposition heat treatment or re-fusion, Capra (2005).



(a) (b)

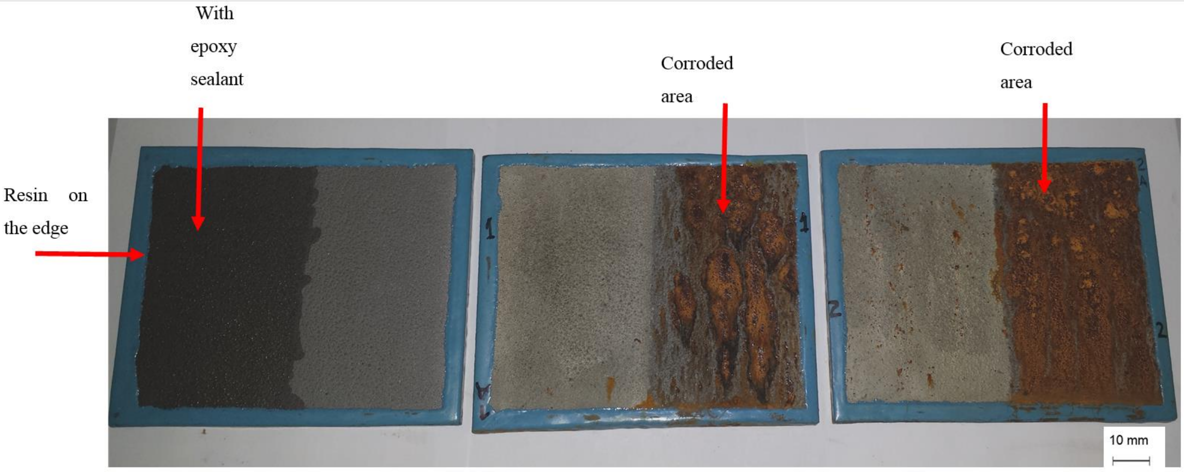
Figure 5. (a) Condition 1 morphology (b) Line EDS for the coating total area.



(a) (b)

Figure 6. (a) Condition 1 morphology (b) Pontual EDS for the spectrum 4.

The results show, according Fig. 7, that on the corrosion process for the salt spray technique, the superficial products of corrosion (sealant) can be very adherent and it also can promote an additional barrier of protection. When was analyzed the side of the sample without sealant the best result was condition 1, Fig. 7, that contain a significant percentage of Co.



A **B** **C**

Figure 7. Aspect of surface for coatings with sealant/without sealant A)Before salt-spray test, B) Co coating, condition 1 and C) Ni coating, condition 2 .

4. CONCLUSION

The results indicated good uniformity of deposited layer, small oxide particles and little porosity for all conditions studied. Coatings applied on plates specimens had a better uniformity and less variation in thickness when compared to pipe specimens. Co and Ni coatings produced significant high microhardness in comparison with the substrate. Thermal sprayed metallic coat of carbon steel with epoxy sealant showed high corrosion resistance in aggressive marine environments, when tested in salt spray chamber. Based on the performed characterizations, the ýndings suggested that the CoCrB deposition, with an epoxy sealing, is suitable to be used as an efýcient coating of carbon steel in aggressive marine environments.

5. ACKNOWLEDGEMENTS

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