Influence of surface roughness and current intensity on the adhesion of high alloyed steel deposits - obtained by thermal spraying in electric arc

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Abstract. In this paper the surfaces of some steel samples, low alloyed, were covered by electric arc thermal spray with a steel layer, high alloyed, containing FeNiCrSiB-WC/TiC, using a core wire. In order to study the influence of process parameters on obtained deposits, the surface roughness and the intensity of electric current varied on three levels and the rest of the technological parameters were kept constant. The microstructural characteristics, chemical composition, physical and mechanical properties of the obtained deposits were investigated by SEM analysis of microhardness and by X-ray diffraction. The deposition porosity was investigated by optical microscopy. The adhesion of the layers was investigated by the traction test. Studies have shown that by increasing the intensity of the electric current respectively the arc temperature, the deposition porosity decreases by 23.4%, the microhardness HV and the adherence of the samples subjected to the test increases.

The FeNiCrSiB-WC/TiC layers, deposited on low alloyed steel support, can be considered as convenient solutions for obtaining hard, wear-resistant surfaces.

1. Introduction

Recognized as particularly efficient, the arc spray process (ASP) is used to improve the physical, chemical and mechanical properties of the parts, [1-3]. This spraying process, which uses as raw material the core wire, has found many industrial applications to increase the resistance to wear, erosion, corrosion or to obtain hard surfaces, [4-6]. The core wire - which presents at the outside part a ductile metal coating, and on the inside the interior material is filled with hard, has extended the application of thermal spraying in electric arc in areas previously dominated by other processes such as plasma cold spray and HVOF, [7-9]. In ASP, the electric arc formed at the contact between two wire electrodes melts the tips of the wire. Under the action of a compressed air jet, the melted drop is spread and projected onto the surface of a substrate that has been previously specially prepared. Each projected drop is flattened on the surface of the substrate, resulting, finally a layer that has a lamellar structure and contains different chemical compounds, oxides, pores or unmelted particles, [10-14]. The deposit properties depend on both the intrinsic properties of the material used and the quality of the layer, respectively the technological process parameters used to obtain the deposits, [15-17]. The purpose of this study is the investigation of the influence of process parameters, respectively the
electrical current intensity and the roughness of the substrate surface on the physical and mechanical properties of FeNiCrSiB -WC/TiC deposits obtained by thermal spraying in electric arc.

2. Experimental procedure

2.1. Materials and equipments

The FeNiCrSiB –WC/TiC layers were deposited by thermal spraying in electric arc using a spraying installation - Tafa CoArc System (made by Praxair-Tafa, USA) equipped with a gun of 9935 model - capable of using high working pressures of 6.5bar, before spraying. In order to carry out our own research on the influence of process parameters on the physical properties of FeNiCrSiB –WC/TiC deposits, we used the addition material as core wires of 97MXC, produced by Praxair Tafa - USA. The 97MXC alloy, which contains eight elements of chemical elements – see Table 1, was deposited on 40x40x15 flat samples of low alloy steel, C15-EN10083.

Before spraying, the surface of the substrate was mechanically cleaned by sanding using Al₂O₃ grit with various granulations (of 217±132, 536±124 and 831±128 μm diameter) and ultrasonically cleaned in an ethanol bath (C₂H₆O) for 10 min. During the spraying process, the electrical current and the roughness of the layer varied on three levels. The technological parameters of the thermal spraying process are presented in Table 2.

Table 1. Chemical composition of the materials used.

| Materials | C   | Si  | Cr  | Ni  | Mn  | B  | WC | TiC | Fe  | P  | S  |
|-----------|-----|-----|-----|-----|-----|----|----|-----|-----|----|----|
| C15       | 0.14| 0.15| 0.3 | 0.3 | 0.43|    |    |     | 0.04| 0.04|    |
| 97MXC     | -   | 1.25| 14.0| 4.5 | 0.55| 1.87| 26.0| 6.0 | balance | - | - |

Table 2. Technical parameters of magnetron sputtering.

| Parameters                        | Value  |
|-----------------------------------|--------|
| Current intensity (A)             | 200/220/250 |
| Voltage (U)                       | 32     |
| Air pressure (bar)                | 6.5    |
| Movement speed of the gun (m/s)   | 0.14   |
| Roughness substrate (μm)          | 8/14/28|
| Spraying gun- sample distance (mm)| 140    |
| Spray angle                       | 90°    |

2.2. Characterization of deposits

The morphology of FeNiCrSiB - WC/TiC deposition and the qualitative elemental analysis was highlighted by SEM investigations, performed using the electronic scanning microscope: FEI - Quanta 200 SEM-EGF. The crystalline structure of deposits has been investigated by X-ray diffraction, using a X-ray diffractometer - type XPERT PRO MRD product by PANalytical Holland, using Cu Kα radiation (λ=0.15406 nm) which works with acceleration voltages of 40kV and an emission current of 40mA.

The adhesion of the deposits was determined by the traction test - in accordance with EN 582.

The Vickers micro-hardness of the deposits was determined in the transversal-section of deposits, using the micro-hardness tester CV Instruments 400 DM, a load of 400g, for 10s. Due to the large variations in the micro-hardness measurement, 15 measurements were made on each layer and their mean values were reported.

The deposition porosity was investigated by image analysis of the transversal section of the specimens using the IQ Materials program (Japan).
3. Results and discussions

In Figure 1 are presented microstructures of the 97MXC deposits, obtained by thermal spraying in electric arc, at different values of the electric current intensity.

![Figure 1](image)

**Figure 1.** SEM images of 97MXC layers obtained under the following conditions, \( p = 6.5 \text{bar}, \ U = 32 \text{V} \): a) \( I = 220 \text{A} \); b) \( I = 250 \text{A} \).

It can be seen that at low values of the electrical current intensity, the deposits present inside them particles of unmelted material – see Figure 1a. It can be said that the heat developed by the electric arc is insufficient to melt the wire. In the electric arc thermal spraying process, the increase of current intensity determines the increase in the wire feed velocity. At low values of the electric currents intensity the heat developed by the spring is insufficient to completely melt the hard material in the arc area. Increasing the intensity of the current determines the increasing of arc temperature and implicitly, of the wire temperature in the immediate vicinity, favouring the complete melting of the input material - aspects detailed by Tillman et al [18]. Therefore, the structure of the deposits becomes homogeneous and the particles of unmelted material are missing – see Figure 1b.

The X-Ray diffraction investigations performed on the obtained deposits demonstrate that they have a structure consisting of a solid solution of Fe alloyed with tungsten (FeW), ferrite alloyed with titanium, hard compounds of WC (WC and W\(_2\)C) and TiC type or complex compounds of FeNiW type, FeNiTi independent of the electric current value - see Figure 2.

![Figure 2](image)

**Figure 2.** The XRD patterns of the 97MXC layer deposited at \( p = 6.5 \text{bar} \) and \( I = 250 \text{A} \).
In Figure 3 it is presented the variation of the porosity of deposits with the intensity of the electric arc.

![Figure 3. Variation of the porosity of the 97MXC deposits with the current intensity.](image)

It can be noticed that the deposit's porosity decreases by approximately 23.4% with the increase of the current intensity.

The microhardness of 97MXC deposits obtained by thermal spraying in electric arc is relatively large - Figure 4. The microhardness of HV varies with the intensity of the electric current - within very wide limits. Thus, for low values of the electric current intensity, the microhardness of the deposits is relatively low of $723 \pm 44HV$ compared to the microhardness of the depositions obtained at values of the electric current intensity higher than $789 \pm 26HV$.

![Figure 4. Variation of the microhardness of the 97MXC deposits with the current intensity.](image)

It can be affirmed that the high degree of homogeneity of depositions obtained at high values of the electric current intensity determines the increase of the microhardness of 97MXC deposits [19,20].

Figure 5 presents the adhesion variation of the deposits with the substrate roughness. It is noticed that at low values of the substrate roughness the layer adhesion to substrate has low values. This aspect can be explained by the fact that the adhesion of the deposits obtained by thermal spraying in the electric arc is predominantly mechanical and by increasing the surface roughness of the layer, the...
contact surface between the layer and the substrate grows and the sprayed particles are fixed on the substrate's asperities - aspect detailed by Toma and al. [21].

![Figure 5. Variation of adhesion of 97MXC deposits with substrate roughness.](image)

The current intensity, respectively the arc temperature, has a positive effect on the adherence of the substrate to the substrate. It can be suggested that, by increasing the intensity of the electric current, the particles are colliding the substrate surface, which is in liquid state and mechanically are fixing in its asperities, an aspect which is accord to the studies of Matz and al. [22].

4. Conclusions

The results of the experimental researches on the influence of the process parameters - respectively the electric current intensity and the surface roughness of the substrate, on the physico-mechanical properties of the FeNiCrSiB -WC/TiC deposits obtained by thermal spraying in electric arc, can be summarized as follows:

The increase of the electric current intensity determines the increase of the electric arc temperature and implicitly the total melting of the wire - see Figure 1. Thus, are obtained homogeneous deposits which contain solid iron solutions rich in tungsten or titanium, hard chemical compounds (WC, W2C, TiC) or complex chemical compounds of the FeNiW or FeNiTi type - see Figure 2, which determines the increase of microhardness - see Figure 4;

The deposits porosity decreases by almost 23.4% with the increase of the arc temperature, respectively with the value of the electric current intensity - see Figure 3;

The increasing of the surface roughness of the substrate, allows the contact surface: layer - substrate and implicitly the increasing of the layer adherence.

5. References

[1] Trifa F I, Montavon G and Coddet C 2007 J. Therm. Spray Technol 16(1) 128-139
[2] Pawlowski L 2008 in: 2nd ed., The Science and Engineering of Thermal Spray Coatings, Ed. Wiley, Chichester, England
[3] Tillmann W, Walther F, Luo W F, Haack M, Nellesen J and Knyazeva M 2018 J. of Therm. Spray Technol. 27 50-58
[4] Panadda S and Hathaiapat K 2014 Wear 317 194–200
[5] Toma S L 2013 Surf & Coat. Technol. 220 261–265
[6] Guilemany J M, J M de Paco, Nutting J and Miguel J R 1999 Metall. Mater. Trans. A 30 1913
[7] Li S; Wang Y; Xiang D; et al. 2016 Rare Metal Materials And Eng. 45 2555-2560
[8] Toma S L, Bejinariu C, Eva L, Sandu I G and Toma B F 2015 Key Engineering Materials 660
86-92

[9] Toma B F, Baciu R E, Bejinariu C, Cimpoiesu N, Ciuntu B M, Toma S L, Burduhos-Nergis D P and Timofte D 2018 IOP Conf. Series: Mat. Science and Engineering 374 012017

[10] Toma S L, Badescu M, Ionita I, Ciocoiu M and Eva L 2014 Applied Mechanics and Materials 657 296-300

[11] Sroka M, Nabialek M, Szota M et al. 2017 Revista De Chimie 68 737-741

[12] Tugui C A, Vizureanu P, Perju M C, Savin C, Nejneru C, Baltatu, S M, Bejinariu C and Benchea M 2018 IOP Conference Series-Materials Science And Engineering 374 012029

[13] Nurisna Z T, Muhayat N and Wijayanta AT 2016 Book Series AIP Conference Proceedings 1717 040012

[14] Bloch K, Titu M A and Sandu A V 2017 Rev. de Chimie 68 2162-2165

[15] Nedeff V, Mosnegutu E, Panainte M, Ristea M, Toma St and Agop M 2012 Powder Technology 221 312–317

[16] Nanu C, Poeata I, Popescu C, Eva L, Toma B F; and Toma S L 2018 Materiale Plastice 55 85-90

[17] Berger L M, Saaro S, Naumann T, Wiener M, Wehnnacht V, Thiele S and Suchánek J 2008 Surf. Coat. Technol. 202 4417

[18] Tillmann W, Hagen L and Kokalj D 2017 Journal of Thermal Spray Technology 26 1685-1700

[19] Tugui C A, Axinte M, Nejneru C, Vizureanu P, Perju M C and Chicet D 2014 Engineering solutions and technologies in manufacturing Book Series: A lied Mechanics and Materials 657 369-471

[20] Tugui C A and Vizureanu P 2017 Conference Series-Materials Science and Engineering 209

[21] Toma St L, Bejinariu C, Baciu R, Radu S 2013 Surf. & Coat. Technol. 220 266–270

[22] Matz M-M, Aumiller M P 2014 Journ. of Thermal Spray Technology 23 (8) 1470-1477