Microstructural Analysis of Multiple Layer Depositions on Cast Iron Using the Electrospark Deposition Method

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Abstract. The present article is focused on the obtaining of a thin layer system on Fe-C alloys by deposition of 3 successive layers with several electrodes. These layers offer to the material a broad range of enhanced properties as: mechanical resistance, surface hardness, compression behavior and a martensitic structure of the carbides, which reduce the effect of the wear, having positive results on the life-cycle of the product. The principle of the hardening consists in an electrical discharge by spark on which the action of the rectified current impulse transfers material from the electrode, considered cathode to the surface of the material which is the anode. This material reacts chemically with the nitrogen, from the atmosphere, with carbon and with support material, forming a diffusion layer, resistant to wear.

1. Introduction

Thin-film coatings are generally used to improve hardness, wear and oxidation resistance. Along with traditional technologies of coatings achievement we assist to the development, improvement and extension of some modern coating methods, through physical and physical-chemical methods, which assure high purity and adherence through a very large variety of coating realizing procedures [1].

Increasingly, nowadays, electro-sparck deposition (ESD) is used for reconditioning the dimensions of used parts, because this method allows the obtaining of high wear resistance coatings [2-5].

The proposal to use the method consists in prolonging the functioning period of Fe-C alloys pieces that work under the intense regime (ex. piston rings for Diesel engines, cutting tools, dies for heat and cold deformation, medical instruments, different mechanical pieces) [6, 7].

Procedure’s advantage is that the heat density of the piece is minimum maintaining chemical composition and the properties of the basic material.

The thin layers system hardened through impulse electric discharges method is divided into an exterior layer with a strongly modified structure at the surface and an interior layer (diffusion layer) with the properties corresponding to the basic material and added material. The hardened layer presents cracks that are advantageous to the lubrication process (during exploitation) by protecting the basic material of excessive wear [8-10].
2. Materials and methods
In this study, gray cast iron with the chemical composition shown in Table 1 was used as base material. The elemental chemical composition was analysed using a Foundry-Master Spectrometer [11].

| Element | Fe  | C   | Si  | Mn  | P   | S   | Cr  | Ni  | Cu  | Mo  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| %, wt.  | 92.23 | 3.89 | 2.84 | 0.27 | 0.05 | 0.06 | 0.29 | 0.14 | 0.19 | 0.04 |

Table 1. Chemical composition of ferritic-pearlitic cast iron.

As consumable materials, three types of electrodes were used: tungsten carbide (WC), titanium carbide (TiC) and tungsten (W).

Furthermore, the depositions were obtained through the electrospark deposition method. The process of hardening the metal surfaces by this method consists in performing electrical discharges between the tool-electrode, designed in the shape of an electrode, and the surface of the processed workpiece. Both, the electrode and the workpiece are connected to the discharge circuit of the pulse generator. In other words, in the case of electric spark discharge, in a gaseous environment, the essence of the process, mainly, consist of the erosion of the electrode material (the anode) and the transfer of the erosion products from the electrode to the surface of the workpiece (the cathode).

In this study, an ELITRON 22A equipment was used to obtain the thin layer depositions through impulse discharge method.

3. Results and discussion
The micromorphology analysis of the triple surface deposition (WC/TiC/W) shows a relatively smooth surface [12-15], with partial stripping of graphite, cracks, splashes and micro-adhesions zones specific to the tungsten layer which was the last deposited layer, i.e. the outer layer, as can be seen in Figure 1.

![Figure 1](image)

Figure 1. Micromorphology of the triple-layer (WC/TiC/W) coating: (a) BSE micrography, 1 mm; (b) BSE micrography, 200 μm.

The high surface tension of the TiC melt results in the appearance of pinches or micro-holes in the deposited layer, however, in this case, the concentration of defects is much lower than in case of deposition with only TiC electrode. Tungsten carbide layers have good adhesion but important non-
uniformities in both structure and layer thickness. The wolfram-carbide (WC) layer is relatively hard and it has a moderate ability to take over the apparent splashing defects from subsequent deposits. The complex tungsten and iron carbides from its composition facilitate the formation of compact and uniform micro-alloy layers with tungsten and titanium carbides. The EDX analysis shows a high percentage of tungsten of 27.35%, a percentage of carbon of 10.08% and a percentage of titanium of 1.54% in the third deposited layer (Table 2 and Figure 2). However, some of the titanium disappeared either by combustion, either by spraying.

| Table 2. Chemical composition of the WC/TiC/W deposited layer. |
|---------------------------------------------------------------|
| *Element* | *Fe* | *C* | *W* | *Ti* |
| %, wt.     | 61.03 | 10.08 | 27.35 | 1.54 |

![Figure 2. EDX spectra of the triple-layer coating (WC/TiC/W).](image)

According to the chemical mapping (Figure 3) the distribution of the elements on the coating surface shows a relatively uniform dispersion of titanium and tungsten even on the areas with carbon lamellae.

![Figure 3. Elemental mapping of the triple-layer coating (WC/TiC/W): (a) Fe distribution; (b) Ti distribution; (c) W distribution; (d) Fe, Ti, W, C distribution.](image)

The triple-layer coating shows a relatively compact surface, with few adhesions and exfoliations, with not too high unevenness. The morphology characteristics are related to the high concentration of tungsten from the deposition, both in the most basic form as tungsten carbide or in the unalloyed state. Usually, in deposited layers, tungsten gives very good properties of hardness and wear resistance, leading to quenching in liquid media (glassy layers are obtained).
Because the titanium carbide deposition shows higher compactness than tungsten and tungsten carbide deposits, it can cover the surface unevenness and the tearings resulting in a homogeneous layer with constant thickness and high quality (lack of defects).

The outer layer (the third) made by tungsten deposition leads to a very hard surface, on which many oxides, burns and cracks are created. However, due to the presence of titanium carbide, the cracks are not so obvious, meaning that the intermediate layer has changed the coefficient of expansion and contraction of the workpiece-deposited layer assembly resulting in a layer with high compactness.

4. Conclusion
The heterogeneous layers deposited have, as the main advantage, the obtaining of a coating with appropriate roughness and hardness of the surface and good adhesion and compactness of the substrate. These characteristics are obtained by combining the advantages of each type of electrode.

Tungsten carbide deposition has good adhesion characteristics to the grey cast iron substrate, therefore, those have good compatibility and doesn’t react with the surface in a normal atmospheric condition which can result in areas with pores and absorbed gases.

The titanium carbide layer increases the fluidity of the complex metal bath that is formed during the second deposition. Therefore, the areas uneven coated after the tungsten deposition, because of the high surface tension of the W drops, are uniformized by the second deposition.

The third layer, made with tungsten, generates the final properties of the workpiece surface, namely high hardness and good corrosion resistance.

Due to the good compatibility between the consumable electrodes materials and the base material, ie lamellar grey cast iron, an adhesive coating with good mechanical, thermal and chemical resistance was obtained.

5. References
[1] Jilani A, Abdel-wahab M S and Hammad A H 2017 Advance Deposition Techniques for Thin Film and Coating, Modern Technologies for Creating the Thin-film Systems and Coatings, Nikolay N. Nikitenkov, Intech Open, DOI: 10.5772/65702
[2] Frangini S and Masci A 2010 Surface and Coatings Technology 204(16-17) 2613–2623
[3] Aghajani H, Hadavand E, Peighambardoust N S and Khameneh-asl S 2020 Surfaces and Interfaces 18 100392
[4] Pliszka I and Radek N 2017 Procedia Engineering 192 707-712
[5] Jiao Z, Peterkin S, Felix L, Liang R, Oliveira J P, Schell N, Scotchmer N, Toyserkani E and Zhou Y 2018 Journal of Materials Engineering and Performance 27(9) 4799-4809
[6] Wang J, Zhang R, Yan 2011 Advanced Materials Research 146-147 1601-1604
[7] Liu D, Gao W, Li Z, Zhang H, Hu Z 2007 Materials Letters 61 165-167
[8] Chen Z and Zhou Y 2006 Surf. Coat. Technol. 201 1503-1510
[9] Padgurskas J, Kreivaitis R, Rukuiža R, Mihailov V, Agafii V, Kriukiene R, Baltušnikas A 2017 Surf. Coat. Technol. 311 90–97
[10] Miller T, Pirolli L, Deng F, Ni C and Teplyakov A V 2014 Surf. Coat. Technol. 258 814-821
[11] Perju M C and Vizureanu P 2014 Revista de Chimie (Bucharest) 65(6) 694-696
[12] Perju M C, Nejneru C, Vizureanu P and Stefǎnica R G 2012 XPS chemical analysis for the multilayer deposition WC/TiC/W on gray cast iron using electric impulse discharge method, ModTech International Conference-New face of TMCR, Proceedings of The 16th International Conference, Modern Technologies, Quality and Innovation, vol II, p 737-740
[13] Dandu-Bibire L, Borsos Z, Matasaru D, Casian-Boțeț I, Nicolescu A and Agop M 2011 University Politehnica of Bucharest Scientific Bulletin-Series a-Applied Mathematics and Physics 73(2) 175-184
[14] Buzea CG, Agop M, Galusca G, Vizureanu P and Ionita I 2007 *Chaos solitons & fractals* **34**(4) 1060-1074
[15] Baltatu M S, Tugui C A, Perju M C, Benchea M, Spataru M C, Sandu A V and Vizureanu P 2019 *Revista de Chimie* **70**(4) 1302-1306