Morpho-Structural Characterization of WC20Co Deposited Layers

C A Tugui¹,² and P Vizureanu¹
¹ Gheorghe Asachi Technical University, Faculty of Materials Science and Engineering, Iasi, Romania
² National Institute of Research and Development for Technical Physics, Nondestructive Testing Department, Iasi, Romania

E-mail: tzugui.andrei@yahoo.com

Abstract. Hydroelectric power plants use the power of water to produce electricity. In this paper we propose a solution that will increase the efficiency of turbine operation by implementing new innovative technologies to increase the working characteristics by depositing hard thin films of tungsten carbide. For this purpose hard tough deposits with WC20Co and Jet Plasma Jet on X3CrNiMo13-4 stainless steel were used for the realization of the Francis turbine with vertical shaft.

1. Introduction
The new technical requirements imposed by rapid technological development must find solutions that meet these functional requirements of new equipment, assemblies and subassemblies.

Materials used in the construction of Francis turbine blades with a vertical shaft have good corrosion resistance [1-2], but have low abrasion resistance properties [3,4], which lead to a lower operating reliability.

The paper tried to solve these problems by depositing hard thin layers [5-8] to improve wear resistance by increasing the surface hardness of the material used in the construction of the blades of Francis turbines with vertical shaft [9]. In this purpose, wear-resistant deposits were made by the plasma jet method with WC20Co based electrodes on stainless steel X3CrNiMo13-4 [10] used for the development of the Francis vertical shaft guide blades.

By this method, different layer thicknesses can be obtained depending on the number of plasma jet passes over the sample. Layers based on tungsten carbide have been deposited since this material increases the hardness of the substrate layer without affecting the corrosion resistance of the blades from Francis turbine with vertical shaft.

Analyzes performed by the electron scanning microscope will highlight the structure of the deposited layer, suport layer and their interface. Chemical analyzes were performed to emphasize the structure of the deposited layer and the substrate as well as the distribution of the deposition elements on the surface and in cross section [11,12].

Chemical analyzes were performed using the EDX probe mounted on the VEGA II LMH I (SEM). Also, cross section microhardness tests were carried out to determine the microhardness of the base material and the deposited layer, these tests were carried out with a Vickers penetrator, and to determine the roughness of the deposited layer, tests were carried out using the equipment Mitutoyo SJ 301.
2. Materials and deposition method
The material on which the thin thin layers were deposited was cut from a blade of a Francis vertical shaft turbine, and then the specimens of the specific dimensions for each type of test and test to which they would be subjected were made from the obtained piece. The sample was cropped on a cooling cutting machine to avoid thermal influence on the base material.

After the cut, some of the samples were left blank and some of them were deposited with thin hard layers to make a comparison between the properties of the material from the blade of Francis turbine with vertical shaft (material not deposited) and the material obtained by plasma jet deposition. Samples obtained will be subjected to SEM and EDX investigations and to microhardness and adhesion tests of the deposited material.

2.1. Basis material
As a substrate, a stainless steel from a Francis vertical-axis turbine was used. The chemical composition of the material from the blade was made using the Foundry Master Spectrometer. The chemical composition of the stainless steel on which thin layer will be deposited is: Fe - 80.9%; C - 0.10%; Cr - 12.7%; Ni - 4.12%; Mn - 0.54%; Others - 1.64%. This material is a stainless steel with a high nickel and chromium content and is part of the stainless steel grade X3CrNiMo13-4 (1.6982) EN 10213-2007.

Optical microscopy analyzes were performed on Olympus optical microscope BX52, at Non-Destructive Testing Department of the National Institute of Research and Development for Technical Physics, Iasi. These tests were performed to analyze the surface, microstructure of the base material, grains shape, and possible material flaws (holes and cracks).

![Figure 1. Optical microscope analysis of base material at 400X magnitude (a) and ternary diagram of Fe-Cr-Ni alloy (b).](image)

The analysis of the structure of the GX3CrNi13-4 base material is shown in Figure 1a, it presents a martensitic acicular microstructure and elongated grains but also some material defects such as some microholes. Figure 1b shows sections of the ternary diagram for Fe-Cr-Ni alloys.

With the green line the zones representing the percentages of the alloying elements of the studied steel (Cr - 13%, Ni - 4.5%, Fe – in balance) are plotted. The diagram shows both the solid state transformation lines and the presence of solid solutions and intermetallic compounds that influence the physico-chemical and mechanical properties of the studied alloy.

2.2. Deposition material
Powders were also studied on Olympus optical microscope, but also in the SEM to highlight the shape and sizes of the grains. The deposition material for thin layer deposition is WC20Co powder.
comprising tungsten carbide with cobalt, its chemical composition is 82.8% Fe, 13% Co, 4.2%. Coatings with this powder have good corrosion and abrasion resistance [13].

![Microscopic image of WC20Co powder](image1.jpg) ![SEM analysis of WC20Co powder](image2.jpg)

**Figure 2.** Analysis of WC20Co powders: a) microscopic image at 200X magnitude; b) SEM analysis and determination of grains sizes at 500X magnitude.

It can be observed that WC20Co have very thin gains, irregular, mainly ovoid.

### 2.3. Deposition method

The Sulzer Metco 9MCE facility of the Faculty of Mechanical Engineering was used for the deposition of thin layers by the plasma jet method (figure 3). The spraying of the melted material by plasma jet was carried out at a temperature of 16000°C [14].

![Sulzer Metco 9MCE plasma jet deposition installation](image3.jpg)

**Figure 3.** Sulzer Metco 9MCE plasma jet deposition installation.

This method consists in melting and spraying metal or non-metal powders by means of plasmatrons on the base material (in our case a stainless steel type GX3CrNi13-4). Due to the high velocity and pressure of the plasma, the powder is sprayed onto the surface of the base material at a speed of 450 to 650 m / s and the spray distance was about 100 mm.

### 3. Results and discussions

Analyzing images obtained at the SEM microscope on the surface of WC20Co powder deposition by the PTJP method, a rugged appearance of the surface with many microdents, microcracks and partially fused powders is observed as presented in figure 4.

The surface does not exhibit visible oxides and layer combustion but exhibits dents and layered areas characteristic of WC20Co powder which melts at very high temperatures.
Figure 4. Analysis of the deposited layer with WC20Co powders by the plasma jet method: a) SEM analysis; b) 3D surface analysis.

Figure 5. EDX line analysis of the sample with WC20Co based powder by the PTJP method.

Line EDX analysis in figure 5 shows that there is tungsten in the layer area and is missing in the contact area between the base material and the substrate. The deposited layer shows a slight non-uniformity along the interface between the layer and the substrate, observing the presence of a thin layer of oxides on the separation line. This phenomenon is due to the plasma jet deposition method that does not create transient structures of melted material but only to the structure formed by flattened droplets due to the spraying dynamics when are sent to the surface.

Figure 6 shows the section through the deposited WC20Co powder layer by the plasma jet method. It is seen in the image obtained by the scanning microscope, that the deposited layer structure is uneven with gaps and oxides at the substrate layer interface, which affects the adhesion of the deposition on the base material. The deposited layer is relatively thin, with a thickness of about 73 μm. The deposited layer shows a slight non-uniformity along the interface and a strong delimitation between the layer and the substrate, even observing the presence of a thin layer of oxides on the separation line.

The adhesion tests were carried out using a tribological and mechanical test equipment Universal Micro-Tribometer (CETR-UMT-2) at the Tribology Laboratory at the Faculty of Mechanical Engineering, Iasi. The following parameters were calculated and plotted with the aid of the equipment.
program: variation of the response force $F_x$ (N), variation of the normal load force, $F_z$ (N), variation of the friction force, $F_f$ (N) and variation of the coefficient of Friction, COF.

Figure 6. EDX analysis of the thin layer deposited with WC20Co powders by the plasma jet method, 1 - layer, 2 - substrate.

The method used to test WC20Co-based powder samples is that of progressive loading. The test parameters are: penetration velocity that is equal to 1 mm/s, normal load force that varies linearly from 0 ÷ 19 N. The load time was 10 seconds and the length at which the adhesion test was performed is 10 mm.

From the analysis of the data on the loading diagram presented in figure 7 it can be shown that the deposited layer primes very fine cracks at an $F_z$ force of approximately 4.8 N, ie 6.3 to 7.1 mm from the start of the test.

Figure 7. Test Adhesion Test Chart of WC20Co Powder Samples by the PTJP method.

Very fine cracks occur at a distance of 6.2 ÷ 6.4 mm from the start of the adhesion test. Upon priming the cracks in the deposited WC floor, COF increases from 0.05 to 1.2 and the frictional force $F_f$ increases from 0.025 N to over 2.4 N. These values indicate a very good adhesion of the deposited WC20Co powder layer by the jet plasma method to the substrate.
4. Conclusions

WC20Co powder deposition can be successfully carried out by the plasma jet method since the plasma jet temperature is over 1600°C which results in a good melting of tungsten carbide having a melting temperature of 2830°C.

The plasma jet method can produce layers of different thicknesses, which can vary depending on the number of passes of the plasma jet over the deposited material in our case over a stainless steel from the blade of Francis turbine with shaft vertical.

In deposition by the plasma jet method, the appearance of superposition deposited is influenced by particle granulation. When depositing with WC20Co powders, fine surfaces are obtained because the powder has a smaller granulation than other types of deposition obtained with other WC-based powders.

Line EDX analysis shows that WC is present in the layer area and is missing in the base and substrate area. The deposited layer has a non-uniformity along the layer-substrate interface, also observing the presence of oxides at the interface. This phenomenon is due to the plasma jet deposition method that does not create transient structures of substrate melt material but only to the structure formed by flattened droplets due to the splashing dynamics that are glued to the surface of the sample.

References

[1] Chang J T, Yeh C H, He J L, Chen K C 2003 Wear 162–169
[2] Nejneru C, Perju M C, Sandu A V, Axinte M., Quaranta M., Sandu I., Costea M., Abdullah M M A B 2016 Revista de Chimie 67 1191–1194
[3] Yahya Z, Abdullah M M A B, Hussin K, Ismail K N, Sandu A V, Vizureanu P, Razak R A 2013 Revista de Chimie 64(12) 1408-1412
[4] Mustafa Al Bakri A M, Kamarudin H, Bnhussain M, Rafiza A R, Zarina Y 2012 ACI Materials Journal 109(5) 503-508
[5] Junaid H Masoodi, Harmain G A 2017 Energy 118, 644 – 649
[6] Perju M C, Nejneru C, Vizureanu P, Axinte M, (2013) Metalurgia International 18 174 – 177
[7] Bull S J, Rickerb D S, 1990, Surface and Coatings Technology 149 – 164
[8] Chen Z, Zhou Y, 2016 Surface and Coatings Technology 2419 – 2430
[9] Țugui C A, Vizureanu P, Savin A, Iftimie N, Perju M C, Cimpoesu N, Nejneru C 2016 Advanced Materials Research 1138 62 – 68
[10] Fedorov A, Rymkevich A, Bazhenov V, Zubchenko A S, Davydova N V 2015 J. Welding International, 894 –900
[11] Mustafa Al Bakri A M, Kamarudin H, Bnhussain M, Nizar K, Rafiza A R, Zarina Y 2012 Reviews on Advanced Materials Science 30(1) 90-97
[12] Sandu A V, Bejinariu C, Nemtoi G, Sandu I G, Vizureanu P, Ionita I, Baciu C 2013 Revista de Chimie 64(8) 825-827
[13] Neopane H P, Dahlhaug O G, Cervantes M, 2011 Global Journal of researches in engineering Mechanical and mechanics engineering 131–149
[14] Istrate B, Mareci D, Munteanu C, Stanciu S, Crimi C I, Trinca L C, Kamel E 2016 Environmental Engineering and Management Journal 15(5) 955-963

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