Ecological process for depositing thin layers with high tribology resistance for reconditioning the hydraulic turbines

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Abstract. Plasma thin-film deposition can be used to refurbish hydraulic turbine assemblies and subassemblies. In the case of reconditioning by the plasma jet deposition method, one or more plasma jet passes may be carried-out over the worn surface until the gaps achieved by the effect of the hydro-abrasive wear are filled with the depositing material. This paper presents the results obtained at the hardness tests of the thin layers deposited by plasma jet with powders based on Nickel and Boron (Deloro 60). Also, the adhesion of the multiple layers to the base material as well as the adhesion between the layers and the defects that appear on its separation surface were studied. The samples were also analysed from the point of view of the chemical composition by EDX probe and structurally by optical and electron microscopy Vickers-type micro-hardness tests were performed to determine the micro-hardness of the base material and the deposited layer. The VEGA II LMH electron microscope (TESCAN) with TAX QX2 EDX module was used to determine the material structure. The samples were obtained by the method of spraying in mesh spray with Ni powder. By this type of deposition, an easy method of obtaining and rectifying the blades of the hydraulic turbines is obtained with aims to harden the turbine’s blades, in order to increase the wear resistance without affecting the corrosion resistance.

1. Introduction
The field of research of the thin layers resistant to the hydro-abrasive wear is one of interest. The use of materials coated with thin layers resistant to wear is very wide, they can be used in the construction of rotors for domestic or industrial water pumps, which operate fluid in impurities (alluvial granules,
quartz sand, clay) and corrosive environments or in the construction of blades from hydroelectric power stations turbines.

The properties of the materials obtained through various deposition technologies are much better than of the material used as substrate. Deposits made by various methods, to be viable must be made at lower costs. The layer and base material assembly must have a lower production cost than other expensive materials used so far, so that such a deposit is cost-effective. However, the alloy chosen for the coating must offer good hardness and high resistance to hydro-abrasion. In order to be able to make a deposit with the properties mentioned above, we have chosen from the list of nickel-based commercial alloys a nickel and boron alloy named commercially (Deloro 60).

In many industrial applications, the devices and spare parts must have abrasive, hydro-abrasive wear and high corrosion resistance. Nickel and boron powders have melting temperatures between 964-1003°C, and hardnesses between 57 - 62 HRC which provides good resistance to hydro-abrasion. Besides the very good properties of hardness, they also have good tribological properties [1,2,3].

2. Materials and methods
The material is taken from a hydraulic turbine blade. The material was prepared to the desired dimensions by cutting with the help of Metacut M250 equipment to obtain the samples for depositing. The samples subjected to micro-hardness tests have the following dimensions: width of 25 mm, length of 35 mm and thickness of 5 mm. The samples were cut under running water using Metacut - M 250 cutting machines, then sanded on polished on sandpaper. The chemical composition of the stainless steel taken from the turbine blade was determined using the Foundry Master spectrometer and determined composition is presented in table 1.

| Chemical elements | Fe | C   | Cr  | Ni  | Mn  | Mo  | Other |
|-------------------|----|-----|-----|-----|-----|-----|-------|
| Percent, wt [%]   | 80.60 | 0.10 | 13.00 | 4.38 | 0.63 | 0.52 | balance |

Figure 1. SEM analysis of the chemically attacked control sample.

The analysis of the structure of the base material is presented in Figure 1. It has an acicular structure with elongated $\alpha$ grains. The samples were prepared metallographically by grinding on sandpaper and felt, then cleaned with alcohol. In order to emphasize the structure, the samples were attacked with Nital.
This paper presents the experimental results obtained on the deposits with Deloro 60 by the plasma jet method. These deposits are resistant to hydro-abrasive wear, corrosion and erosion at high temperature, these materials have been chosen as protective solutions for some devices that should have good mechanical and thermal resistance, namely the hydraulic turbine blades used in energy industry [4].

The samples deposited were investigated with Scanning Electron Microscopy (SEM) and by Energy Dispersion X-ray Microanalysis (EDX) but also by micro hardness and hydro-abrasion tests. The chemical composition of Deloro 60 powders is shown in Table 2 according to manufacturer's product sheets (Kennametal Stellite Deloro).

Table 2. The chemical composition of Deloro 60 powder.

| Chemical elements | Cr  | C   | Fe  | Si  | B   | Ni  |
|-------------------|-----|-----|-----|-----|-----|-----|
| Percent, wt [%]   | 13.0| 0.7 | 3.0–5.0 | 4.3 | 3.0 | Balanced |

Deloro 60 powders are characterized by their ease of application and ability to form a hard, smooth protective film that prevents atmospheric oxidation. It is also less expensive than its alternatives, such as cobalt alloys. These nickel and boron powders can be deposited by several methods such as: HVOF and thermal spray, PTA and laser deposition, spray-fuse and powder welding. The Deloro 60 layers deposited by the plasma jet method are used in aeronautics, oil and food industries.

![Figure 2. SEM micrography analysis of Deloro 60 powders.](image)

![Figure 3. Plasma jet deposition method a) principle sketch of the method [5]; b) the installation.](image)
The spray method of plasma jet [6] is based on spraying a powder (ceramic [7], metallic [8,9], etc.) melted / deposited on a substrate (base material) to obtain thin layers, Figure 3 (a). Thin layers are obtained by thermal spray in plasma jet using the Sulzer Metco 9MCE facility provided by the Faculty of Mechanics, "Gheorghe Asachi" Technical University of Iași, Figure 3 (b). In the case of deposits with Deloro 60 powder, the deposition was carried out with speed between 450 and 650 m/s, and the spray distance was about 100 mm.

This method can be used for depositing different layers with pure metals or alloys, being very used for the nickel coatings, which possess very good properties: uniform and adaptable thickness, high hardness, good behavior at hydroabrasive wear, good resistance corrosion [8,9,10].

3. Results and discussions

There are several methods used to make the hard surfaces, in the present study, Deloro 60 was used for deposition. The coatings were made on stainless steel samples.

The hardness measurements were performed with a load of 50 gf with the help of the CV-400 DM microdurimeter from the Faculty of Materials Science and Engineering in Iasi, the Department of Materials Processing Technologies and Equipment within the Plastic Deformation laboratory.

![Microhardness](image)

**Figure 4.** Comparative analysis of the micro-hardness of the control sample and of the deposited sample.

From the analysis of the variation graph of micro-hardness it is observed that all four deposits have higher microhardness than of the base material which has a hardness of approximately 280 HV. Deloro 60 powder deposition is four times harder than the control sample, Figure 4.

Most coatings containing Ni-based powders form in their structure a solid dendritic Ni solution whose hardness depends on the amount of dissolved C and Fe atoms. Chromium forms hard phases - carbides of (Fe,Cr)\(_2\) (C, B)\(_3\) and borides (Fe,Cr) (B, C) [11,12].

Deloro 60 powder-jet plasma deposits have a multi-drop and flattened appearance. This is due to the small surface stresses of the droplets sprayed by the plasma jet, which results in a better adhesion and a smoother appearance of the surface [12]. The microstructure of the coatings with Deloro 60 has easy pathways for crack propagation. They also present precipitates of primary and secondary solid solution of Ni, Figure 5 a.
These hard precipitates act as a barrier that prevents the slipping of the abrasive particles from the water during the wear process. Boron and Silica create low melting eutectic phases; they ensure adequate coherence between carbides, borides and matrices Figure 5 b.

![Figure 5](image)

**Figure 5.** Analysis of the sample deposited with Deloro 60 powder plasma: a) SEM 250 X microscopy; b) EDX analysis.

In order to increase the service life of the hydroelectric constructions and to maintain them in a safe and reliable condition for as long as possible, the hydraulic turbine blades must have a high durability and resistance to high hydro-abrasion. Hydro-abrasive wear caused by carborundum abrasive particles are the main problems of hydraulic constructions. Hydro-abrasive wear of hydraulic turbines is a long-term problem; it usually takes several months or even years before a damage can be assessed.

![Figure 6](image)

**Figure 6.** SEM analysis of the samples deposited with Deloro 60 by the plasma jet method subjected to the hydro-abrasive wear process.

Figure 6 shows the traces left by carborundum particles the abrasive particles in water used in the test facility. It is also observed that in the cavity of the trace left by abrasive particles on the surface of the layer deposited with Deloro 60 powders by the plasma jet method, there are no cracks that indicate a good compatibility between the layer and the substrate.

Silicon carbide particles were used for hydro-abrasive wear tests. The hardness of silicon carbide used as abrasive particles is between 900-1100 HV being higher than that of the coated surface [13]. The abrasive particles have sharp angles, which are the main causes of the removal or wear of the coating materials with Deloro 60. The carborundum particles was obtained by crushing therefore, the particles have different sizes and angular shapes.

In case of coatings made with Deloro 60 it is observed that the hydro-abrasive wear begins to appear after a long test period and the deterioration of the hard precipitates leads to the appearance of cracks. It was observed that for the first time during the tests of hydro-abrasive wear, the roughness peaks formed on the surface of the deposits with Deloro 60 are flattened. This statement can be supported by the comparative aspect between figure 5a (before) and figure 6 (after wear).
4. Conclusions
In case of plasma jet deposits, the thickness of the layer may vary depending on the number of passes of the plasma jet. Analysing the results obtained from the micro-hardness tests and the graph obtained, it is observed that the micro-hardness of the layer deposited with Deloro 60 is approximately four times higher than the base material.

The high hardness of coating deposited with Deloro 60 is given by the presence of the borides forming. This element, even in percentages less than 0.2%, increases the hardness, mechanical strength and tenacity.

The percentage of boron, in the case of the deposition with Deloro 60 powders is 3.1 ± 3.5%, sufficiently large amount to form complex, hard compounds of Fe, Cr and Ni even after it was partially burned in the deposition process. Deposits with Deloro 60 have a significant amount of boron in the composition, which is the main element that intervenes in the formation of a very hard layer.

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