Ecological process of energy growth of hydraulic turbines used in protected areas in Romania

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Abstract. The energy-boosting of hydraulic turbines by improving efficiency and service life is a continuing concern of this century when trying to move from a fossil fuel polluting energy to a wider use of electric power to propel cars. Increased performance of these hydraulic turbines can be achieved by depositing thin, hydro-abrasion-resistant, thin layers. In this paper we will analyze mechanically and structurally thin, adherent-hard layers that have been deposited on a special stainless steel. The aim is to increase the energy efficiency of hydraulic turbines by increasing the hydro-abrasion resistance of the blades. The deposits are made with plasma-based thermal spraying powders / electrodes. The microstructural tests will consist of optical and SEM microscopic analysis of the deposited material and layer, and the mechanical ones will consist of the analysis of elasticity and adhesion.

1. Introduction

Stainless steel coated with wear-resistant thin layers are used today for a wide variety of applications, they are used to make rotors of pumps for oil platforms, hydraulic turbine blades, drinking water pumps or household pumps, are also employment in the development of subassemblies in the naval industry. The properties of metallic materials are improved by depositing thin layers of special materials. The deposited layer has better resistance to hydroabrasive wear and corrosion.

In achieving these thin layers, adhesion should be considered, but the realization costs should be as small as possible. Thin layer deposits [1-3] have a number of applicative features such as: they are used to alter the physical appearance and roughness of the constructive device; are suitable to create a barrier to protect against physical and chemical factors that may affect the substrate [4,5]; these depositions can also be applied in obtain metallic and non-metallic thin layers with certain stress-resistant [5-9] characteristics (high magnetic susceptibility, electrical conductivity and superficial heat, refractory properties, good weldability, wear resistance etc.).

The mechanism of protection by metallic layers [10] is different and depends on the ratio of the electrochemical equilibrium potential of the metal in the deposited layer toward the potential of the support metal. This criterion distinguishes layers of anodic coating and cathode layers [10-12]. Due to the extraordinary properties of the deposited materials, systems with a substrate with much better properties than those of the base material (stainless steel) have been obtained and realized by vibrating
electrode deposition. These newly obtained systems with good strengths were made at a much lower cost than if the subassembly was entirely made of the depositing material (e.g., Wolfram, Titan, Nickel).

2. Materials and methods
The base material used is a material from a Francis high-speed turbine. A stainless steel from a blade of this turbine has been reliance as a base material as it is frequently subjected to a hydroabrasive wear [14-16] process. This hydroabrasive phenomenon is more pronounced in this type of turbine because it is a flow-response turbine that combines radial and axial concepts. Francis turbines are today the most used hydraulic turbines [16-18]. They operate in a wide range of heights from 20 meters to several hundred meters, which is why the blades of these turbines are very much subject to hydroabrasive phenomena. The power developed by these turbines is great, so they are used in the largest hydroelectric plants in the world.

The base material was cut from a turbine blade to obtain sandblasted and deposited samples to then perform EDX chemical tests and to be microfitted. The samples are \( l = 25 \) mm, \( L = 25 \) mm and \( h = 5 \) mm. The chemical composition of AISI 415 steel was determined by spectroscopy and is presented in Table 1.

| Element | Fe  | C   | Cr  | Ni  | Mn  | Mo  | balance |
|---------|-----|-----|-----|-----|-----|-----|---------|
| Content [%] | 80.6 | 0.105 | 13  | 4.38 | 0.637 | 0.521 | 0.757   |

![Figure 1. SEM analysis of AISI 415 steel cut from the Francis turbine blade: a) polished sample; b) sample blasted.](image_url)

After the samples were cut to the desired size, they were prepared by removing a superficial layer to avoid chemical artefacts from previous operations and even from the exploitation process, because the materials are from a used Francis blade. After etching, the samples were blown with hot air to remove impurities.

Figure 1a then, in order to uniform the roughness obtained using pneumatic sandblasting, Figure 1b, it also can lead to a better adhesion of the deposited layer to the base material. To avoid superficial oxidation of the base material, tungsten carbide deposition was performed within one hour of sandblasting.

SEM analysis was performed to examine the surface of the base material before blasting and after to highlight how the surface of the material had changed and whether it had a more roughness surface that would lead to a better adhesion of the deposited material.
A powder with a high tungsten content (above 80) was used for deposition because it creates a very tough, compact corrosion-resistant layer. Considering that there is a direct proportionality relationship between hardness and wear, it can be said that it will withstand wear well. In the chemical composition of the powder there is also a significant amount of cobalt of about 13% which leads to a better resistance to friction.

**Figure 2.** SEM analysis of WC powders.

Plasma jet deposition is one of the deposition processes with varying deposition parameters (temperature, atmosphere, pressure, particle size and deposited material, layer thickness) of all thermal spray deposition processes. The most commonly used plasma deposition method is in the normal atmosphere and is called APS (Atmospheric Plasma Spray). In case of deposition in controlled atmosphere this is done in an inert gas inside an enclosure that has previously been vacuumed.

Analysis of W powders at SEM reveals a collapsed form. This aspect of the WC particles is due to the process of making it consisting of casting it into ingots that are then crushed Figure 2. The particles contain angular tungsten carbide crystals with a diameter of 6-26 μm [4] a matrix Co.

### 3. Results and discussions

In this paper thin films based on tungsten carbide powder that have been deposited by plasma spraying are tested. The base material is a martensitic stainless steel with an elongated acicular structure of Fa [5]. The structure and properties of the deposited multiple layer are influenced by deposition parameters.

Layer composition was investigated using the EDAX probe. The microstructure was studied using both optical microscopy and electronic electron microscopy scanning. For these studies, as well as for micro-hardness measurements, the cross-sectional sections of the sample were polished on felt.

In order to increase the efficiency of the hydraulic turbine blades used in the area, thin layers of WCs were deposited by plasma spray resist hydroabrasive.

SEM analysis of the deposited layer was performed using the TESCAN VEGA II LMH microscope having an EDX-type TAX QX2 module.

When examining the SEM microscopy of the layer (Figure 3), a good adhesion of the layer is observed, but the presence is also microprecipitation or inclusions. EDX analysis (Table 2) was also used for a more in-depth examination and identification of constituents. From the SEM images obtained, it can be seen that the adhesion is very good and has a small amount of inclusions. From the analysis of the surface of the samples submitted and following the above, we conclude that an appropriate method of deposition has been chosen and the deposition parameters are also correctly chosen.
Figure 3. SEM analysis of the tungsten carbide layer: a) 750x; b) 1250x.

Table 2. Chemical composition of the sample deposited by plasma spray methods using WC based powder determined by EDX.

| Elements | %     |
|----------|-------|
| Tungsten | 76.37 |
| Carbon   | 9.84  |
| Cobalt   | 6.97  |
| other    | 6.82  |

Figure 4. In-line EDX analysis of the plasma-jet sample with WC-based powders.

The deposited layer shows a slight no uniformity along the interface and a strong delimitation between the layer and the substrate, even observing the presence of a thin start of oxides on the separation line. This affects the adhesion of the deposition, and the irregularity of the structure has a negative impact on the refractoriness (the non-uniformity at cooling-heating).

Analyzing Figure 5 where the microstructure of the deposited layer (right) is shown, a small number of gaps and inclusions are observed between the base material and the first deposited layer. Between the first layer and the other layers there are a number of larger retouches and inclusions. The plasma jet does not create transient structures of layer-substrate melted material, but only of the structure formed by flattened droplets due to the splashing dynamics that are glued to the surface of the sample.
The indentation technique evaluates the mechanical properties of the thin layers by measuring the Young (E) modulus of elasticity. The modulus of elasticity was determined by means of the Universal Micro-Tribometer (CETR-UMT-2) which calculates this indicator with the following parameters: the force P, the depth of the fingerprint left by penetrator h and the area left by the penetrator on the surface A.

Figure 5. Sample indentation curve with WC.

The modulus of elasticity obtained from the indentation tests is about 12 GPa. By depositing with thin layers, it was desired to produce hard and medium elastic materials which increase the resistance to hydroabrasive wear. As is known, the relationship between elasticity and resistance to hydroabrasive wear and dry wear is often inversely proportional.

4. Conclusions
The plasma deposited WC layer has good adhesion to the base material with a small number of very fine inclusions at the substrate layer. The layer contains some non-metallic inclusions that are common and common in the case of plasma jet deposition. Microstructures exhibit very low non-metallic inclusions, especially distributed to the grain boundary. Deposition of a layer of a material containing chemical elements with good hardness properties together with a correct choice of deposition parameters leads to a layer with good wear behavior.

The results have shown that this deposition process can be an important solution to increase the hydroabrasive wear resistance without affecting the corrosion resistance of the deposited stainless steels. The thickness of the layers was presented using the SEM electronic microscopy performed in the sample section. It has been observed that the adhesion of the substrate to the substrate decreases as the thickness and layer thickness increase.

5. References
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