

Study on the structure of hard composite layers from iron and tungsten carbide powders

I. VIDA-SIMITI*, N. JUMATE, N. SECHEL

Department of Materials Science and Technology, Technical University of Cluj-Napoca, 103-105 Muncii Ave., 400641 Cluj-Napoca, Romania

Hard composite layers were deposited by tubular electrodes coating using a core of blended powders containing iron and FTC – fused tungsten carbide (eutectic mix of WC+W₂C). The layers were obtained using different technological parameters for the oxyacetylene flame and for the TIG process. The deposited layers were analyzed using scanning electron microscopy, X-ray diffraction, hardness and micro-hardness tests. The interface phases, of reactive and diffusive type, between the carbide particles and metallic matrix were also studied. The carbide particles distribution in the composite layer is uniform. Dissolving phenomena of the carbide particles in the matrix is influenced by the thermal deposition parameters.

(Received December 29, 2009; accepted January 19, 2010)

Keywords: Composite layers, Hardfacing, Carbide, Interface

1. Introduction

The required conditions for a composite layer, deposited by hardfacing, are: good adhesion between layer and substrate, low residual stresses, low porosity, low dilution between layer and substrate, no dissolution of hard reinforcing particles in the matrix, formation of reactive or diffusive type strong interfaces between the matrix and the hard particles, tribological properties that must satisfy the functioning requirements etc. [1, 2, 3, 4]. These requirements are difficult to be met simultaneously, being frequently contradictory or dependent on each other, due to the multitude of physical, chemical and metallurgical factors that influence the hardfacing process [4].

In the case of composite layers coating there are two types of interfaces: layer-substrate interface and matrix-reinforcing particle interface. Special problems can appear at the metallic matrix - ceramic reinforcing particle interface because the interface quality assures the structural integrity of the composite layer and its behaviour to mechanical loads by stress transfer from one component to another [5]. The coupling between metallic and ceramic materials is difficult due to chemical nature and phase differences between the two components. Electronic type particularities hinder the formation of continuous chemical bonds at the metal-ceramics interface. In general, the metal-ceramics interface forms as a result of chemical reaction processes and reciprocal diffusion of the chemical elements.

Regardless of the thermal deposition regime, the layer will always present a random dispersion of the reinforcing particles and an inherent porosity that depend on the tubular electrode composition and deposition parameters.

2. Materials and experimental method

Deposition of composite layers by oxyacetylene flame and tungsten inert gas (TIG) processes using tubular electrodes with a core containing ceramic particles does not require an electrode covering. Protection of the deposited layer is assured by the gases used in these two deposition processes.

Tubular electrodes were made from steel tubes having 10 mm outer diameter, 2 mm wall thickness and 400 mm length. The core was prepared from FTC – fused tungsten carbide (eutectic mix of WC+W₂C) – powder with 100÷500 µm grain size, iron powder with 63÷200 µm grain size and an organic binder. Powder core blends contained 60 %vol. FTC.

Plain carbon steel samples (0.45% C), with a thickness of 10 mm, were coated using these cored tubular electrodes. Layers of 3÷5 mm thick were deposited by neutral oxyacetylene flame and electric arc (TIG process), at different deposition regimes. From the coated samples there were cut metallographic specimens which were polished and etched for electronic microscopy analysis, hardness and micro-hardness measurements, etc.

Local chemical composition analysis of the tubular electrodes and of the layers was performed by using scanning electron microscope (SEM) equipped with an EDX analyzer.

3. Experimental results and discussions

The core blend (Fig. 1) is formed of large angular FTC particles and smaller iron particles, with irregular shape, randomly distributed.

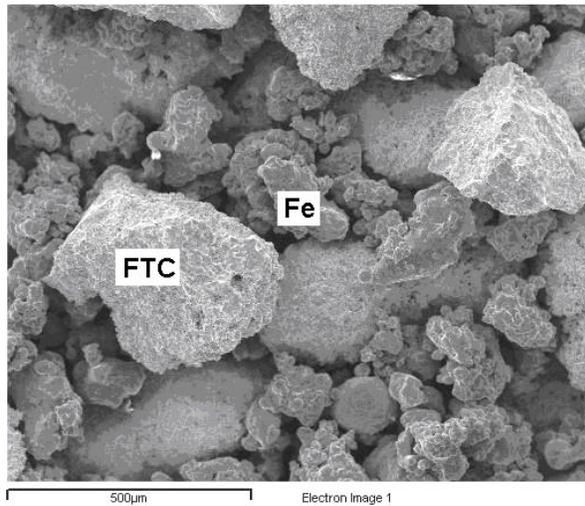


Fig. 1. SEM micrograph of FTC and iron particles blend for the electrode core.

A cross-section through a cored tubular electrode is shown in Fig. 2.

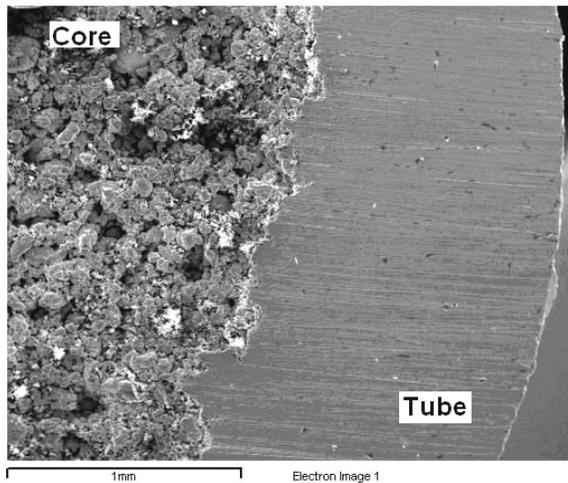


Fig. 2. SEM micrograph of the cross-section through the tubular electrode.

Cobalt is the most important metal used as a matrix for hard alloys based on carbides due to its wetting properties and adhesion to the surface of the carbide phase. However, it is a very expensive metal. For composite layers deposited by thermal processes, iron is preferred because it is cheaper than Co or Ni. Nevertheless, iron has lower resistance to oxidation and corrosion. The microstructure of the alloys deposited by TIG process consists of tungsten carbides embedded into a metallic iron based matrix (Fig. 3). Particles distribution in the composite layer is relatively uniform and this fact was confirmed by high hardness of about 55-63 HRC measured in different places on the layer. Tungsten carbides dissolve relatively rapidly into the molten metal at temperatures

above 1200°C. For this reason, electric arc deposition using covered electrodes is not recommended for hardfacing. Deposition can be done in this case by induction, oxyacetylene flame or TIG process, provided that deposition parameters are optimized.

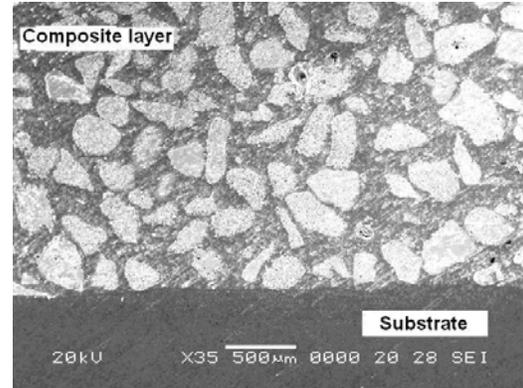


Fig. 3. Composite layer deposited by TIG process.

For the particular case of deposition of wear resistant coatings containing carbide type reinforcing particles, the dissolution phenomena are encountered at the interface between carbide particles and metallic matrix, but also at the interface between deposited layer and the solid substrate (Fig. 4) [5, 6].

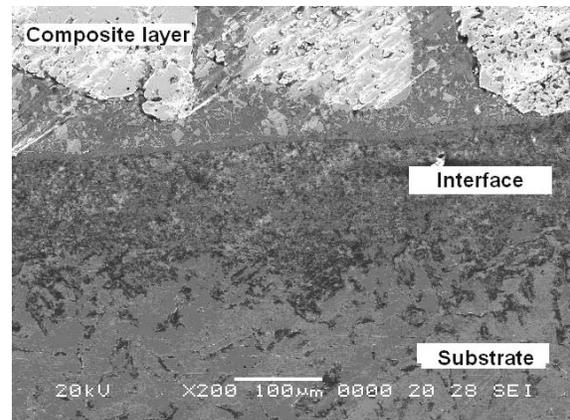


Fig. 4. Layer-substrate interface (deposition by TIG process).

Experiments revealed that during depositions using oxyacetylene flame but also using TIG process, the deposited layer may not have the required composition, perhaps due to the inappropriate mixed composition for the electrode core (filling coefficient) or due to inappropriate optimization of depositions parameters. Thus, Fig. 5 shows that in the case of oxyacetylene flame deposition, with inappropriate parameters, carbide particles are much smaller compared to the initial particles from the electrode core. It can also be observed their rounded edges due to their partial dissolution in the metallic matrix.

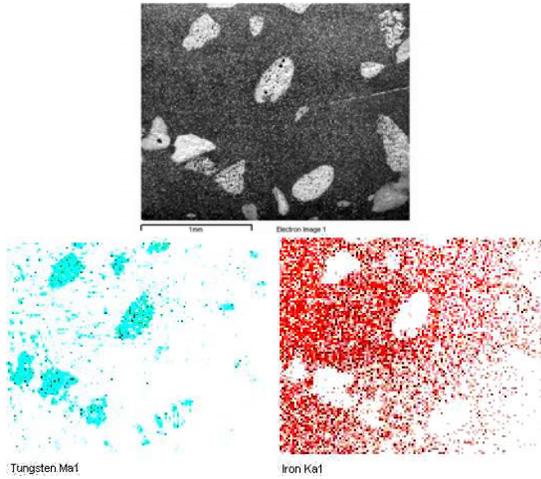


Fig. 5. Structure of a layer that was inappropriate deposited (hardfacing using oxyacetylene flame; SEM image; distribution maps for W and Fe).

When the electrode core was initially sintered and deposition was performed using an electrical arc at 150A, FTC particles decomposed and formed together with the iron matrix the lamellar eutectoid structure located at the edges of alloyed iron crystallites that are specific to high alloyed steel (Fig. 6). During deposition of composite layers using low speeds or with stationary electrode, possible segregations and considerable dissolution of carbide particles can be encountered.

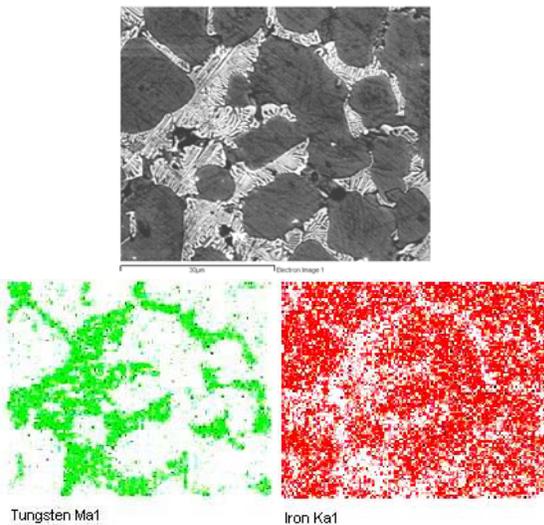


Fig. 6. Structure of a layer deposited by TIG process using a sintered electrode (SEM image; distribution maps for W and Fe).

Due to high density difference between carbide and iron melted matrix, carbide particles may segregate and deposit at the bottom of the liquid pool. In this case it can be observed a non-uniform distribution of particles within the layer (Fig. 7). The oxidation reactions that are taking place at the surface during deposition are affecting the interaction between WC-W₂C and melted metal.

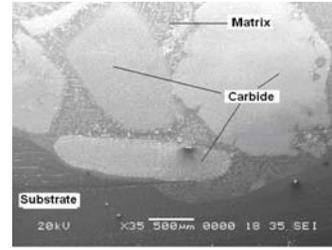
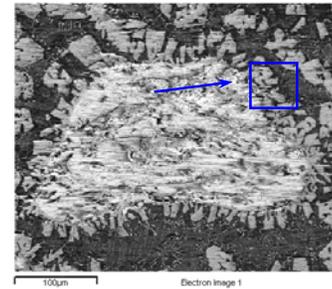


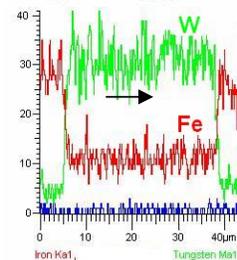
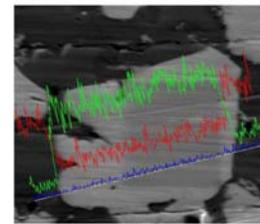
Fig. 7. Segregation due to density differences and dissolution of some carbide particles.

Along with the system metal – FTC other systems are formed as well, with a different surface energy. The diffusion zone between the matrix elements and carbide can be continuous or discontinuous (Fig. 8 and 10).

Fig. 8 (b) shows the image of a crystalline grain that belongs to the carbide-matrix discontinuous interface of the particle that is presented in Fig. 8 (a). By analyzing W and Fe distribution on one direction, it can be observed that the ratio Fe/W is about 1/3, showing that these grains have the probable composition FeW₃C [7].



(a)



(b)

Fig. 8. Discontinuous interface between matrix and FTC particle: (a) SEM image of carbide particle with discontinuous diffusion interface (green colour); (b) Iron distribution in the carbide grain at the discontinuous interface matrix - FTC particle, W and Fe distribution on one analysis direction.

Fig. 9 shows the continuous interface formation between carbide particle and iron matrix after dilution by iron atoms diffusion in the FTC particle.

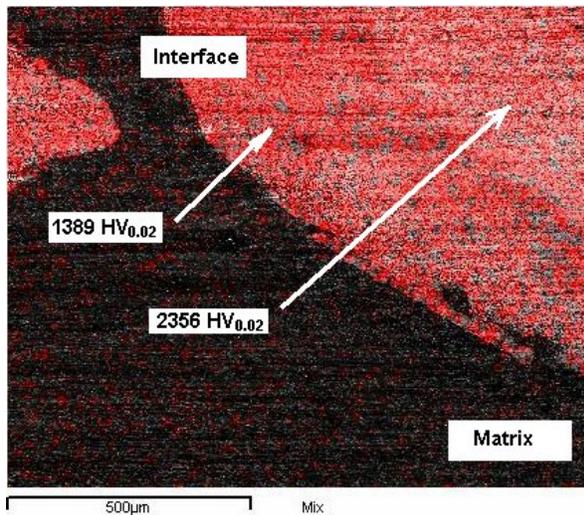


Fig. 9. Continuous interface between matrix and FTC particle.

The micro-hardness of FTC particle is decreasing on a distance of approx. 80-100 µm from its edge, and complex iron and tungsten carbides (Fe_nW_n)C are forming within the matrix. Due to this process, the matrix micro-hardness is increasing (Figs. 9 and 10).

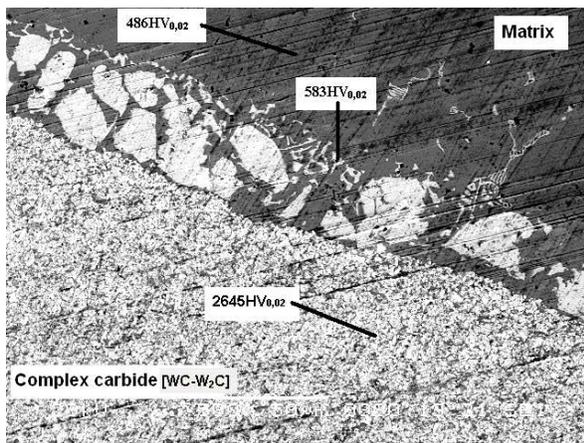
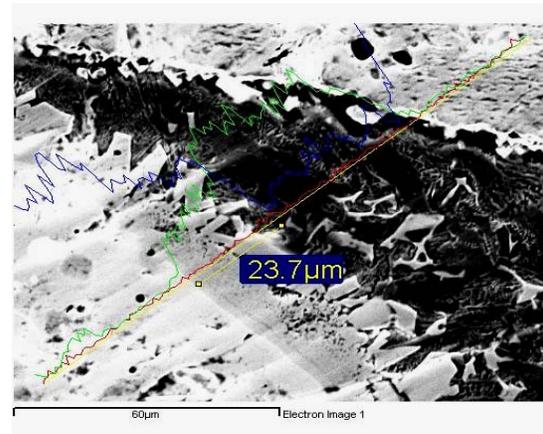


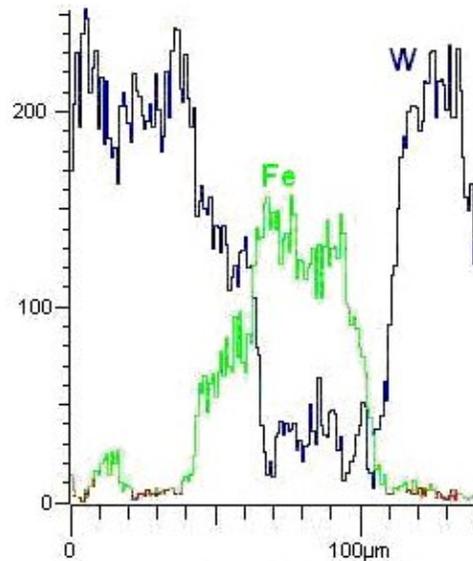
Fig. 10. Discontinuous interface between matrix and complex carbide particle [$WC-W_2C$].

Fig. 11 shows images of interfaces and the elements' distribution along an analyzing line (line-scan) that crosses the particle-matrix-particle interfaces in a sample that was deposited using the oxyacetylene flame. From the line-scan distribution (Fig. 11 (b)), it can be very well observed the variation of tungsten and iron composition at the interface zones between carbide particles and iron matrix. Therefore, a diffusive type of interfaces is formed. However, the interfaces formed between the hard particles and the matrix display the grey colour, showing that

compositional changes are taking place due to diffusion at interfaces (Fig. 11 (a)).



(a)



(b)

Fig. 11. SEM image of the particle-matrix-particle interfaces: (a) line-scan analysis; (b) (Deposition using oxyacetylene flame).

Phases of the type $(Fe_xW_y)C$ are forming in the matrix of Fe-FTC composite layer [8]. Such double carbides can be observed during microscopic investigation and they have specific "fish bone", or Chinese characters shape (Fig. 14). These carbides have a growing tendency in the iron based matrix due to W and C diffusion. The following phases were identified in the composite layers by X-ray diffraction analysis: solid solution of Fe, WC, W_2C , and double carbides of $Fe_3W_3C - Fe_4W_2C$.

During the cooling there is a tendency of forming fragile double carbides of $(Fe_xW_y)C$, (Fig. 12 and 13), and precipitation of cementite (Fe_3C), (Fig. 13) with no benefit

for the composite as the tensile strength of the deposited layer is diminished.

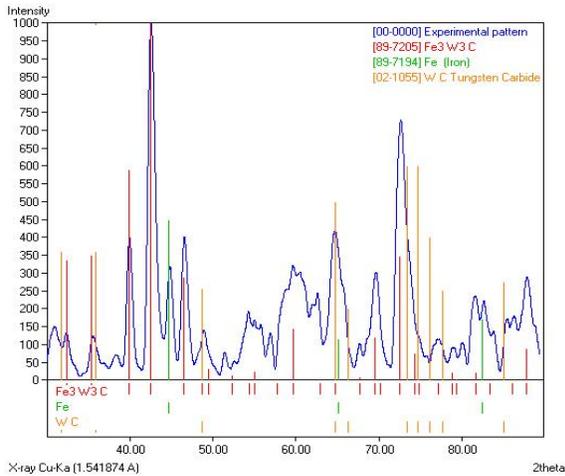


Fig. 12. X-ray diffraction pattern for a sample obtained by TIG process.

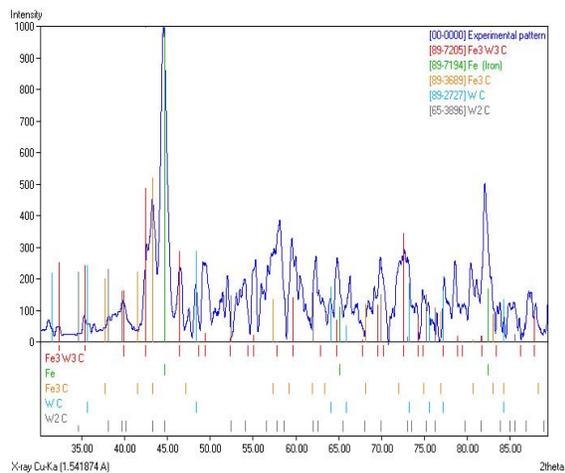


Fig. 13. X-ray diffraction pattern for a sample obtained by oxyacetylene flame process.

Hardness measurements of Fe – FTC composite layers are evidencing high hardness values of 50...70 HRC. High hardness values of the layers can be obtained even if the layer does not have a composite structure. As an example, the layers from the Fig. 6 have high hardness due to double carbides of the type $(Fe_xW_y)C$. These type of composite layers do not have good functionality and do not display acceptable wear resistance (carbide phase ensures the hardness and wear resistance and the metallic matrix ensures the toughness and mechanical strength that is necessary for the composite material) [8, 9].

Due to this reason, the composite layers of the type Fe-FTC should have a structure similar with the structure presented in Fig. 14:

- the carbide particle-matrix interface should be continuous (Figs. 9, 11 and 14) and discontinuous (Figs. 8 and 10);

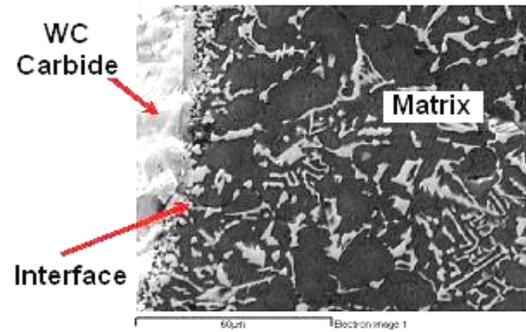


Fig. 14. SEM image of the carbide particle – matrix interface for a specimen that was deposited with oxyacetylene flame.

- the carbide particle-matrix interface should be small (5-20 μm in the case of carbide particles of 100-500 μm);
- the shape of particles should remain angular after deposition (the conservation of the shape can be obtained by minimizing the dilution);
- the matrix should have less fragile double carbide of the type $(Fe_xW_y)C$ or cementite.

4. Conclusions

By applying the thermal deposition technique with tubular iron electrodes and with the core composed of a mixture of iron powders and carbides can be obtained composite layers that are reinforced with wear resistant particles.

Between the iron matrix and tungsten carbide particles interfaces of the type diffusive – reactive are forming following the reciprocal diffusion of iron and tungsten. The interface that is formed can be continuous or discontinuous.

During the deposition, in the case of a liquid bath temperature higher than 1200 °C and for maintaining the liquid state longer periods of time, the carbide particles are decomposing and dissolving in the iron matrix and, as a result, high alloy steels are forming. Using this procedure, the deposited layer is losing the composite material character.

Within the matrix and within the discontinuous interface dispersed phases are forming that have the composition of a fragile complex carbides of the type $(Fe_xW_y)C$. These phases exhibit weak mechanical performances or the composite layer. Therefore, it is very important to use technological parameters that ensure the formation and conservation of the composite structure having continuous interface and narrow width, with no dissolution of carbide particles during the thermal deposition process.

For high currents during deposition, while the electrode is stationary, a liquid bath is formed and this can dissolve even large grain size carbides.

The deposition rate is a very important parameter during the hardfacing process. In the case of a low speed

and for stationary electrode, a non-uniform composition can be obtained due to the segregation and particle dilution, while too high a speed or a fast cooling rate leads to the formation of the dendritic structure of the matrix.

In the case of hardfacing by welding in an oxidizing atmosphere, the structure of the carbides-matrix interface displays defects related to secondary carbide precipitation at the grain boundaries where there is a high content of tungsten and carbon oxides.

References

- [1] H. D. Steffens, R. Kaczmarek, *Powder Metall. Int.* **2**, 105 (1991).
- [2] A. M. Korsunsky, M. R. Gurk, S. J. Bull, *Surf. Coat. Technol.* **99**, 171 (1998).
- [3] R. W. Smith, R. P. Krepski, R. O. Drossman, *Proc. Int. Thermal Spray Conf.*, Orlando, USA, 653, 1992.
- [4] V. V. Sobolev, J. M. Guilemany, A. J. Martin, *Int. Mater. Rev.* **42**(3), 118 (1997).
- [5] A. G. Metcalfe, *Interfaces in Metal Matrix Composites*. Composite Materials, Acad. Press, New York and London, **1**, 1974.
- [6] G. K. Budinski, *Surface Engineering for Wear Resistance*, Prentice Hall, 1988)
- [7] N. Jumate, I. Vida-Simiti, G. Negrea, *EuroPM 2008 Conf. Proc.*, EPMA **2**, 117 (2008).
- [8] W. H. Jiang, J. Fei, L. Han, *J. Mater. Sci. Lett.* **20**, 283 (2001).
- [9] J. R. Davis, *Surface Engineering for Corrosion and Wear Resistance*, ASM Int., Materials Park, OH, USA, 2001.

*Corresponding author: Vida.Simiti@stm.utcluj.ro