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Influence of the Fusing Process on the Wear and Corrosion Properties of NiCrBSi-Coatings

In this study the NiCrBSi feedstock powder was deposited by flame spraying on to C45 steel substrate. After spraying the coated material was differently fused at 1000°C. The microstructure evolution respectively the phase composition was evaluated by means of scanning electron microscopy (SEM) and by X-ray diffractometry. The corrosion resistance of the differently fused coatings was assessed by potentiodynamic corrosion tests carried out in 3,5 % NaCl solution at room temperature, using a saturated calomel electrode (SCE) as reference. In addition, the variation of the friction coefficients in time for the two tested coatings was determined using the pin-on-disk method. The investigations showed that the characteristics of the inductive remelted coating are better in comparison with the flame fused one.

Keywords: *fusing process, corrosion, self-fluxing coatings, wear*

1. Introduction

Ni based self-fluxing alloys of type NiCrBSi are usually used as coatings for protection against wear and corrosion, especially at higher temperatures. The demands on performance and lifetime of different components are continuously increasing. In the particular case where wear and corrosion resistance at low and moderate temperature are required, the use of Ni-base self-fluxing alloys has received widespread use [1]. Atmospheric plasma spraying (APS) or flame spraying, respectively that with a high velocity (HVOF) is the most applied techniques for deposition of such alloys [2-5]. Both types of technologies are not imposing special characteristics for the coating material. Moreover, it is possible to deposit coatings with thicknesses ranging from several micrometers up to some millimeters. The characteristics of the as sprayed coatings cannot be satisfactory for industrial applications because of the high degree of porosity, internal oxides as well as of the susceptibility to delamination.

The flame sprayed coatings exhibit usually a higher degree of porosity and a poor adhesion to the substrate in comparison to the plasma sprayed coatings. In order to improve this properties and to increase the coating adhesion to the substrate, a subsequent surface treatment has to be applied [6], [7]. This induces shrinkage of the coating volume in the order of 20%. The porosity is reduced from 10-20% down to 0.3–5%. During fusing, the coating is heated to a point between the solidus (975°C) and the liquids (1038°C) temperatures [8].

The dependence between the microstructure of laser treated NiCrBSi coatings and corrosion resistance was already investigated by potentiodynamic polarization measurements in 3.5 wt.% NaCl at room temperature. The obtained results demonstrated that, the corrosion resistance was increased because of a finer structure and higher densities of the coatings, but corrosion mechanisms occurring in all cases were different [9, 10]. The wear behavior of the NiCrBSi coatings is strongly influenced by the phase composition after fusion. The matrix of fused coatings contains almost a Ni-rich solid solution and low melting point Ni–Ni3B eutectic. Binary silicide's (Ni5Si2 and Ni3Si) can also be observed in alloys containing more than 6% in weight of Si, depending on the Cr content [1].

This paper reports about the characteristics of the flame sprayed coatings which were differently fused. The type of post treatment technique may influence the corrosion and wear behavior of the NiCrBSi coatings depending on the features of the new refined and dense structure as well as on the induced phase composition. The aim of this paper is to study the influence of the type of fusion process (induction and oxy-acetylene flame) on the coating structure and properties. Concerning this aspect, the corrosion resistance as well as the sliding wear behavior of these coatings were investigated and compared.

2. Materials and methods

NiCrBSi -106+45µm feedstock powder (M-772.91 from FST Company/Cr, 10.0%; Fe, 2.5%; Si, 3.1%; B, 2.1%; C, 0.4%; Ni, balance) was used for the flame spraying deposition of the investigated coatings. These powders were sprayed on a C45 steel substrate. Before spraying, the specimens were cleaned, degreased and surface finished.

The main parameters associated with the flame spraying process were: oxygen flow 1.6 m^3/h; acetylene flow 0.85 m^3/h; spray distance 200 mm. After spraying the coated material were differently fused (induction and oxy-acetylene flame) at 1000±10 °C. Coating coupons were cross-sectioned in respect of the coating surface and then mounted and polished according to conventional metallographic procedure. The morphological investigations of the coatings were carried out using a scanning electron microscope (SEM / Philips XL 30 ESEM – FEI Company) combined with an energy dispersive x-ray analysis (EDX / EDAX). X-ray diffractometer (XRD / Philips X'Pert) was used to determine the phase composition of the fused coatings, applying a Cu-K_α radiation. The data were collected for 2θ = 20-100°.

Microhardness measurements HV0.3 (applying a 0.3 kgf load) were performed on mounted samples using a Zwick tester of type Z3.2A. The value presented is the average of 10 measurements after the highest and lowest values being discarded. Electrochemical measurements were carried out in order to compare the corrosion behavior of the differently fused coatings. Polarization curves were recorded in the positive direction at room temperature in a 3,5% NaCl solution with a three electrode cell using a saturated calomel electrode (SCE) as reference. The applied potential was varied between -1000 and +1500 mV using a rate of 50 mV/min.

The sliding wear resistance was determined using the pin-on-disk testing method by calculating the variation of the wear track depth with applied load (Tribometer CSM Instruments). The normal load applied to the pin (WC-Co ball with a 6 mm diameter) was 10 N, the relative velocity between the ball and surface was v=20 cm/s, and the testing distance 1000 m (the radius of the sliding path was 5 mm). The relative humidity was 65 %.

3. Results and discussion

SEM investigation of the powder morphology reveals a high content of spherical particles, some of them exhibiting some satellites on it (fig. 1). The microstructure of the differently fused coating is represented in the cross-sectional micrographs from figure 2. Considering the SEM-micrographs at lower magnification (fig. 2a and 2c), the coating reveals a very compact structure with a good adhesion to the substrate. The dark spots better visualized on the micrographs at higher magnitude (2b and 2d) are not pores. The EDX-analysis identified the presence of Si and O. Besides those black inclusions there are some dark gray particles which were identified as containing Cr, Si and O.

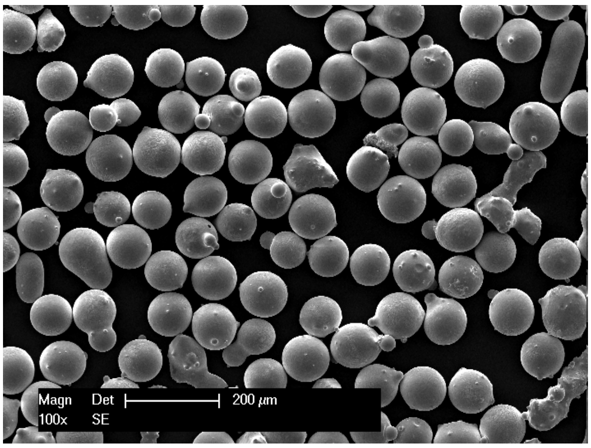
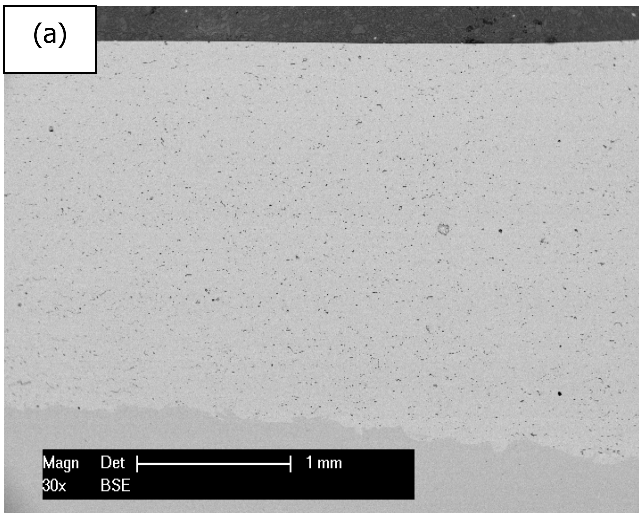
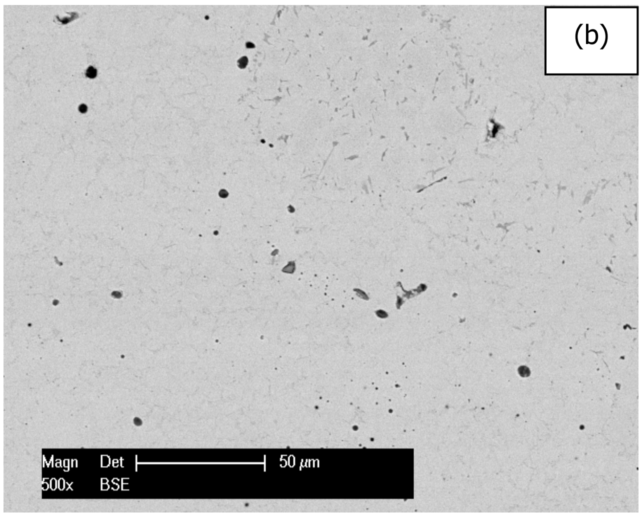


Figure 1. SEM-micrograph of the NiCrBSi powder

Concerning the composition of the main phases of the fused coatings, the only observation which can be made based on the results of the EDX analysis is that the light gray phase contains a high Ni amount whereas the slightly dark gray phase exhibits a quite high Cr amount beside small amounts of Ni and Si. However, some morphology differences can be observed by comparing the coatings microstructure. The black spots are considerably larger in the case of the induction fused coating but otherwise, the oxy-flame fused coating exhibits larger oxide particles containing Cr and/or Si.





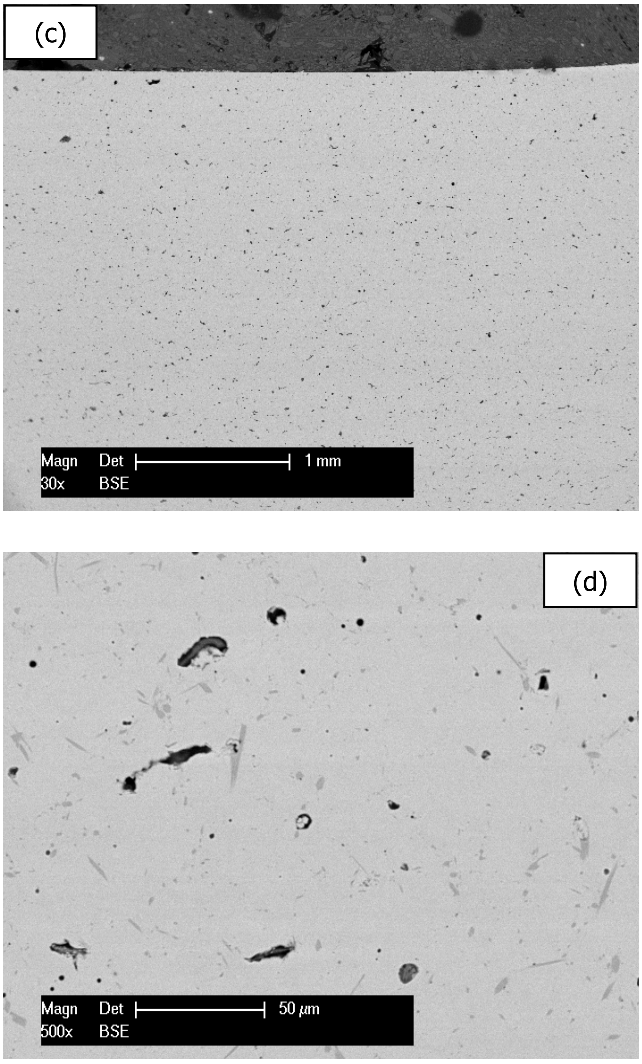


Figure 2. Cross-section SEM-micrographs of the fused coatings: induction (a, b) and oxy-acetylene flame (c, d)

XRD spectra (see Figure 3a and b) reveal the existence of metallic phases like Ni or Cr respectively of some hard phases responsible for the hardness of the coating, like borides (Ni3B) or silicide's (Ni_3Si_2 or Cr_xNi_ySi). These borides and silicides are well distributed in matrix of Ni solid solution. Therefore, the microhardness measurements correlate very well with the morphology respectively with the phase composition of the investigated coatings.

The microhardness value measured for the inductive remelted coating (390±8 $HV_{0.3}$) was higher than that measured for the coating remelted by oxy-acetylene flame (315±5 $HV_{0.3}$).

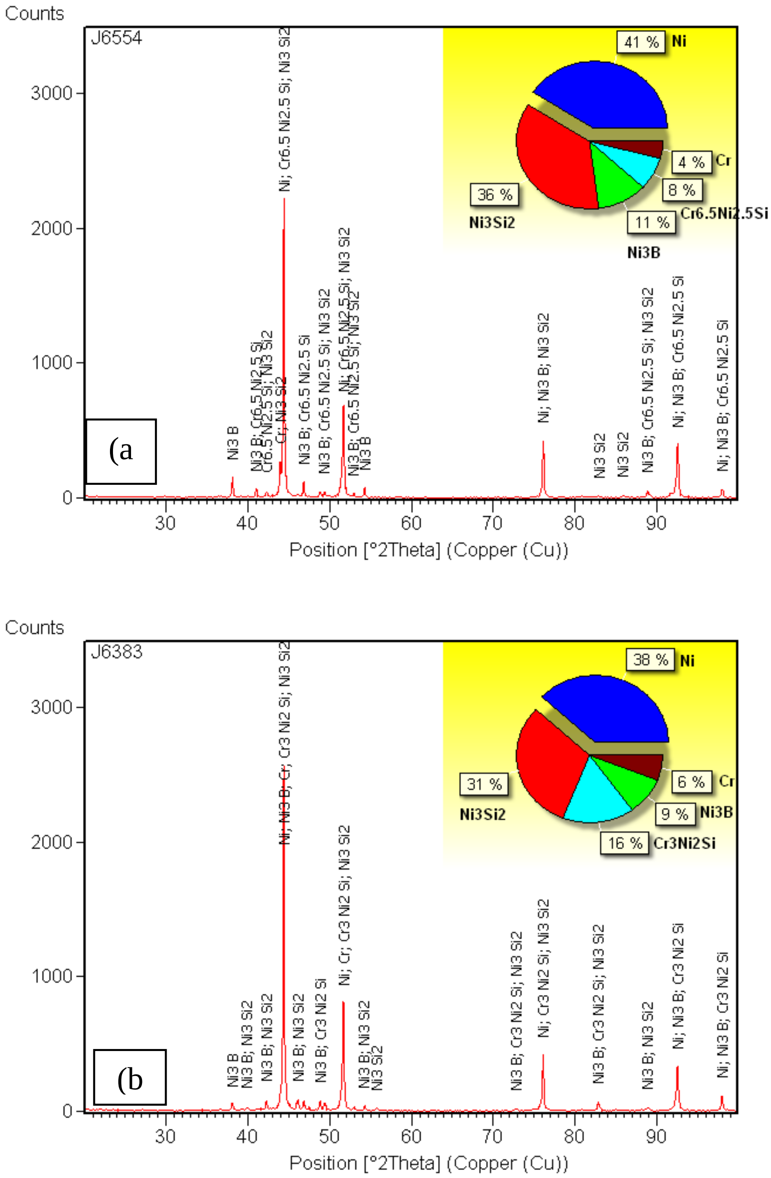


Figure 3. XRD-patterns of the fused coatings: induction (a) and oxy-acetylene flame (b)

Figure 4 shows typical potentiodynamic polarization curves for the samples tested in a 3,5 % NaCl solution at room temperature. Both, the cathodic curve as well as the anodic one are quite similar concerning the corrosion potential respectively the corrosion current density. This observation correlates very well with the metallic amount of the coatings phase composition, which is also quite similar. Even than this type of alloy contains only 10% Cr, it exhibits a certain tendency to passivate during exposure at anodic potentials, contributing to a good corrosion behavior.

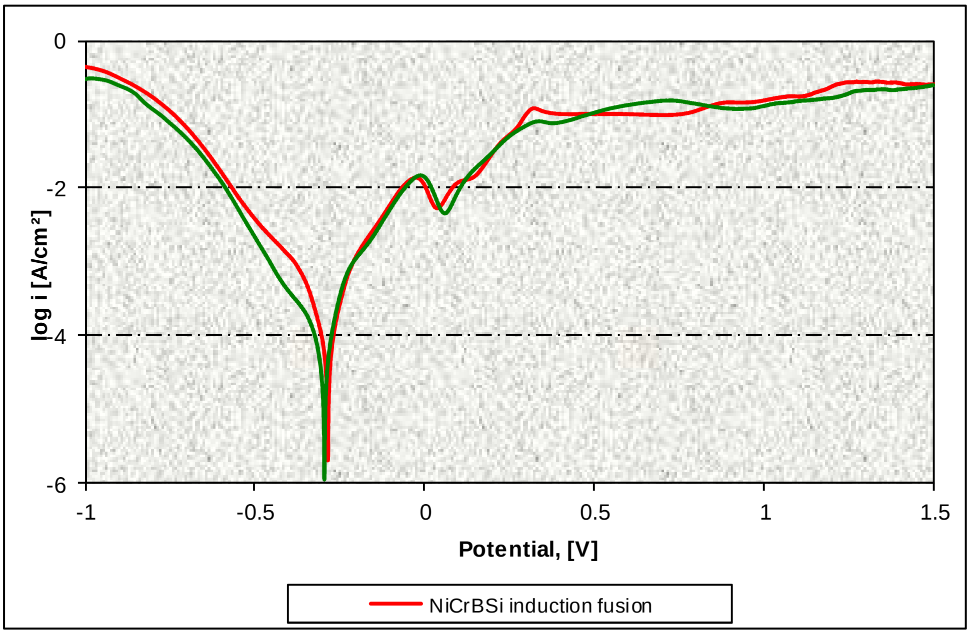


Figure 4. Potentiodynamic polarization curves of the samples tested in a 3,5% NaCl solution

The variation of the friction coefficients in time is quite different for the two tested coatings (see figure 5) even than the values at the end of the tests are nearly the same. One may observe that in the initial stage, the value of the friction coefficient increased for both coatings, due to highly adhesive micro-contacts between the tested surfaces. Anyway, due to the fact that the induction fused coating revealed a stabilization of the friction coefficient until the end of the sliding wear test, whereas the value for the friction coefficient of the flame fused coating increased continuously, one may conclude that the first coating exhibited a better wear behavior under these testing conditions.

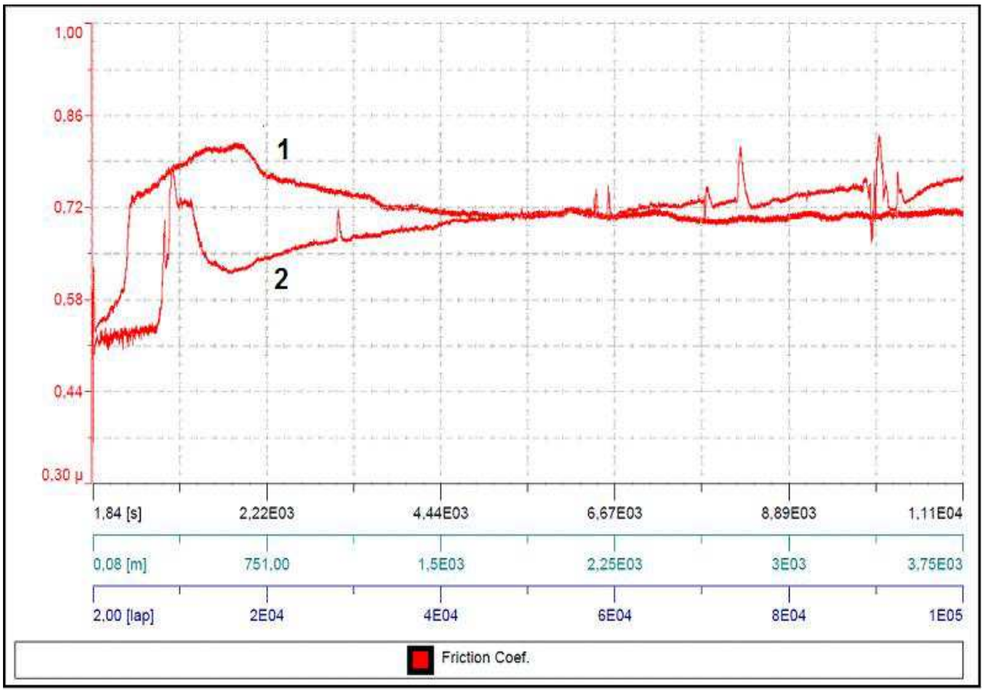
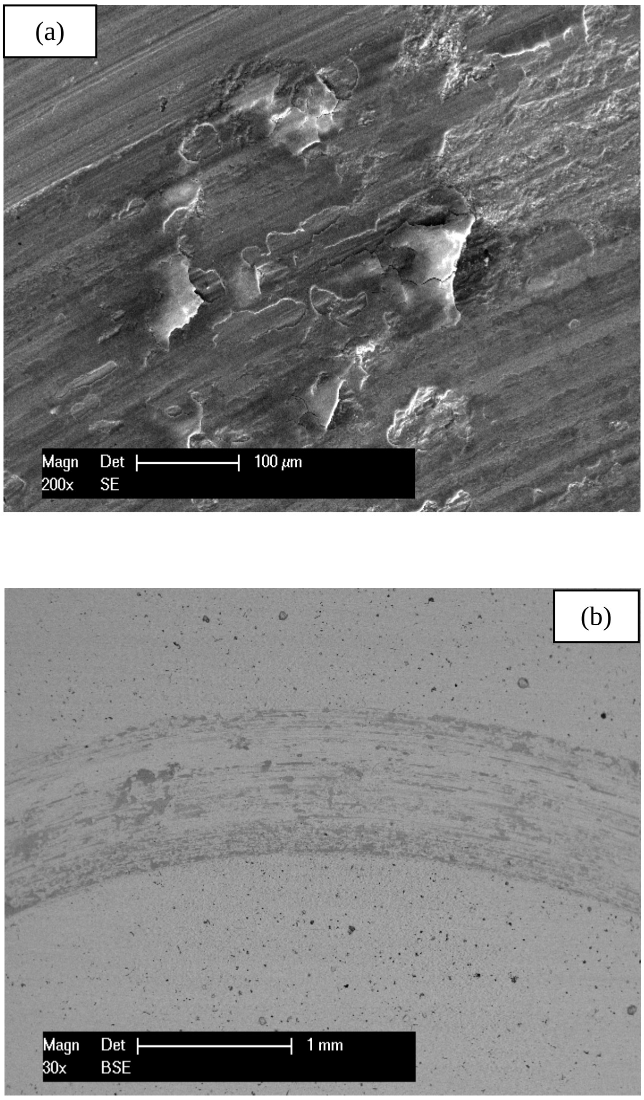
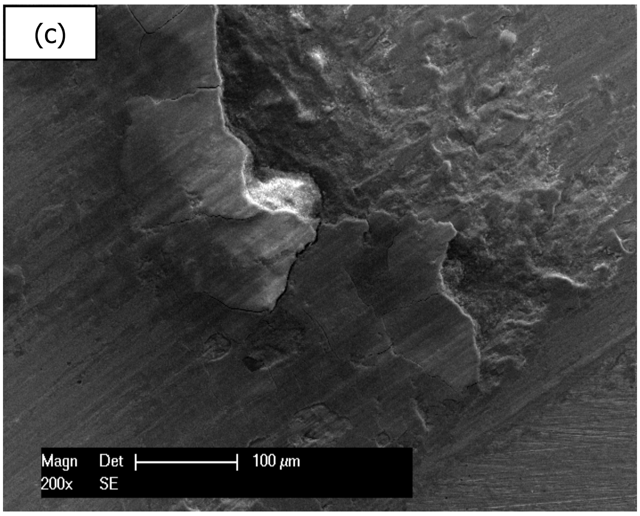


Figure 5. Sliding wear friction coefficients of the tested coatings: induction fused (1) respectively flame fused (2)

The morphologies of the worn surfaces after dry sliding wear are shown in figure 6. SEM micrographs at higher magnification (Figure 6a and 6c) show the degree of particles delamination at the surface. There were interlamellar interfaces and relatively smooth patches on these worn surfaces. The micrometer-sized defects such as pores, interlamellar and intralamellar cracks in the coatings might act as the cracking origins during sliding. The characteristics of the wear tracks of the tested coatings at lower magnification (figure 6 b and 6d), correlate very well with the curves of the sliding wear coefficients. Whereas the wear track of the tested induction fused coating reveals a homogeneous morphology, the wear track of the flame fused coating exhibits some regions where the spallation and fracturing of lamellae is more intense. That explains the irregularities on the curve profile (peak-like appearances).


(a)
Magn Det 100 µm
200x SE
(b)
Magn Det 1 mm
30x BSE



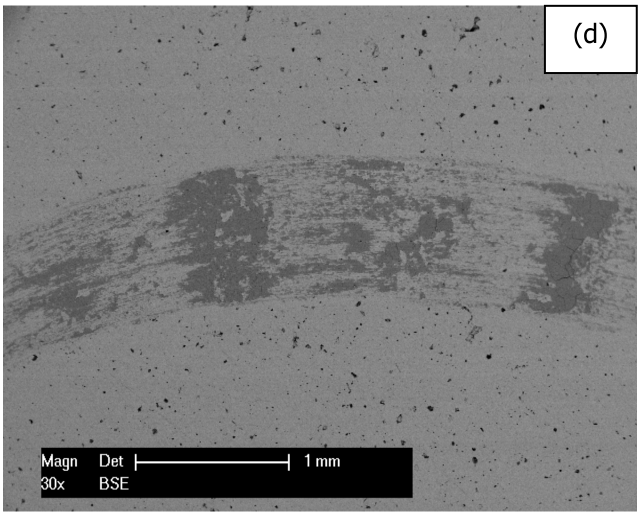


Figure 6. SEM-micrographs of the worn surface of the induction fused coating (a, b) respectively of the flame fused coating (c, d)

4. Conclusions

The microhardness measurements correlate very well with the morphology respectively with the phase composition of the investigated coatings thereby the value measured for the inductive remelted coating was higher than that measured for the coating remelted by oxy-acetylene flame.

Investigations carried out in order to evaluate the corrosion resistance of the coatings demonstrated that both types of layers are quite similar concerning the corrosion potential respectively the corrosion current density.

The results delivered from the sliding wear test reveal clearly the influence of the fusing process on the variation of the friction coefficients in time, and hereof also the ability of the coating to develop a thin tribofilm along the wear track.

Acknowledgments

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References:

[1] Kim H.J., Hwang S.Y., Lee C.H., Juvanon P., *Assessment of wear performance of flame sprayed and fused Ni-based coatings*, Surface and Coatings Technology 172 (2003), 262–269.

[2] Serres N., Hlawka F., Costil S., Langlade C., Machi F., *Microstructures and mechanical properties of metallic NiCrBSi and composite NiCrBSi–WC layers manufactured via hybrid plasma/laser process*, Aplied Surface Science 257 (2011), 5132-5137.

[3] Rodríguez J., Martín A., Fernández R., Fernández J.E., *An experimental study of the wear performance of NiCrBSi thermal spray coatings*, Wear 255 (2003), 950–955.

[4] Kushner B.A., Novinski E.R., *Thermal Spray Coatings*, ASM Handbook, vol. 18, American Society of Metals, Cleveland, OH, 1992, pp. 829–833.

[5] González R., García M.A., Peñuelas I., Cadenas M., Fernández Ma. del Rocío, Battez H. A., Felgueroso D., *Microstructural study of NiCrBSi coatings obtained by different processes*, Wear, 263 1-6 (2007) 619-62.

[6] Shengfeng Zhou, Xiaoqin Dai, *Laser induction hybrid rapid cladding of WC particles reinforced NiCrBSi composite coatings*, Applied Surface Science 256 (2010) 4708–4714.

[7] Serres N., Hlawka F., Costil S., Langlade C., Machi F., *Combined plasma spray and in situ laser melting treatment of NiCrBSi powder*, Journal of optoelectronics and advanced materials, vol. 12, no. 3, March 2010, p. 505 – 510.

[8] Patel, Mahesh S. (Albertson, NY), *Wear resistant alloy coating containing tungsten carbide*, United States Patent 4075371, 1978.

[9] Serres N., Hlawka F., Costil S., Langlade C., Machi F., *Corrosion properties of in situ laser remelted NiCrBSi coatings comparison with hard chromium coatings*, Journal of Materials Processing Technology 211 (2011) 133–140.

[10] Liu S., Zheng X., Geng G., *Dry sliding wear behavior and corrosion resistance of NiCrBSi coating deposited by activated combustion-high velocity air fuel spray process*, Materials and Design 31 (2010), 913–917.

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