Corrosion and sliding wear behavior of Cr_3Cr_2-NiCr coatings alloyed by electron beam treatment

V. A. ŞERBAN, D. UŢU*, G. MĂRGINEAN[a]
University "Politehnica" Timisoara, Mechanical Engineering Faculty, Timisoara, Romania
[a]University of Applied Sciences Gelsenkirchen, Germania

Cr_3Cr_2-NiCr cermet coatings were deposited by high velocity oxygen fuel (HVOF) spraying technique, onto the surface of Ni-based superalloy namely INCONEL 617 and subsequently remelted using the electron beam (EB) technique. The corrosion and sliding wear behaviour of the coatings was investigated before and after EB remelting. The scanning electron microscopy SEM and X-ray diffraction were used to characterize the coating morphology and to determine the phase modifications appeared during the alloying process. The electrochemical corrosion tests were conducted in a 0.5M H_2SO_4 solution on uncoated as well as on HVOF sprayed and EB remelted coated superalloy. The wear behaviour of the coating before and after remelting was evaluated using the pin-on-disk method. The achieved results demonstrated that a certain alloying degree of the investigated cermet coatings leads to the improvement of the corrosion behavior.

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1. Introduction

Cr_3Cr_2–NiCr systems constitute a group of carbide materials used in order to improve the corrosion and wear resistance and to decrease the friction coefficient between various sliding components in automotive applications and could be used for the replacement of hazardous hard chromium plating technology [1,2]. Usually they are obtained by thermal spraying technologies [3]. With this process, the coating material, in powder form, is fed into the combustion chamber of a gun where, a fuel, such hydrogen, ethylene or kerosene, is burned with oxygen, and the heated and softened powders are expelled as a spray with the supersonic gases [4-6].

However, because of the spraying process, these deposits present a lamellar microstructure characterized by the presence of numerous porosities and cracks. They decrease strikingly the efficiency of the coating by allowing contacts of the substrate with corrosive agents or by leading to scaling. Moreover, these weaken the adhesion, which is due essentially to the physical bonding of particles sprayed to the substrate [6, 7].

Through surface alloying one may develop a modified top layer on the substrate obtained by localized melting and solidification which exhibits improved properties regarding the drawbacks presented above [8, 9].

This work presents a study of the corrosion and sliding wear resistance of electron beam (EB) alloyed Cr_3Cr_2-NiCr layer on a nickel superalloy INCONEL 617 substrate.

2. Materials and experimental procedure

The materials tested were powders of chromium carbides (Cr_3Cr_2-NiCr20 75-25) which were deposited onto INCONEL 617 substrates using a High Velocity Oxygen-Fuel spraying technique at the company Thermico GmbH, Germany. The coatings thickness was about 60 µm. The chemical composition of the Inconel 617 is given in Table 1.

Table 1. Chemical composition of Inconel 617 (wt. %)

Ni	Cr	Co	Mo	Al	C	Fe	Mn	Si	S	Ti	Cu
Balance	22	12.5	9	1.2	0.07	1.5	0.5	0.5	0.008	0.3	0.2

The samples were remelted with an EBW700/3–60 apparatus. Maximum beam input power was 3 kW. The electron beam was focused onto the specimen surface and oscillated (scanned) with an amplitude of 15 mm in order to assure a certain remelting depth. The parameters of the EB-remelting process were optimised in previous research work [9].

The chromium carbide containing coatings were examined before and after electron beam remelting, by scanning electron microscopy (SEM-Philips ESEM 30 XL) and X-ray diffraction technique (XRD-Philips X'Pert) using a Cu–K_α radiation in order to determine the phase modification.

The sliding wear resistance was investigated using the pin-on disk testing method by calculating the variation of the wear track depth with applied load. The normal load applied to the ball (WC Co 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 trajectory was a circle with a radius of 5.4 mm). The relative humidity was 65%.

The corrosion behavior of the materials was measured by electrochemical method. The samples were tested potentiodynamically, at room temperature, in a 0.5 M H_2SO_4 solution with a three electrode cell using a saturated calomel electrode (SCE) as reference.

3. Results and discussions

3.1 Structural characterization

Fig. 1 shows SEM image of the as sprayed Cr_3Cr_2-NiCr coating (cross-section) deposited onto INCONEL 617 substrate. It can be seen that the as sprayed coating exhibits a certain amount of porosity and a non-homogeneous microstructure. The coating was unveven, too.

Under electron beam irradiation, the coating and underneath substrate were melted and intermixed, and rapidly solidified to form a modified layer (Fig. 2a, b). The alloyed layer was free from pores and cracks and bonded to the INCONEL substrate by metallurgical fusion bonding [9].

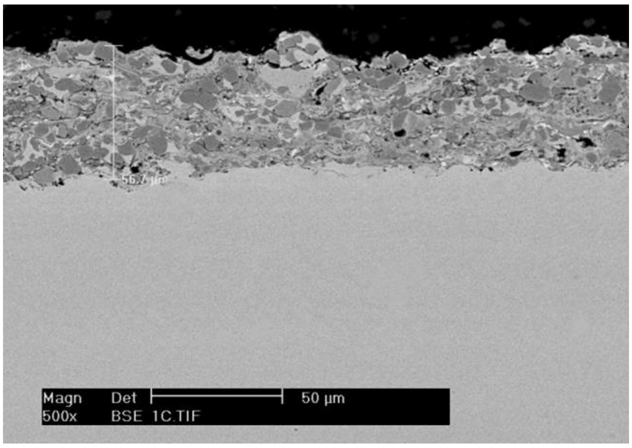

Fig. 1. SEM micrographs of the as sprayed Cr_3Cr_2–NiCr coating.

After EB remelting the alloyed layer shows a dendrite casting structure, its orientation being in the direction of the thermal gradient respective in normal direction to the substrate surface. The EDX analysis (Fig. 3) shows the presence in this zone beside Ni and Cr as base elements also the presence of some small quantities of Mo and Co as a result of the partial melting of the substrate which contains these elements.

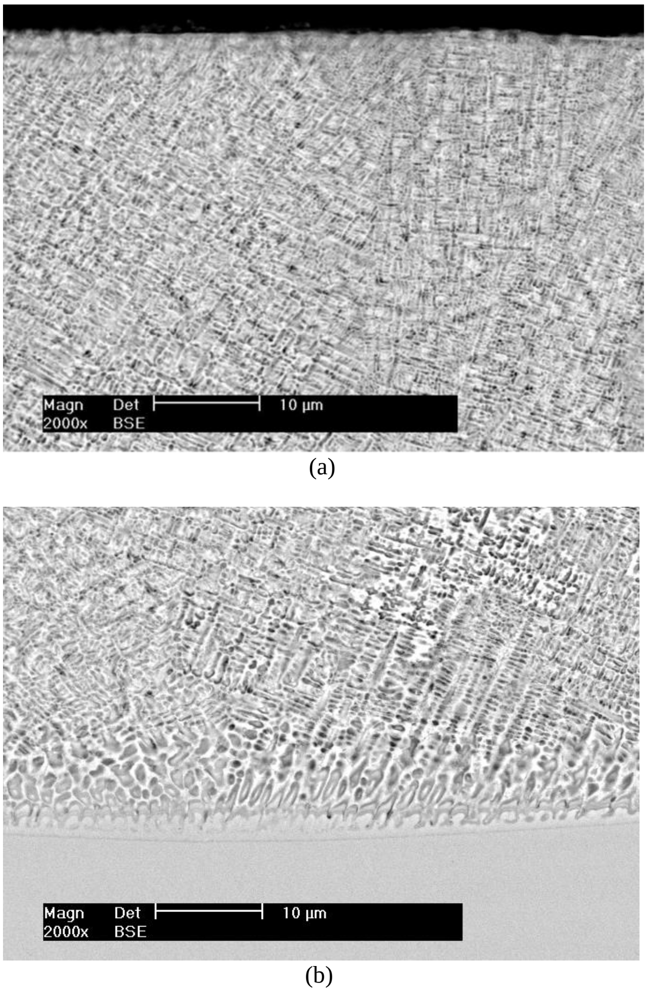

Fig. 2. SEM micrographs showing the microstructure of the Cr_3Cr_2–NiCr coating after the EB-remelting: (a) upper region, (b) interface coating/substrate.

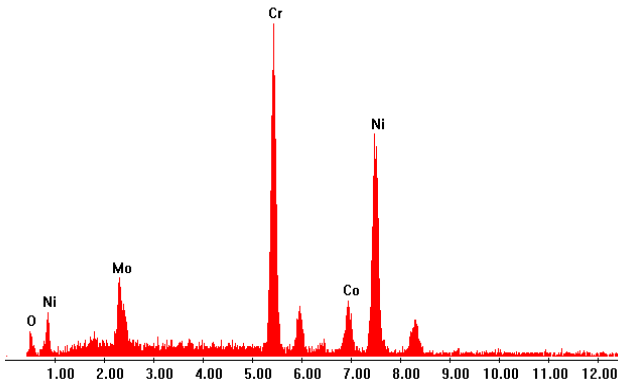

Fig. 3. EDX spectrum of the alloyed zone.

3.2 Phases analysis

The XRD pattern of the as-sprayed coating (Fig. 4) reveals a partial decomposition of the Cr_3C_2 phase from the chemical composition of the used feedstock powder to another phase with the chemical formula $Cr_{23}C_6$. In addition to these signals, the metallic matrix based on Cr and Ni was also identified.

The EB remelting process induced a certain alloying degree of the coating with the substrate material. Therefore, one may observe that the XRD pattern of the remelted sample surface (Fig. 5) contains additional signals especially for the Cr-Mo-Ni and Co-Ni intermetallic phases. This result correlates with the EDX-analysis of the same sample which identified the elements Co and Mo belonging to the chemical composition of the substrate, as well.

The ratio between the amount of the ceramic component related to the amount of the metallic one changed after the EB alloying procedure, fact which correlates with the results of the sliding wear respectively of the corrosion exposure of the investigated samples.

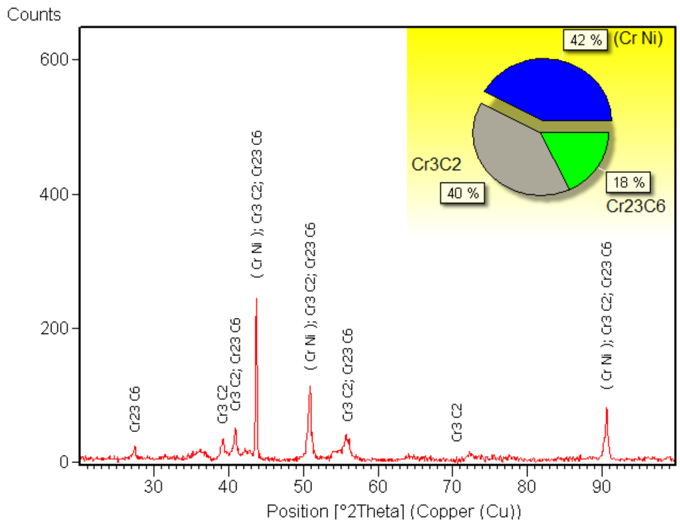

Fig. 3. XRD pattern of the as-sprayed Cr_3Cr_2 NiCr coating.

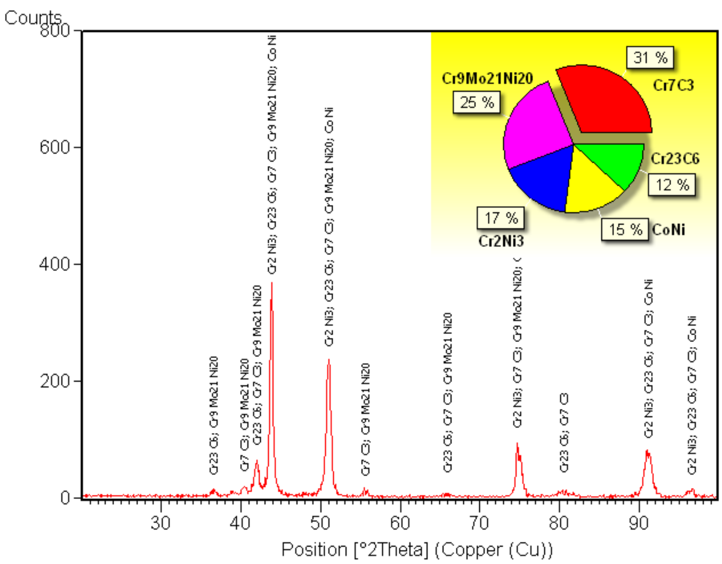

Fig. 4. XRD pattern of the alloyed surface.

3.3 Sliding wear resistance

Fig. 6 presents the sliding wear diagrams of the tested samples and Table 2 the corresponding values. Analyzing the results it can be seen that in as sprayed state the Cr_3Cr_2-NiCr coating provides the best sliding wear resistance in comparison with the other tested materials. After the HVOF spraying process at the surface of the alloy 617 substrate is obtained a material which from structural point of view consists of carbides uniformly distributed in a matrix of solid solution γ.

According to Fig 6 the sliding wear resistance of the alloyed layer has slightly decreased due to the high temperatures developed during EB remelting, which provoked the dissolution of the carbides particles and of the other intermetallic compounds in the liquid phase and because of the rapid cooling by solidification the phase's reprecipitation was partially stopped.

As it was expected the alloy 617 exhibited the worse sliding wear resistance.

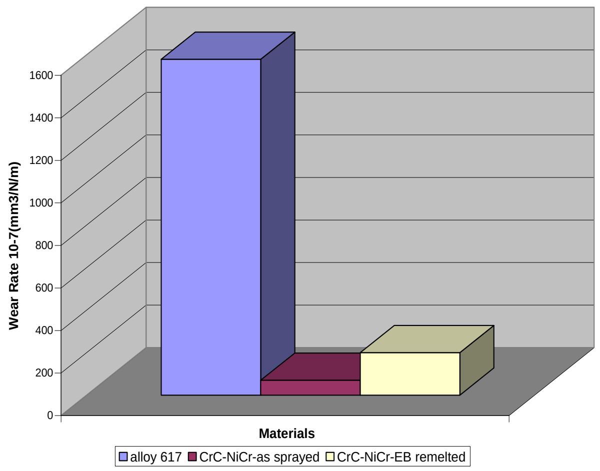

Fig. 5. Sliding wear rates of the tested coatings.

Table 2. Wear rates values of the tested materials.

Material	Wear rate * 10^{-7}[mm^3/N/m]
Alloy 617	1579
Cr_3Cr_2-NiCr-AS	70
Cr_3Cr_2-NiCr-EB	200

3.4. Corrosion resistance

The corrosion behavior of the tested materials was investigated by pottentiodynamic measurements in sulfuric acid. From the polarization curves (Fig. 7) which were drawn for the tested materials the corrosion current density (i_{corr}) and corrosion potential (E_{corr}) were determined (Table 3).

Analyzing the results it can be observed that all materials presented good chemical properties but the alloy 617 had the best corrosion resistance (having the lower value for i_{corr}).

The corrosion current density i_{corr} for the samples with as-sprayed Cr_3Cr_2-NiCr coatings is higher than that of the other coated sample because the coating is not compact and homogenous. On the surface of the material in contact with the electrolyte solution, some galvanic microelements are formed, which lead to the increasing of the corrosion rate.

The EB remelting procedure made the Cr_3Cr_2-NiCr coating more homogenous and uniform, fact which explains the lower corrosion rate. Based on the results obtained from the corrosion tests, one may conclude that the EB remelted Cr_3Cr_2-NiCr coating exhibited a similar behaviour like that of the Alloy 617.

Table 3. Values of the measured current density and corrosion potential.

Sample	Electrochemical data	
	i_{corr} (mA/cm^2)	E_{corr} (mV)
Alloy 617	0.0075	- 103.4
Cr_3Cr_2-NiCr (as-sprayed)	0.0109	- 94
Cr_3Cr_2-NiCr (EB-remelted)	0.0272	- 115.1

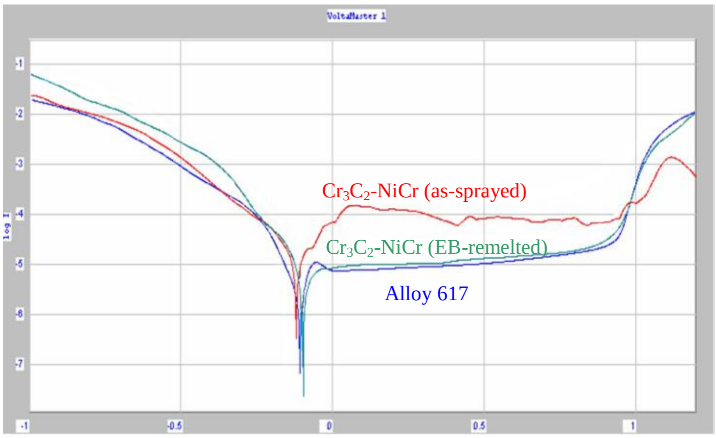

Fig. 6. Sliding wear rate of the tested materials.

4. Conclusions

Cr_3Cr_2-NiCr coatings have been deposited on Inconel 617 by HVOF spraying technique and subsequently remelted by electron beam in order to optimize the corrosion and wear properties of the new surface.

The results showed that the deposition of Cr_3Cr_2-NiCr coatings onto the surface of Inconel 617 before and after remelting had a positive effect regarding the sliding wear behavior.

The best sliding resistance was found at the Cr_3Cr_2-NiCr coating in as sprayed state. EB alloying of the CrC NiCr with the substrate slightly decreased the mechanical properties because of the high temperatures developed during the treatment which provoked the dissolution of the carbides.

However the EB remelting treatment had a positive effect on the chemical properties. The alloyed Cr_3Cr_2-NiCr coating exhibited a similar corrosion behavior like that of the Alloy 617.

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*Corresponding author: dragos.utu@mec.upt.ro