Engineering, 2010, 2, 322-327
doi:10.4236/eng.2010.25042 Published Online May 2010 (http://www.SciRP.org/journal/eng)

Corrosion Behavior of Laser Remelted CoNiCrAlY Based Composite Coatings

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Received November 27, 2009; *revised February* 5, 2010; *accepted February* 12, 2010

Abstract

The corrosion behavior of High-Velocity Oxygen Fuel (HVOF) sprayed MCrAlY coatings obtained from CoNiCrAlY particles (wt. 8% Al) mechanically doped with Al_2O_3 nanopowder was investigated before and after laser remelting. The latter process was applied in order to achieve a homogeneous structure as well as better mechanical properties for the coating (reduced brittleness offered by the presence of the Al_2O_3 nanoparticles). Another important task of the laboratory investigations was the investigation of the corrosion behavior of the modified coatings. The results obtained from the potentiodynamic polarization measurements carried out in a chloride environment revealed an enhanced corrosion resistance of the laser remelted coatings comprising a refined microstructure. Microhardness measurements of the modified coatings revealed lower values in comparison with that of the samples in as-sprayed status. This observation leads to the assumption that a concomitant improvement of coatings ductility occurred as well.

Keywords: Laser Remelting, Conicraly Coatings, Corrosion Behaviour

1. Introduction

In the turbine blades section of the engines, the overall operating conditions became progressively more hostile in terms of temperature and mechanical environment. A solution in order to solve this problem is applying of protective thermal barriers consisting of a ceramic insulating layer bonded to an oxidation resistant MCrAlY coating. The latter one belongs to the family of high temperature coatings (around 850-1200°C), where M is selected from one or a combination of iron, nickel and cobalt [1,2]. Cr and Al are present in the MCrAlY chemical composition because they are able to form highly tenacious protective oxide scales [3], whilst Y promotes formation of these stable oxides [4]. Their protection role is given by the formation of a compact, stable, and adherent oxide layer (usually α-A_2O_3) on the surface, which exhibits any interaction between the base material and the corrosive medium. Without this protective scale, the coating and ultimately the substrate, would come under rapid oxidation and/or corrosion attack [5]. The durability or service life of the MCrAlY coating depends mainly on the stability of the formed alumina scale [6].

The microstructure of the grown oxide scales depends strongly on the coating properties, the manufacturing process and the operating conditions.

In a previous research work it has been demonstrated that the mechanical alloying of MCrAlY powders with nano-Al_2O_3 leads o a better high temperature oxidation behavior of the HVOF-sprayed coating in comparison with the conventional MCrAlY coating. This conclusion is based mainly on the reduced oxidation rate of the Al_2O_3 doped MCrAlY coating, which is a very important parameter concerning the kinetics of the oxide scale growth [7,8]. Therefore, another supplementary task should be settled in the coatings investigation, namely their behavior under mechanical loadings. Doping of the MCrAlY coatings with ceramic particles which are uniformly distributed along the grain boundaries between the MCrAlY particles, showed the main disadvantage concerning its negative influence on the coating ductility (due to the presence of brittle compounds).

Rapid melting and solidifying of the MCrAlY coatings achieved using a laser beam can offer good mechanical behavior of the whole system (coating-substrate).

2. Experimental Procedures

CoNiCrAlY coatings (280-350 μm) with wt. 8% Al content (Co-32Ni-22Cr-8Al-0.5Y) and mechanically mixed with wt. 2% Al_2O_3-nanopowder were sprayed onto an alloy 617 substrate (5 mm thick) using the HVOF (High Velocity Oxygen-Fuel)-spraying technique.

The equipment used was a CJS Gun of the company Thermico, Germany, which is operated with a hydrogen-stabilized liquid fuel oxygen combustion.

The coatings were remelted using a CO_2 laser from TRUMPF company, by applying an unfocussed beam for a witdth about 100 mm. The remelting treatment was performed using argon as shielding gas. The optimized parameters used during the laser treatment process are presented in **Table 1**. The beam power, P and the working distance, d were kept constant during the treatment, while advancing velocities, v were varied.

In order to determine the corrosion resistance of the coatings before and after laser remelting electrochemical measurements were also carried out. The tests were performed in a 5% H_2SO_4 solution containing 58 g/L NaCl, using an electrochemical corrosion cell and a potentiostat/galvanostat PGP201 from Radiometer.

Polarization curves were recorded in the positive direction starting from free potential at room temperature in a three electrode cell using calomel electrode (SCE) as reference. The applied potential was varied between –1000 and 1000 mV using a rate of 50 mV/min.

Table 1. Experimental conditions for laser remelting.

Material	Coating thickness [μm]	Remelting parameters			Penetration depth [μm]
		P [kW]	d [mm]	v [mm/s]	
CoNiCrAlY 8% Al	280-350	3	310	5	239
				10	110

3. Results and Discussions

3.1. Coatings Morphology

SEM-investigation of the as-sprayed coating (**Figure 1**) shows the presence of oxides in the structure of the material. It can be seen that the deformation degree of the CoNiCrAlY particles during spraying was not very pronounced. The insulating Al_2O_3 ceramic nanoparticles form a thermal barrier for the MCrAlY powders which are exposed to a reduced thermal energy during the HVOF spraying process. This phenomenon is demonstrated by the presence of partially molten particles.

Depending on the parameters of the laser remelting treatment (see **Table 1**), different penetration depths were obtained (compare **Figure 2(a)** with **3(a)**). Increasing the advancing velocity of the remelting process led to a reduced penetration depth as well as to a finer coating microstructure (**Figure 2(b)** respectively **3(b)**). In both

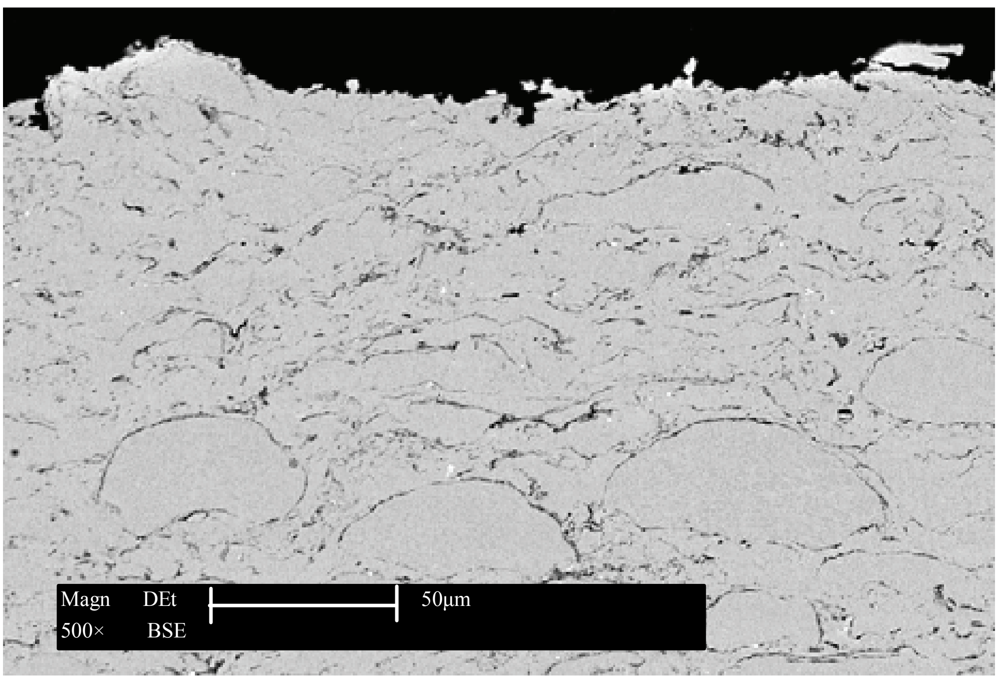

Figure 1. SEM micrograph (cross-section) of the as-sprayed MCrAlY+2% Al_2O_3 coating [8].

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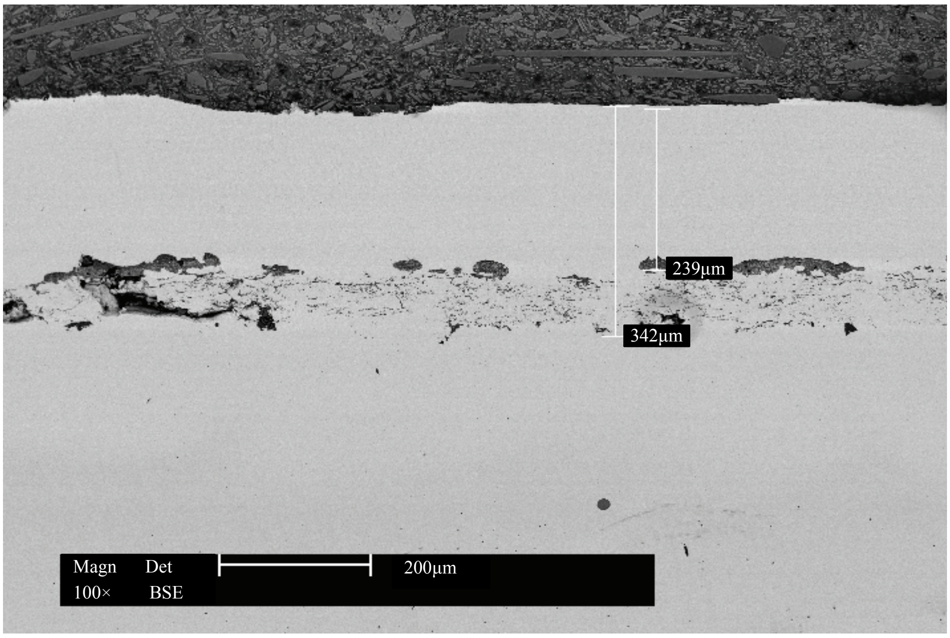
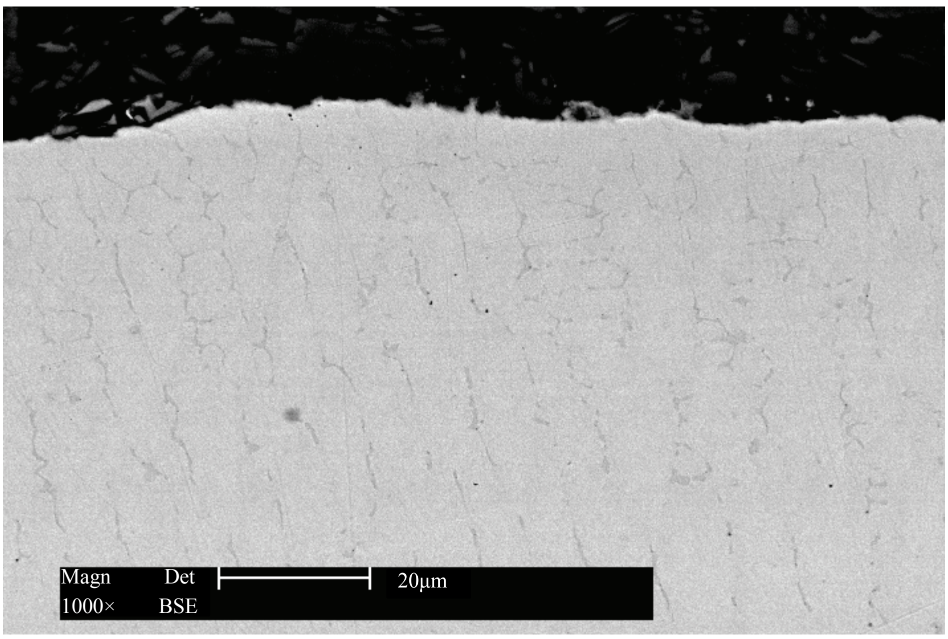


(a)



(b)

Figure 2. SEM micrographs of the laser remelted coatings (v = 5 mm/s).

cases the remelted zone was free from pores and oxides.

3.2. X-ray Diffraction Measurements

The X-ray diffraction tests were performed on a Philips X'Pert X-ray diffractometer using a Cu-K_α radiation, in order to determine the phase composition of the coatings before and after laser remelting.

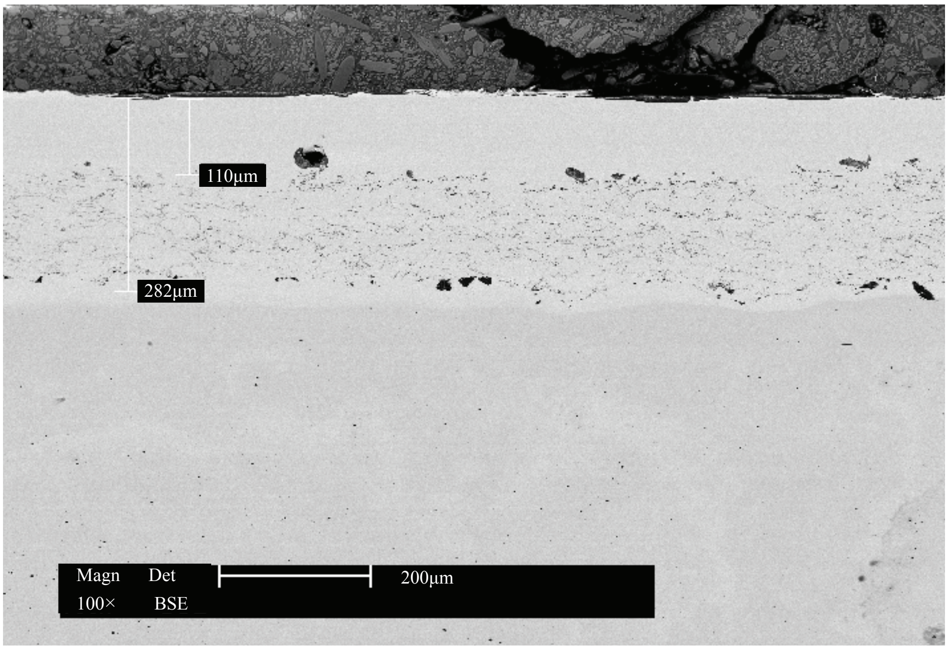
X-ray diffraction patterns (**Figure 4**) show for all the investigated samples the presence of a phase-mixture consisting of γ-Ni/$\gamma^{'}$-Ni_3Al, β-NiAl, α-Al_2O_3 and Cr_2O_3.

The XRD patterns from **Figure 4** indicate that in the case of the laser remelted samples the Al_2O_3 oxide phase was partially dissolved in solution increasing the matrix content γ-Ni/$\gamma^{'}$-Ni_3Al. The appearance of the β-NiAl phase can be also noticed (phase precipitation during the laser remelting process – see the dark-grey cellular structures on the SEM-micrographs **Figure 2(b)** respectively **3(b)**).

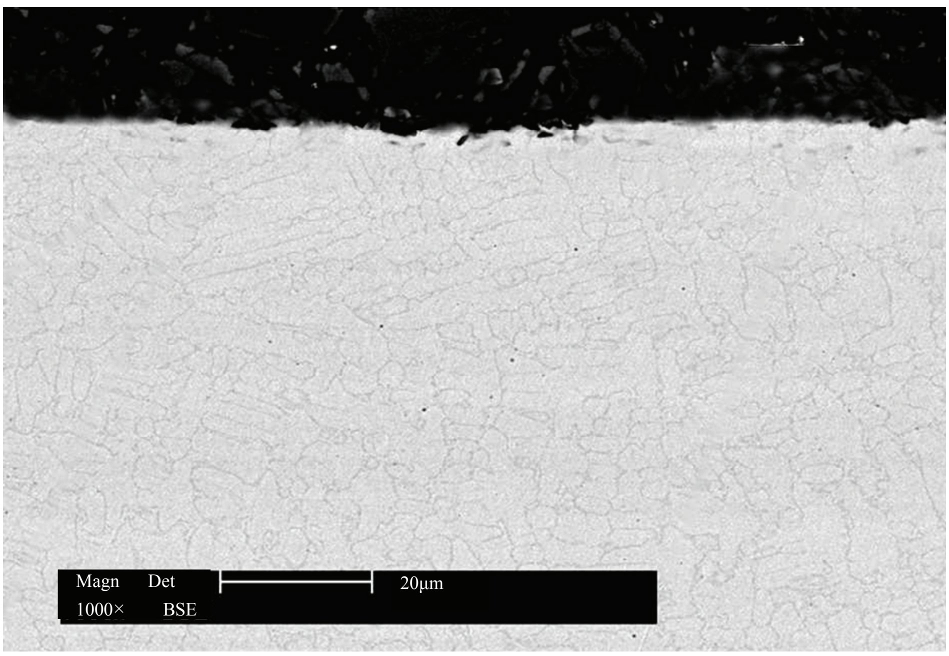
3.3. Microhardness Tests

The microhardness of the coatings was measured with a Vickers tester from Wolpert applying a 0.1 kgf load. The reported values (**Figure 5**) represent the indentations made along the coating cross-section, where P0 is the as-sprayed coating and P1 and P2 are the laser remelted coatings using v = 5 mm/s respectively v = 10 mm/s.

The hardness curves evidence that the laser remelting



(a)



(b)

Figure 3. SEM micrographs of the laser remelted coatings (v = 10 mm/s).

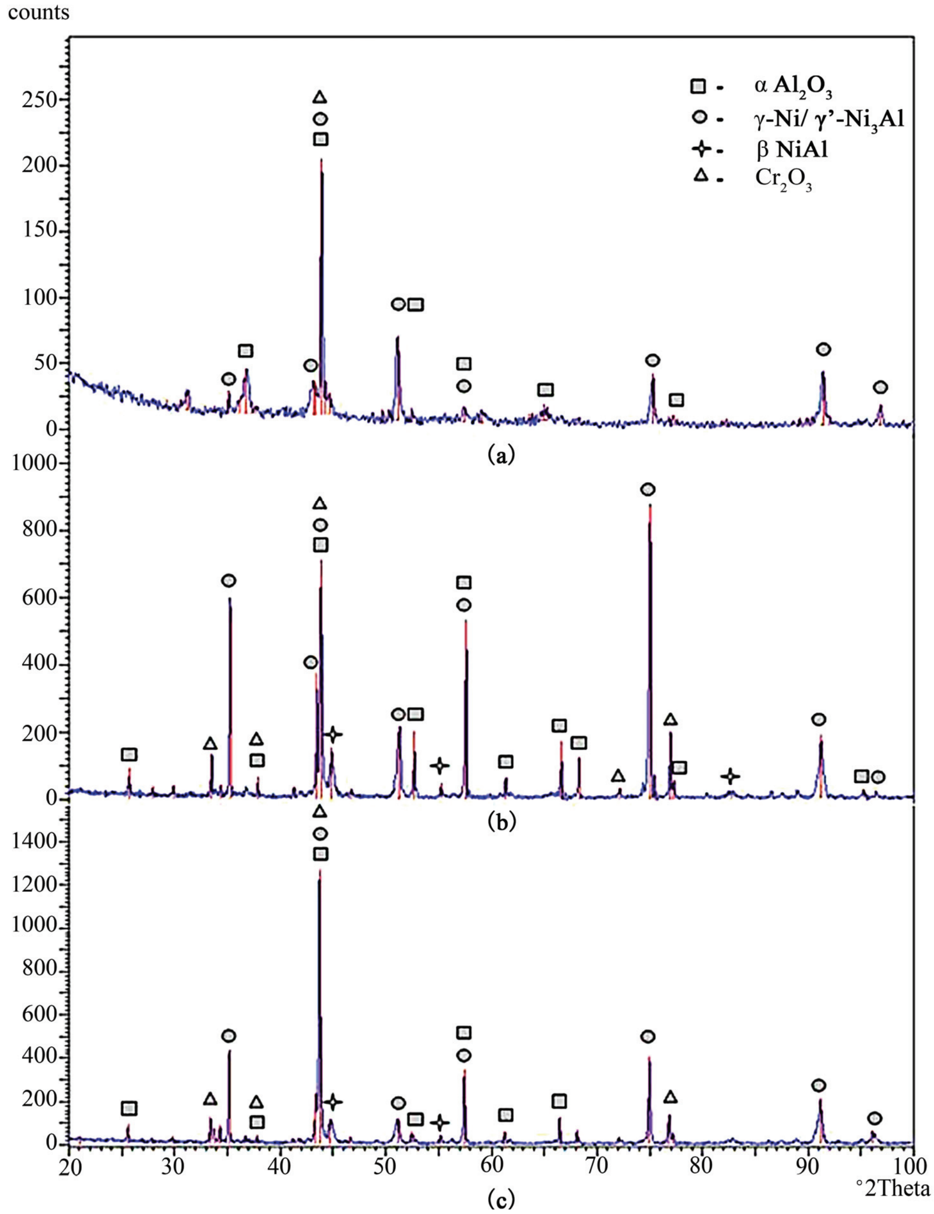


Figure 4. XRD diffraction patterns: a-as sprayed sample, b-laser remelted v = 5 mm, c-laser remelted v = 10 mm.

process led to decreasing of the values from 450 HV to almost 200 HV. This result has a positive effect on the ductility of the material. The values of the measured hardness along the coating thickness correlate very well with the structures shown in the **Figures 2(a)** and **3(a)**. In the domain where the Al_2O_3 particles were dissociated by the laser energy, the coating has a lower hardness in comparison with the zones where the oxide particles are steel present.

3.4. Corrosion Tests

The polarization curves obtained for the tested materials (P0, P1 and P2) are presented in **Figure 6**.

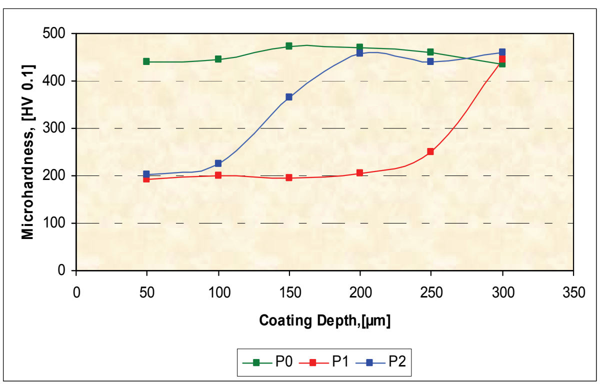


Figure 5. Microhardness curves of the tested materials.

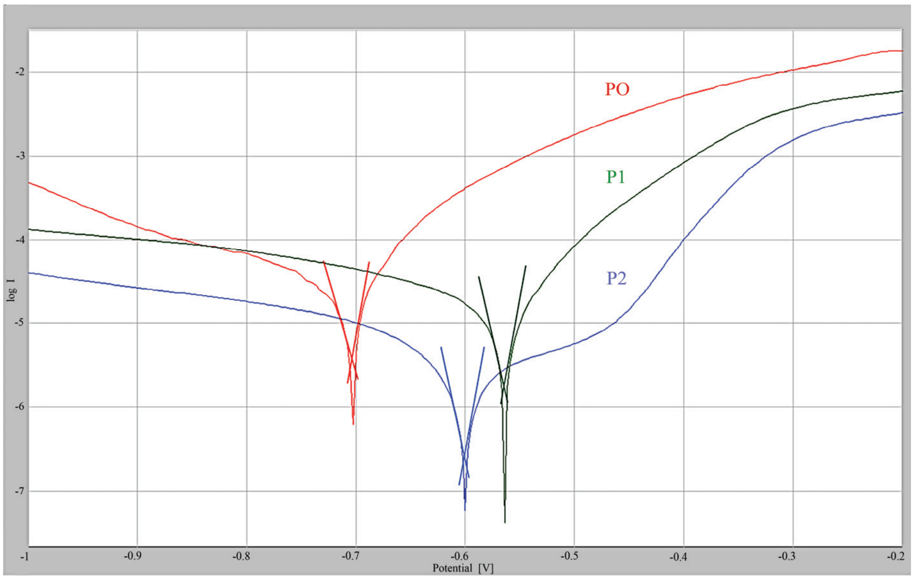


Figure 6. Polarization curves of the samples exposed in 5% H_2SO_4 with 58 g/L NaCl.

Table 2. Values of the measured corrosion potential and current density.

Sample	Electrochemical data	
	i_{corr} (μA/cm^2)	E_{corr} (mV)
P0	95.4	-685.9
P1	17.5	-550.4
P2	1.71	-592.2

Comparing the determined results for the corrosion current density (i_{corr}) it can be seen that the values of the laser remelted coatings (**Table 2**) were shifted to lower values in comparison with P0 (from 95.4 μA/cm^2 to 17.5 respectively 1.71 μA/cm^2) which means an improving of the corrosion behavior in chloride environment compared with the as-sprayed sample.

4. Conclusions

The investigations performed show a general improveement of the coating properties due to the advantageous microstructure of the remelted composite powder obtained by applying a CO_2 laser beam.

The corrosion behavior in a 5% H_2SO_4 solution containing 58 g/L NaCl of the HVOF sprayed CoNiCrAlY coatings (wt. 8% Al) doped with Al_2O_3 nanopowder was investigated before and after laser remelting. The experimental results demonstrated that the laser treatment had a positive effect on the corrosion resistance of the coatings because of the structure refining (free from pores and oxides).

Moreover, the ductility of the tested CoNiCrAlY coatings mechanically doped with Al_2O_3 nanopowder was improved by laser irradiation. It has been found a hardness decreasing of the refined structure.

5. References

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