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EFFECT OF FINISHING ON THE CORROSION PROPERTIES OF FLAME SPRAYED Ni-5%Al AND Ni-5%Al-Al_2O_3 COATINGS

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Abstract

The Ni-5%Al alloy and Ni-5% Al-Al_2O_3 composite coatings were obtained by a flame spraying method, "Casto-Dyn DS 8000" torch was used. The coatings onto a substrate made of austenitic stainless steel (X5CrNi18-10) were sprayed. The coatings were subjected to turning, burnishing and grinding. The evaluation of corrosion properties were based on the measurements of direct current (potentiodynamic method) and the alternating current (EIS method). Corrosion tests were performed in a 3.5% sodium chloride solution.

On the basis of studies, the effect of finishing type on the corrosion properties of flame sprayed coatings has been demonstrated. The lowest corrosion current density was found for Ni-5%Al coatings after burnishing, i_{corr} value equal to 0.76 $\mu A/cm^2$, and the charge transfer resistance was 31063 Ω/cm^2. The lowest resistance to corrosion of grinded Ni-5%Al-Al_2O_3 composite coatings was observed. These coatings were characterized by the following parameters of corrosion process: i_{corr} = 14.01 $\mu A/cm^2$, R_{ct} = 3260 Ω/cm^2.

Burnishing caused increased corrosion resistance of both coatings. Due to reduced roughness and waviness are obtained reduction of the area of the actual burnished coatings compared to turned coatings. Thus, it is resulting in reduced values of corrosion current density.

After finishing treatment, the thermally sprayed Ni-5%Al-15%Al_2O_3 coatings characterized by lower corrosion resistance compared to the alloy coating. The presence of the reinforcing phase in the coating promotes the increase of the porosity. Burnishing does not cause a significant change in porosity of the coating. The flame sprayed coatings on nickel-based have a tendency to localized corrosion in seawater environment.

Keywords: *flame spraying, composite coating, Ni-Al, burnishing, corrosion, potentiodynamic test, EIS test*

1. Introduction

The effect of burnishing on the corrosion resistance of materials is ambiguous. There is a dual impact burnishing on corrosion of engineering materials. The effect of burnishing is primarily a reduction in roughness of the machined surface and the reduction or complete elimination of surface defects. Surface defects (such as scratches furrows, microcracks), are places where corrosion microcells are formed. At the same time levelling the surface by reducing the height and number of peaks and reduces the active corrosive of surface. It is resulting in increased corrosion resistance of burnished material [1, 4, 6, 7].

The plastic deformation occurring in the surface layer after burnishing, especially its inhomogeneity may be for specific values of deformation degree cause of decreasing corrosion resistance. This is due to the electrochemical potential differences existing between the grains deformed in varying degrees, resulting in the formation of galvanic microcells and accelerating the electrochemical corrosion [7].

Corrosion resistance of burnished workpiece depends mainly on two factors: the degree of deformation and surface structure that affect the corrosion process in opposite directions. In the case of the burnishing, where the deformation degree is minimal burnished workpieces items have greater corrosion resistance than after burnishing with large draft. There is a limit of the deformation, which corresponds to the maximum resistance to corrosion. The value of this deformation depends on the technological parameters of burnishing and plastic properties of the workpiece [3, 5, 8].

Burnishing treatment has been used to increase the resistance of aluminum alloys to pitting [4], stress [2] and fatigue corrosion [3].

2. Preparation of sample

The coatings were sprayed on steel shafts pivots (X5CrNi 18-10) with diameter $\phi = 40$ mm. To increase the adhesion of the coatings, the pivots were threaded. For spraying Casto-Dyn DS 8000 gas torch were used. Two kind of material powders were used, a) ProXon 21021 (Ni – 93.45%, Al – 5%, B – 0.8%, Fe – 0.34%, Cr – 0.18%, Si – 0.15%, C – 0.08%) and b) MetaCeram 28020 (Al_2O_3 – 97.7%, TiO_2 – 2.2%, SiO_2 – 0,1%). The powders made by Castolin. The 15% volume fraction of powder MetaCeram 28020 in composite coating material was used

The following parameters of flame spraying have been applied:

- acetylene pressure: 0.07 MPa,
- oxygen pressure: 0.4 MPa,
- air pressure: 0.1 MPa,
- spraying speed: 25 m/min,
- feed: 3 mm/rev,
- burner distance from the sprayed surface: 150 mm,
- number of applied layers: 6, coatings thickness were 1-1.2 mm.

Spraying coatings were obtained on pre-heated steel substrate to a temperature of 60°C. Then, it was sprayed coating process with a so that the temperature of the shell shall not exceed 80°C. In the case of the first layer of composite coating was applied without phase dispersion, in order to improve adhesion of coatings to the steel substrate.

After spraying, the coating was subjected to initial treatment in order to obtain the required dimensions and reduce of deviations shape (roundness and cylindricity) of the pivots shafts. Three types of finishing treatments and turning, burnishing and grinding was used.

Ni – 5%Al alloy and Ni – 5%Al – 15%Al_2O_3 composite coatings were machining by means of trigon inserts. Its catalogue number is GC 3210 (Sandvig Coromant). GC 3210 is a material based on tungsten carbide with a supplement of titanium nitride, covered with a TiN coating obtained by CVD method. In the DWLNRL-2525M08 holder a WMNG 080408-KM insert was mounted. Insert and the holder was manufactured by Sandvik Coromant. The geometry of the cutting tool, takes into account the insert and tool holder are follows:

- cutting inserts angle – $\beta = 80^o$,
- approach angle – $\kappa_r = 95^o$,
- rake angle – $\gamma = -6^o$,
- clearance angle – $\alpha = 6^o$,
- nose radius – $r_\varepsilon = 0.8$ mm.

Turning parameters were used:

- cutting speed – $v_c = 100$ m/min,
- feed rate – f = 0.06 mm/rev ,
- cutting depth – $a_p = 0.3$ mm.

After turning, burnishing treatment was performed. The burnishing process was conducted with use one-roller Yamato SRMD burnisher. Burnishing parameters were as follows:

- burnishing force – $F_n = 700$ N (during the processing of composite coatings) and 1100 N (during the processing of alloy coatings)
- burnishing speed – $v_n = 28$ m/min,
- burnishing feed – $f_n = 0.044$ mm/rev (during the processing of composite coatings) and 0.08

mm/rev (during the processing of alloy coatings).

In the case of flame sprayed coatings obtained by using Casto-Dyn DS 8000 torch also, the effect of grinding treatment on contact fatigue was assessed. For the grinding Chris Marine 75H lathe grinder was used. Grinding treatment according to the manufacturer of the coating material was performed. For treatment of coatings, the 01-90x10x32 39C-60-H6V grinding wheel was used. Grinding parameters were as follows:

- wheel feed-in – a_e = 0.02 mm,
- workpiece peripheral speed – v_p = 28 m/min,
- wheel peripheral speed v_s = 25 m/s,
- axial feed f_o = 0.06 mm/rev.

3. Experimental method

The corrosion tests were performed in 3.5% NaCl (artificial seawater) solutions by two techniques (polarization and impedance). Potentiodynamic method was taken in three-electrode system. Degreased with acetone sample 1 cm^2 in size, an auxiliary electrode (polarizing) from platinised titanium and a reference electrode (saturated calomel electrode) were placed in a vessel filled with 500 ml 3.5% NaCl solution of ambient temperature. The measurement was taken after 1-hour exposure of a sample in the electrolyte to stabilize corrosion potential. The electrolyte was being continuously stirred.

Testing involved registering of polarization curves i=f(E) in range ±150 mV from corrosion potential. Cathode curve was registered first, and then anode curve. Potential change rate in all occurrences equalled 10 mV/min. By computer, program 'Elfit – corrosion polarization data fitting program' the value of corrosion current density was made calculation.

The second technique, impedance measurements of the base–coating-electrolyte system were performed in range of frequency from 100 to 0.01 kHz, by sequential induction by sinusoidal voltage signal in range of ±10 mV from stationary potential. The ATLAS 053 EU&IA instrument was used. The obtained results were analysed by the AtlasLab and EIS Spectrum Analyser software in order to determine the charge transfer resistance, the resistance of the electrolyte contained in the pores and the exponent component of the capacitive impedance.

4. Results

Figure 1 shows the polarization curves of coatings after turning and burnishing treatments. In Fig. 2 presents the results of measurement of the corrosion current density of the evaluated coatings. The resulting average values i_{corr} allow us to conclude that the finishing process affects the rate of coatings corrosion in seawater environment. Flame sprayed coating, the surfaces of which have been shaped by turning, characterized by the corrosion current density equal to 2.95 $\mu A/cm^2$. Burnishing was caused four-fold reduction of evaluate of tested quantity, to the value of i_{corr} = 0.73 $\mu A/cm^2$. Greater resistance to corrosion of burnished coatings was the result of ten times smaller roughness [9], which is associated with a reduction in the surface area of the actual field.

With the proposed technology, machining and finishing least favourable in terms of corrosion resistance is grinding. The average value of the corrosion current density was 11.11 $\mu A/cm^2$. Due to the high ductility of the coatings after turning and burnishing treatments was observed the increase their hardness compared to untreated coatings for finishing. It is related to the strain hardening of material. The plastic deformation reduces the porosity of the coatings in the subsurface zone.

The average value of the corrosion potential of Ni – 5%Al coatings subjected to burnishing was -184 mV (Fig. 3). As a result of the burnishing shifted the corrosion potential in the cathodic direction, about 140 mV was occurred, compared to a turning operation. The values of corrosion potentials of burnished alloy coatings and austenitic steel X5CrNi18-10 in seawater are similar. Limited is the possibility created corrosion cells: coating – steel substrate, which might be formed by the penetration of the corrosive environment through the pores of the flame, sprayed coating.

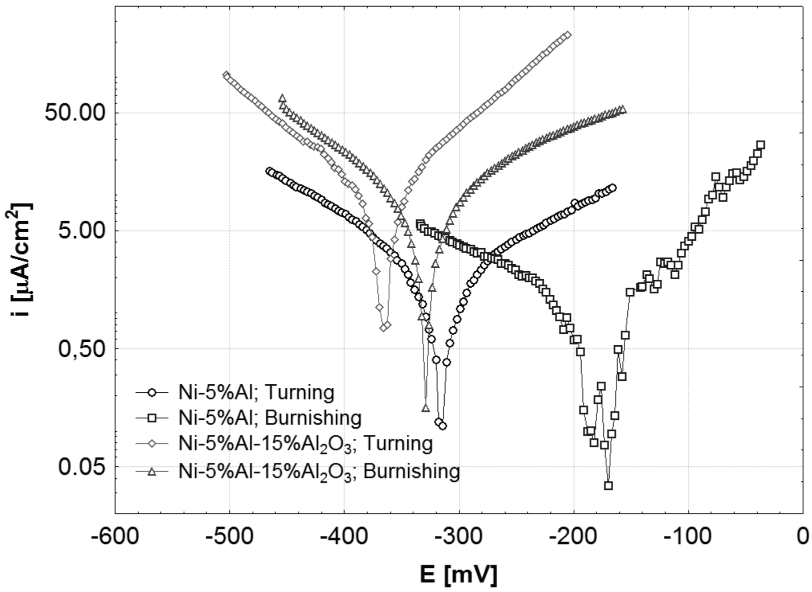

Fig. 1. The examples of polarization curves of flame sprayed coatings

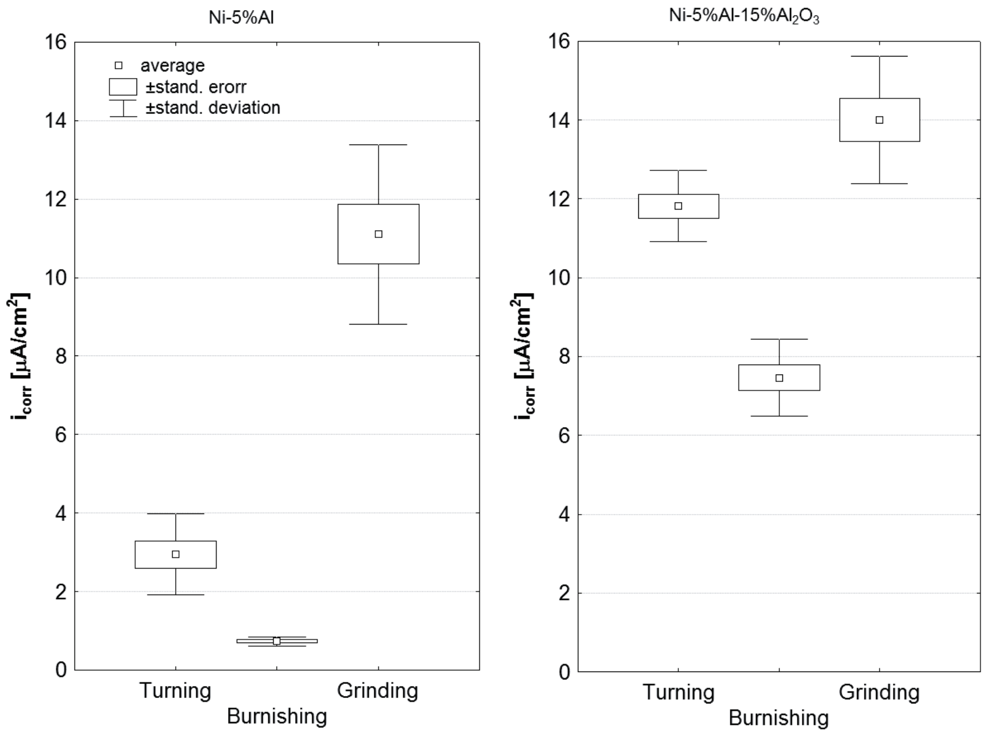

Fig. 2. The impact of finishing on the corrosion current density of the flame sprayed coatings on the Ni-5% Al matrix

The values of corrosion current density showed that the flame sprayed composite coatings are characterized by a lower resistance to corrosion compared to the alloy coatings. In the case of Ni – 5%Al – 15%Al_2O_3 composite coatings after turning determined the value of corrosion current density was 11.82 µA/cm^2 (Fig. 2). Composite coatings after burnishing characterized by a current density of 7.46 µA/cm^2. The highest value of i_{corr} equal to 14.01 µA/cm^2 was found for

Ni – 5% Al – 15% Al_2O_3 coatings subjected grinding. After burnishing said ten times lower corrosion current density for alloy coatings with respect to the composite coatings with a 15% volume fraction of the reinforcing phase. The reason for this is the presence of open greater porosity of composite coatings.

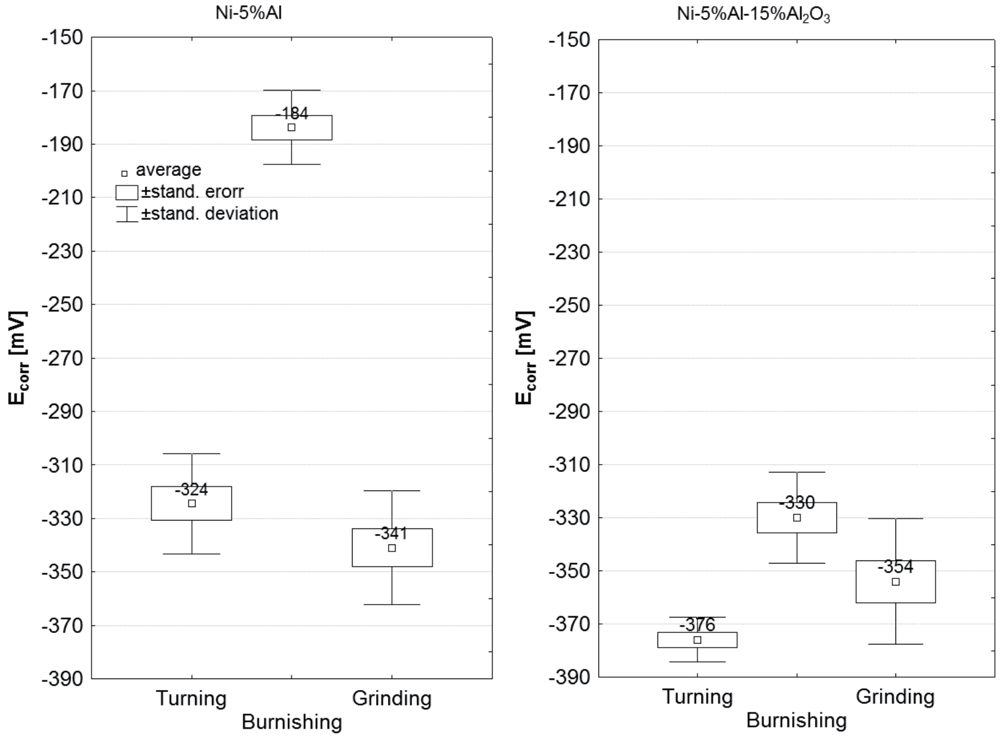

Fig. 3. The impact of finishing on the corrosion potential of the flame sprayed coatings on the base Ni – 5% Al

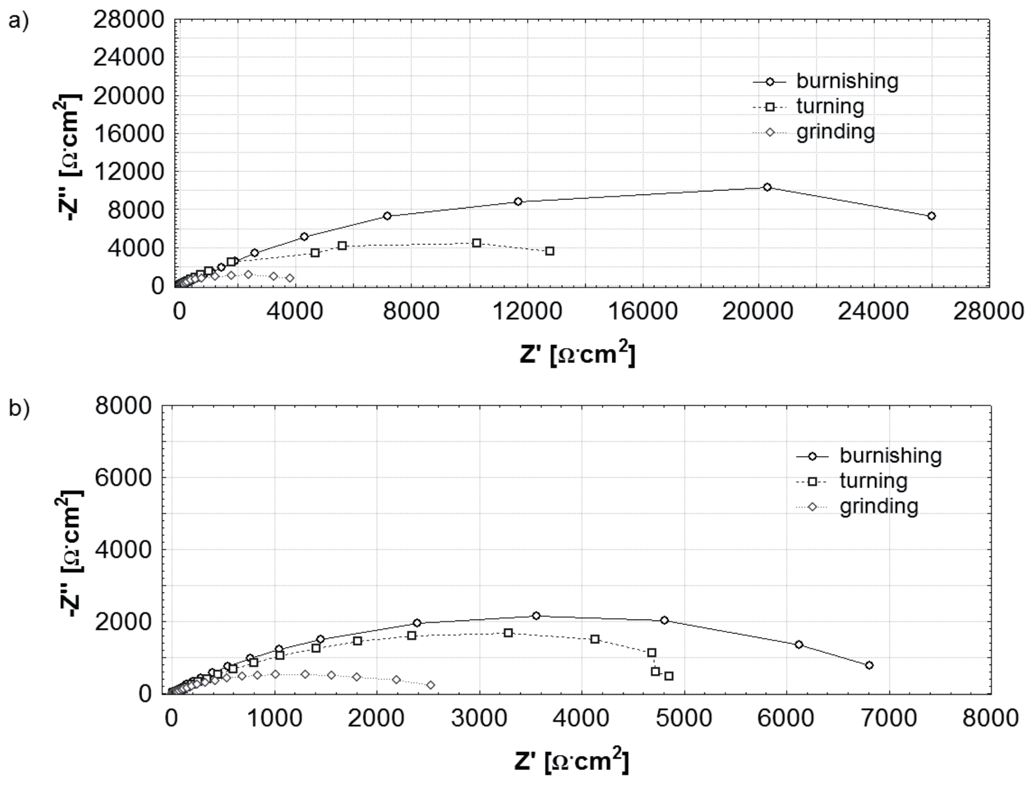

Fig. 4. Examples of Nyquist plots for the flame sprayed by Casto-Dyn DS 8000 torch a) Ni – 5% Al b) Ni – 5% Al – 15% Al_2O_3 coatings, after finishing treatment

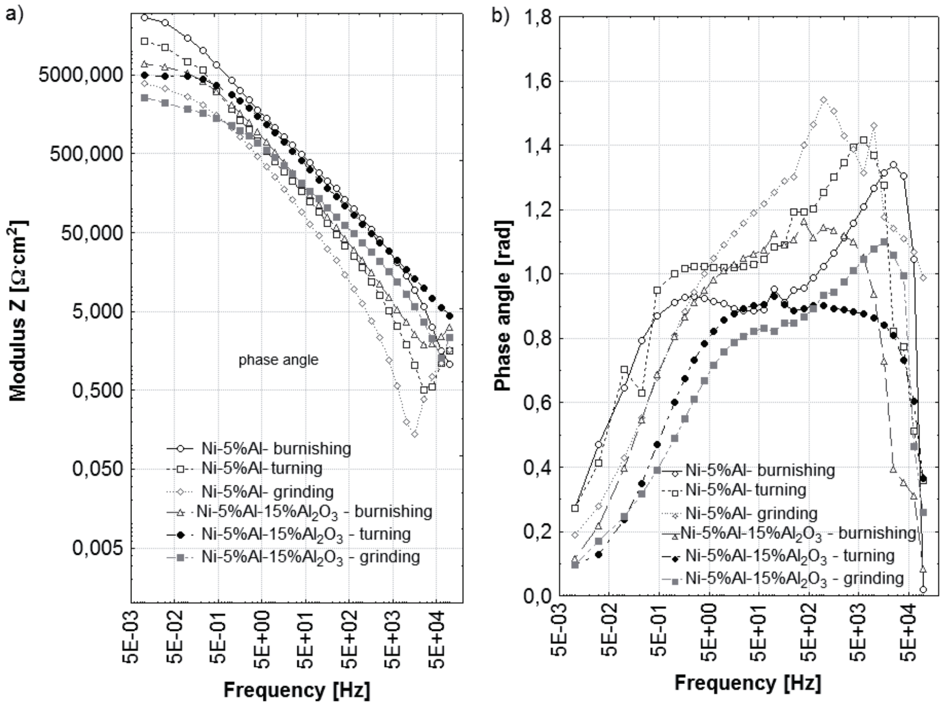

Fig. 5. Examples of Body plots: a) modulus of impedance and b) phase angle for the flame sprayed by Casto-Dyn DS 8000 torch Ni – 5% Al and Ni – 5% Al – 15% Al_2O_3 coatings, after finishing treatment [10]

Tab. 1. The average values of charge transfer resistance (R_{ct}), the resistance of the electrolyte contained in the pores (R_p) and the exponent component (n) of the capacitive impedance of flame sprayed coatings after finishing treatment (average of 6 measurements) [10]

Parameter	**n [-]**		**R_{ct} [Ωcm²]**		**R_p [Ωcm²]**	
Coating	**average**	**stand. deviation**	**average**	**stand. deviation**	**average**	**stand. deviation**
After turning						
Ni-5%Al	0.72	0.087	16215	2131	257	104
Ni – 5%Al – 15%Al_2O_3	0.66	0.02	4576	402	205	112
After burnishing						
Ni – 5%Al	0.78	0.067	31063	2567	143	71
Ni – 5%Al – 15%Al_2O_3	0.72	0.05	7857	750	148	45
After grinding						
Ni – 5%Al	0.66	0.039	4204	802	294	34
Ni – 5%Al – 15%Al_2O_3	0.59	0.02	3260	483	280	32

Kind of finishing treatment of flame sprayed composite coatings Ni – 5% Al – 15% Al_2O_3 exerted a significant influence on the corrosion potential. Turned composite coatings were characterized by the average value of E_{corr} equal to -376 mV (Fig. 3). Burnishing is associated with a 12% increase corrosion potential of composite. Composite coatings treated by grinding characterized by the average value the corrosion potential equal to -354 mV.

The shape of the curves in the Nyquist plots (Fig. 4.) shows the shift centres semicircle below the real axis component of the impedance. It is characteristic of the surface on which they are porous coating. Impedance tests show that none of the treatments used for finishing not allow removal of porosity of coatings.

The Bode plot the frequency of potential effect on the value of the modulus of impedance (Fig. 5.a) and the phase angle (Fig. 5.b) was presented. It was found that the flame coating corrosion process is accompanied by two time constants. The value of impedance modulus depends on the phase composition of and finishing treatment of the coatings. Larger values of the module, at the frequency of potential changes amounting 0.01 Hz were obtained for a coatings, for which the geometrical structure of the surface was constituted by burnishing compared to the machined surfaces of the other methods. Ni – 5%Al alloy coatings were characterized by a higher impedance modulus values as compared to the of the Ni – 5 %Al – 15%Al_2O_3 composite coatings.

Table 1 contains the mean values and standard deviations of the charge transfer resistance (R_{ct}), the resistance of the electrolyte contained in the pores (R_p) and the exponent component (n) of the capacitive impedance of flame sprayed coatings by Casto-Dyn DS 8000 torch after finishing treatment. Measurements made by electrochemical impedance spectroscopy, showed less corrosion resistance of composite coatings when compared to alloy coatings. Evidenced by the lower values of charge transfer resistance and component exponent of capacitive impedance of coatings, after all finishing treatments applied.

As a result of finishing treatments obtained different mean values for the component exponent (n) of the capacitive impedance of flame sprayed coatings, which may suggest a different susceptibility of nickel-based coatings for corrosion pitting after finishing treatments applied. The greatest susceptibility to non-uniform corrosion processes proceed showed alloy and composites coatings treated by grinding. The lowest values of component of exponent n were the equal to 0.66 and 0.59 for the alloy and composite coatings. The highest value of the exponent component of n = 0.78 for burnished coatings was found.

5. Conclusions

Selection finishing treatment influences the corrosion, in seawater environment, of the flame sprayed Ni – 5%Al and Ni – 5%Al – 15%Al_2O_3 coatings. Burnishing in compared to turning and grinding contributes more to reducing the corrosion current density value, increasing the values of the corrosion potential, charge transfer resistance and exponent component of the capacitive impedance.

Composite Ni – 5%Al – 15%Al_2O_3 coatings subjected to a finishing treatment are less resistant to general corrosion and a greater susceptibility to local corrosion in compared to alloy Ni – 5%Al coatings.

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