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EFFECT OF BURNISHING ON THE CORROSION PROPERTIES OF Ni-5%Al AND Ni-5%Al-15%Al_2O_3 COATINGS OBTAINED BY PLASMA SPRAYING

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Abstract

The Ni-5%Al alloy coatings and Ni-5% Al-15%Al_2O_3 composite coatings were obtained by plasma spraying method. The PN120 gun was used. The coatings onto a shaft made of austenitic stainless steel (X5CrNi 18-10) were sprayed. The coatings were subjected to turning, burnishing. The evaluation of corrosion properties were based on the measurements of corrosion current density and corrosion potential (polarization method), the charge transfer resistance and exponent of constant phase element impedance (electrochemical impedance spectroscopy method). Corrosion tests were performed in replacement seawater (3.5% sodium chloride solution).

On the basis of studies, the effect of finishing type on the corrosion properties of plasma sprayed coatings has been demonstrated. The lowest corrosion current density was found for Ni-5% Al coatings after burnishing, icorr value equal to 0.96 μA/cm², and the charge transfer resistance was 27007 Ωcm². The lowest resistance to corrosion of turned Ni-5%Al-15%Al_2O_3 composite coatings was observed. These coatings were characterized by the following parameters of corrosion process: i_{corr} = 17.64 μA/cm², R_{ct} = 2137 Ωcm2.

Burnishing caused increased corrosion resistance of 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 plasma 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. The plasma sprayed coatings on nickel matrix had a tendency to localized corrosion in sodium chloride solution.

Keywords: *plasma spraying, composite coating, Ni-Al, burnishing, corrosion, polarization test, EIS test*

1. Introduction

The use of coatings is one of the most effective strategies to increase the wear resistance and protect against corrosion of materials. This allows for developing materials with optimized surface behaviour. Thermal spraying allows for using cheaper or less processable materials, like mild carbon steel. Methods of thermal spraying allow obtaining coatings from various materials, for example, metals (including stainless steel, bronze, brass, aluminium and nickel alloys), polymers, ceramics and composites. Thermal spray is a technique that produces a wide range of these coatings for diverse applications. In the spray process, thermal energy is used to melt coatings feedstock, a gas velocity is used to accelerate the melted of particles. Then particles influence with substrate where coating followed rapid solidification is formed. Thermal spraying uses two principal energy sources, chemical energy of the combusting gases (e.g. flame spray torches and high velocity oxygen fuel (HVOF) spraying) and electric currents, providing energy for the plasmatrons (e.g. atmospheric plasma spraying (APS) and arc wire spray). All these techniques allow for the deposition of coating on materials generally ductile to improve their corrosion and wear resistance. APS and HVOF coatings have small structural defects, e.g., pinholes, pores and microcracks. These local defects are formed during or after spraying, and act as channels, which cause a direct path between the corrosive environment and substrate, leading to rapid local galvanic attacks and pitting corrosion of coatings and the base materials. In recent years, thermal sprayed nickel-based alloys are used in a variety of applications, e.g. as bond coats for thermal barrier coatings on turbine components, as restorative layers for machine parts, as bond coats in internal combustion engine cylinders, for corrosion protection of boiler tubes, and in numerous other applications requiring wear, high temperature, and corrosion-resistant surface [2, 6, 7].

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, 2, 10, 11].

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 [11].

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 [5, 9, 12].

Burnishing treatment has been used to increase the resistance of aluminum alloys to pitting [8], stress [4] and fatigue corrosion [5].

In this article, the application of Ni-Al alloy and Ni-Al-Al_2O_3 composite coatings for the regeneration pivots of pump shaft are proposed by plasma spraying. Matrix nickel coatings are characterized by high plasticity, adhesion to steel substrates, abrasion resistance and a passive state. A reinforcing phase of alumina particles with a diameter of $\phi = 60$ μm are used. Spraying method does not require great skill from the operator and is not associated with expensive equipment workstation, so it can be used by ship engine room crew or repair brigade during the voyage [3].

2. Preparation of simple

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 PN120 plasma torch (APS methods) was 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 plasma spraying have been applied:

- argon pressure: 0.35 MPa,
- the distance of the nozzle from the surface: 70-100 mm,
- current: 450-600 A,
- voltage arc internal: 47-60 V.

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 were 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 [14]:

- 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).

3. Experimental method

The corrosion tests were performed in 3.5% NaCl (artificial seawater) solutions by two techniques (potentiodynamic and impedance). Polarization 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 ±10m V 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

In Fig. 1 examples of the polarization curves of plasma sprayed Ni-5% Al alloy and Ni-5%Al-15%Al_2O_3 composite coatings were presented. The seawater was environment in which the measurements were performed.

The average values of the corrosion current density, depending upon the mechanical treatment of plasma sprayed coatings ranged from 0.99 to 17.98 μA/cm^2 (Fig. 2). Smaller values during polarization measurements of alloy coatings were recorded, higher values for composite coatings.

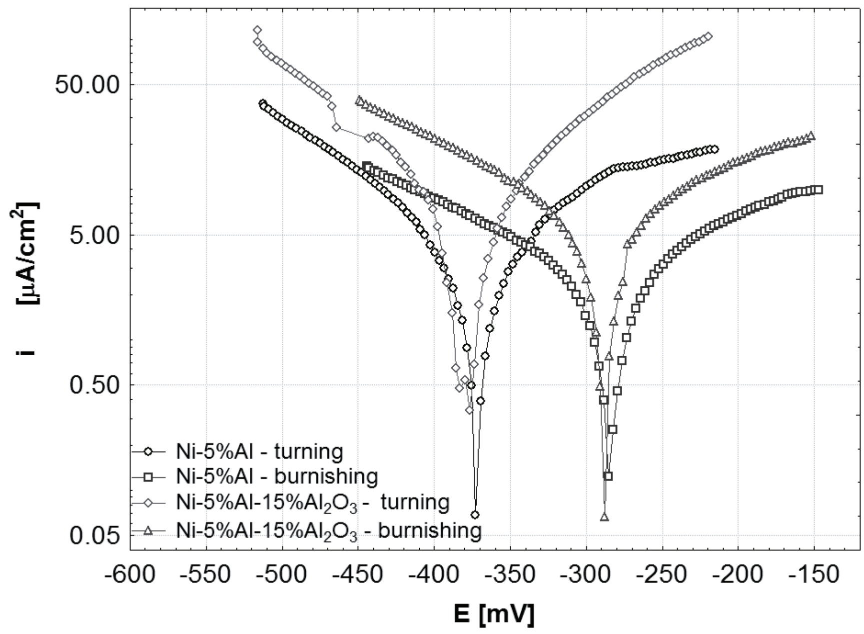

Fig. 1. The examples of polarization curves of plasma sprayed coatings [13]

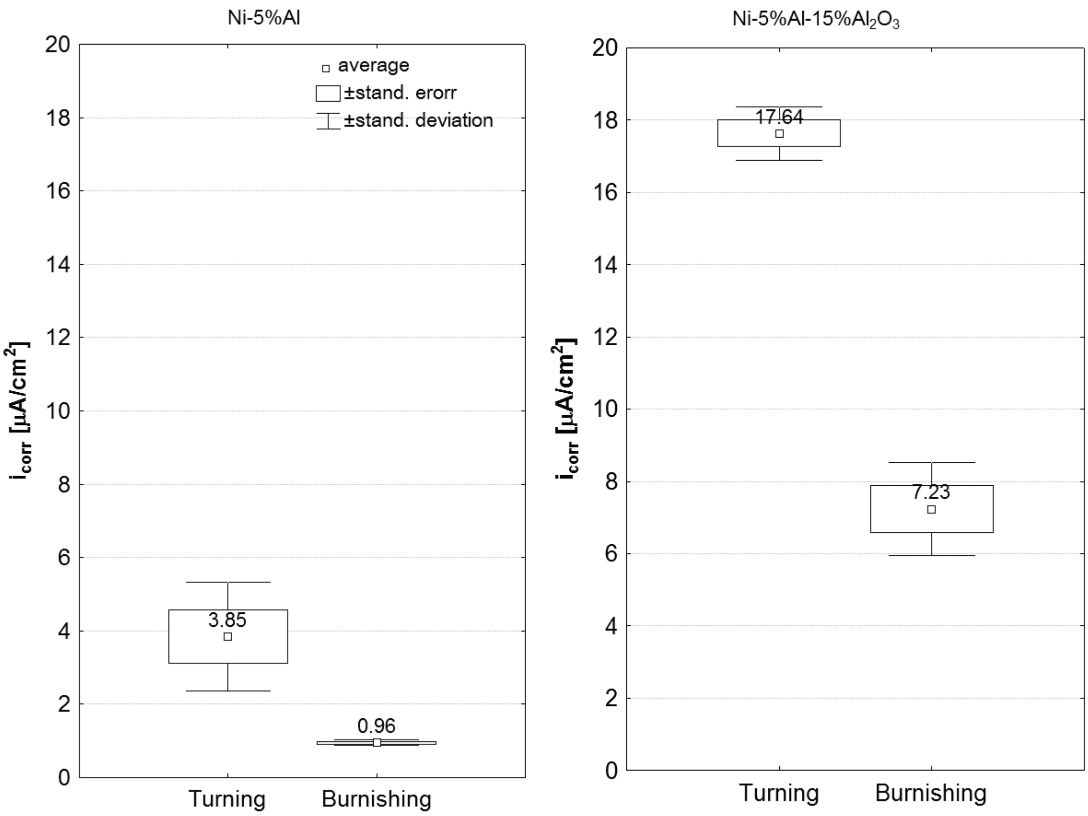

Fig. 2. The impact of finishing on the corrosion current density of the plasma sprayed coatings on the Ni-5%Al matrix

In the case of plasma sprayed Ni-5% Al coatings, after turning the assessed value of quantity was 3.85 μA/cm^2. Coatings, which have been, subjected the burnishing after turning treatment, proved more resistant to wear caused by corrosive environment. Burnishing four times improved analysed operational property. The corrosion current density of burnished Ni-5% Al coatings was equal to 0.96 μA/cm^2.

Corrosion current density of the Ni-5%Al-15%Al_2O_3 composite coatings equal to 17.64 µA/cm^2, when their surfaces of were formed as a result of turning. As a result of burnishing of i_{corr} value decreased 2.5 times.

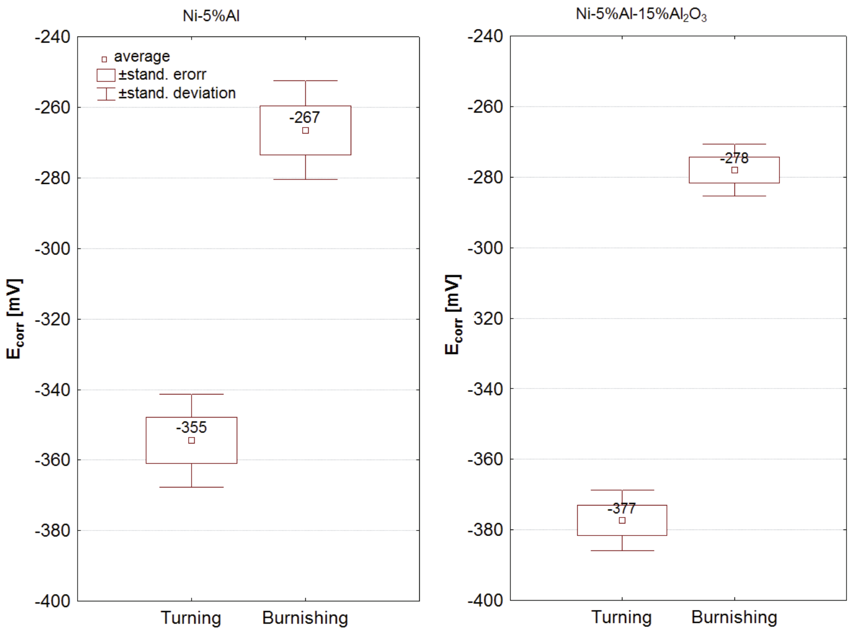

Fig. 3. The impact of finishing on the corrosion potential of the plasma sprayed coatings on the Ni-5%Al matrix

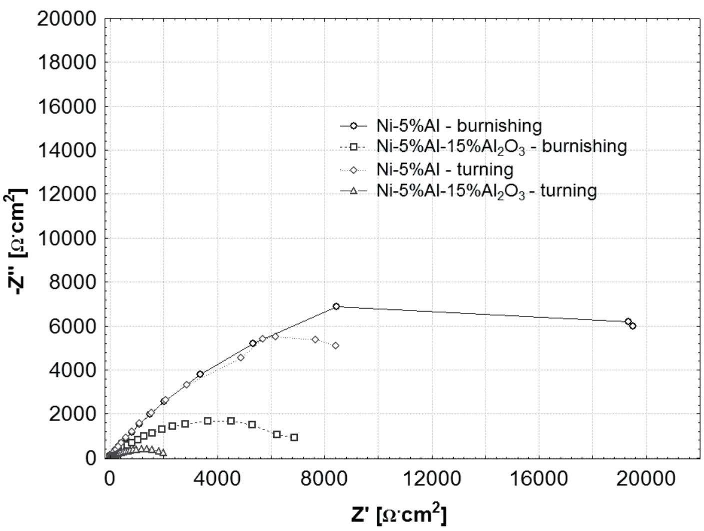

Fig. 4. Examples of Nyquist plots for the plasma sprayed) Ni-5% Al and Ni-5% Al-15% Al_2O_3 coatings, after finishing treatment

In Fig. 3 the mean values of corrosion potential of plasma sprayed alloy and composite coatings were presented. The geometric structure of surface coatings geometric structure had been formed as a result of turning and burnishing. The corrosion potential of turned coatings was – 355 mV. Burnishing able to increase in the E_{corr} value of about – 267 mV, in comparison to the coatings subjected to machining only. Burnishing the surface of plasma sprayed composite coatings also caused an increase in the value of the corrosion potential. The corrosion potential of Ni-5% Al-15%Al_2O_3 coatings after turning was – 377 mV. Plastically deforms the irregularities on the surface of coatings allowed to obtain corrosion potential value equal – 278 mV. This effect shows on less susceptible to corrosion of burnished surface compared to the coatings turned.

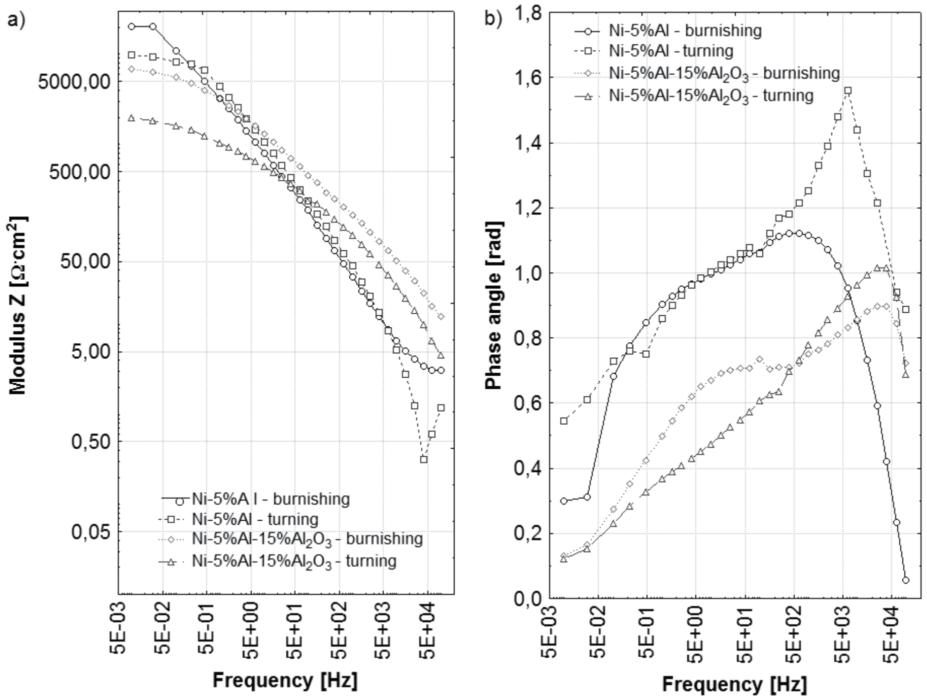

Fig. 5. Examples of Body plots: a) modulus of impedance and b) phase angle; for the plasma sprayed (PN 120 torch) Ni-5% Al and Ni-5% Al-15% Al_2O_3 coatings, after finishing treatment [15]

In Fig. 4, the examples of Nyquist plots obtained during of measurements the corrosion process by EIS method of plasma sprayed Ni-5%Al and Ni-5%Al-15% Al_2O_3 coatings after a finishing treatment in an environment of replacement seawater were presented. Semicircles forms on the Nyquist plots indicate that in the case of plasma sprayed coatings treatments they did not allow for the complete elimination of the open porosity of the coatings.

Corrosion processes of Ni-5%Al alloy coatings treated burnishing can be analysed using equivalent circuit model with one time constant (Fig. 5b). In other cases, the corrosion process of coatings after finishing treatment pass is more complex. During the analysis of these coatings used equivalent circuit models with two time constants. After the burnishing treatment when measurements by electrochemical impedance spectroscopy method were made the Ni-5 percentage Al, coatings obtained the highest modulus value of the impedance in the low frequency potential changes. After the burnishing treatment when measurements by electrochemical impedance spectroscopy method were made the Ni-5 percentage Al, coatings obtained the highest modulus value of the impedance in the low frequency (Fig. a). After turning the Ni-5%Al-15%Al_2O_3 coatings were characterized by smallest value of the impedance modulus at 0.01 Hz frequency.

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 plasma sprayed coatings, after finishing treatment (average of 6 measurements) [15]

Parameter	n [–]		R_{ct} [Ωcm²]		R_p [Ωcm²]	
coating	**average**	**stand. deviation**	**average**	**stand. deviation**	**average**	**stand. deviation**
After turning						
Ni-5%Al	0.68	0.036	12015	1025	36	21
Ni-5%Al-15%Al_2O_3	0.65	0.05	2137	207	26	6
After burnishing						
Ni-5%Al	0.74	0.025	27007	1720	–	–
Ni-5%Al-15%Al_2O_3	0.68	0.02	7258	696	18	7.1

The values of the parameter of corrosion process of plasma sprayed alloy and composite coatings, determined from measurements using electrochemical impedance spectroscopy, are presented in Tab. 1.

The average value of the charge transfer resistance of turned coatings Ni-5% Al was 12 015 Ωcm^2. Burnishing contributed to improving the corrosion properties of the evaluated coating material. Burnishing resulted are more than doubling of electrical resistance, which accompanies the passage of electrical charge from the metal to the electrolyte. The value of the charge transfer resistance of burnished plasma alloy coatings was equal to 27 007 Ωcm^2. Mean value of R_{ct} for composite coatings which surface structure formed by turning was equal to 2137 Ωcm^2. After burnishing approximately 3.5 – fold increase R_{ct}, resistance was found.

After finishing treatment, the average values of exponent component (n) of the capacitive impedance of plasma sprayed coatings were ranged from 0.65 to 0.74. They may indicate susceptibility for corrosion pitting of received nickel-aluminum matrix coatings. The smallest component n value was observed during the EIS study of turned composite coatings. The largest value of component n for burnished alloy coatings was observed. Based on the presented results in Tab. 1, it can be seen that for both evaluated compositions of coatings after burnishing there was a trend to decrease pitting corrosion in an environment of 3.5% sodium chloride solution. However, due to the large scatter of the results of measurement, represented by the standard deviation and performed Statistical tests of significance, it must be concluded that the lack of a statistically significant effect applied of finishing treatments on the value of the component exponent (n) of the capacitive impedance of plasma sprayed Ni-5% Al and Ni-5%Al-15%Al_2O_3 coatings.

5. Conclusions

- After finishing treatment of Ni-5%Al-15%Al_2O_3 composite coatings are less resistant to corrosion in the environment of sea water replacement than Ni-5%Al alloy coatings.
- The burnishing increases the corrosion resistance of plasma sprayed coatings.
- Burnishing is not affected in a statistically significant effect on susceptibility of coatings to pitting corrosion.

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