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Research paper

Corrosion behavior of electro-deposited nickel aluminum composite coating on the stainless steel 316L

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Abstract

The characterization of aluminum particulates charging in a coating cell on the morphology and corrosion behavior of nickel aluminum composite coating by an electro-chemical co-deposition coating were evaluated. The aluminum reinforced nickel matrix composite coatings were co-deposited on Austenitic Stainless Steel (316 L) work pieces by a nickel-ion electrolytic solution firmly postponed with -10 µm max. diameter aluminum particulates. The extreme limit of codeposited aluminum can be occurred at a particulate gratified of 50 g/l in cell, a current density of 4.5 A/dm^2, a PH of 4.0 – 4.1, and a circulation rate of 400 rpm.
Entirely codeposited specimens were heat treated under vacuum atmosphere for five hours at 950 °C prior to Potentiostatic testing. Throughout heat treatment, coating morphological development was initiated to occur by the exothermic reaction nickel +aluminum = nickel aluminum.
Surface morphology was inspected by scanning electron microscopy(SEM) and X-ray diffraction (XRD) and atomic absorption. Furthermore, The electrochemical enactment of the coatings was considered by Potentiostatic test in 3.5wt.% NaCl. It was originate that, combination of aluminum particulates in nickel matrix sophisticated the nickel grains coatings. Though , polarization curves raised to negative potentials and the rate of corrosion is reduced.

Keywords: *Composite Coating; Stainless Steel (316 L); EMMC; Nickel Aluminide Electroplating.*

1. Introduction

Electroplating has increased profitable requests for components that requirement to corrosion besides wear resistant. Particularly, certain types of coating approaches dispersed ceramic particulates in metal matrixes are attractive general in many wear applications [1]. The electro-deposition of metal coatings including inactive particulates can be drawn back to investigate that manufactured a graphite- copper composite coating for self- oiling exteriors in wagon machines [2]. Detectives were attentive on obligation of creating coatings with better corrosion and mechanical possessions. To this assumption, irresoluble particulates are adjourned in a communal electroplating electrolyte and are seized in the developing metal cover. These particulates can be stiff oxide or carbides like zirconium oxide, tungsten oxide[3], aluminum oxide [4] and silicon carbide [5, 6]. Extra recommended which the oxidation resistance coverings could be ready by co-electrodepositing of metal, for instance with micro-meter sized metallic particulates like chromium [6].
Two public procedure complicated with combination of particulates into metal coatings could be documented , specifically, physical dispersal of particulates in the electrolyte and of electrophoretic relocation of particulates [7]. The mutual procedure Complicated in the co-deposition of particulates into full-grown metallic layer. Five stages throughout the co- deposition procedure can be recognized :

1) Creation clouds of ions on the particulates.
2) Convections near cathode electrode
3) Dispersion concluded a hydrodynamic boundary film, and
4) Fascination at the cathode, wherever particulates are deceived inside the metal deposit [8]

Izaki et al. [9]described electrodeposited nickel-aluminum coatings from Watts nickel solution by using 9 micron aluminum particulates. When animated in vacuum at temperature of 800°C for three hour, the microstructure of alloy coating muscularly altered from single γ-nickel phases to single γ′-NiAl phase with growing aluminum content. Extra lately, Susan et al. [10] shaped nickel aluminide coatings from nickel sulphamate solutions, that controlled concentrated 20 volume percentage aluminum particulates. Two phases nickel-aluminum coatings (γ Ni+ γ′-Ni_3Al were got subsequently thermal distribution treatments at 825 °C for three hours in free air space. Outcomes of Test displayed the nickel aluminum coating had decent oxidation resistant underneath 900 °C [11, 12]. Though for attain worthy oxidations resistant exceeding 900 °C, aluminum gratified in composite would be augmented therefore more thermodynamics steady phases similar γ′–Ni_3Al as well as ß-NiAl could be formed. For instance, creation of solitary phase γ′–Ni_3Al needs an aluminum gratified of 22-28 mol% (30-37 volume percentage) in the covering layer [9].
Maximum nickel aluminum composite coatings are prepared by composite electro deposited coating method , i.e. the anodic and Cathodic electrodes are straight up introduced in the cell. Research by Susan et al [10] presented a higher limit of twenty volume percentage aluminum were shaped nearly in 300g/ l of particulates packing , more increase in particulates loading did not cause advanced particulates fraction of volume in coating.
Unique method usage surfactant to get additional combination of particulates in composite, Nickel -PTEE composite coverings with seventy volume percentage PTFE particulates remained got by cationic and non-ionic surfactants [13]. Though , extreme surfac-

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tants will minimize the Cathodic proficiency [14] and rise deposits fragility[13].
The goal of current research were to manufacture nickel aluminum composite coating on the St. St.316L as well as to explore the belongings of deposition limits on aluminum particulates depositions in the coating as well as to investigate the corrosion behavior of the composite coatings comprising numerous percentage of aluminum particulates.

2. Experimental detail

2.1. Work piece alloy

The base alloy usage in this research was Austenitic Stainless Steel (316 L). The nominal constituent of austenitic stainless steel 316L alloy is exposed in Table1. Whereas Table 2 gives Spectrochemical constituent of austenitic stainless steel in weight percentages.

Table 1: Preventive Chemical Constituent of Austenitic Stainless Steel 316L in Weight Percentage Rendering to [15]

EL	Fe	C	Mn	Si	Cr	Ni	P	S	Mo	V	Cu
Wt.%	bal.	<0.02-<0.03	2.0	1.0	16-18	10-14	_	_	2-3	_	_

Table 2: Spectrochemical Constituents of Austenitic Stainless Steel 316L in Weight Percentage

EL	Fe	C	Mn	Si	Cr	Ni	P	S	Mo	V	Cu
Wt.%	bal.	0.041	1.42	0.27	19.38	10.24	0.025	0.003	0.283	0.080	0.218

The Austenitic Stainless Steel (316 L) specimens were censored into quadrangles formula with aspects (20 x 20 x 4 mm) and an entire exterior 1120 mm^2. Specimens were censored from a pane vertical to the progressing path. Slight hole of two mm breadth was bored in every specimen for farm. Totally outsides, counting the boundaries were showery polished using graded SiC papers. These specimens were formerly gutted with purified water, grease removed by alcohol and formerly by ultrasonic device gutted for thirty minutes by ethanol as an intermediate. Later aeration, the specimens were reserved in polyethylene zip-lock belongings.

2.2. Electro-chemical code position coating

Formerly nickel aluminum Electro-chemical Codeposition Coating initiates, tinny layer of nickel deposits as a groundwork stage were performed as to the following stages [16]:

1) Cold washing.
2) Involvement in 20% HCl (1.098 specific gravity) at room temperature for one minute.
3) Cold washing.
4) Anodic scratch in wood's nickel- strike cell, that limited of 240 gram per liter $NiCl_2$ and 86 mil per liter HCl (concentrated of thirty seven percentage) at forty three centigrade as solution temperature and by deposition current density of 0.0538 amp / cm^2 for twenty sec.
5) Plate in wood's cell at forty three centigrade, by deposition current density of 0.0538 amps per square centimeter for two minutes.
6) Cold wash.

The goal of this stage is to become supplement film (Ni) between Austenitic Stainless Steel (316 L) superficial and the electro-deposited composite coating (Ni-Al). Electro-deposition of nickel aluminum composites was achieved in a characteristic watts cell on the Austenitic Stainless Steel (316 L). A nickel sulfamate electrolyte was secondhand by the subsequent constituent: 300 g/l nickel sulfamate Ni $(NH_2SO_3)_2$, 30 g/l boric acid, 5 g/l nickel chloride ($NiCl_2$), 0.2 g/l sodium laurel sulfate (wetting agent), and 0.1 g/l coumarin (smoothing mediator). Entirely of the cell constituents were varied in one liter of deionized water. The cell constituent is like to that of Guglielmi [17] and extra lucrative plating cell [18]. It was originate that extreme quantities of the surfactant (coumarin) could reason "effervescing" of the plating cell as aluminum particulates were supplemented and, consequently, least amounts of preserving were added.
Afterward the plating cell was performed, aluminum powder was supplemented. Powders were co-deposited in the nickel matrix to transport for nickel aluminide creation. Aluminum powder got from BDH Chemicals Ltd., Poole England, great purity (99% Al), 10 μm max. size. Powder accompaniments of 10, 20, 30, 40 and 50 g/l were fixed in all tests.
Deposited was performed in a cell of plating consist of three hundred cm^3 of the electrolytic solution. The work piece was located straight in the cell at one cm underneath the level of solution and fixed steeply in the motivated tributary of the electro-deposition cell (Fig. 1) [19]
The cell was retained at fifty centigrade and PH ≅ 4.0. It was originate that deposition current density nearly 4.5 amps / dm^2 gave the greatest outcomes, and this current density was stable for all coatings in this research. To précis Table 3 illustrates the main exemption parameters for characteristic coating deposition.
Subsequently plating, the nickel aluminum composite coating was washed, ultrasonically gutted with purified water, and desiccated. Microstructures and chemical constituents of the coatings were estimated by a scanning electron microscopy (Olympus BX51M-Japan made) was depended.
Phases constituents of the coating was evaluated by X-ray diffraction analysis model (Minifcex II, Rgaku-200g-Japan prepared) with CuKα radiation (U =40 kV; I = 20 mA).

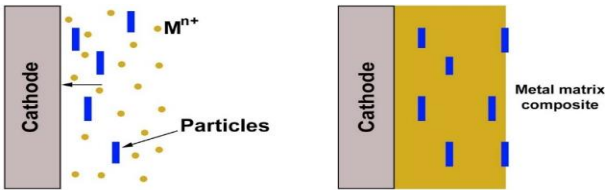


Fig. 1: Graphic Showing the Growing of Metal Matrix Composite System by Electro-Deposition [19].

Table 3: Main Dispensation Limitations for A Characteristic Electrochemical Code Position Coating

Coating Cell	Nickel Sulfamate
The particulate size~	10 μm max.
Particulate filling (Al)	10,20,30,40, and 50 g/l
Temperature	50 ºC
PH	4.0 – 4.1
Current Density	4.5 A/dm^2
Moving Speed	400 rpm
Coating Time	3 hrs.

2.3. Heat treatment procedure

To explore nickel aluminide coating creation, specimens were heat treated in vacuum furnace type (GSL-1600x). 10^{-4} torr was the pressure of vacuum furnace to avoid the oxidation problems of the fundamental materials through the procedure.
A two-step heat treatment outline was led on the specimens for the creation of inter-metallic alloys. Specimens were excited from 25°C to 500 °C with a stable heating rate of (10 °C/min) and holding time three hours at 500 °C. Then heated to (950 °C ,5 °C/min) and holding time five hours at 950 °C. A sluggish heating rate was selected to avoid a severe reaction of nickel and aluminum. After that the specimens were furnace-cooled to lab. temperature.

3. Results and discussion

3.1. Morphology of coating

Subsequently aluminum particulates are dispersed into cell, they exhibit a positive charge owing to a film of Ni^{+2} ions on their external. Cell stirring provisions particulates at a fixed amount to the specimen external surface where they adherence to the comparatively charging work piece [20].

Throughout deposition, a stable condition must be controlled that the coating produces everywhere the particulates as renewed particulates and renewed electrolyte are incessantly provided at the cathode external. Though, since of the electro-static desirability, the steady state particulates packing limited to the surface is higher than the bulk cell loading. In immediate, the outcomes demonstration that the composite electro-deposition methods could be using to effectively manufacture nickel aluminum composite coatings.

The Scanning electron microscopy descriptions exhibited that all the electro-deposits restricted aluminum particulates settled comprised in the surface includes the formation of week chemical bonds between the surface and aluminum particulates postponed in the electrolyte. The particulates are thus at first chemically bonded to the surface, good-looking built into the coating as the plating process proceeds. This unsystematic procedure outcomes in a uniform dispersion of aluminum particulates through nickel matrix. SEM image from the surface of nickel aluminum composite coating with 50 gram per liter aluminum particulates are available in Fig. 2.

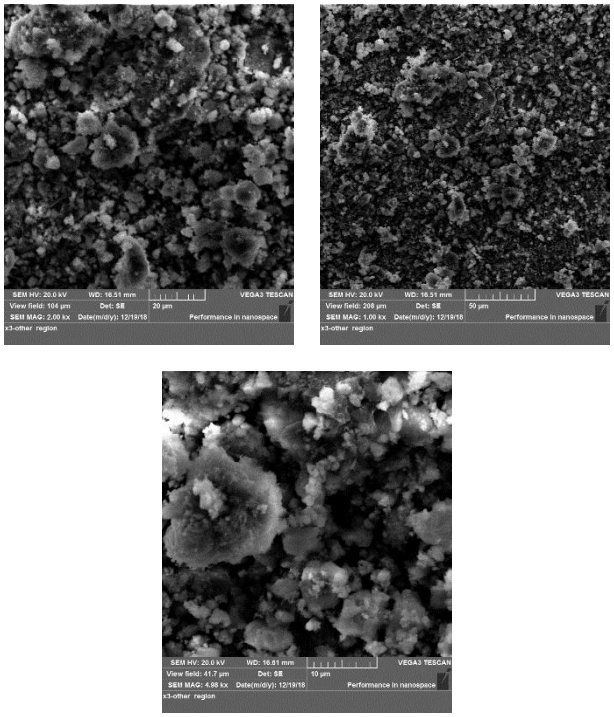


Fig. 2: Scanning Electron Microscopy Image at the Surface of Nickel Aluminum Composite Coating (50 gram per liter).

3.2. Phase study of the codeposited nickel aluminum coatings

The aluminum discrete nickel matrix composite coatings were effectively created over codeposition. The achieved coatings have exposed an even gray rough metallic surface with grains of combined aluminum particulates.

The characteristic X ray diffraction outcomes illustrated that all the coated specimens are considered by identical X ray diffraction outline exhibiting nickel aluminide peaks whereas no symbol of some oxides or other metallic complex phases.

X ray diffraction outcomes of these specimens subsequent the heat treatment procedure, existing in Fig. 3, display that after annealed treatment of specimen consists of the main phase counting nickel aluminum. Clearly, the nickel and aluminum phases existing in the as-deposited specimens entirely convert into nickel aluminide intermetallic compound.

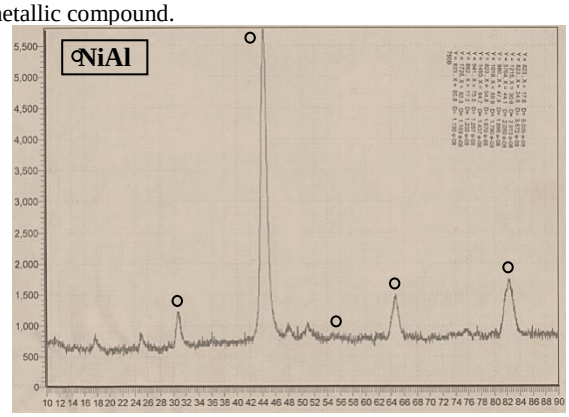


Fig. 3: Diffractograms from the Surface of Nickel Aluminum Electrodeposited Composite Coating of St. St. 316L.

Further, the results of atomic absorption spectroscopy test (type Phoenix-986s Japan made) indicated that the average aluminum concentration in the coated layer are ≅ 5, 9, 17, 23, and 28% in case using aluminum particles concentration in coating solutions (10, 20, 30, 40, and 50 g/liter) respectively.

3.3. Potentiation test

The corrosion behavior of all used specimens in 3.5%NaCl solution has been studied to give estimation about the corrosion behavior of all specimens. The corrosion rates were calculated based on following equation [21]:

$$\text{Corrosion rate(mpy)} = \frac{0.13\ Icorr(Ew)}{\rho} \qquad (1)$$

Where:

E. W= equivalent weight (g/eq.)

ρ= density (g/cm³)

0.13 = metric and time change factor

icorr. = corrosion current density (µA/cm²).

mpy = Corrosion rate (mils per year)

The outcomes of the electro-chemical test for nickel aluminum composite coating are exposed in Table 4 that mention corrosion potential, corrosion current, and corrosion rate. It is detected that by cumulative aluminum particulates in the coating , corrosion rate is decreased and the potential is shifted to more active regions. The corrosion current density ($i_{corrosion}$) and the corrosion potential ($E_{corrosion}$) considered from the intersection of the Cathodic and anodic Tafel curves by consuming the extra polarization technique which is summarized in Table 4. It could be noticed that there is an important shift toward lower current densities of the polarization curves for specimens with different aluminum particulates amount in the coating solution. For example St. St. 316L corrosion current density is around 0.6731µA/ cm^2 while for 10% Al is about 0.4632 µA/ cm^2 and for 30% aluminum is about 0.0765 µA/ cm^2 but at 50% aluminum the corrosion current density is 0.0150 µA/ cm^2. Further, it can be seen the most improvement percentage is 97% when the concentration of aluminum particulates in coating solution is 50 g/liter (Fig. 4). These out-

comes specify stability behavior of nickel aluminum coating layer. This layer is able to change the surface properties of st. st.316 L without affecting the base alloy.

Table 4: Corrosion Potential ($E_{corr.}$), Corrosion Current Density (µA/ cm^2), and Corrosion Rate (mpy) For St. St. 316L with and without coatings in . 3.5%Nacl

Concentration of Al in coating solution(g/liter)	$I_{corr.}$µA/ cm^2	E_{corr} mv	Corrosion rate*10^{-3} mpy	Improvement percentage
St. St. 316L	0.6731	- 140.71	2.0965	-
10	0.4632	-132.86	1.7547	16%
20	0.1042	-127.65	0.8376	60%
30	0.0765	-102.45	0.3212	85%
40	0.0438	-82.31.	0.1912	91%
50	0.0150	-60.43	0.0643	97%

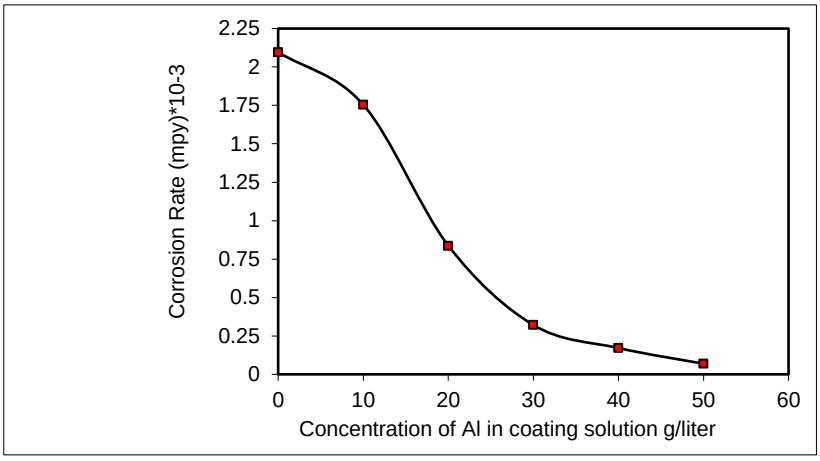


Fig. 4: Corrosion Rate (mpy) for St. St. 316L with and without Coatings in. 3.5%Nacl.

Then since the aluminum particulates are so vigorous consequently aluminum oxide created simply round the particulates and render them unbiased [22]. Hence , they act as unbiased particulates in corrosive ambient [23, 24] and dispense homogeneously in the coating.

4. Conclusions

The extent of aluminum co-deposited particulates in to a nickel base rise as the extent of particulates in the cell is increased. A maximum quantity of codeposited particulates is gotten at cell loading of 50 gram per liter and deposition current density of 4.5 A/ dm^2. Codeposition of aluminum particulates into a nickel matrix products coating with an even distribution of particulates.

1) Conferring to atomic absorption test, the maximum aluminum content in coating was 28 wt.%. when the concentration of aluminum particulates is 50 g/liter.
2) Heat treatment at 950 ^oC for 5 hrs. under argon atmosphere outcomes in diffusion reaction between the aluminum particulates and nickel matrix to produce a nickel aluminide intermetallic compound.
3) Increasing Aluminum metal particulates in coated specimens moved polarization curves to negative potentials and corrosion rate is decreased.
4) Maximum improvement is 97% and minimum corrosion rate is (0.0643*10^{-3}) mpy in 3.5%NaCl solution when the concentration of Al is 50 g/liter in coating solution.

References

[1] Cui Xinwei, Wei Weifeng, Liu Haifeng, Chen Weixing, Electrochemical study of co-deposition of Al particle nan crystalline Ni/Cu composite coatings Electrochimica Acta 2008:54:415-20. https://doi.org/10.1016/j.electacta.2008.07.066.

[2] Low CCTJ, Wills RGA, Walsh FC, Electrodeposition of composite coatings containing nanoparticles in metal deposits, Surf Coat Techno 2006:201:371-83. https://doi.org/10.1016/j.surfcoat.2005.11.123.

[3] Guglielmi N, Kinetics of the deposition of inert particles from electrolytic cells, J. Electrochem, 1972,119. 1009. https://doi.org/10.1149/1.2404383.

[4] Verelst M, Bonino JP, Rousset A., Electroforming of metal matrix composite dispersoid grain size dependence of thermo structural, mechanical properties, Mater Sci Eng. 1991:135:51. https://doi.org/10.1016/0921-5093(91)90536-V.

[5] Feng Qiuyuan, Li Tingji, Yue Hongyun, Qi Kai, Bai Fudong, Junze Jin, Preparation and Characterization of nickel nano –Al_2O_3 composite coating by sediment co- deposition, Applied Surf. Sci, 2008, 254:2262-8. https://doi.org/10.1016/j.apsusc.2007.09.014.

[6] Sheng Chang W, Wen Cheng JW. Kinetics of electroplating process of nano sized ceramic particle /Ni composite Mater Chem Phys, 2003, 78, 573-80.

[7] Yang X, Peng Y, Wang F, Effect of annealing treatment on the oxidation of an electrodeposited alumina forming NiAl Nano composite corr sci 08:50:3227-32.

[8] Liu Haifeng, Chen Weixing, Reactive Oxide –dispersed Ni_3Al intermetallic coating by sediment co-deposition. Intermetallics, 2005, 13,805-17. https://doi.org/10.1016/j.intermet.2005.01.004.

[9] M. Izaki, M. Fukusumi, H. Enomoto, T. Omi, Y. Nakayama, J. Jpn. Inst. Met. 57(2), 1993, 182-189. https://doi.org/10.2320/jinstmet1952.57.2_182.

[10] D. F. Susan, K. Barmark, A.R. Marder, Thin Solid Film 307 (1997) 133-140. https://doi.org/10.1016/S0040-6090(98)80004-7.

[11] D. F. Susan, A. R. Marder, Oxid. Met. 57 (1-2)2002, 131-157. https://doi.org/10.1023/A:1013398830293

[12] D. F. Susan, A. R. Marder, Oxid. Met.57 (1-2)2002, 159-180. https://doi.org/10.1023/A:1013350914363.

[13] A. Hovestad, L.J.J.Janssen, J.Appl. Electrochem. 25 (1995) 519-527. https://doi.org/10.1007/BF00573209.

[14] S. A. Watson, Organic Addition Agents for Nickel Electroplating Solution Nickel Development Institute, Toronto, Ontario, Canada, 1989.

[15] David Talbot and Lames Talbot, "Corrosion Science and Technology", CRC Press LLC, 1998.

[16] A. K. Graham, Electroplating engineering handbook, Carnes publication service. Inc. USA, 1971, p.198.

[17] N. J. Guglielmelli, Electrochemical. Soc., Vol. 119, No. 8, 1972, pp. 1009-1012. https://doi.org/10.1149/1.2404383.

[18] American Society for Metals, Metals Handbook, 9th Ed., John Wiley and Sons, LTD, London, Vol. 5, 1979, pp. 199-218.

[19] Casey R. Thurber, Adel M.A. Mohamed and Teresa D. Golden, Electrodeposition of Cu-Ni composite coatings, https://doi.org/10.5772/62111.

[20] Bercot P, Pena-Munoz E, Pagetti J. Electrolytic composite Ni-PTFE Coating adaptation of Guglielmis model for the phenomena of incorporation surf coat, Dec 2002, 157:288-9.

[21] Ali H. Hallem, Nawal Mohammed Dawood, Investigation the effects of zirconium addition on wear and corrosion behavior of alpha

brass alloy (Cu 30Zn), International Journal of Mechanical Engineering and Technology (IJMET), Vol. 9, Issue 12, December 2018, pp. 844-857.

[22] Ali madad H,Ahmadi M, Aliofkhazraei M, Younesi SR. Corrosion properties electrodeposited nanocrystalline and amorphous patterned Ni-W alloy. Mater Des 2009:30: 1356-61 https://doi.org/10.1016/j.matdes.2008.06.036.

[23] Walsh FC, Ponce de leon, kerr C, Count S, Barker BD. Electrochemical characterization of the porosity and corrosion resistance of electrochemically deposited coatings. Surf Coat Technol 2008:202:5092-102. https://doi.org/10.1016/j.surfcoat.2008.05.008.