

SELECTION OF PROCESSING PARAMETERS FOR CONVERSION COATINGS ON HIGH-STRENGTH ALUMINIUM ALLOYS BY CYCLIC VOLTAMMETRY

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A method of recording copper enrichment on AA2000 series alloys by means of cyclic voltammetry in borate buffer preceded by immersion of the samples in 0.6 M NaCl solution is extended to the assessment of various surface treatments like alkaline cleaning, desmutting, phosphating and also inorganic and organic corrosion inhibitors. Since the height of the peak determined from voltammograms results from Cu/Cu⁺ charge transfer taking place on Al–Cu surface a selection of adequate substances or technological parameters inhibiting this reaction may find an application in elaboration or modifying of surface technology. In this work the particular technological steps of the complex electro-phosphating process of AA2017 were elaborated using results obtained from voltammetric transients. It was shown that a partial removal of Cu from the surface without affecting bulk content was the most effective de-smutting stage while inhibitors of Al/Cu corrosion were effective in the post-treatment stage.

Keywords: *Al alloys, 2000 series, surface inhomogeneity, corrosion, Cu enrichment, cyclic voltammetry, phosphate coatings, impedance*

Pure aluminium is resistant against corrosion due to passivity. The oxide film is adherent, transparent, stable in pH 4–9, self-healing and also is an electrical insulator. However, for increased strength the metal is alloyed with several mass.% of Mg, Zn, Cu and other elements producing a large number of alloys, usually inferior in corrosion resistance in comparison with the pure metal. One of the most common representative alloy used in an aircraft industry is AA2024-T3. Even newer and improved variants of precipitation age hardened Al alloys which offer combinations of strength, toughness, and weight reduction often exhibit susceptibility to localised corrosion, as a result of surface heterogeneity. Numerous constituent particles formed in these alloys can be divided into three major types based on composition [1]:

1. Al–Cu–Fe–Mn particles, which are more noble than Al matrix and act as cathodes;
2. Al–Cu–Mg particles, which are less noble than Al matrix and act as anodes;
3. Al₂Cu particles, which are more noble than Al matrix.

According to [2], corrosion leads to preferential dissolution of Al and Mg leaving Cu-rich remnants which act as cathodes. Pitting is often induced by local galvanic cells formed by Cu-intermetallics or replated Cu on AA2024-T3 surface. According to [3] the deleterious effect of intermetallic compounds in Al–Cu alloys on their corrosion resistance especially in the presence of conversion coating is considered to be the result of copper dissolution and re-deposition creating Cu-rich cathodic areas on which the oxygen reduction reaction occurs at a faster rate than on the Al alloy. The re-deposition

of Cu takes place during formation of majority of conversion coatings. The early stage of this process is pickling of a surface layer leading to $\text{Al} = \text{Al}^{3+} + 3\text{e}$. At the same time cleaned and reduced, thus very active un-noble surface area is an excellent place to re-deposit more noble Cu.

While in the case of chromate coatings on AA2024-T3 surface the effect is not so pronounced, an application of non chromate conversion coatings on Cu-containing Al alloys may lead to a dramatic decrease in corrosion resistance. Conversion coating (CC) process, whether it is chromating or non-chromium treatment, consists of the following steps: cleaning, rinsing, deoxidising, rinsing, conversion coating, post-treatment rinsing or decorative colour rinsing and drying. At least three of them: cleaning, deoxidising and main CC process create the risk of copper re-plating due to the high or/and low pH of solutions used. Therefore protection against corrosion of AA2000 series is a challenging task. Some problems are also related to the methods of assessment of corrosion resistance of protecting substance, coating or system. The common method of determination of pitting potentials is doubtful for many high strength alloys since pitting occurs in the vicinity of the open circuit potential, impedance spectra are difficult to interpret, chamber tests are too simplistic and field exposition is time consuming. Therefore a robust and precise set of methods for the evaluation of protective systems, especially on high strength Al alloys would also be useful. The results presented in this paper are taken from the extensive research on chemical and electrochemical surface treatments of high strength aluminium alloys [4]. The aim of this paper is to show, how simple electrochemical characterisation of the surface of aluminium alloy originally described in [5] may be helpful in establishing the anticorrosion protective system.

Experimental. Materials. Discs of 30 mm diameter cut from a rod of AA2017 alloy were used in most of the experiments. A number of tests were also carried out on AA2024-T3 samples cut from sheet.

The dimensions of the samples were 2.5×7.5 cm but the measured area was restricted to 1 cm² for both kinds of the samples. The following solutions for surface treatments were used:

- for alkaline degreasing: 0.5 M Na₃PO₄ adjusted to pH 12, temperature 50°C;
- for de-smutting: 3% HNO₃, ambient temperature and so called chromosulphuric acid treatment; a procedure contains hexavalent chromium;
- for electrochemical de-smutting: a solution and procedure indicated below.

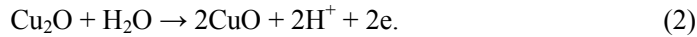
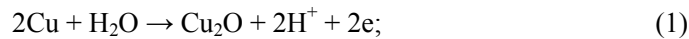
In terms of electrochemical treatment a process of Cu removal is based on US Patent 5635084:1997 [6]. The method relies upon a the sample polarization in HNO₃/NaNO₃ solution at –55 mV vs. SCE during 30 min. This procedure has got an abbreviation here as US patent. A number of substances which belong to inhibitors of Cu corrosion was tested usually in 0.1 M concentration and they are mentioned along with description of the results.

Methods. Electrochemical corrosion tests were carried out by means of polarisation curves and by means of electrochemical impedance spectroscopy. Both measurements were recorded mainly in 0.5 M Na₂SO₄ + 0.01 M NaCl of pH 6.0. Some of tests were also carried out in 0.15 M NaCl. Potential scan rate was fixed to 1 mV/s. Impedance spectra were recorded at the open circuit potential using AC amplitude 10 mV in the frequency range of 10⁶...10^{–3} Hz. A cyclic voltammetry method based on a work published in [5] is applied for the assessment of Cu enrichment in corrosive medium (0.6 M NaCl) in the presence of inhibitors / complexing agents. The first step of the procedure is 24-hour immersion of the samples in 0.6 M NaCl containing inhibitor. Afterwards a sample is transferred to electrochemical cell containing borate buffer of pH 8.4. Cyclic voltammetry is conducted at a rate 1 mV/s from –700 mV to + 300 mV and back to –1200 mV (all potentials quoted vs. SCE). These voltages are in the range

of copper oxidation / reduction but not for the corrosion of the base metal. Three scans are performed and the result of the 3rd scan is taken into consideration. Electrochemical methods were carried out alternatively by the following systems: Autolab Eco Chemie, Solartron 1287 and ACM Instruments along with relevant software for experiment control, data acquisition and data analysis. Surface examination was carried out by means of SEM/EDXS analysis using scanning electron microscope LEO model VP435 equipped with EDXS produced by Roentec. “Preliminary attempts were also undertaken to analyse quantitatively surface components by means of glow discharge mass spectrometry along with a depth profile analysis. In the depth profile analysis the sputtering process in a glow discharge erodes the sample surface rather evenly, i.e. “atomic layer by layer”. The methodology was elaborated using SMWJ-01 glow discharge prototype spectrometer [7]”.

Results. Assessment of Cu enrichment as a result of corrosion of aluminium alloy. The first step of the testing procedure is the exposition of a sample in 0.6 M NaCl to initiate Cu enrichment. Detection of this Cu enrichment is recorded in the second step in borate buffer. Cyclic voltammograms of two representatives of AA2000 series recorded after 18 h of samples immersion in 0.6 M NaCl are shown in Fig. 1. Two anodic peaks at $E = -0.09$ V and $E = 0.03$ V vs. SCE are recorded in borate buffer. The second peak is more pronounced for AA2017.

The two anodic current peaks correspond to the following reactions:



In order to check whether Cu enrichment is a dominating factor of the electrochemical behaviour a surface analysis was carried out by means of Glow Discharge Mass Spectrometry (GDMS). The results are shown in Fig. 2.

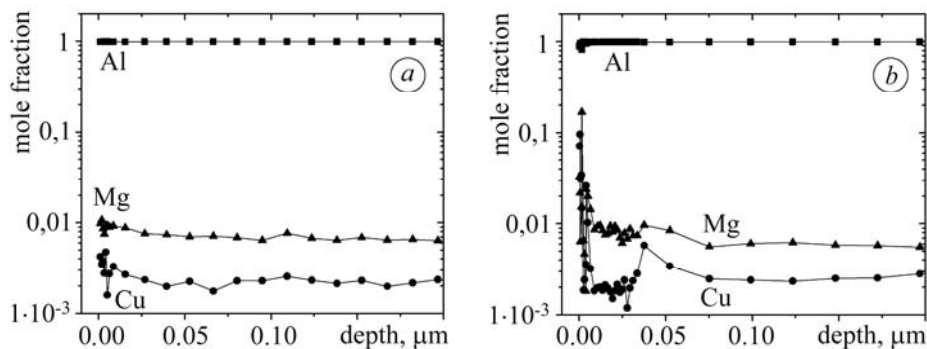


Fig. 2. Concentration profiles of Al, Cu and Mg in surface layer of AA2017 before (a) and after (b) 18 h of the samples exposition in 0.6 M NaCl.

It is seen from the results presented above that significant Cu surface enrichment takes place during 18 h of samples immersion in NaCl solution. Therefore cyclic voltammograms show two well defined anodic current peaks which is consistent with the results published in [5]. The results of surface analysis presented in this work proved

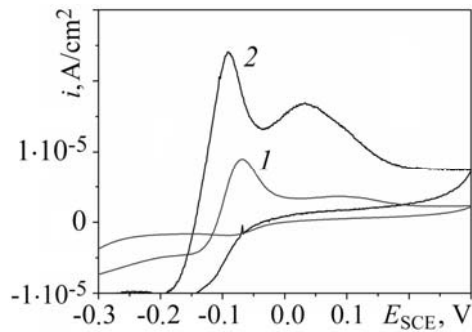


Fig. 1. Cyclic voltammograms for AA2024 (1) and AA2017 (2) alloys recorded in borate buffer (pH 8.4) after 18 h immersion in 0.6 M NaCl.

that cyclic voltammograms can be used as direct indication of Cu active presence on the Al surface and indirectly may be related to initiation of corrosion process. The current peaks are related to Cu/Cu^+ and $\text{Cu}^+/\text{Cu}^{2+}$, however, we cannot exclude that the second peak may also contain additional contribution due to the direct oxidation of Cu/Cu^{2+} . Hence for further analysis the height of both peaks was measured, but the height of the 1st peak was usually considered as a measure of Cu activity on the surface of aluminium alloy.

Applicability of the voltammetric method to the assessment of conversion coating. A common process used as a pre-treatment prior to organic coating on AA2000 series was known as Alodine process which was carried out in the solution containing chromates and phosphates with some minor additives [8]. The “pure” phosphating was never applied because of technical difficulties related probably also to Cu enrichment of the surface. The best result which was obtained in our trials for chemical phosphating of AA2017 is shown in Fig. 3a. As it is seen from this result and data presented in a caption of Fig. 3a, coverage of the surface is incomplete and Cu rich areas are determined between phosphate crystals. Such results were independent of the chemical content of a phosphating solution, as well as on the process parameters. From this reason the efforts were focused on the elaboration of modified phosphating process which was supported by electrochemical aid of cathodic polarization (Fig. 3b). The details of such process were presented in [9]. Comparison of surface coverage obtained in each process leaves no doubt that the latter process is much more effective. These variants are signed here as un-modified and modified, respectively.

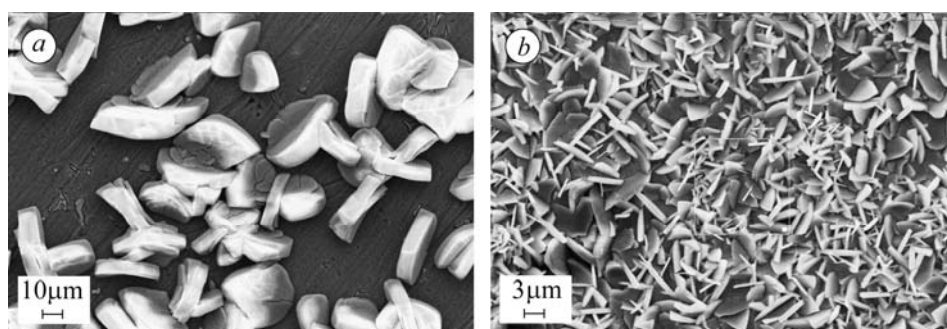


Fig. 3. The effect of the type of phosphating process un-modified (a), modified (b) on the topography and substrate coverage of zinc phosphate coating. Elemental concentration of Cu measured by EDAX between crystals: a – 13.24; b – 1.02 mass.%.

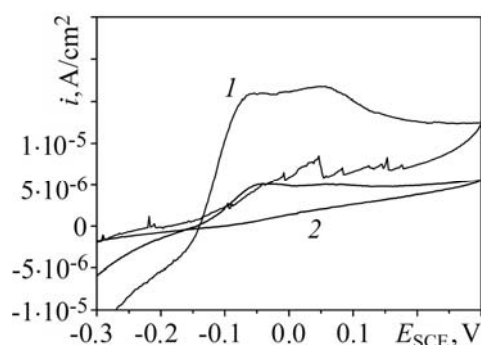


Fig. 4. Cyclic voltammograms for AA2017 phosphated in un-modified (1) and modified (2) process recorded in phosphate buffer after 18 h exposition in 0.6 M NaCl.

Since crystalline phosphate coatings exhibit a certain degree of porosity it is also interesting whether a substrate at the bottom of the pores and voids of the coating contains Cu deposit. Basically, phosphate nuclei should crystallize on cathodic areas of the surface, hence Cu remnants have to be covered by the phosphate coating, but due to the mobility of Cu during dissolution process of intermetallics [2] a nucleation of phosphate crystals may proceed in different way. Therefore, the next example served as a verification of applicability of the monitoring of Cu release from the phosphate samples by means of cyclic volt-

ammetry. The results of the tests are shown in Fig. 4.

It can be concluded that a coverage of Cu-rich surface remnants by the layer of hardly soluble phosphates is much more efficient for modified version of the process. The question is how this result corresponds to the assessment of anticorrosion properties evaluated by common electrochemical methods. Therefore, a set of the samples coated in phosphating solutions described above was tested by means of electrochemical impedance spectroscopy (EIS). The measurements were carried out in 0.15 M NaCl after 1 and 24 h of immersion (Fig. 5).

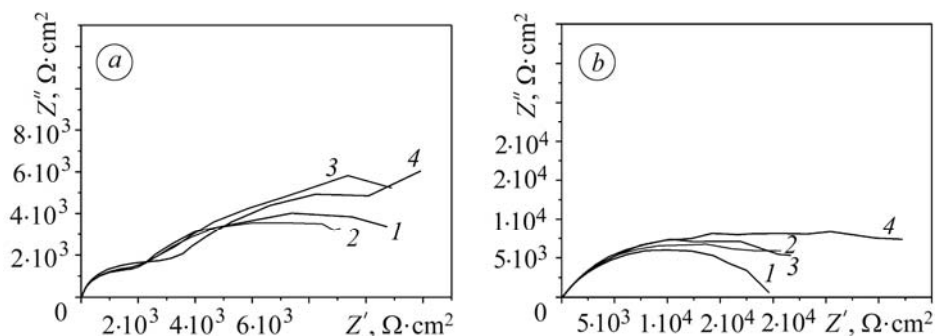
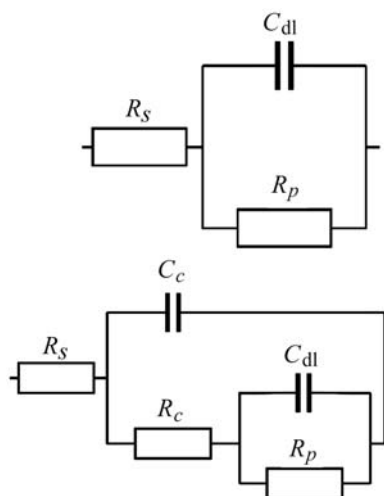


Fig. 5. Impedance spectra for AA2017 coated with phosphate coating of different quality: *a* – un-modified; *b* – modified process recorded in 0.15 M NaCl after 1 (1), 3 (2), 6 (3), 24 h (4) of immersion.

Fig. 6. Electrical equivalent circuits used for the analysis of impedance spectra. R_s – solution resistance, R_p – polarisation resistance, C_{dl} – capacity of the metal–solution interface (double layer), R_c – electrolytic resistance of the solution in the coating pores, C_c – capacity of the coating. In most results a constant phase element (CPE) was used instead of capacitance.



The results of EIS measurements confirm the results obtained from the cyclic voltammetry in borate buffer (Fig. 4). The values of charge transfer resistance and interfacial capacitance calculated using equivalent circuit (Fig. 6) were estimated after 1 h of immersion as $R_t = 10^3 \Omega \cdot \text{cm}^2$, $C_{dl} = 10^{-5} \text{ F/cm}^2$ and $R_t = 10^4 \Omega \cdot \text{cm}^2$, $C_{dl} = 10^{-8} \text{ F/cm}^2$, for un-modified and modified process respectively. It can be assumed that surface Cu enrichment, in this particular case, which takes place at the bottom of pores and voids of the coating can be a direct measure of the initiation/onset of substrate corrosion. Therefore a modification of pre-treatment and post-treatment of the conversion coating process in order to decrease undesirable activity of intermetallics was undertaken. Two possible routes were taken into consideration. The first one is to remove surface copper without affecting a bulk material. The second relied upon a use of inhibitors that may adsorb on Cu rich areas during pre- or post-treatment. For both approaches a voltammetric method served as a screening tool.

Surface pre-treatment. It is common that a surface pre-treatment affects corrosion behaviour of a surface. Prior to every surface treatment a clean and free of foreign matter surface is required. Aluminium alloys frequently undergo alkaline degreasing

followed by deoxidising (de-smutting). The latter is carried out in acidic solutions. A traditional solution was called a chromosulphuric treatment. Alternative preparations are based on HNO₃ or mixtures of inorganic/organic acids.

The treatment tested in this work is based on already cited US patent [6], known as Cu removal method. The comparison of the effect of particular surface pre-treatments on the electrochemical state of the surface characterized by cyclic voltammetry is presented in Fig. 7.

For acetone degreasing and alkaline degreasing followed by HNO₃ de-smutting both peaks of Cu oxidation are relatively high which means that copper enrichment was taking place during 18 h of sample immersion in 0.6 M NaCl. On the other side, two other treatments changed the state of the alloy surface resulted in significantly lower 1st current peak and also lower but to a lesser extent 2nd peak. The lowest value of peak current densities corresponding to Cu oxidation process for electrochemical treatment decreasing the Cu content on the surface was obtained which seems to be logic. However, in the case of regular alkaline degreasing without de-smutting an accumulation of impurities containing also Cu oxides takes place covering the surface with black smut. This deposit loosely adheres to the surface but may block some areas against action of NaCl during 18 h exposition. This feature as well as inactivity of already formed CuO leads to recording of a current signal from the smaller area. These are probable reasons of lower heights of current density peaks for alkaline etched AA2017 surface.

The method based on cyclic voltammetry in borate buffer was previously applied to assess mixtures of inhibitors used for the protection of high strength Al alloys [5]. In our studies two types of substances were tested. The first one belongs to the group of inhibitors of Cu corrosion. An application of substances of this type is due to the fact that re-plated Cu is detected on investigated Al alloy surfaces. The second group is related to corrosion inhibition of both Cu and Al-Cu substrate. The results are shown in Fig. 8.

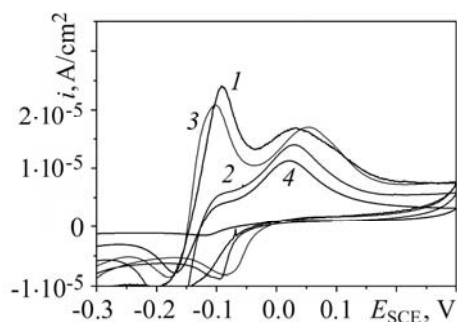


Fig. 7.

Fig. 7. CV voltammograms for AA2017 in borate buffer at pH 8.4 after 18 h exposition in 0.6 M NaCl. The effect of surface preparation: 1 – acetone; 2 – alkaline degreasing; 3 – alkaline degreasing, HNO₃ deoxidising; 4 – alkaline degreasing, potentiostatic treatment [6].

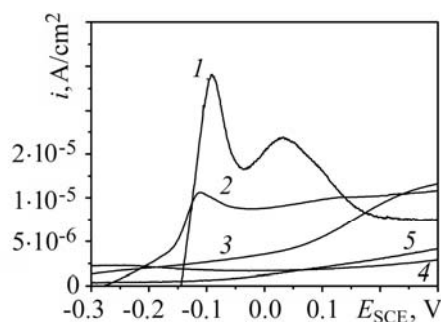


Fig. 8.

Fig. 8. The effect of inhibitors: 1 – without inhibitor; 2 – 1-allyl-2-thiourea; 3 – sodium gluconate + citric acid; 4 – chromates; 5 – benzotriazole, added to 0.6 M NaCl and exposed for 18 h on the course of CV voltammograms recorded in borate buffer after exposition.

Backward cathodic transients are eliminated for the clarity of the figure.

The AA2017 sample exposed to 0.6 M NaCl without any additional substance shows the highest cd peaks related to Cu two-step oxidation. On the other hand, samples immersed in Cr(VI) containing chloride solution show almost negligible current signal. This means that chromates effectively inhibit reactions of Cu species. Similar properties were obtained for citric acid-sodium gluconate mixture. There is however an increase of current density observed at +300 mV vs. SCE but it appears beyond the po-

tential range of two peaks determined for the AA2017 reference sample. Therefore this mixture can also be considered as effective. A lower ability to inhibit Cu enrichment for 1-allyl-2-thiourea is observed, however a certain positive effect is still recorded. The values of current densities at relevant potentials are shown in Table 1.

From comparison with the results obtained in the previous chapter one may conclude that both attempts decreasing the possibility of surface reactions involving Cu ions are effective in terms of significant decrease of current densities. Again, the question is how these results correspond to corrosion resistance of a phosphate coating formed in electrochemical process on AA2017 aluminium alloy.

The effect of pre-treatment on corrosion resistance of the phosphate coating. Electrochemical impedance spectroscopy was employed to study corrosion resistance of pre-treated phosphate coatings (Fig. 9). For all the treated samples, the impedance spectra exhibit two time constants (see relevant Bode plots) which comply with the so-called “coating model” (Fig. 6) [10]. The results of EIS data analysis are shown in Table 2.

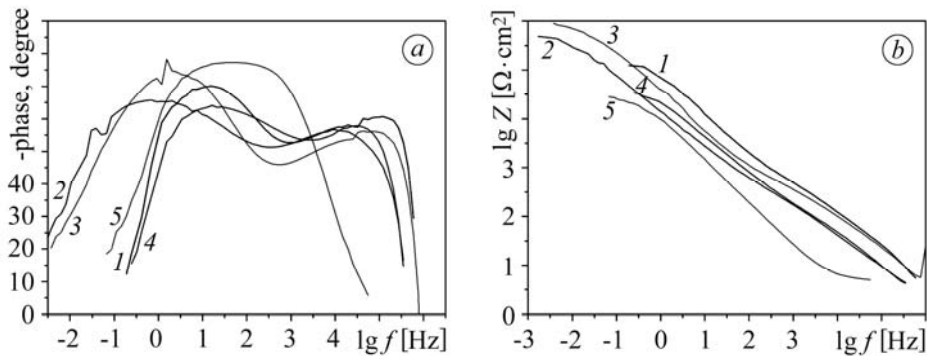


Fig. 9. Impedance spectra of phosphated AA2017 depending on surface pre-treatment: 1 – HNO₃; 2 – chromosulphuric; 3 – US patent; 4 – benzotriazole + butindiol; 5 – pre-treatment with HNO₃ (no coating) after 1 h of immersion in 0.5 M Na₂SO₄ + 0.01 M NaCl, pH 6.

Table 2. Electrochemical parameters for phosphated AA2017 resulted from the analysis of EIS spectra (Fig. 9)

Electrochemical parameters	HNO ₃	Benzotriazole + butindiol	chromo-sulphuric	US patent	HNO ₃ pre-treatment (no coating)
$R_s, \Omega\cdot\text{cm}^2$	3.94	3.079	3.31	4.03	4.47
$\text{CPE}_{\text{coat}}, \text{F}/\text{cm}^2$	$4.28\cdot 10^{-8}$	$1.11\cdot 10^{-7}$	$1.11\cdot 10^{-7}$	$3.16\cdot 10^{-6}$	–
n_1	0.83	0.78	0.74	0.75	–
$R_{\text{coat}}, \Omega\cdot\text{cm}^2$	$5.73\cdot 10^2$	$2.88\cdot 10^2$	$5.19\cdot 10^2$	$7.12\cdot 10^2$	–
$R_p, \Omega\cdot\text{cm}^2$	$1.56\cdot 10^5$	$4.17\cdot 10^4$	$6.15\cdot 10^5$	$9.69\cdot 10^5$	$4.36\cdot 10^4$
$\text{CPE}_{\text{dl}}, \text{F}/\text{cm}^2$	$1.08\cdot 10^{-7}$	$1.48\cdot 10^{-7}$	$1.70\cdot 10^{-7}$	$3.33\cdot 10^{-7}$	$3.54\cdot 10^{-6}$
n_2	0.83	0.78	0.74	0.85	0.89

Table 1. Peak current densities and potentials shown in Fig. 7

Treatment with	1 st current peak	
	E, V	$i, \mu\text{A}/\text{cm}^2$
HNO ₃	-0.092	24
Benzotriazole	-0.092	0.67
Chromates	-0.261	2.25
Citrates/gluconates	-0.092	3.2
1-allyl-2-thiourea	-0.112	10.7

The results indicate that surface pre-treatment directly influences the protective properties of the phosphate coatings which are represented here by polarization resistance. This parameter is related to the physicochemical state of the substrate in the pores of the coating and reflects corrosion resistance. Another matter is whether all pre-treatments applied here affect positively crystals structure. From our experience [4] chromosulphuric acid and mixture of inhibitors favor the formation of coarse crystals which is not acceptable prior to organic coatings while de-smutting by nitric acid or electrochemical Cu removal stage provide formation of the coating with much more finer crystals. Unless it is stated, in all cases described above an activation step using Ti colloid containing solution was used after de-smutting. As a final conclusion from this part of the work it is concluded that some kind of Cu removal as exemplified here by cited treatment is more beneficial for the formation of the phosphate coating than a direct inhibition of copper relating reactions by inhibitors. The latter however may be applicable in the final stage of the complex process which is post-treatment.

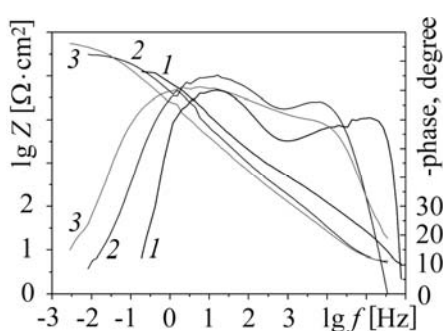


Fig. 10. Bode plots for phosphated/sealed AA2017 and exposed to 0.5 M Na₂SO₄ + 0.01 M NaCl without sealing (1), benzotriazole + butindiol (2), Cr(VI) (3).

The effect of post-treatment. Every crystalline phosphate coating is porous. Its corrosion resistance depends on the degree of porosity and physicochemical state of the substrate at the bottom of the pores. Concerning properties of the coatings obtained in this work, an additional element is included. This is Cu content in pores or/and voids of the coating. Therefore just for highlighting the problem two kinds of sealing were applied. One, taken from the former investigations related to sealing by Cr(VI) added as K₂Cr₂O₇ and another related to actual work on Cu inhibitors which is a solution containing benzotriazole. The main constituent of sealing solution was

0.01% H₃PO₄. The pH of both solutions was equal to 3.3.

The results are shown in Fig. 10 and Table 3. All spectra exhibit two time constants and can be represented by already described “coating model”. The results of calculations of particular elements of the equivalent circuit are given in Table 3. The results indicate that an improvement of protective properties can be seen, especially taking into account the values of polarisation resistance (R_p). It should be underlined that sealing solutions as well as parameters were not optimised in this experiment.

Table 3. The results of fitting the data to the “coating model” (Fig. 10)

Electrochemical parameters	without sealing	sealing: benzotriazole + butindiol	sealing: Cr(VI)
$R_s, \Omega \cdot \text{cm}^2$	3.94	5.66	4.41
$\text{CPE}_{1s}, \text{F}/\text{cm}^2$	$4.28 \cdot 10^{-8}$	$3.76 \cdot 10^{-7}$	$2.48 \cdot 10^{-7}$
n_1	0.834	0.936	0.774
$R_{\text{coats}}, \Omega \cdot \text{cm}^2$	$5.73 \cdot 10^2$	$2.18 \cdot 10^2$	$5.15 \cdot 10^2$
$R_p, \Omega \cdot \text{cm}^2$	$1.56 \cdot 10^5$	$3.15 \cdot 10^5$	$5.94 \cdot 10^5$
$\text{CPE}_{\text{dl}}, \text{F}/\text{cm}^2$	$1.08 \cdot 10^{-7}$	$1.41 \cdot 10^{-7}$	$1.75 \cdot 10^{-7}$
n_2	0.826	0.793	0.854

It is obvious that the best sealing and hence protective properties for Cr(VI) are obtained. It is also necessary to conclude that the improvement in this case is not as significant as for commercial products but in the present work simplified solutions were used just for evaluation of the effects and trends. However, it is proved that other compounds like Cu inhibitors can be employed for sealing rinse of the phosphate coatings as potential candidates. As a result of the conclusion stated above, one may assume, that the procedure comprising sealing rinse with solution containing inhibitor of Cu corrosion which adsorbs on the substrate containing Cu remnants shall be optimised in terms of the chemical content and technological parameters.

CONCLUSIONS

The method of recording surface copper enrichment of AA2000 series alloys by means of cyclic voltammetry in borate buffer preceded by immersion in 0.6 M NaCl solution which was originally used as an assay for screening of inorganic inhibitors performance was extended in this work to the assessment of various surface treatments related to Cu surface enrichment like alkaline cleaning, de-smutting, phosphating and also inorganic and organic inhibitors. The applicability of the method to this wider range of subjects was basically proved positively but some situations need an additional knowledge on the system in order to withdraw proper conclusions. It means that the results obtained by this method can not be accepted without prior knowledge analysis of an investigated system.

It was proved that surface enrichment of Cu can be assumed as a direct indicator of corrosion of Al-Cu alloys, especially at the beginning of degradation process. For this kind of a substrate the corrosion process is always preceded by the activity of intermetallics. It can be also useful for Al-Cu alloys coated by crystalline phosphate coatings which are porous and their corrosion resistance depends mainly on the state of the substrate in pores and voids of the coating. It is also applicable for other protective coatings that locally expose bare substrate as well as for selection of components and content of various surface treatments and their partial operations (pre- and/or post-treatments).

The extension of the applicability of the method to the evaluation of the effect of surface treatment performed in this work shows that a peak height is not only proportional to the amount of Cu on the surface as was assumed earlier but may also be dependent on the form of Cu compound formed on the surface and the electrochemical activity of this substance under corrosion load that means depend not only on the amount but also on kinetics of Cu reactions on AA2000 series surface.

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РЕЗЮМЕ. Розширено застосування методу дослідження збагачення міддю сплавів серії AA2000 за допомогою циклічної вольтамперометрії у боратному буфері після попереднього витримування зразків у 0,6 М розчині NaCl для оцінки різних поверхневих обробок, зокрема лужного очищення, освітлення, фосфатування, а також неорганічних та органічних інгібіторів корозії. Оскільки висота піка, визначена з вольтамперограм, є результатом перенесення заряду Cu/Cu^+ на поверхні Al-Cu, вибір відповідних речовин чи технологічних параметрів, що інгібують цю реакцію, може знайти застосування у розробці або модифікації технологій поверхневої обробки. Розроблено конкретні технологічні кроки для комплексного електрофосфатування сплаву AA2017 з використанням результатів вивчення вольтамперометричних перехідних процесів. Показано, що часткове усунення Cu з поверхні, без впливу на її об'ємний вміст у сплаві, найефективніше на стадії освітлення, тоді як інгібітори корозії сплаву Al/Cu найкраще діють на стадії фінальної обробки.

РЕЗЮМЕ. Расширено применение метода исследования обогащения медью сплавов серии AA2000 с помощью циклической вольтамперометрии в боратном буфере после предварительной выдержки образцов в 0,6 М растворе NaCl для оценки разных поверх-

ностных обработок, в частности щелочной очистки, осветления, фосфатирования, а также неорганических и органических ингибиторов коррозии. Поскольку высота пика, определенная из вольтамперограмм, является результатом перенесения заряда Cu/Cu^+ на поверхности Al-Cu, выбор соответствующих веществ или технологических параметров, ингибирующих эту реакцию, может найти применение в разработке или модификации технологий поверхностной обработки. Разработаны конкретные технологические шаги для комплексного электрофосфатирования сплава AA2017 с использованием результатов изучения вольтамперометрических переходных процессов. Показано, что частичное устранение Cu из поверхности, без влияния на ее объемное содержание в сплаве, наиболее эффективно на стадии осветления, тогда как ингибиторы коррозии сплава Al/Cu лучше всего действуют на стадии финальной обработки.

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