UPOTREBA NIKLA KAO MEĐUPREVLAKE U CILJU SMANJENJA KONTAKTNE KOROZIJE NA ELEKTRIČNIM KONTAKTIMA AL-CU

USE OF NICKEL AS AN INTERMEDIATE COATING TO REDUCE CONTACT CORROSION ON ELECTRICAL CONTACTS AL-CU

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Do kontaktne ili galvanske korozije dolazi jer svaki metal ima svoj specifični električni potencijal. To je prvenstveno elektrohemijski proces koji se javlja kada je razlika potencijala elektroda veća od 0,25 V. Aluminijsko-bakarni kontakti široko se koriste u elektrotehnici (izloženi atmosferskoj koroziji) i tipičan su primer kontaktne korozije jer su vrednosti standardnih elektronskih potencijala +0,337 V (Cu) i -1,662 (Al). Iz tog razloga se nikl (potencijal elektrode –0,25 V) obično koristi kao međupravlaka za sprečavanje kontaktne korozije. U ovom radu urađena su uporedna istraživanja korozije i mehaničkih osobina kontakta Al-Cu, Al-Ni i Al-Ni-Cu.

Ključne reči: *galvanska korozija, međuprevlaka, električni kontakti*

Contact or galvanic corrosion occurs because each metal has its own specific electrical potential. It is primarily an electrochemical process which occurs when the electrode potential difference is greater than 0.25V. Aluminum-copper contacts are widely used in electrical engineering (exposed to atmospheric corrosion) and are a typical example of contact corrosion since the values of standard electrode potentials are +0.337 V (Cu) and -1.662 (Al). For this reason, nickel (electrode potential -0.25 V) is usually used as an intermediate coating to prevent contact corrosion. Thes studie will include comparative investigations of the corrosion and mechanical properties of Al-Cu, Al-Ni, and Al-Ni-Cu contact.

Key words: *galvanic corrosion, intermediate coating, electrical contacts*

1 Introduction

Aluminum, the third most represented metal in the earth's crust, is widely used in the aviation and automotive industries. It is extremely resistant to corrosion and is therefore of considerable use in the construction of small and medium-sized yachts [1-2]. Copper is a very widely used material for its excellent electrical and thermal conductivities in many industrial applications [3- 4].

In electronics, contacts, Al-Cu, are used. The common corrosion forms occurring in the metallic materials include pitting corrosion, intergranular corrosion, stress corrosion, corrosion fatigue, and high-temperature corrosion. [5-7].

It is difficult to make a stable and reliable copper-aluminum joint due to these difference between Cu and Al such as large melting point differences, thermal expansion coefficient, electrode potential and mass formation of brittle intermetallic compounds. Besides, the intermetallic compounds formed in the joint are very different from both Cu and Al in these aspects. To solve these joining problems, many joining technologies were employed [8]. Flash welding was firstly utilized to join copper to aluminum, [9] and then other welding technologies were employed, such as diffusion welding, friction welding, friction stir welding, laser beam welding and ultrasonic welding [10-13]. However, the problem of Cu-Al joints corrosion is still existing and it deteriorates the properties of Cu-Al joints, which severely shorten the service life of components.

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2 Experperimental investigatons

In this research, the influence of nickel as an intermediate coating on the mechanical and corrosion properties of the electrical contacts (contact corrosion of Al-Cu) was investigated. Figure 1 (a – d) shows the most commonly used Al-Cu contacts.

a) b) c) d)

Figure 1. The most commonly used Al-Cu contacts in practice

Laboratory research was performed in four phases:

1. Deposition of copper directly on aluminum
2. Deposition of nickel directly on aluminum
3. Deposition of nickel as an intermediate coating on aluminum/copper
4. Investigation of the physico-mechanical and electrochemical properties of pure metals (Al, Cu, and Ni) and contacts (Al-Ni, Al-Cu, and Al-Ni-Cu).

Aluminum samples (sheet 3x1 cm, 0.3 mm thickness) were chemically degreased with preparation ALOKSIL HOALB (for aluminum and aluminum alloys). After chemical degreasing, the surface of aluminum samples was activated using a solution of sodium chloride. Prepared plates are chemical copper plated with the BAKROHEM preparation. For the electrochemical nickel plating process by the NISAL EXTRA preparation aluminum samples are prepared in the same way as for the chemical copper plating process. Freshly nickel plated plates were electrochemically copper coated using the BAKROCIN CBB preparation.

Figure 2 shows the samples: a) pure copper; b) pure aluminum; c) pure nickel; d) aluminium-copper; e) aluminum-nickel; f) copper- aluminum with nickel as an intermediate coating.

a) b) c) d) e) f)

Figure 2. Aluminum samples: a) pure copper; b) pure aluminum; c) pure nickel; d) aluminium-copper; e) aluminum-nickel; f) aluminu - copper with nickel as an intermediate coating.

2.1 Measuring microhardness and electrical conductivity

The microhardness was measured by the Vickers hardness test method and the specific electrical conductivity by the 4 point method [14,15].

In Table 1 are shown the measured values of microhardness and electrical conductivity for the tested samples.

From Table 1, it can be concluded that the use of nickel as an intermediate coating in the Al-Cu electrical contacts significantly improves the mechanical properties. The microhardness of the Al-Ni-Cu (91.0 HV) sample is higher than of the Al-Cu (75 HV) contact while the electrical conductivity is almost the same.

Table 1. Microhardness and electrical conductivity of pure metals and contacts

	Microhardness (HV)	Electrical conductivity (MS/m)
Al	40	37.7
Cu	69.1	57.6
Ni	63.0	14.3
Al-Cu	75.3	36.6
Al-Ni	31.0	17.5
Al-Ni-Cu	91.0	35.1

2.2 Measuring the open circuit potential (POC)

The electrochemical properties of the contacts were examined by measuring the open circuit potential (OCP) for 60 minutes. The open circuit potential (OCP) represents the potential of an electrochemical system when the current in it is negligibly small (weighs zero). In real systems (depending on the impedance of the measuring device), these are currents (for electrodes of the order of cm^2 size) of the order of nanoamperes or picoamps. This makes this value very close to thermodynamically equilibrium.

The open circuit potential is measured over a period of minutes to several hours, based here on ASTM G3-89 (2010) and ISO 17474: 2012 corrosion standards for metals and alloys, which defines an OCP measurement duration of 3600 seconds (one hour).

Typically, higher OCP values mean higher corrosion resistance ("noble" metals in an electrochemical series, more resistant alloys), or slower corrosion processes. However, since corrosion itself is kinetic (non-equilibrium) and not just a thermodynamic process (especially for alloys), there are many exceptions to this rule. This is most often conditioned by passivation processes, where metals (such as aluminum) with low values of this parameter have low values of corrosion current. Simply, oxides created on the surface (can be hydrates or mixed oxides, as well as other insoluble compounds) prevent further corrosion. Here it is applied in a standard suitable form - as a comparative method for multiple alloys in the same environment.

Gamry Instruments Inc.'s Interface 1000E model potentiostat/galvanostat/equilibrium ammeter was used for electrochemical experiments with the framework software package (version 6.25). Gamry Echem Analyst software was used to analyze the results.

Two-electrode experiments performed. In a two-electrode setup, the current-carrying electrodes are also used for sense measurement. The physical setup for two-electrode mode has the current and sense leads connected together: Working (W) and Working Sense (WS) are connected to a (working) electrode, and Reference (R) and Counter (C) are connected to a second (aux, counter, or quasi-/pseudo-reference) electrode (Figure 3. - diagram of a 2-electrode cell setup).

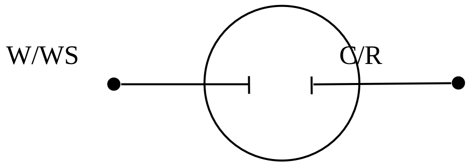

Figure 3. Two-electrode cell setup

The working electrodes were of the pure aluminum, copper and nickel and contacts: Al-Cu, Al-Ni, and Al-Ni-Cu. The counter electrodes were copper and nickel. Experiments were performed at a temperature of 25 ± 1 ° C. Open Circuit Potential (POC) were measured for 60 minutes in three solutions: 0.5 M Na_2SO_4, NaCl, and $NaNO_3$.

Results of the open circuit potential measurements are shown in Tables 2,3 and 4 as the initial value (the first second of measurement), and as the final value after 1 h.

Table 2. Results of the open circuit potential measurements in 0.5M Na2SO4

	OCP (mV) initial value	OCP (mV) final value after 1 h
Al-Cu (pure metals)	-659,9	-486,4
Al-Ni (pure metals)	-558,0	-411,0
Ni-Cu (pure metals)	-307,8	-188,1
Al+Ni - Cu	-257,1	-210,1
Al+Cu-Cu	-133,1	-62,2
Al+Ni+Cu-Cu	-79,1	-47,56

Table 3. Results of the open circuit potential measurements in 0.5M NaCl

	OCP (mV) initial value	OCP (mV) final value after 1 h
Al-Cu (pure metals)	-580,7	-516,7
Al-Ni (pure metals)	-710,7	-732,9
Ni-Cu (pure metals)	-206,9	-177,1
Al+Ni - Cu	-269,4	-284,3
Al+Cu- Cu	-111,1	-88,3
Al+Ni+Cu-Cu	-87,2	-49,3

Table 3. Results of the open circuit potential measurements in 0.5M NaNO3

	OCP (mV) initial value	OCP (mV) final value after 1 h
Al-Cu (pure metals)	-469,8	-420,2
Al-Ni (pure metals)	-279,7	-249,5
Ni-Cu (pure metals)	-289,39	200,1
Al+Ni - Cu	-166,0	-145,2
Al+Cu- Cu	-69,3	55,6
Al+Ni+Cu-Cu	-66,3	38,3

3 Conclusion

Tests have shown that the use of nickel as an intermediate coating on Al-Cu electrical contacts improves mechanical and electrical properties. The Al-Cu contact hardness was increased from 75.3 HV to 91.0 HV (Al-Ni-Cu). The electrical conductivity was decreased by just from 36.6 MS/m to 35.1 MS/m (for 4%), which is acceptable. The difference in potential of Al-Cu contact was reduced approximately ten times for all three test solutions. It is also lower in comparison with Al+Cu without Ni intermediate layer for 60 mV in the sulfate solution. The overall effect of the Ni coating between Al and Cu can be considered as positive.

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