

## Corrosion Behaviour of Al<sub>2</sub>xxx Electroplated of (Ni, Cu, or Zn) Metals towards Acid Rain

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### Abstract

Regarding to aluminum specimens, galvanic coating was a technique as a film of (Ni, Cu, or Zn) was deposited on aluminum specimens with specific process parameters. The heat treatment for the specimens was performed to ensure the coating layer was homogeneous. Acid rain corrosion test was performed in laboratory, measuring specimen weights to assess the effect of coating on corrosion resistance.

Using (Cu, Zn, or Ni) as salts copper acetate, zinc acetate and nickel chloride to coat aluminum samples with applied concentrations 0.5 mol/ℓ and 1 mol/ℓ and the coating time for each metal was 15 and 30 minutes. Nickel-coated samples exhibit greater weight accuracy and the worst was Zink-coated samples.

**Keywords:** aluminum protection, acid rain, galvanic coating, Cu, Zn, Ni

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## سلوك تآكل طبقات $Al_2xxx$ المطلية بمعادن من Ni و Cu و Zn لوقايتها من الأمطار الحامضية

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### الملخص

تم ترسيب أفلام رقيقة من Ni و Cu و Zn على عتبات من الألمنيوم بطريقة الطلي الكهربائي. تمت معالجة العينات حرارياً لتأمين طبقة غلغنة متجانسة. وأجريت اختبارات تآكل الأمطار الحامضية للعينات المدروسة في المخبر بقياس أوزان العينات للحصول على تأثير عملية الطلي على مقاومتها للتآكل. استخدمت أملاح معادن Ni و Cu و Zn (خلات الزنك، خلالات النحاس، كلوريد النيكل) لتغليف عينات الألمنيوم بتركيز 0.5mol/l و 1mol/l؛ واستغرق زمن طلي كل معدن 15min و 30min. وأظهرت النتائج أنَّ العينات المطلية بالنيكل، أبدت أفضل الأوزان، والمطلية بالزنك أسوأها. كلمات مفتاحية: حماية الألمنيوم - الأمطار الحامضية - الطلي (الغلغنة) - Ni, Zn, Cu.

## Introduction

Aluminum is the most common element in the earth's crust, and the bauxite ore is the largest source of aluminum. Aluminum and its alloys actually come second behind iron and steel. Despite of its diverse properties, aluminum has spread across many technological applications and industries.  $Al_2xxx$  used in the building of bridges, car structures, and freight containers, but exposed to a variety of factors that lead to corrosion. Therefore, it is necessary to find a way to overcome the problem of corrosion [1]. Galvanic coatings are methods, which give good results for the properties of corrosion and surface. In this study we will examine the effect of galvanic coating and the change in coating process parameters on aluminum corrosion resistance [2].

Electroplating is a surface engineering application. An electrical current which passes through the solution causes the metal to coat objects in the cathode or work piece in the solution. Coatings can be formed in the electroplating process either from pure metals, multi-metal alloys, metal and non metal alloys, multilayers, or composite coatings.

Layers of paper depend on their intended use. Electroplating (one of the techniques of surface engineering) is now used in many industries such as electrical, automobile, aviation, telecommunications, jewelry, biomedical engineering, etc. Electroplating gained popularity from 1840, when Brimingham, England, granted Henry Elkington et al the first patent to apply this technique to gold and silver deposition using potassium cyanide as an electrolyte [3]. This led to the establishment of Brimingham as the electroplating industrial center, where on 1876 the first large scale plant was built. Earlier, Jacobi announced another major industrial advancement involving the use of more durable ferrocyanides in gold plating, thus having the ability to deposit silver and copper-containing gold alloys.

Since then on, electroplating spread quickly across the rest of the world and became a common method for the deposit of precious and unprecious metals, including copper, gold, nickel, brass, tin, and zinc. In addition to the introduction of electrical power generation and hard chromium plating, during the late 19th and early 20th centuries few major technological advances were made. After World War II the rediscovery of electroplating occurred with the invention of transistors and the rise of the electronics industry [4-6].

Electrochemical deposition [12,13] is commonly used for the growth of metals and the conduction of metal oxides because of the following advantages: the thickness and morphology of the nanostructure can be managed precisely by changing the electrochemical parameters, fairly uniform and compact deposits can be synthesized in template based structures, higher deposition levels can be obtained, and the system is inexpensive due to either high vacuum or high reaction temperature non-requirements [7,8,9].

The corrosion rate of a given metal in a given medium is defined as the amount of weight lost to the metal per unit area per unit time in that medium. The corrosion rate can be calculated laboratory by exposing a piece of metal with a clean surface to the medium in which the corrosion rate is to be calculated for a certain period of time, then calculating the weight it lost during that time period by using the following formula:

$$\text{Corrosion rate} = (\text{amount of weight lost} / \text{area}) \times \text{time}$$

The corrosion rate value extracted in this way is used to express the extent of the metal's general corrosion resistance as the proportion is inversely proportional between the corrosion rate value and the metal's resistance to corrosion.

The basic units used to express the corrosion rate are: mg / dm<sup>2</sup> / day, meaning that the lost weight is measured in milligrams, the surface area is in decimeter square, and the time is in days. This unit is symbolized by mdd [13]

Furthermore, protective coatings used to protect the base metal, usually iron and steel (e.g. Zn), form a thin protective layer of one metal that is prone to corrode on the surface of another. Decorative coatings used to enhance the appearance of the surface (color, shine, smoothness) decorative protective coatings primarily used to give an appealing look to certain protective qualities, e.g. Ni on steel and Cu-Ni-Cr on steel. Ni, Cu, or Zn have been chosen for their properties. Table 1 shows the properties of these metals.

**Table 1: properties of metals which chosen in this research**

Metal	Mass (gr/mol)	Density (gr/cm <sup>3</sup> )	Covalent radius (pm)	Crystal structure	Magnetic ordering
Al	26.98	2.700	121 ± 4	FCC	Paramagnetic
Ni	58.69	8.908	124 ± 4	FCC	Ferromagnetic
Cu	63.54	8.940	132 ± 4	FCC	Diamagnetic
Zn	65.38	7.140	122 ± 4	HCP <sup>3</sup>	Diamagnetic

## Experiment and material

### 1. Verification of the chemical composite of alloy:

According to the aforementioned composition in the American Society for Testing and Materials (ASTM), Table 2 indicates the results of the alloy study that our samples belong to the second category of aluminum called Al<sub>2</sub>xxx [10].

**Table 2: chemical composition of the alloy**

element	Al	Cr	Ti	Mn	Zn	Cu	Ni	Fe	Mg	Si
Wt%	97.8	0.012	0.058	0.180	0.380	0.500	0.016	0.212	0.170	0.500

### 2. Preparation of specimens:

Specimens were fitted with measurements (25 × 15 × 2) mm using the automatic saw.

### 3. Preparation of surfaces:

Using abrasive paper (400-800-1200-2000) water proof, the specimen's surfaces were prepared for coating processes.

### 4. Preparation of solutions:

The solutions required have prepared according to the concentrations as shown in Table 3. by using copper acetate, zinc acetate, and nickel chloride respectively. Following the preparation of the specimens according to the above steps, the specimens were placed in the paint cistern where the aluminum was connected to the cathode, the anode was carbon, and the whole solution was stirred at 80 rpm [8].

**Table 3: concentrations of solution and weights added [6].**

conc. / chem. com.	1 mol/ℓ	0.5 mol/ℓ
Zn	21.95 gr	10.97 gr
Cu	19.96 gr	9.98 gr
Ni	17.20 gr	8.60 gr

### 5. Coating cistern parameters [11]:

<sup>3</sup>Hexagonal close packed

Table 4 displays the parameters of the coatings cistern, where all specimens were heat treated for 12 hours at 500 °C and the pH values were stable by adding a buffer solution [8].

**Table 4: coating cistern parameters.**

	Conc. (mol/ℓ)	pH	Temperature, (°C)
Ni cistern A	0.5	4.5 - 5.5	35 – 55
Ni cistern B	1.0	4.5 - 5.5	35 – 55
Zn cistern A	0.5	3.5 - 4.5	15 – 30
Zn cistern B	1.0	3.5 - 4.5	15 - 30
Cu cistern A	0.5	4.0 - 5.5	20 - 40
Cu cistern B	1.0	4.0 - 5.5	20 - 40

**6. Preparation of the acid rain:** Dissolve 3 gr of sodium acetate with 100 ml of distilled water and then add 14 ml of expanded acetic acid to 400 ml (pH 5.6).

**7. Specimen's symbols:** The samples were named as shown in Table 5 after weighed them before and after the painting.

**Table 5: the studied samples with their solutions.**

Specimen symbol	Cistern	Weight (gr)	Conc. (mol/ℓ)	Time (min)
A01	Cu	1.8118	0.5	30
B01	Cu	1.1003	0.5	30
A02	Cu	2.0336	1.0	15
B02	Cu	2.3874	1.0	15
A03	Cu	2.3530	0.5	15
B03	Cu	1.5743	0.5	15
A04	Cu	1.6172	1.0	30
B04	Cu	2.2863	1.0	30
A05	Zn	1.6584	0.5	15
B05	Zn	1.5052	0.5	15
A06	Zn	2.0965	1.0	15
B06	Zn	1.9520	1.0	15
A07	Zn	2.3109	1.0	30
B07	Zn	1.9190	1.0	30
A08	Zn	1.7570	0.5	30
B08	Zn	1.8002	0.5	30
A09	Ni	2.6599	1.0	30
B09	Ni	2.4820	1.0	30
A10	Ni	2.3728	1.0	15
B10	Ni	1.6608	1.0	15
A11	Ni	1.7449	0.5	30
B11	Ni	1.8462	0.5	30
A12	Ni	1.8150	0.5	15
B12	-	1.0079	-	-
B13	-	1.3151	-	-

## Results and discussion

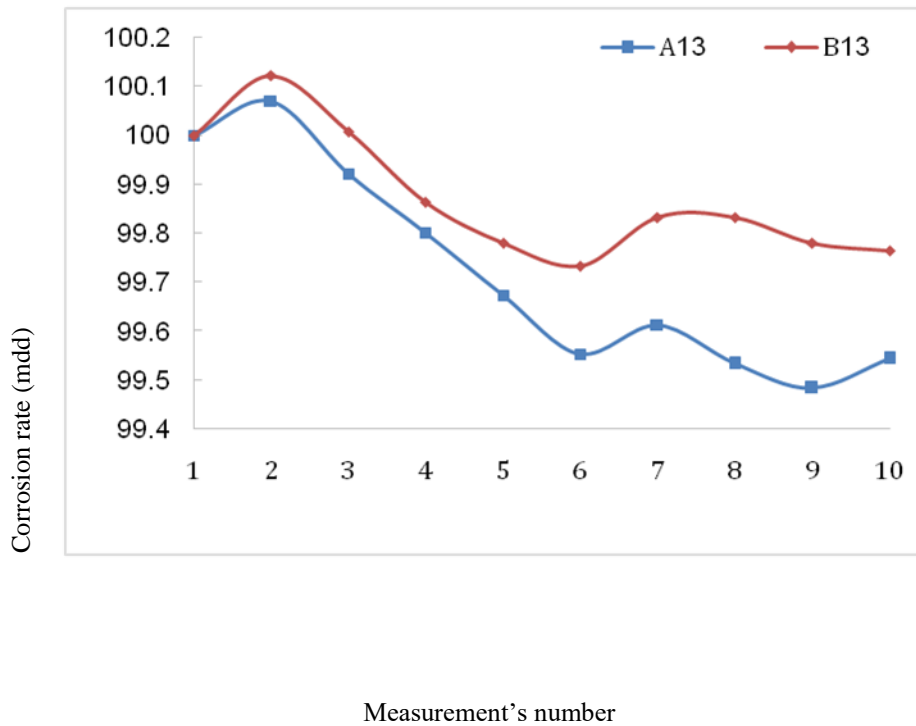
### 1. Aluminum corrosion compared to thermally treated aluminum

[11]:

The corrosion rate studied versus thermally treated aluminum without any metal cover (blank). The Fig. 1 shows that the curves have the same corrosion behavior.

### 2. Corrosion of thermally treated aluminum compared to (Cu, Zn, or Ni) coated aluminum concentricity 0.5 mol/ℓ, coating at 15 min:

The corrosion rate for thermally treated aluminum by using (Cu, Zn, or Ni) to coat aluminum samples with applied concentration of 0.5 mol/ℓ and the coating time was 15 min. Nickel coated sample shows greater consistency in weight and the zinc coated samples were the worst compared, as shown in Fig. 2.



**Fig. 1: Aluminum corrosion compared to thermally treated aluminum**

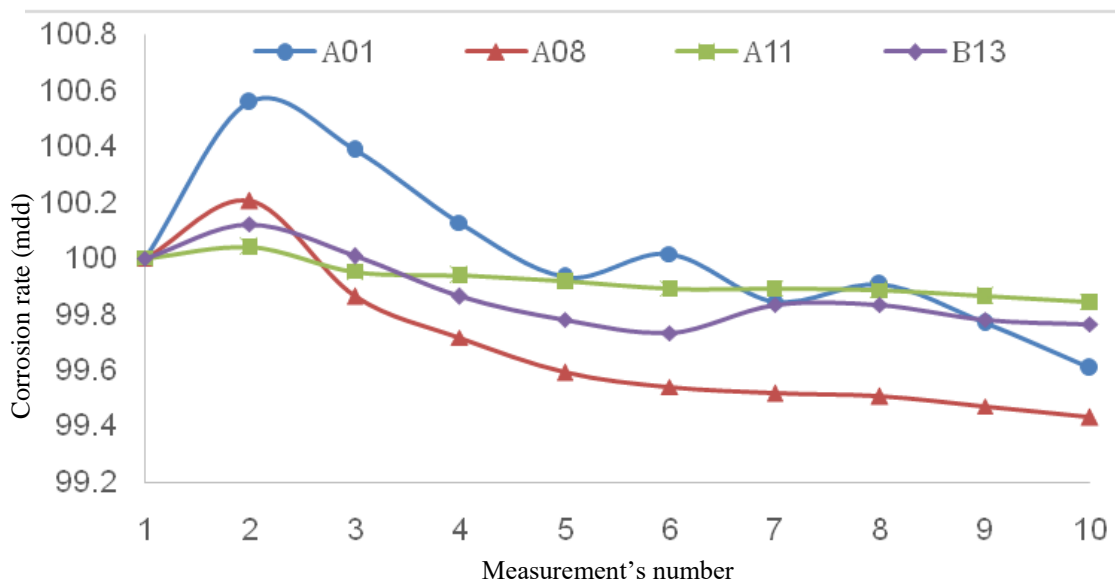


Fig. 2: Corrosion of thermally treated aluminum compared to (Cu-Zn-Ni) coated aluminum, concentricity 0.5 mol/ℓ, and coating at 15 min

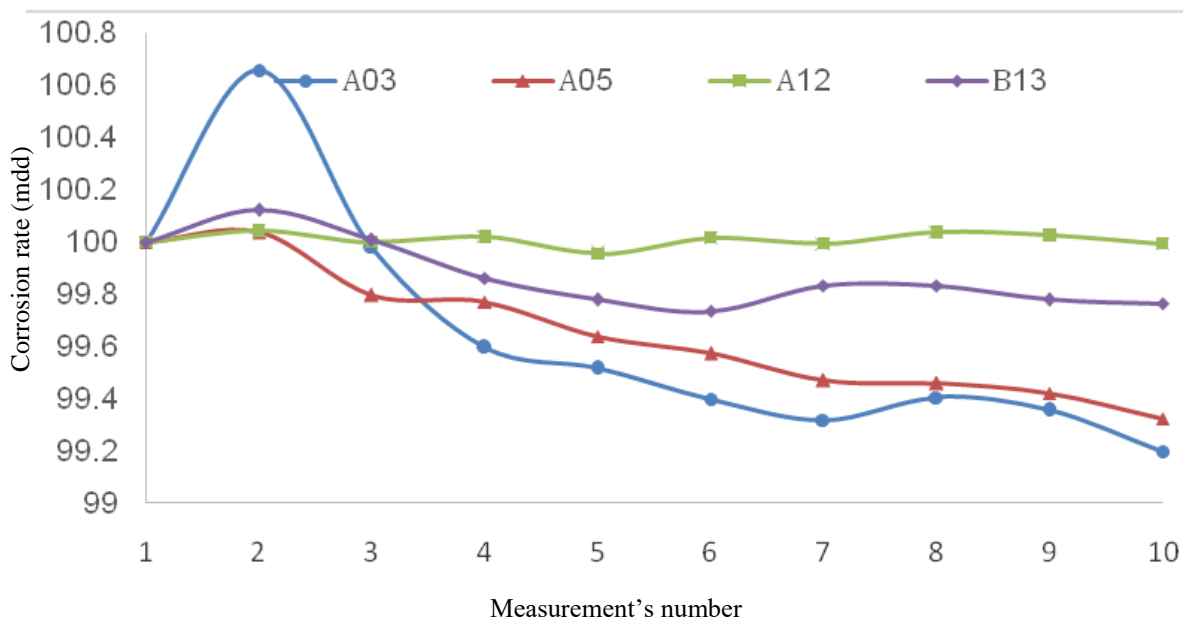
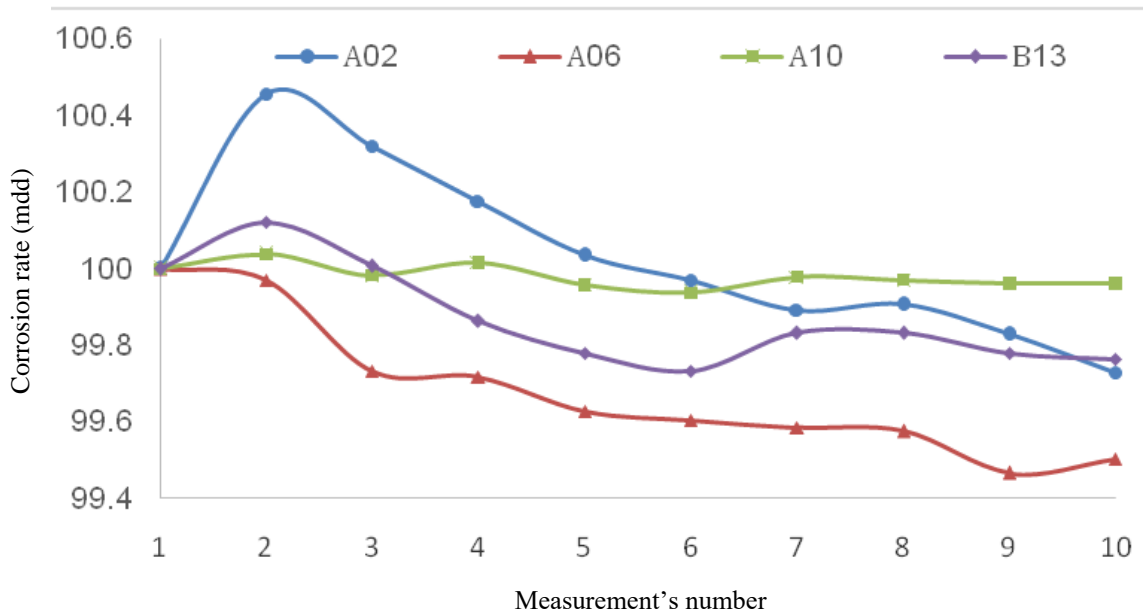


Fig. 3: Corrosion of thermally treated aluminum compared to (Cu-Zn-Ni) coated aluminum, concentricity 0.5 mol/ℓ, and coating at 30 min

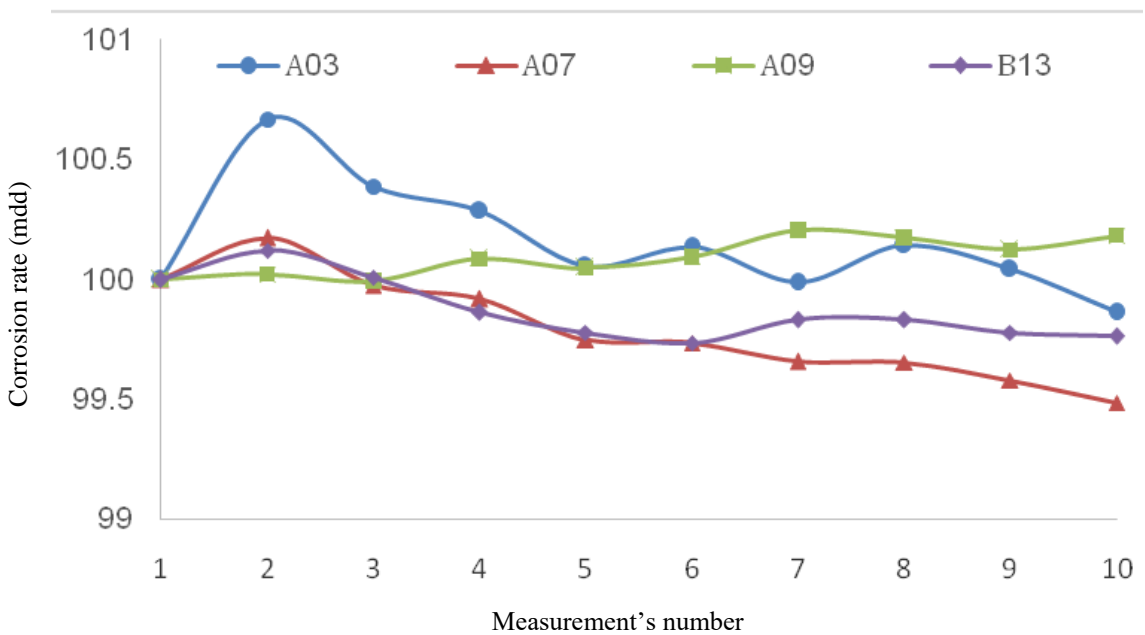
**Corrosion of thermally treated aluminum compared to (Cu, Zn, or Ni) coated aluminum concentration 1 mol/l, coating at 15 min:**

Using (Cu, Zn, or Ni) to paint aluminum samples with an applied concentration of 1 mol/l, the corrosion rate for thermally treated aluminum was 15 min. Here, we can see, that the nickel-coated sample shows greater weight consistency, zinc coated samples were the worst, and the coating time improved corrosion resistance, as shown in Fig. 3.

**3. Corrosion of thermally treated aluminum compared to (Cu, Zn,**



**Fig. 4: Corrosion of thermally treated aluminum compared to (Cu-Zn-Ni) coated aluminum, concentration 1 mol/l, and coating at 15 min**



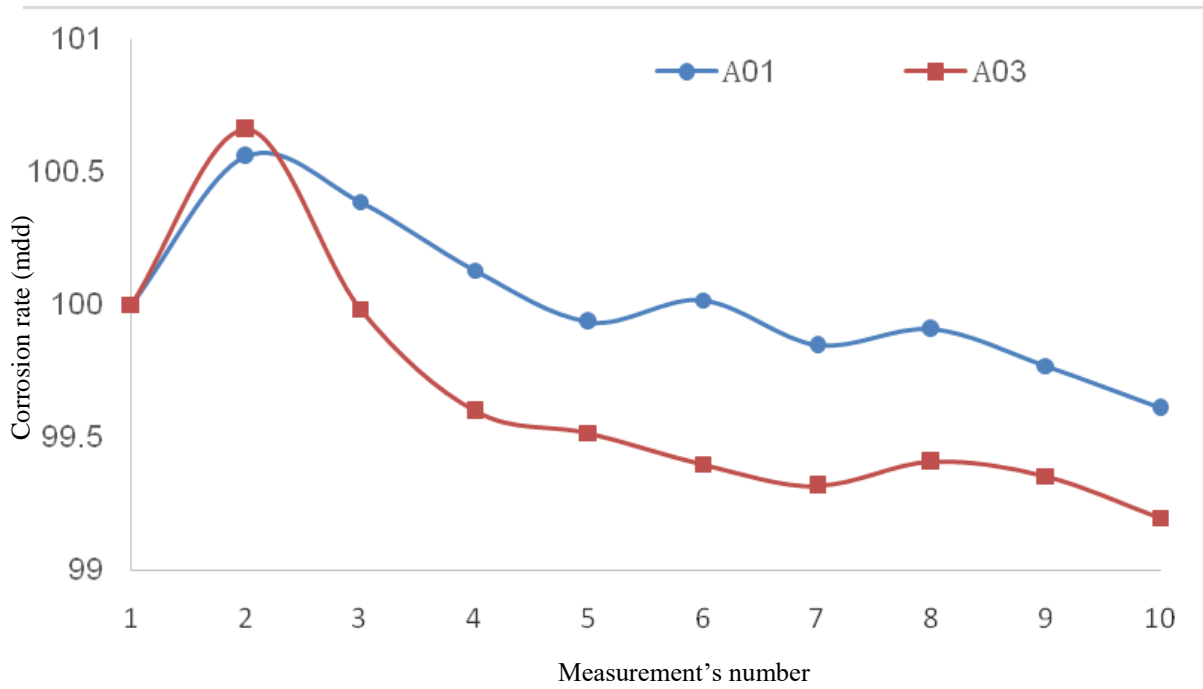
**Fig. 5: Corrosion of thermally treated aluminum compared to (Cu-Zn-Ni) coated aluminum, concentration 1 mol/l, and coating at 30 min**



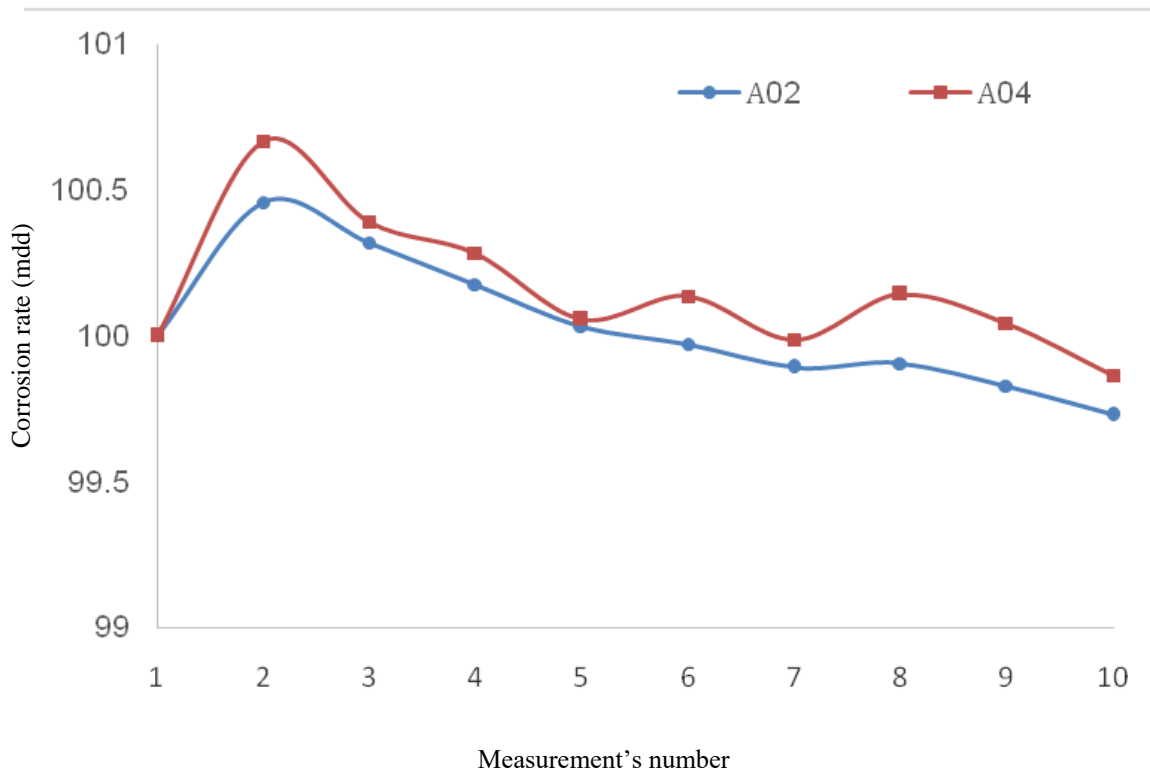
**or Ni) coated aluminum concentration 0.5 mol/ℓ, coating at 30 min:**

Using (Cu, Zn, or Ni) to paint aluminum samples with an applied concentration of 0.5 mol/ℓ, the corrosion rate for thermally treated aluminum was 30 min. We can note that the nickel-coated sample shows greater weight consistency, as shown in Fig. 4.

**4. Corrosion of thermally treated aluminum compared to (Cu, Zn, or Ni) coated aluminum concentration 1 mol/ℓ, coating at 30 min:**



**Fig. 6: Corrosion of copper-coated aluminum 0.5 mol/ℓ according to coating time**



**Fig. 7: Corrosion of copper-coated aluminum 1 mol/ℓ according to coating time**

The (Cu, Zn, or Ni) have been used to paint aluminum samples with an applied concentration of  $1 \text{ mol} / \ell$ , the corrosion rate for thermally treated aluminum was 30

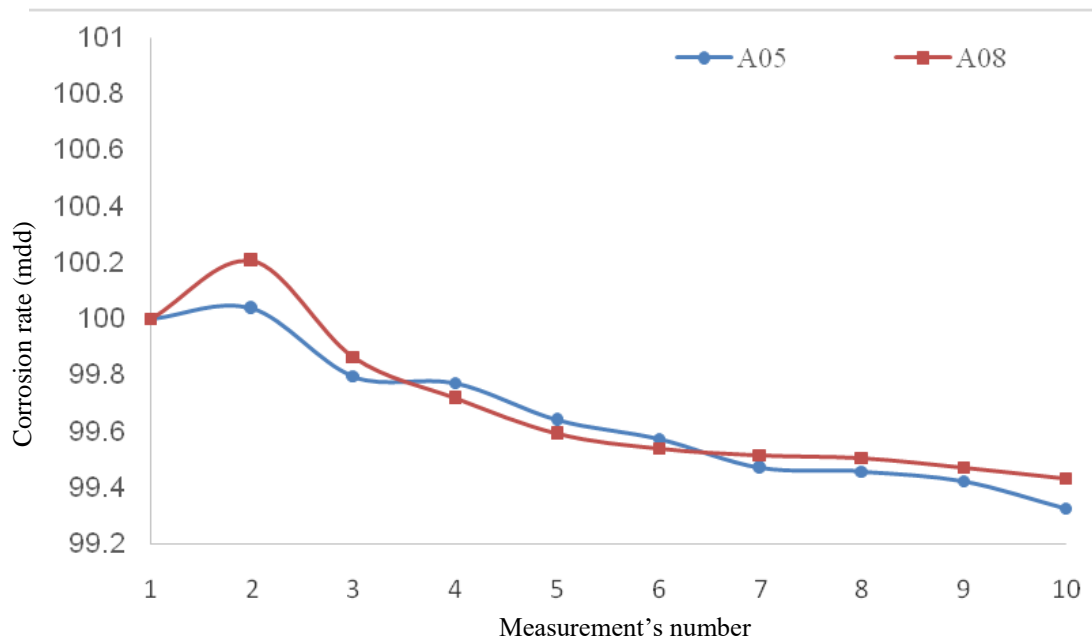


Fig. 8: Corrosion of copper-coated aluminum  $0.5 \text{ mol} / \ell$  according to coating time

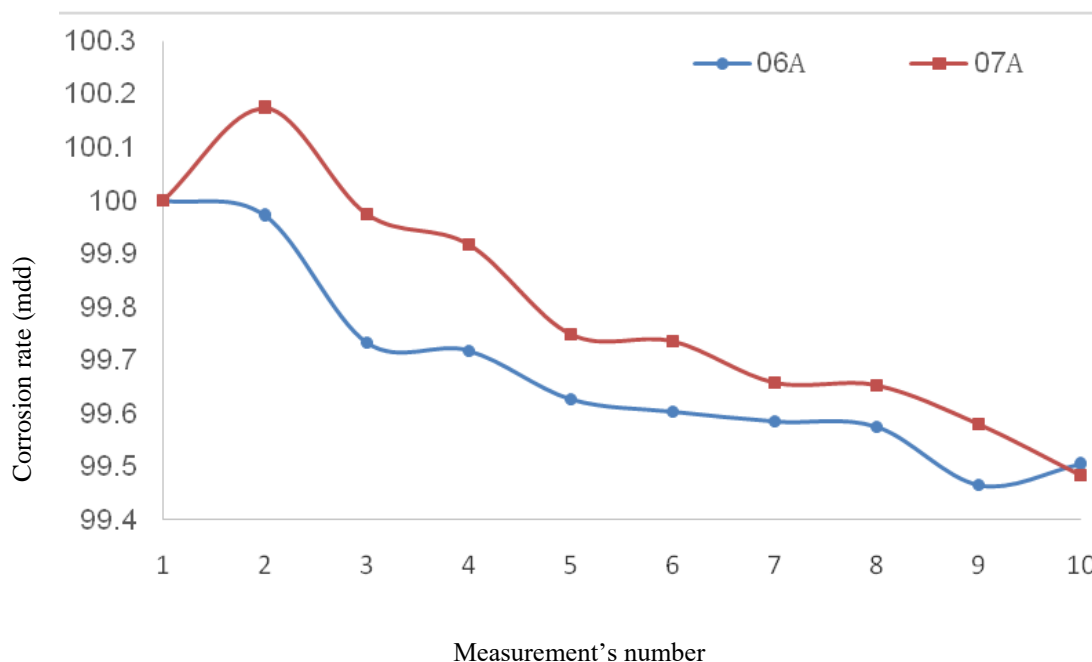


Fig. 9: Corrosion of copper-coated aluminum  $1 \text{ mol} / \ell$  according to coating time

min. We can see that the nickel-coated sample displays greater weight stability, while the zinc-coated sample lost more weight by corrosion, as shown in Fig. 5.

**5. Corrosion of copper-coated aluminum 0.5 mol/ℓ according to coating time:**

Increasing time increases the corrosion resistance, as shown in Fig. 6.

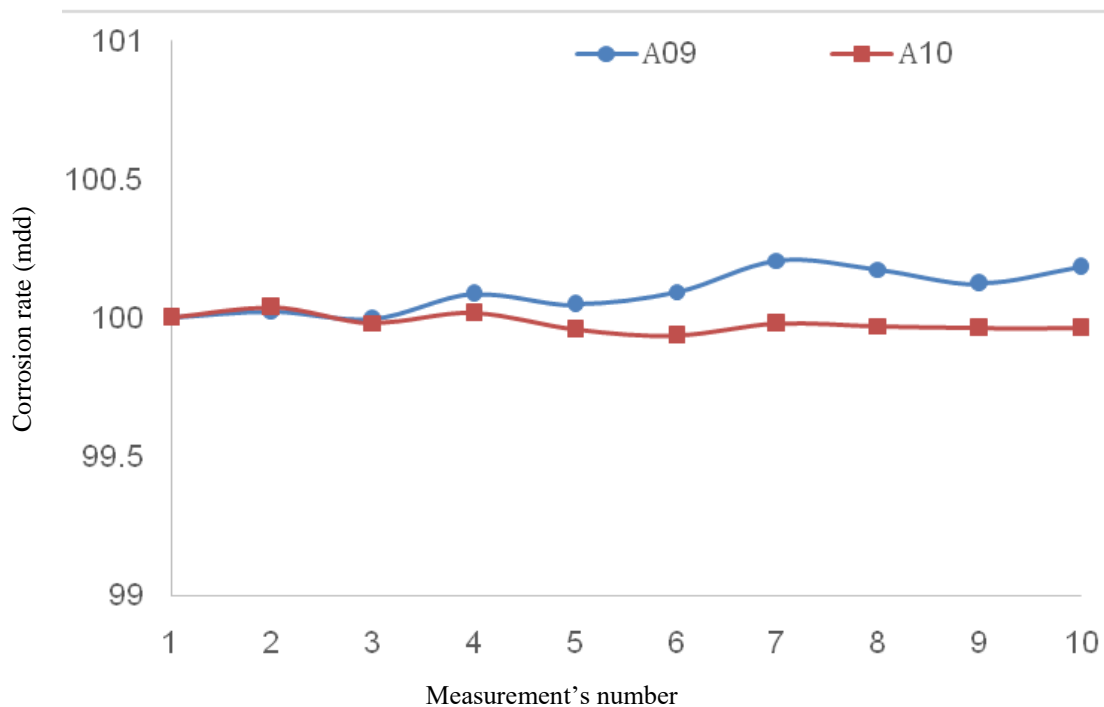
**6. Corrosion of copper-coated aluminum 1 mol/ℓ according to coating time:**

The copper-coated aluminum corrosion 1 mol/ℓ depends on the coating period. As increased coating time, as increased the resistance to the corrosion, as shown in Fig. 7.

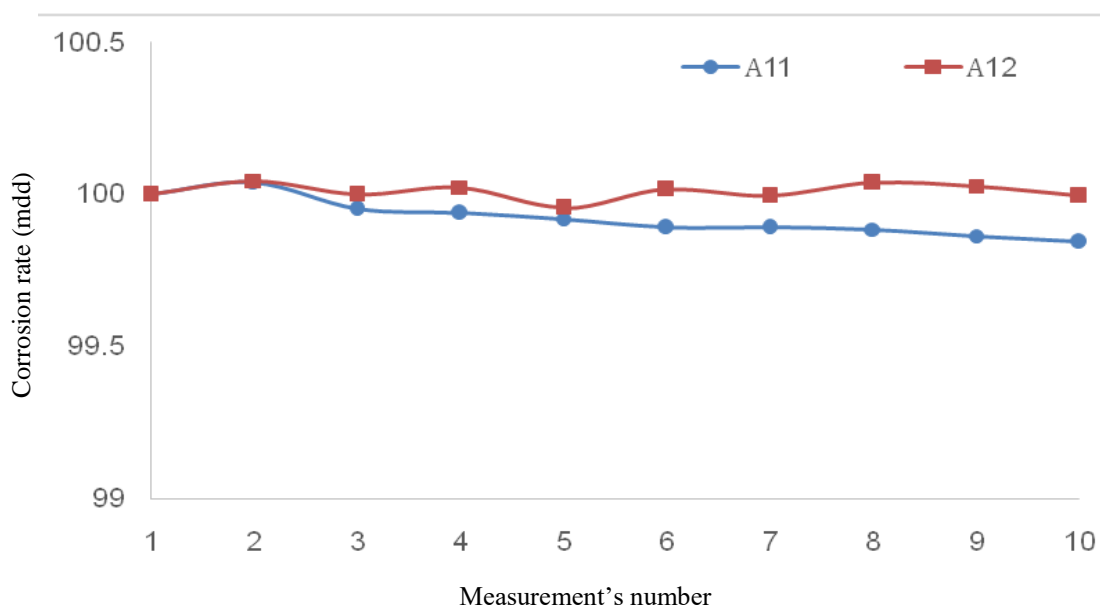
**7. Corrosion of zinc-coated aluminum 0.5 mol/ℓ according to coating time:**

The zinc-coated aluminum corrosion  $0.5 \text{ mol}/\ell$  depends on the coating period. Increasing concentration has no effect on the resistance to the corrosion, as shown in Fig. 8.

**8. Corrosion of zinc-coated aluminum  $1 \text{ mol}/\ell$  according to coating time:**



**Fig. 10: Corrosion of nickel-coated aluminum  $0.5 \text{ mol}/\ell$  according to coating time**



**Fig. 11: Corrosion of nickel-coated aluminum  $1 \text{ mol}/\ell$  according to coating time**

For the zinc-coated aluminum corrosion  $1 \text{ mol}/\ell$  we found that changing the coating time doesn't affect on the corrosion resistance to the, as shown in Fig. 9.

**9. Corrosion of nickel-coated aluminum  $0.5 \text{ mol}/\ell$  according to coating time:**

The nickel-coated aluminum corrosion  $0.5 \text{ mol}/\ell$  depends on the coating period. Reducing coating time leads to the better and less rate of the corrosion, as shown in Fig. 9.

**10. Corrosion of nickel-coated aluminum  $1 \text{ mol}/\ell$  according to coating time:**

For the nickel-coated aluminum corrosion  $1 \text{ mol}/\ell$  we found that reducing the coating time gives better results and less in corrosion rate, as shown in Fig. 11.

**Conclusion**

Galvanic coating is an aluminum specimen technique a film of (Cu, Zn, or Ni) was deposited on aluminum specimens with specific process parameters. Heat treatment of specimens was performed to ensure the coating layer was homogeneous.

Corrosion monitoring of acid rain was conducted in laboratory. Weights of the specimens were measured to assess the impact of the coating on corrosion resistance. The corrosion rate for thermally treated aluminum (Cu, Zn, or Ni) was 15 and 30 min for coating aluminum samples with 0.5 and  $1 \text{ mol}/\ell$  concentration added for coating. Nickel-coated samples exhibit greater weight accuracy, the worst was the zinc-coated ones. The prosperities of these metals are found to be distinctive according to Table 1; such as zinc has a hexagonal crystal structure whereas the other ones have FCC's face centered cubic.

Therefore, the magnetic ordering for nickel is ferromagnetic and for aluminum it is paramagnetic, while for copper and zinc it is diamagnetic. This in turn means that the nickel over the aluminum metal is the best coating sheet.

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