Corrosion properties of aluminum-based alloys used in building constructions for different purposes

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Abstract. The corrosion resistance of an aluminium alloy AD 31, that is used in building constructions, is investigated. The connection between change of samples weight and time of corrosion tests is established. It is shown, that the corrosion is accompanied by simultaneous course of two processes: by oxide film formation and dissolution of more active metal. The temperature dependences have shown, that with the temperature increase higher 80°C the corrosion resistance is reduced. The accounts of weight and deep parameters of corrosion are made.

Keywords: corrosion resistance, aluminium alloy AD 31, gravimetric method, weight and deep parameters of corrosion.

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INTRODUCTION

In connection with the development of technology and the increase in the load on metals, the corrosive destruction of metals under the influence of the external environment and operating conditions has become a national problem of almost all industrially developed countries. Therefore, it is necessary to search for such structural materials that could satisfy the working conditions in certain environments due to their corrosion resistance and mechanical properties. Aluminum and its alloys are promising as such materials for building constructions [1, 2]. In terms of application area, they took second place after iron, because aluminum and its alloys combine such important properties as: low specific weight, high strength, thermal conductivity, as well as sufficiently high corrosion resistance in a number of aggressive environments, which allows these materials to be used in various construction structures as facade materials operated in atmospheric conditions [3].

Pure aluminum is characterized by high corrosion resistance, but has low mechanical strength. Therefore, aluminum alloys with increased strength characteristics are used to satisfy various requests of building industry [4]. Each alloy is developed and used to provide a certain complex of properties for a given object. One of the important requirements for any kind of building constructions is corrosion resistance [5], since all construction objects are susceptible to environmental influences and how high corrosion resistant of this object is depends on its service life and operational safety. At the same time, information on systematic studies of the corrosion properties of aluminum alloys used in building constructions in the literature is limited.

The aim of these studies is to study the corrosion resistance of AD 31 aluminum alloy, which is widely used for various purposes in building constructions.

MATERIALS AND METHODS

Research of aluminum alloys for corrosion resistance was carried out in artificially created conditions that imitate a complex of corrosion and climatic factors that act on products in real operating conditions in distilled water (composition close to rainwater) and in a 3% solution of NaCl at three temperatures: +20, +80, –10^{o}C. Before the research, an external inspection of the samples was carried out, their dimensions and weight were measured. Corrosion tests were carried out with samples completely immersed in corrosive environments under static conditions. The samples were studied in cells made of chemically resistant glass, which has no influence on the chemical composition of corrosive environment and, respectively, the course of the corrosion process.

Corrosion resistance studies were carried out by the gravimetric method [3] in static mode. The test time was 1000 hours, measurements were performed on 10 samples every 10...20 hours.

The condensates microstructure was studied using Neofot-21 optical microscopes and a REM-200 scanning electron microscope. Cross-sectional microsections of condensates were made for metallographic studies.

Ion etching of samples was carried out on the VIP-4 installation at a residual air pressure of 1.0×10^{-2} Pa according to the regime: U = 4 kV, I = 15...20 mA for 7...15 minutes.

The thin structure of condensates was studied by electron microscopy using a JSEM - 200 electron microscope. Foils were prepared by the jet method in a 20% HNO_3 solution. Radiographic studies of composite materials were carried out using a DRON-3 diffractometer.

RESULTS AND DISCUSSION

Corrosion of aluminum alloys can occur in environments with different humidity. Atmospheric corrosion, which occurs at humidity above 98% in conditions of droplet condensation or direct impact of atmospheric precipitation on the metal surface with the formation of phase films of moisture, is called "wet" atmospheric corrosion. By its mechanism this process is similar to electrochemical corrosion, when the metal is fully immersed in the electrolyte and is related to the functioning of local microelements.

The standard electrode potential of aluminum is –1.66 V, which indicates its low thermodynamic stability. In air, aluminum is covered with a film of aluminum oxide Al_2O_3, the presence of which increases the electrode potential of aluminum and, accordingly, its corrosion resistance.

The conducted studies of changes in the mass of the samples per unit area of aluminum alloy AD 31 over time in distilled water and 3% NaCl solution (Fig. 1) showed that samples mass increases, passes through a maximum and then decreases. The nature of the mass change of the AD 31 alloy sample in a 3% NaCl solution is the same as in distilled water. The difference is that, taking into account the environment aggressiveness, the course of processes in a 3% NaCl solution occurs more intensively.

The given dependences of the sample mass change from the time of corrosion tests are explained by the fact that corrosion processes consist of several stages. At the anode, ionization of aluminum occurs according to the scheme:

$$Al - 3\bar{e} = Al^{3+}.$$

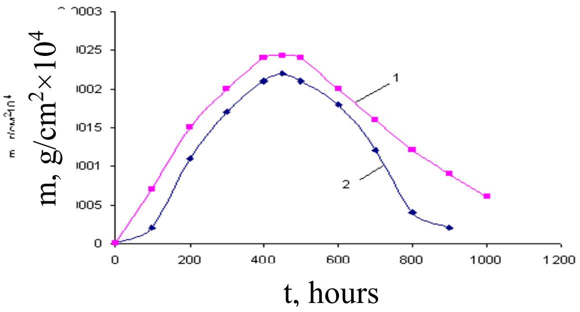

Fig. 1. Change in the mass of AD 31 alloy samples at a temperature of 20ºC: 1 — in 3% NaCl solution; 2 - in distilled water

At the cathode, the process proceeds with oxygen depolarization:

$$O_2 + 2\,H_2O + 4\bar{e} = 4\,OH^-$$

In this case, the mass of the samples should decrease. But in the process of electrochemical corrosion, secondary corrosion processes may occur: interaction of primary corrosion products with each other, with the electrolyte or with gases dissolved in the electrolyte. The formation of secondary corrosion products increases the mass of the samples and slows down the corrosion progress, since poorly soluble secondary corrosion products prevent access of the electrolyte to the surface of the sample. The general result of the change in the mass of the samples is the action of two processes: the process of aluminum dissolution and the process of corrosion products formation. Depending on which of the processes will exceed, samples mass may increase, decrease or not change at all.

The increase in the mass of the samples during the first 450 hours of corrosion tests in distilled water is associated with the formation of secondary corrosion products: poorly soluble aluminum oxide and hydroxide, in other words, the process of oxide film build-up occurs.

Studies of the chemical composition of samples surface testify in favor of this idea. Comparing the composition of original samples with the composition of the surface of samples after corrosion tests, it can be seen that the aluminum content decreases from 98.8% to 95.07%, and the oxygen content increases from 0% to 3.38% (Table 1).

The process of film formation begins to slow down over time due to diffusion and concentration limitations. The advantage of the dissolution process over the process of secondary products formation leads to a general decrease in the mass of the samples.

Analysis of the corrosive environment (distilled water and sodium chloride solution) for the content of aluminum ions after the tests confirms the transition of aluminum ions to the corrosive environment. The content of aluminum ions in distilled water increases to 0.01 mg/l and in sodium chloride solution to 0.015 mg/l.

Table 1. Chemical composition of the surface of AD 31 alloy samples before and after corrosion tests

Test conditions	Chemical composition, wt.%.			
	Al	Mg	Si	O
Initial state	98,8	0,55	0,65	-
After corrosion tests at t= 20ºC	95,07	0,51	0,67	3,38
After corrosion tests at t= 80ºC	91,85	0,55	0,93	7,4
After corrosion tests at t= −10ºC	92,65	0,58	0,8	5,96

As the temperature increases and decreases, the process course of the mass changing of AD 31 alloy samples occurs more intensively. Studies of the chemical composition of samples surface testify in favor of this idea. Comparing the initial samples composition with the composition of samples surface after corrosion tests at elevated temperature, it can be seen that the aluminum content decreases from 98.8% to 91.85%, and the oxygen content increases from 0% to 7.4%, respectively; at a lower temperature, the aluminum content decreases from 98.8% to 92.65%, and the oxygen content increases accordingly to 5.96%.

Based on the conducted research, the values of weight and depth corrosion indicators were calculated according to the following formulas:

$$K = \frac{\Delta g}{S \cdot 1000},\ g/m^2h;$$

$$\pi = \frac{K \cdot 8.74}{\rho_{me}}, \text{ mm/year},$$

where Δg – change in sample mass after 1000 hours of corrosion tests; S – sample area; K – weight index of corrosion; π – depth indicator of corrosion.

The calculated indicators for the above systems are presented in the table. 2.

Conducted microstructure studies of the surface of the samples after corrosion tests in different environments and at different temperatures showed that in all cases the samples had corrosion damage in the form of separate points and pitting (Fig. 2, a, c, e, g).

Table 2. Weight and depth indicators of aluminum alloy corrosion

Environment	K, g/m²h ·10³	π, mm/year·10³
Distilled water 20ºC	1,11	3,59
Distilled water 80ºC	2,8	9,08
Distilled water - 10ºC	1,15	3,72
3% solution of NaCl	1,10	3,56

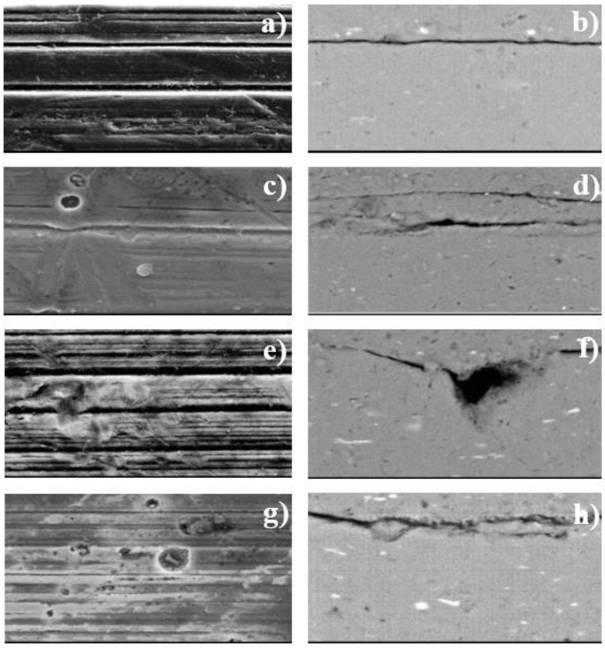

Fig. 2. Separate points and pitting on the samples surface after corrosion tests in different environments and at different temperatures

Pitting formations have a rounded shape and contain corrosion products inside. The cross-section microstructure indicates that corrosion develops at the metal-oxide film interface. When the temperature rises, the corrosion processes accelerate, which is observed by the increase of destruction areas. The bigest delamination at the metal-oxide film interface is observed in seawater, the research conditions in which are simulated in a 3% NaCl solution.

CONCLUSIONS

Systematic studies of the corrosion resistance of aluminum alloy AD 31 in distilled water and 3% NaCl solution at normal, elevated and lowered temperatures were carried out.

The relationship between the change in the mass of the samples and the time of the corrosion tests is established. It is shown that corrosion is accompanied by the simultaneous occurrence of two processes: the formation of an oxide film and the dissolution of a more active metal.

Temperature dependences showed that the corrosion resistance decreases as the temperature rises over 80ºC.

Calculations of weight and depth indicators of corrosion were carried out. It is shown that the corrosion resistance is characterized by rather high resistance score.

On the basis of the conducted research, it was established that AD 31 alloy can be recommended for use in construction industry.

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Корозионі властивості сплавів на основі алюмінію, які використовуються в будівельних конструкціях різного призначення

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Анотація. Досліджено корозійну стійкість алюмінієвого сплаву АТ 31, що використовується в будівельних конструкціях. Встановлено зв'язок між зміною маси зразків та часом корозійних випробувань. Показано, що корозія супроводжується одночасним перебігом двох процесів: утворенням оксидної плівки та розчиненням більш активного металу. Температурні залежності показали, що з підвищенням температури вище 80°C корозійна стійкість знижується. Зроблено розрахунки вагових та глибинних показників корозії.

Ключові слова: корозійна стійкість, алюмінієвий сплав АТ 31, гравіметричний метод, масові та глибинні показники корозії.