

Effect of calcium doping on the anodic behavior of E-AlMgSi (Aldrey) conducting aluminum alloy in NaCl electrolyte medium

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Abstract

The design of new materials intended for operation under severe conditions faces the task of rendering the materials corrosion resistant. The practical solution of this task is interrelated with the knowledge of corrosion protection of metals and alloys. The use of conducting aluminum alloys for the manufacture of thin wire may encounter specific problems. This is caused by the insufficient strength of these alloys and a small number of kinks before fracture. Aluminum alloys have been developed in recent years which even in a soft state have strength characteristics that allow them to be used as a conductive material. The E-AlMgSi (Aldrey) aluminum alloy is a well-known conducting alloy. This alloy is a heat-strengthened one, possessing good plasticity and high strength. After appropriate heat treatment this alloy acquires high electrical conductivity. Wires made from this alloy are almost exclusively used for air transmission lines.

This work presents data on the corrosion behavior of calcium containing E-AlMgSi (Aldrey) aluminum conducting alloy in 0.03, 0.3 and 3.0% NaCl electrolyte medium. The anodic behavior of the alloy has been studied using a potentiostatic technique with a PI-50-1.1 potentiostat at a 2 mV/s potential sweep rate. Calcium doping of the E-AlMgSi (Aldrey) aluminum alloy increases its corrosion resistance by 15–20%. The corrosion, pitting and repassivation potentials of calcium doped alloys shift toward the positive region. An increase in the sodium chloride electrolyte concentration leads to a decrease in these potentials.

Keywords

E-AlMgSi (Aldrey) aluminum conducting alloy, calcium, potentiostatic technique, NaCl electrolyte, corrosion rate, free corrosion and pitting potentials

1. Introduction

Aluminum and its alloys are widely used in electrical engineering as conductor and structural materials. As a conductive material, aluminum is characterized by high

electrical and thermal conductivity. After copper, aluminum has the maximum conductivity level among all technically used metals. Aluminum also has a low density, high atmospheric corrosion resistance and resistance to chemicals [1].

Another property of aluminum is neutrality to insulating materials. For example, aluminum is inert to oils, varnishes and thermoplastics, including at high temperatures. Aluminum differs from other metals by a low magnetic susceptibility. It forms a nonconductive easily removable powder material (Al_2O_3) in an electric arc [2, 3].

The use of aluminum and its alloys is regulated by specific instructions or general construction guidelines, especially regarding materials for switching devices, air transmission line poles, electric motor or switch casings etc.

The economic feasibility of using aluminum as a conductive material is explained by the favorable ratio of its cost to the cost of copper. In addition, one should take into account that the cost of aluminum has remained virtually unchanged for many years [2].

When using conductive aluminum alloys for the manufacture of thin wire, winding wire, etc., certain difficulties may arise in connection with their insufficient strength and a small number of kinks before fracture [1].

A well-known conducting alloy is the E-AlMgSi (Aldrey) aluminum alloy. This alloy is a heat-strengthened one, possessing good plasticity and high strength. After appropriate heat treatment this alloy acquires high electrical conductivity. Wires made from this alloy are used exclusively for air transmission lines [1–3].

The task of increasing the corrosion resistance of aluminum alloys is of great practical importance since power transmission lines made from these alloys are used in the open air [4–6].

The aim of this work is to study the effect of calcium doping on the corrosion and electrochemical behavior of the E-AlMgSi (Aldrey) aluminum conducting alloy containing 0.5 Si and 0.5 Mg (wt.%).

2. Experimental

The alloys were synthesized in the 750–800 °C range in a SShOL type resistance laboratory shaft furnace. A6 grade aluminum which was additionally doped with the calculated amount of silicon and magnesium was used as a charge in the preparation of the E-AlMgSi alloy. When doping aluminum with silicon, the metallic (0.1 wt.%) silicon present in primary aluminum was taken into account. Magnesium wrapped in aluminum foil was introduced into the molten aluminum using a bell. Calcium was introduced into the melt in the form of master alloy with aluminum. The alloys were chemically analyzed for silicon and magnesium contents at the Central Industrial Laboratory of the State Unitary Enterprise Tajikistan Aluminum Company. The alloy compositions were controlled by weighing the charge and the alloys. Synthesis was repeated if the alloy weight deviated from the target one by more than 1–2% rel.u. Then the alloys were cleaned from slag and cast into graphite molds in order to obtain samples for corrosion and electrochemical studies. The cylindrical samples had a diameter of 8 mm and a length of 140 mm.

Specimens for electrochemical studies were positively polarized relative to the potential established upon submerging into the test NaCl solution (E_{fc} is the free or steady-state corrosion potential) until the potential at which the current density increased dramatically (Fig. 1, Curve I). Then the specimens were polarized in the reverse direction (Fig. 1, Curves II and III) until a –1.3 V potential. This polarization caused oxide film dissolution. Finally the specimens were positively polarized again (Fig. 1, Curve IV). During this polarization the pitting potential E_{pf} of the alloys is recorded upon the transition from cathodic to anodic current.

The following main electrochemical potentials of the alloys were determined from the polarization curves recorded: E_{fc} is the steady-state or free corrosion potential, E_{rp} is the repassivation potential, E_p is the pitting potential, E_{cor} is the corrosion potential and I_{cor} is the corrosion current.

The corrosion current was calculated from the Tafel slope ($A = 0.12$ V) for the cathodic curve, taking into account that pitting corrosion of aluminum and its alloys in neutral media is determined by the cathodic reaction of oxygen ionization. In turn, the corrosion rate is a function of the corrosion current and calculated using the following equation:

$$K = I_{cor} k,$$

where $k = 0.335$ g/(A·h) is the electrochemical equivalent of aluminum.

The reproducibility of the data on the electrochemical potentials was $\pm 1 \div \pm 2$ mV, the current

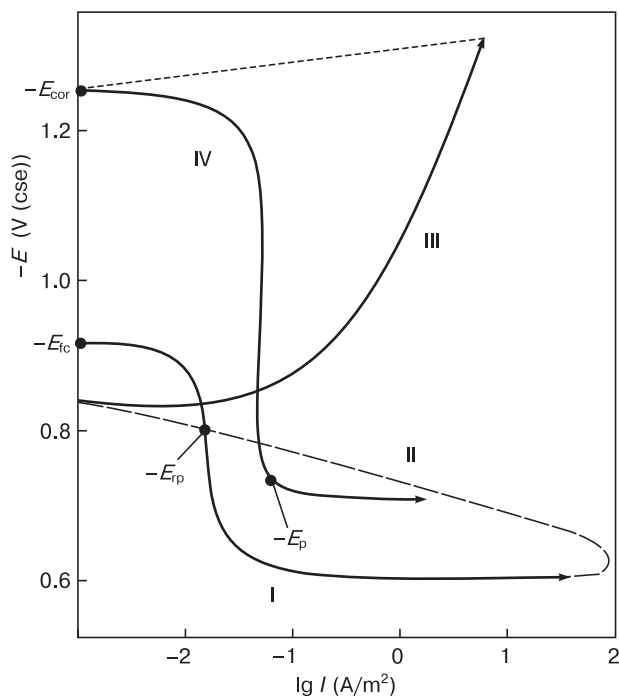


Figure 1. Anode and cathode polarization (2 mV/s) curves of E-AlMgSi (Aldrey) aluminum alloy in a 3% NaCl electrolyte medium

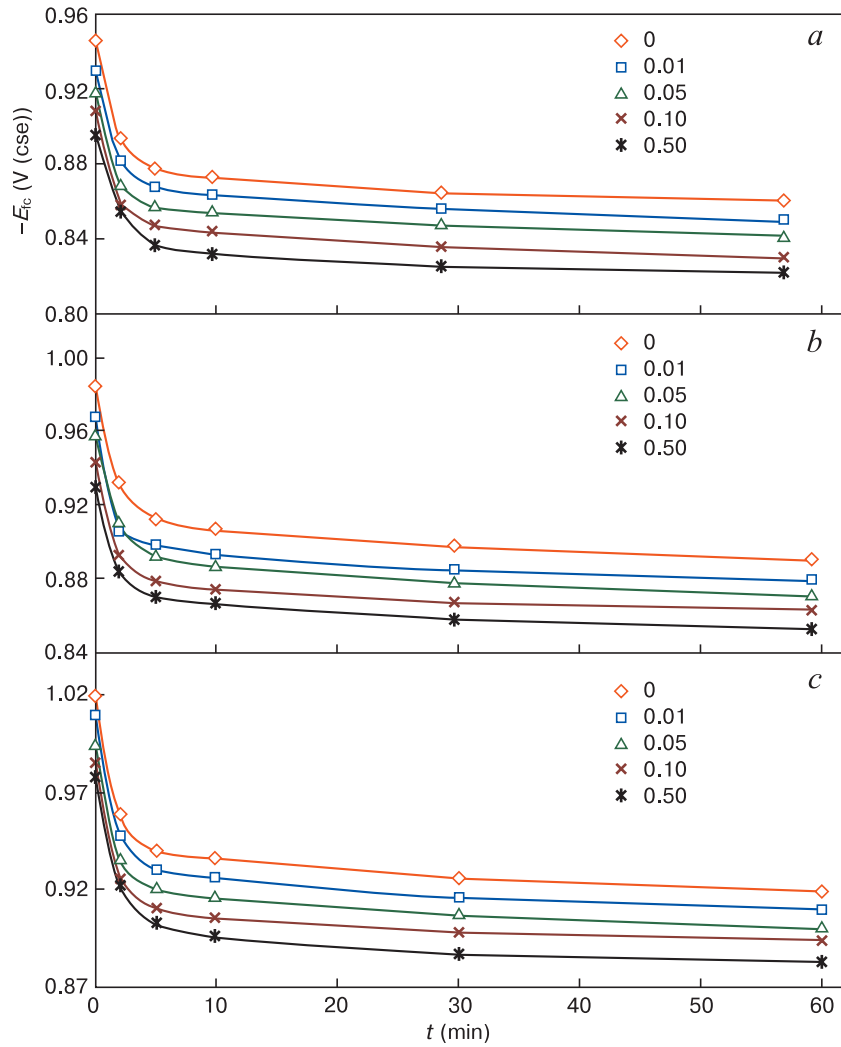


Figure 2. Temporal dependence of the free corrosion potential of calcium-doped E-AlMgSi (Aldrey) aluminum alloy in (a) 0.03%; (b) 0.3% and (c) 3.0% NaCl electrolyte media

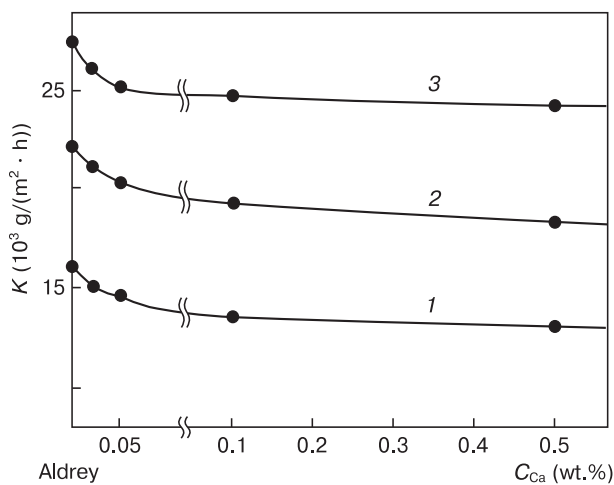


Figure 3. Corrosion rate of E-AlMgSi (Aldrey) aluminum alloy as a function of calcium concentration in (1) 0.03%, (2) 0.3% and (3) 3.0% NaCl electrolyte medium

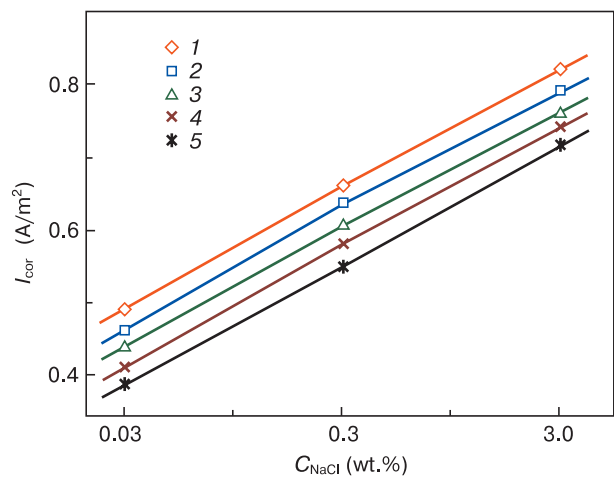


Figure 4. Corrosion current density of (1) pure E-AlMgSi (Aldrey) aluminum alloy and with calcium content, wt.%: (2) 0.01; (3) 0.05; (4) 0.1; (5) 0.5 as a function of NaCl concentration

density being $(0.001\text{--}0.005) \cdot 10^{-2} \text{ A/m}^2$. The polarization curve recording method was described in detail earlier [5–14].

3. Results and discussion

The results of corrosion and electrochemical studies of calcium doped E-AlMgSi (Aldrey) aluminum alloy in

NaCl electrolyte medium are summarized in Table and shown in Figs. 2–5. Figure 2 shows free corrosion potential (E_{fc} , V) as a function of time for specimens of calcium containing alloy in a NaCl electrolyte medium. It can be seen that upon the submersion of the specimens in NaCl electrolyte the E_{fc} potential shifts toward the positive region.

It can be seen from table that 0.01 to 0.5 wt.% calcium doping of the initial aluminum alloy in the test

Table. Corrosion and electrochemical characteristics of calcium-doped E-AlMgSi (Aldrey) aluminum alloy in NaCl electrolyte medium

NaCl medium (wt.%)	Calcium content in alloy (wt.%)	Electrochemical potentials (V (cse))				Corrosion rate	
		$-E_{fc}$	$-E_{cor}$	$-E_p$	$-E_{rp}$	$I_{cor} \cdot 10^2$ (A/m ²)	$K \cdot 10^3$ (g/(m ² · h))
0.03	–	0.860	1.100	0.600	0.720	0.049	16.41
	0.01	0.850	1.088	0.590	0.715	0.046	15.41
	0.05	0.842	1.072	0.578	0.715	0.044	14.74
	0.1	0.830	1.055	0.566	0.710	0.041	13.73
	0.5	0.822	1.040	0.552	0.707	0.039	13.06
0.3	–	0.890	1.180	0.680	0.768	0.066	22.11
	0.01	0.878	1.169	0.664	0.760	0.064	21.44
	0.05	0.870	1.152	0.656	0.754	0.061	20.43
	0.1	0.863	1.137	0.647	0.750	0.058	19.43
	0.5	0.852	1.124	0.640	0.750	0.055	18.42
3.0	–	0.919	1.240	0.735	0.800	0.082	27.47
	0.01	0.910	1.230	0.724	0.785	0.079	26.46
	0.05	0.900	1.228	0.718	0.780	0.076	25.46
	0.1	0.894	1.216	0.710	0.780	0.074	24.71
	0.5	0.883	1.205	0.700	0.770	0.072	24.12

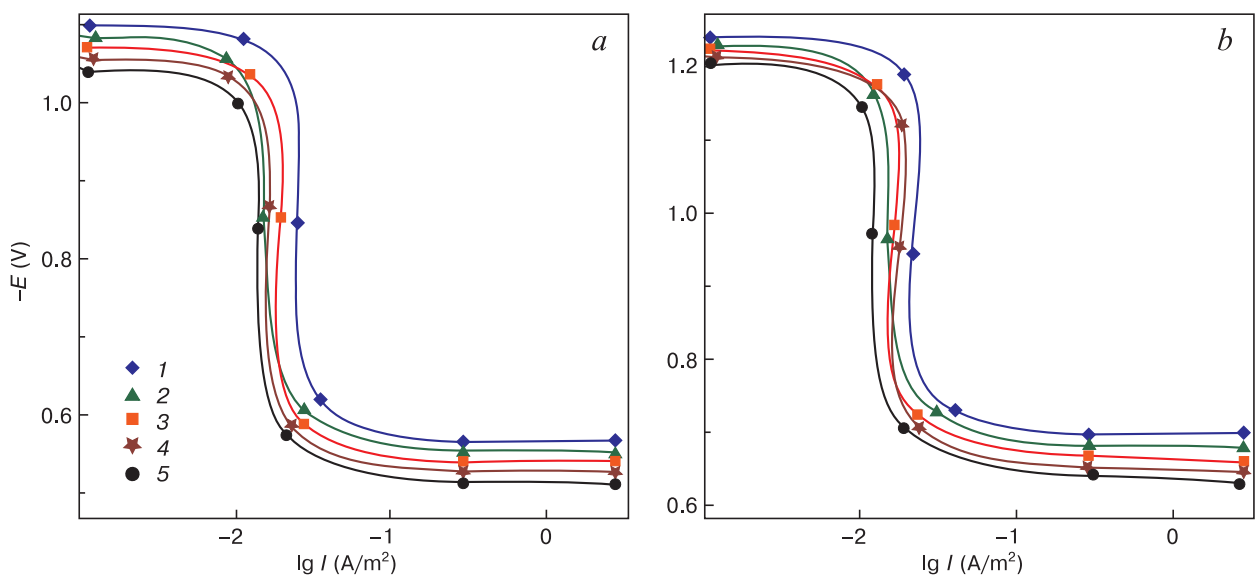


Figure 5. Anodic polarization curves (2 mV/s) of (1) pure E-AlMgSi (Aldrey) aluminum alloy and with calcium content, wt.%, (2) 0.01, (3) 0.05, (4) 0.1 and (5) 0.5 in (a) 0.03% and (b) 3% NaCl electrolyte medium

media shifts the corrosion, repassivation and pitting potentials toward the positive region. This is accompanied by an increase in the pitting corrosion resistance of the alloys.

Figure 3 shows the corrosion rate of the E-ALMgSi (Aldrey) aluminum alloy as a function of calcium content for 0.03, 0.3 и 3.0% NaCl electrolyte media. Calcium doping of the alloy reduces its corrosion rate in all the test media by 15–20%.

An increase in the concentration of NaCl electrolyte leads to an increase in the corrosion rate of the alloy (Fig. 4). At a calcium concentration of 0.5 wt.% the corrosion rate and the corrosion current density of the E-ALMgSi (Aldrey) aluminum alloy were the lowest. Thus this composition is the optimum one for corrosion resistance.

The anodic branches of the polarization curves for calcium-doped ALMgSi (Aldrey) aluminum alloy are shown in Fig. 5. The curve patterns suggest that an increase in the content of the calcium dopant shifts all the electrochemical potentials of the alloy in a NaCl electrolyte medium

towards positive values. This indicates a decrease in the anodic dissolution rate of calcium doped alloys in comparison with the initial alloy.

4. Conclusion

The anodic behavior of calcium containing E-ALMgSi (Aldrey) aluminum alloy was studied using a potentiostatic technique (at a 2 mV/s potential sweep rate) in a NaCl electrolyte medium. We show that calcium doping to 0.5 wt.% increase the corrosion resistance of the initial alloy. The pitting corrosion resistance of the alloy grows as indicated by a shift of the pitting corrosion potentials towards positive values.

An increase in the concentration of chloride ions in the electrolyte leads to a 1.5-fold increase in the corrosion rate of the alloy.

Experiments suggest that calcium doping to within 0.1–0.5 wt.% is optimum for the design of new compositions on the basis of the Aldrey alloy.

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