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Research Article

E-AlMgSi (Aldrey) aluminum conductive alloy with the solid state cadmium oxidation kinetics

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Abstract

In the development of new materials designed for use under particularly harsh conditions, the task of making them corrosion-resistant arises. The practical solution to this task correlates with knowledge in the field of high-temperature oxidation of metals and alloys. When using conductive aluminum alloys for the production of fine wires, such as winding wire, certain difficulties may arise due to their insufficient mechanical strength and inflection before breaking. The solution of modern technological problems is associated with the use of highly oxidation- resistant materials. As a consequence, the study of the interaction of oxygen with metals and alloys has become very important due to the widespread use of new materials with special physical and chemical properties. The E-AlMgSi (Aldrey) aluminum conductive alloy occupies a special place among others. The oxidation process of the alloys was studied under isothermal air atmosphere by thermogravimetric method with continuous fixation of the sample mass for 1 h at temperatures of 723, 773 and 823 K. The oxidation kinetics curves and the value dependencies of the specific mass increase of cadmium in the E-AlMgSi (Aldrey) alloy quantity, time and temperature were constructed on the experimental data basis. The processing of the quadratic kinetic curves of the oxidation of the alloys at the above temperatures has shown that the oxidation of the alloys obeys the hyperbolic dependence $y = kx^n$, where the value of n varies from 1 to 4. The lg k dependence on $1/T$ for the alloy E-AlMgSi (Aldrey) with cadmium shows that the oxidation rate increases with temperature and cadmium content increasing.

Keywords

E-AlMgSi (Aldrey) aluminum conductive alloy, cadmium, thermogravimetry, oxidation, oxidation rate, activation energy

1. Introduction

Aluminum and its alloys are widely used in electrical engineering as a conductor and structural material. As a conductor, aluminum is characterized by high electric thermal conductivity (the highest among all technically applicable metals except copper). Aluminum is also characterized by low density, high corrosion resistance under atmospheric conditions, and chemical attack high resistance [1].

Another distinguishing aluminum characteristic consists in its neutral behavior respecting insulating materials such as oils, lacquers and thermoplastics, in particular at elevated temperatures. From other metals aluminum differ by its low magnetic susceptibility and non-electrically conductive, easily eliminated powdery product formation (Al_2O_3) in an electric arc [2, 3].

The use of aluminum and its alloys as material for switching units, power line poles, motor and circuit breaker enclosures, etc. is subject to special regulations or general technical rules.

When using conductive aluminum alloys, certain difficulties may arise due to their inadequate strength [1]. However, the alloys developed in recent years have sufficient strength properties even in the soft state to enable their use as conductive materials [4–6].

E-AlMgSi (Aldrey) is one of the conductive aluminum alloys, which belongs to the heat-strengthened alloys. It is characterized by high strength and good moldability. This alloy acquires high electrical conductivity with appropriate heat treatment. Wires made of it are used almost exclusively for overhead power transmission lines [7–9].

Since high-voltage power lines made of aluminum and its alloys are operated in the free atmosphere, the question of the corrosion resistance of the alloys is particularly important.

The objective of the research is to study the cadmium additives effect on the E-AlMgSi (Aldrey) aluminum conductor alloy oxidation kinetics, chemical composition, of the alloy (wt.%): Si – 0.5; Mg – 0.5. The method of thermogravimetry with continuous weighing of samples [10–14] was applied to solve the problem.

2. Experimental

Alloys synthesis was carried out in the shaft laboratory-size resistance furnace SSHOL type at a temperature of 750–800 °C. Alloy aluminum grade A6, that in addition was doped with silicon and magnesium calculated amount, was used as a charge in obtaining the E-AlMgSi. When doping aluminum with silicon, metallic silicon (0.1 wt.%) present in the primary aluminum composition was taken into account. Magnesium wrapped in aluminum foil was added up into the aluminum melt using an alloying basket. Metallic cadmium was introduced pure. The chemical analysis of the silicon and magnesium content of the alloys obtained was conducted in the Central Plant Laboratory of SUE “Tajik Aluminum Company”.

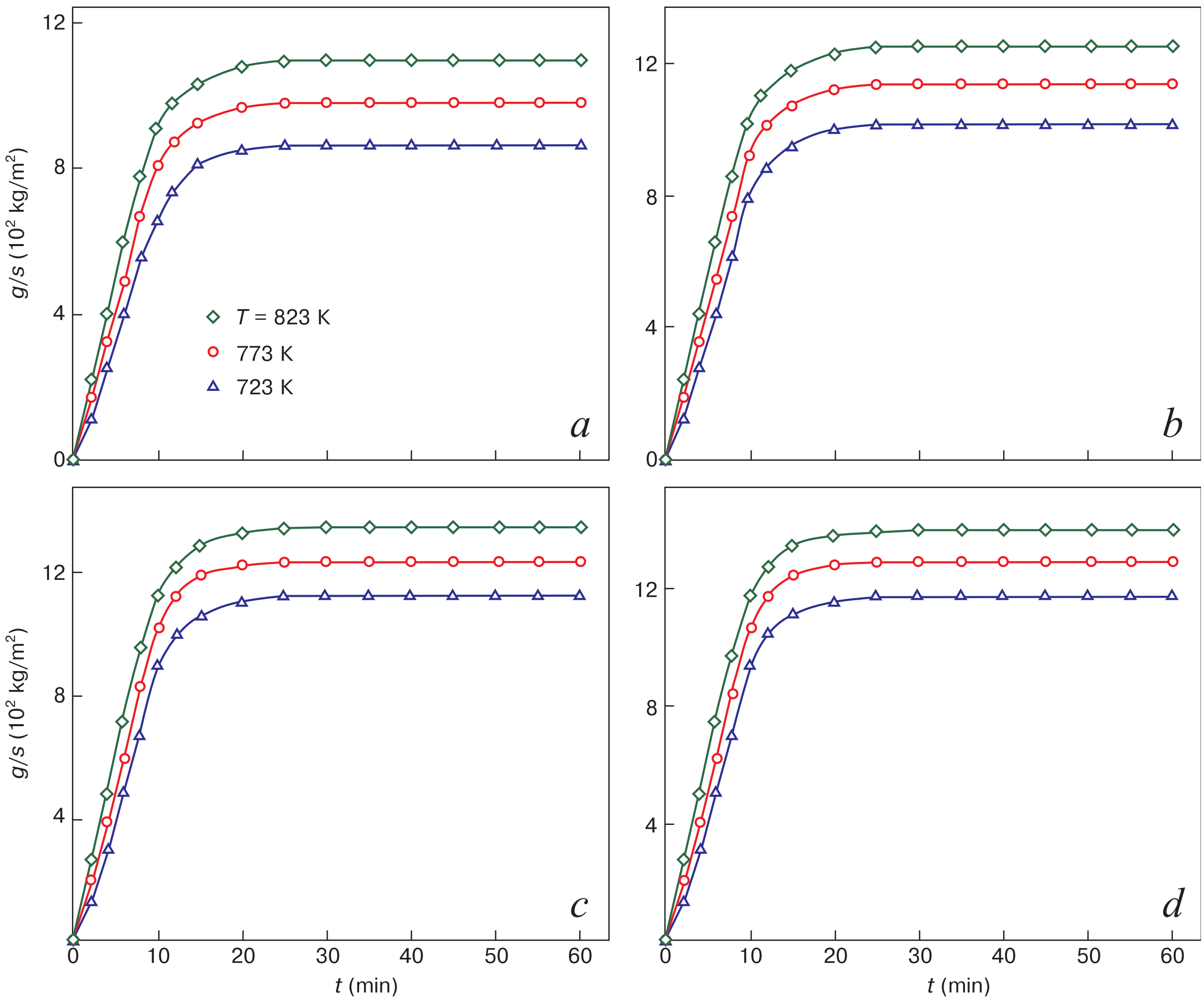

Figure 1. Kinetic curves of oxidation of the aluminum conductive alloy E-AlMgSi (Aldrey) (*a*) doped with cadmium, wt.%: 0.05 (*b*); 0.1 (*c*); 0.5 (*d*)

Table 1. Kinetic and energy parameters of the oxidation process of the aluminum conductive alloy E-AlMgSi (Aldrey) with cadmium, in the solid state

Cadmium content in alloy (wt.%)	Oxidation temperature (K)	True oxidation rate (10^4 kg/($m^2 \cdot s$))	Oxidation activation effective energy (kJ/mol)
0	723 773 823	2.67 2.89 3.28	128.5
0.01	723 773 823	2.73 2.94 3.35	119.9
0.05	723 773 823	2.77 2.99 3.39	114.2
0.1	723 773 823	2.81 3.05 3.46	107.0
0.5	723 773 823	2.86 3.11 3.50	99.5

The alloys composition was controlled by weighing the charge and the obtained alloys. In case of a weight deviation of the alloys of more than 1–2 rel.%, the alloy synthesis was carried out again.

3. Results and discussion

E-AlMgSi (Aldrey) aluminum conductive alloy oxidation additionally doped with cadmium in an air atmosphere was carried out at constant temperatures of 823, 773 and 723 K. The kinetic curves of the high-temperature oxidation process of the alloys investigated are shown in Fig. 1. With increasing temperature, the growth of the specific mass of the sample g/s as a function of time t was observed. The oxidation process of the alloys was intensive for the first 10–20 min and was linear, i.e. the protective properties of the formed thin oxide film on the surface of the studied alloy samples were not sufficiently manifested in the early stages of the oxidation process. At 873 K temperature, the initial alloy and the alloy, containing 0.01 wt.% of cadmium true oxidation rate varied from $3.28 \cdot 10^{-4}$ to $3.35 \cdot 10^{-4}$ kg/($m^2 \cdot s$) respectively, and the alloys effective activation energy value ranged from 128.5–119.9 kJ/mol (Table 1). Further, due to the dense protective oxide layer formation, the oxidation process slowed down and the curves acquired hyperbolic form, as evidenced by the alloys' oxidation non-straight-line

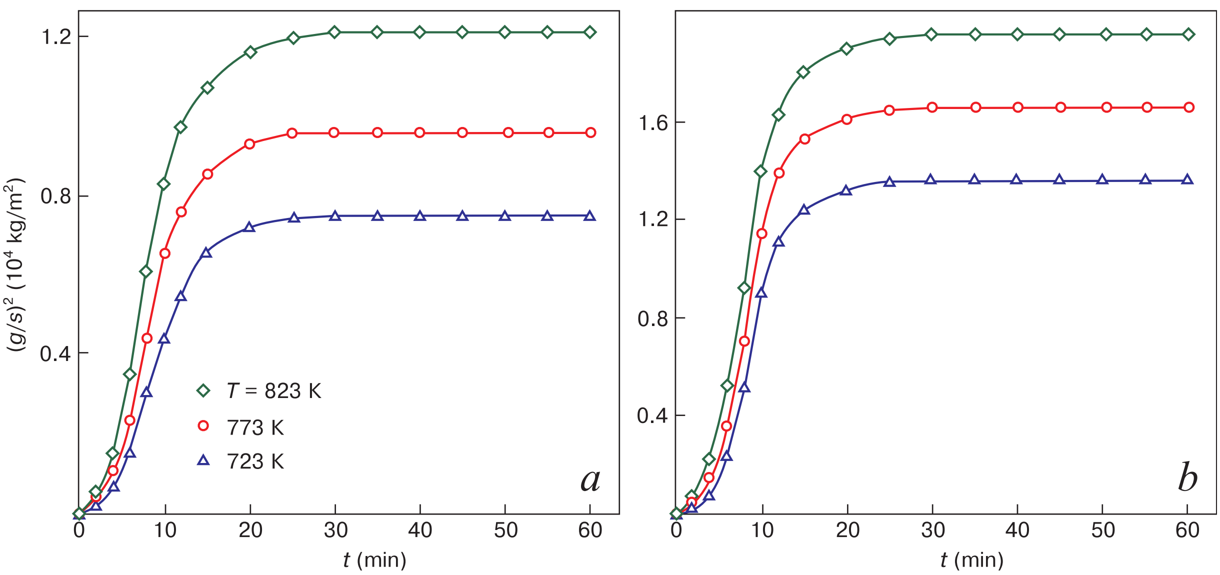

Figure 2. Quadratic kinetic curves of oxidation of an aluminum conductive alloy E-AlMgSi (Aldrey) (*a*) doped with 0.5 wt.% cadmium (*b*)

Table 2. Results of processing the quadratic kinetic curves of the oxidation process of the aluminum conductive alloy E–AlMgSi (Aldrey) with cadmium in the solid state

Cadmium content in alloy (wt.%)	Oxidation temperature (K)	Oxidation polynomials of alloy oxidation quadratic kinetic curves	Regression coefficient R
0	723 773 823	$y = -0.6 \cdot 10^{-5}x^4 + 0.001x^3 - 0.044x^2 + 0.973x$ $y = -0.6 \cdot 10^{-5}x^4 + 0.001x^3 - 0.038x^2 + 1.109x$ $y = -0.6 \cdot 10^{-8}x^4 + 0.002x^3 - 0.041x^2 + 1.289x$	0.981 0.988 0.994
0.01	723 773 823	$y = -0.5 \cdot 10^{-2}x^4 - 0.001x^3 - 0.016x^2 + 0.934x$ $y = -0.5 \cdot 10^{-1}x^4 - 0.5 \cdot 10^{-7}x^3 - 0.032x^2 + 1.168x$ $y = -0.6 \cdot 10^{-3}x^4 + 0.001x^3 - 0.057x^2 + 1.455x$	0.987 0.989 0.993
0.05	723 773 823	$y = -0.5 \cdot 10^{-3}x^4 - 0.000x^3 - 0.011x^2 + 0.95x$ $y = -0.6 \cdot 10^{-9}x^4 + 0.001x^3 - 0.045x^2 + 1.414x$ $y = -0.6 \cdot 10^{-2}x^4 + 0.001x^3 - 0.059x^2 + 1.526$	0.983 0.988 0.992
0.1	723 773 823	$y = -0.5 \cdot 10^{-2}x^4 - 0.001x^3 - 0.017x^2 + 1.033x$ $y = -0.5 \cdot 10^{-1}x^4 - 0.5 \cdot 10^{-1}x^3 - 0.038x^2 + 1.321x$ $y = -0.6 \cdot 10^{-5}x^4 + 0.001x^3 - 0.073x^2 + 1.770x$	0.984 0.987 0.994
0.5	723 773 823	$y = -0.5 \cdot 10^{-3}x^4 - 0.001x^3 - 0.011x^2 + 1.042x$ $y = -0.5 \cdot 10^{-2}x^4 - 0.001x^3 - 0.033x^2 + 1.323x$ $y = -0.7 \cdot 10^{-9}x^4 + 0.001x^3 - 0.62x^2 + 1.636x$	0.980 0.984 0.990

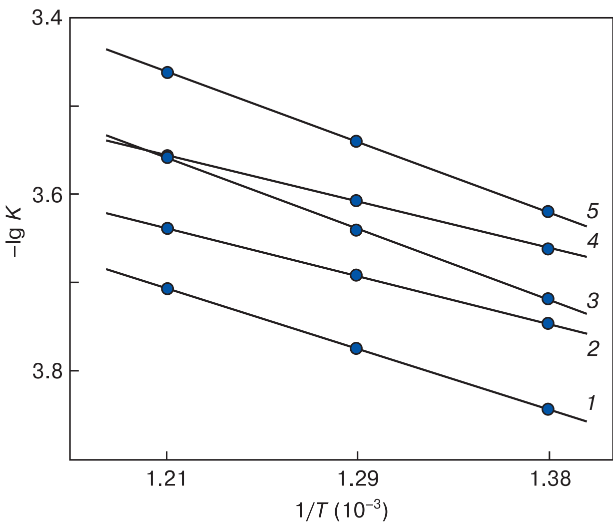

Figure 3. Dependence of lg$K$ on $1/T$ for aluminum conductive alloy E-AlMgSi (Aldrey) (*1*) doped with cadmium (wt.%): 0.01 (*2*), 0.05 (*3*), 0.1 (*4*), 0.5 (*5*)

quadratic kinetic curves (Fig. 2) and the analytical dependence $y = kt^n$, where $n = 1–4$ (Table 2). Fig. 2 and Table 2 show that the high-temperature oxidation process of the alloys investigated does not follow the parabolic laws of oxide film growth in the selected temperature range.

Alloys oxidation process kinetic parameters depend on the oxide film structure. 20 min alloys oxidation does not lead to a specific mass increase. The true oxidation rate maximum value and the effective activation energy minimum value of the process correspond to the alloys containing 0.1 and 0.5 wt.% of cadmium, which are characterized by low samples interaction energy with the gas phase oxygen in the solid state (see Table 1).

In the lg$K$–$1/T$ coordinates, the alloys high-temperature oxidation process curves are represented by straight lines (Fig. 3), which slope angle predetermines the effective oxidation activation energy.

The kinetic curves of the high-temperature oxidation process of the aluminum alloy E-AlMgSi with cadmium are characterized by a monotonic increase in the true oxidation rate and a decrease in the effective activation energy as a function of the content of the cadmium doping component in the initial alloy E-AlMgSi.

According to the research results, the oxidation isochrones of the E-AlMgSi aluminum alloy of different cadmium concentrations were plotted and are shown in Fig. 4. The curves are characterized by an oxidation rate monotonic increase with temperature growth, both at 10-minute alloys soaking in an oxidizing atmosphere and at 20-minute one. This behavior is more clearly expressed at the temperatures studied, as evidenced by the

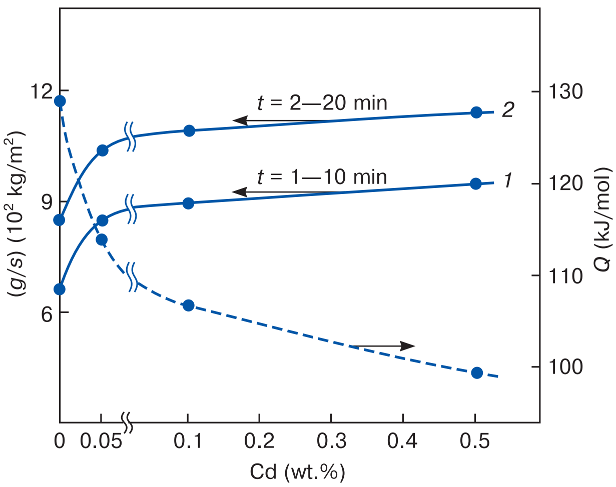

Figure 4. Isochrones of oxidation (723 K) of the aluminum conductive alloy E-AlMgSi (Aldrey) doped with cadmium

alloys oxidation apparent activation energy decrease with increasing cadmium concentration.

4. Conclusion

As is known, temperature has a major impact on the thermodynamic reaction possibility between the metal and the gas phase oxygen and respectively on the of gas corrosion rate. The temperature increase causes the same effect for the rate constant of the alloys oxidation chemical reaction (see Table 1), which is calculated by the Arrhenius equation, and for the reagents diffusion rate of the oxidation products film. Temperature also has a significant impact on the formed films composition and their growth law.

In the oxidation of the aluminum alloy E-AlMgSi (Aldrey) the oxidation products are mainly composed of α-Al_2O_3, as confirmed by IR spectroscopic studies. Absorption frequencies at 457, 599, 630 and 1097 cm^{-1} correspond to the O = Al — O — Al = O bonds in the α-Al_2O_3 oxide structure.

Doping E-AlMgSi (Aldrey) alloy with cadmium increases its oxidation rate (see Table 1), which is associated with the protective capacity deterioration of the Al_2O_3 and CdO oxides resulting oxidation. The latter, mechanically penetrating into the composition of Al_2O_3, deteriorates its protective capacity. It can be assumed that CdO oxide is insoluble in Al_2O_3 oxide.

As provided by the V.I. Arkharov theory, the increase of heat resistance is achieved if the doping element forms a double spinel-type oxides with the base metal. According to the theory, the doping elements should prevent the formation of separate oxides on the surface of the samples.

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