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The structure, mechanical properties and corrosion resistance of aluminium AlMg1Si1 alloy

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Properties

ABSTRACT

Purpose: The aim of this investigation was to define optimum heat treatment parameters so as to received the alloy resistant for stress corrosion cracking, within the limits of the corrosion factor i.e. artificial sea water (3 % NaCl solution).

Design/methodology/approach: The corrosion tests (in corrosion environment and inert-glycerol) were carried out on the device, making possibility extension of the samples with constant speed until break. Another investigations: SEM, tensile and Vickers hardness tests, X-ray Phase Analysis, light microscopy and TEM.

Findings: The researches included structural analyze, mechanical and corrosion investigations, which allow to define the optimum parameters (quenching at 560ºC temperature, in water, artificial ageing at temperature160ºC/12h) so as to received the alloy resistant for stress corrosion cracking.

Research limitations/implications: Contributes to research on corrosion protection for aluminium and its alloys.

Practical implications: Conducted investigations lay out the areas of later researches, especially in the direction of the possible, next optimization tests of their structure, e.g. in the range of raising resistance on corrosion cracking in chosen media.

Originality/value: The range of possible uses the regard also increases from this, as materials on working constructions in the investigated aggressive environment.

Keywords: Corrosion and erosion; Stress corrosion cracking; Metallic alloys; Aluminium; Mechanical properties

1. Introduction

Present tendencies of the development of different groups of materials evidence the fact, that the mass- participation of modern products (such as products of the aircraft industry, aerospace industry or biomaterials) is constantly increasing.

Prevailing are still metal materials, because nowadays it is not yet possible using everywhere for example polymers, because of their small abrasion resistance, resistant to corrosion, and also for temperature range of the usage, not exceed the temperature range 300÷400°C.

By the reason of this the basic materials in the mechanical engineering, automotive industry, shipbuilding industry, metal industry, the household, and building industry there are so still metals and their alloys.

Nowadays the technology makes many requirements to construction materials in the range of their low production costs, availability and good mechanical properties, great heat resistance, the resistance on corrosions and the not large specific gravity.

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Application of aluminium alloys meet above requirement in many branches of industry (Fig. 1) [1].

The combination of acceptable cost, low component mass (derived from its low density), appropriate mechanical properties, structural integrity and ease of fabrication are also attractive in other areas of transport.

Aluminium is used in buildings for a wide spectrum of applications. These include roofing for factories which incorporate foil vapour barriers, windows and pre formed sheet cladding features, doors, canopies and fronts for shops and prestigious buildings, architectural hardware and fittings, rainwater goods and replacement windows [2].

The successful use of aluminium alloys as foil for food wrapping and for containers utilizes their good corrosion resistance and barrier properties against UV light, moisture and odour. Foil can be readily formed, attractively decorated and can be usefully combined with paper and plastic if required.

Among all aluminium alloys are use alloys on the groundmass AlMgSi.

They have good mechanical properties, good corrosion resistance in many environments. There is also possibility to improve their mechanical properties (precipitation strengthening), with parcipitation some phases, in this case Mg_2Si precipitations [3].

One from important factors characterizing materials is their resistance on the corrosive fissuring. Connected problems with the corrosion of analysed alloy deserve nowadays on the greater attention than till now for :

- the more and more wider use aluminium in all spheres of the techniques,
- the elevated corrosive aggressiveness of the environment in consequence of the increasing air pollution and water,

application more lightweight metal construction .

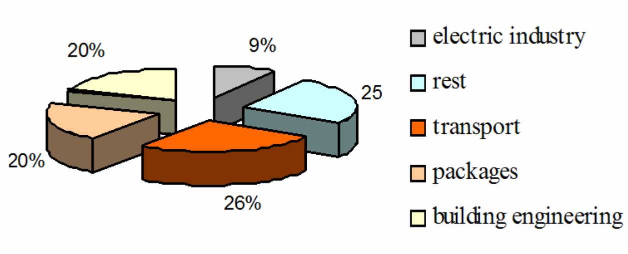

Fig. 1. Main applications of aluminium alloys [1]

2. Stress corrosion of aluminium alloys

Stress corrosion cracking (SCC) is a form of localized damage that refers of cracking under the combined influence of tensile stress and corrosion environment (Table 1).

The macroscopic fracture appearance tends to be of the “brittle” type, even if the metal/alloy is of a mechanically ductile variety.

Stresses that can contribute to (SCC) include the applied, residual and thermal varieties, and also those generated by the build-up of corrosion products. Welding, heat treatments, fitting and forming operations can produce significant residual stress levels, in some cases approaching the yield strength (often surprising the unsuspecting) [4-6].

Consequently activities of tension corrosion come into being crevices being developed in general perpendicularly to the direction of the activity of tensions and at last leading to the lack of tightness in installations or to the damage of the construction or devices [7-9].

Stress corrosion cracking proceeds in three stages [5]:

- first stage – cracks initiation and the height speed of the fissuring (brittle fracture). If metal is coated a passive layer this in such place she surrenders to the break. The surface becomes an anodal place and surrenders to the dissolution,
- the second stage is characterized with the steady speed of the fissuring (brittle fracture),
- the third stage then the distributive crack; the progressive tension crack causes the diminution of the active section of the sample and material is damage (the plastic fracture).

Stress corrosion cracking generally considered to be the most complex of all corrosion types. Cracking can have a transgranular or intergranular morphology (Fig. 2.) [10, 11].

The detection and monitoring of SCC and data interpretation tend to be highly challenging. Even in closely controlled laboratory experiments, it is very difficult to obtain reproducible results. Some stress corrosion cracks are so fine, that metallographic examination is required for their identification. Stressed coupons have been used for monitoring purposes. Electrochemical noise has been employed as an on-line monitoring technique in selected applications but it provides no direct information on the rate of crack growth. The use of in-line inspection tools is an approach related to pipeline inspection.

There are several methods to prevent stress corrosion cracking [12]:

- Select suitably resistant materials of construction.
- Keep stress levels as low as possible (stress-relief where possible).
- Keep stress levels as low as possible (stress-relief where possible).
- Be aware of all of the constituents in the service environment. SCC problems are often caused by trace impurities !
- Avoid designs that allow stagnant regions where impurities can concentrate or deposit.
- Use lower operating temperatures if possible.
- Apply cathodic protection (for chloride-induced SCC only).
- Use inhibitors.

3. Experimental procedures

The investigations were carried out on aluminium alloy AlMg1Si1, using cylindrical specimens about diameter 1,98 mm. The chemical composition of the investigated alloy is presented in Table 2.

The heat treatment was consisted of quenchning (in water) and next artificial ageing. The specification of different heat treatment cycles applied to the specimens are presented in Table 3.

Metallographic examinations of the material structure were made on Leica light microscope with magnification from 500 to 1300x. X-ray examinations of investigated aluminium alloy was

Table 1
Some combinations of environment and material known to cause stress corrosion [6]

Material	Environment known to cause stress corrosion
Al alloys	Moist air, Sea Water, Chloride, Bromide and iodide solutions
Cu alloys	Ammonia solutions and vapours, amines, moist SO_2, solutions of acetates, citrates formates, tartrates, nitrites and sodium hydroxide.
Ni alloys	Hydroxide solutions and hydrofluoric acid vapour
Ti alloys	Solutions of chlorides, bromides, and iodides, liquid N_2O_4, methanolic solutions and dry salts and elevated temperatures
Low strength ferritic steels	Solutions of hydroxides, nitrates, carbonates, phosphates, molybdates, acetates, cyanides, and liquid ammonia
High Strength ferritic steels	Moist air, water, aqueous and organic solutions. Susceptibility increases with increasing stregnth of materials
Stainless Steels	Solutions of chlorides , fluorides, iodides, bromides, sulphates , Phosphates, nitrates and polythionic acids

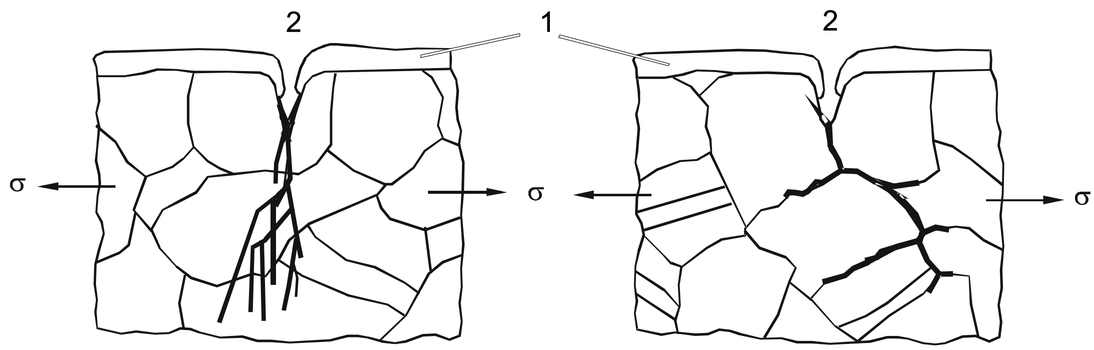

Fig. 2. Scheme of stress corrosion cracking (1- passive layer, 2 – places of the damages of passive layer, σ- tensile stresses) [10]

made using a XRD-7 (SEIFERT-FPM) diffractometer with a Co anode. The X-ray tube was supplied with the current I= 40 mA under a voltage of U=35 kV. Diffraction examinations were performed within the range of angles 2θ from 20º to 90º. The measurement step was 0,5º in length whilst the pulse counting time was 4s.

Table 2.
Chemical composition of the investigated AlMg1Si1 alloy

Alloy type	Average mass concentration of elements, %							
	Mg	Si	Fe	Mn	Ni	Zn	Cu	Al
AlMg1Si1	1,33	1,07	0,38	0,63	0,3	0,03	Minute quantities	rest

Table 3.
Specification of heat treatment

Alloy	Heat treatment			
	Qquenching temperature / quenching time [h]			Artificial ageing Temperature/ageing time [h]
AlMg1Si1	500°C/3h	520°C/3h	560°C/3h	160°C/3, 6, 9, 12, 24h

Examinations of the chemical composition in micro-zones and local analyses distribution of alloying elements in specimens from the investigated alloy were made on the XL-30 PHILIPS scanning electron microscope with EDAX energy dispresive X-ray spectrometer with 20 kV accelerating voltage.

The investigations of diffraction and thin foils were made on the JEOL 2000 FX transmission electron microscope at the accelerating voltage of 160 kV.

Mechanical properties included tensile tests and Vickers hardness tests.

The corrosion tests were made on the INSTRON type 1195, making possibility extension of samples with constant speed until break. The corrosion resistance of the investigated alloy have been determine by the tests in corrosion environment, which was sea water and inert (glycerol) [13].

The composition of the corrosion environment was following:

- 3 % NaCl solution,
- buffered solution, which should maintain pH = 3,5:
    - 0,5N CH_3COONa
    - 0,5N CH_3COOH.

4. Result and discussion

The selected typical structure of investigated alloy in initial state is shown in the Figure 3a. The basic structure of aluminium AlMg1Si1 alloy consists of the solid solution matrix on the Al base, Mg_2Si precipitations and evenly distributed, dark precipitates of AlSiMnFe with characteristic anchor shape.

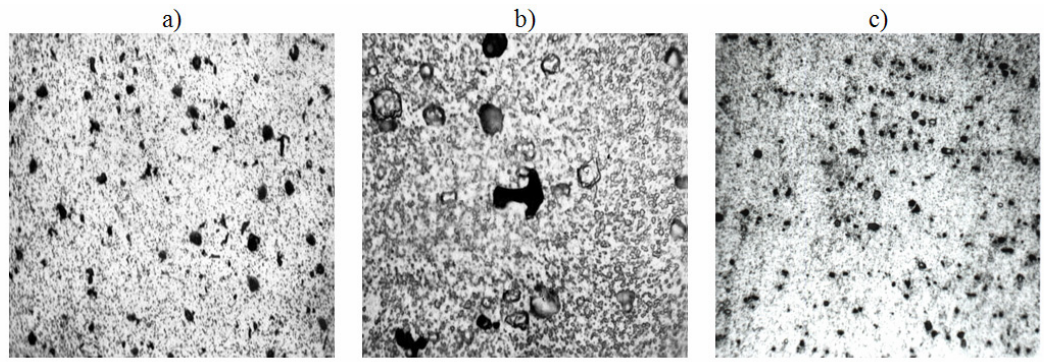

Fig. 3. Structure of the aluminium alloy AlMg1Si1, a) initial state 600x, b) after quenching at 520°C temperature, 1300x c) after quenching at 560°C temperature and ageing at temperature160°C/12h, 600x

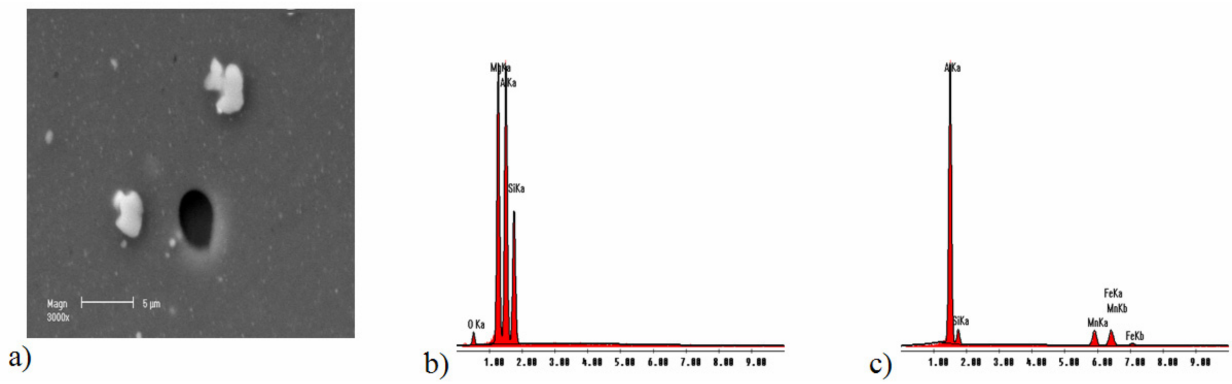

Fig. 4. a) Structure of AlMg1Si1 alloy after quenching at temperature 560°C and ageing at temperature 160°C/12h, b) dark precipitations, c) light precipitations

It possible to observe similar differences in structures in samples after heat treatment. During quenching at temperatures 500°C, 520°C and 560°C phase β Mg_2Si has dissolved in groundmass while dark etched precipitates of AlSiMnFe phase hasn't dissolved (Fig. 3b).

In structure after artificial ageing at temperature 160°C is visible very small precipitations of phase β Mg_2Si and AlSiMnFe phase. Evident systems of dark precipitations as chains are phase β Mg_2Si nucleationed heterogeneous (Fig. 3c)

Investigations of the chemical composition in micro-zones suggested presence of intermetallic phase contained Al, Si, Mn Fe (light precipitations, Fig. 4c.) but by the reason of too much amount of aluminium (because of induction precipitation and also metallic matrix) proportions of this elements doesn't correspond to the stoichiometry of known phases.

In the case of dark precipitations the results of the analyse of the chemical composition in micro-zones suggested presence Mg_2Si phase, but by above mentioned reason, it is not possible to finally determine presence of this phase (Fig. 4b.).

In order to determine the kind of the precipitation it has been carried out X-ray qualitative analyze. As a result of qualitative X-ray analyses it was found only phase α (Al) (Fig. 5).

Besides the amount of another phases is too small quantity, undetectable in this method. So there was the reason to carried out farther investigations to specify phase composition.

On the ground of the investigations of diffraction and thin foils in transmission electron microscope it was found that the structure of aged alloy consists of aluminium and characteristic phases of this alloy - Al_3Mg_2 precipitations and also Mg_2Si - which is hardening phase (Fig. 6 and 7).

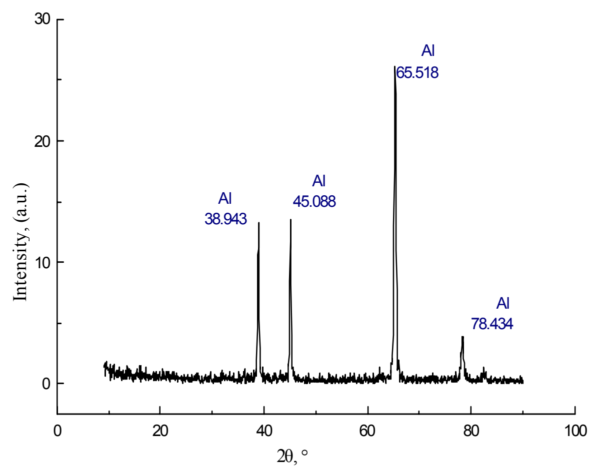

Fig. 5. X-ray diffraction of AlMg1Si1 alloy in initial state

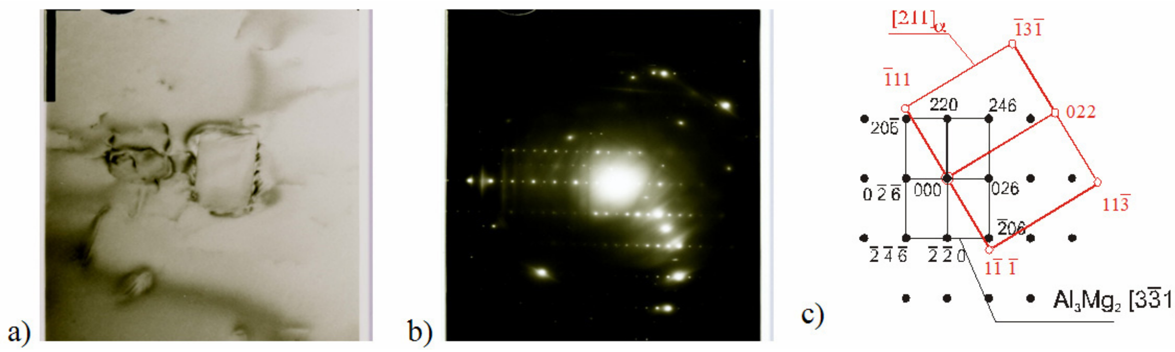

Fig. 6. a) Structure of the thin foil from AlMg1Si1 alloy after quenching at temperature 560°C and ageing at temperature 160°C/12h b) diffraction pattern from the area as in figure a, c) solution of the diffraction pattern from the figure b

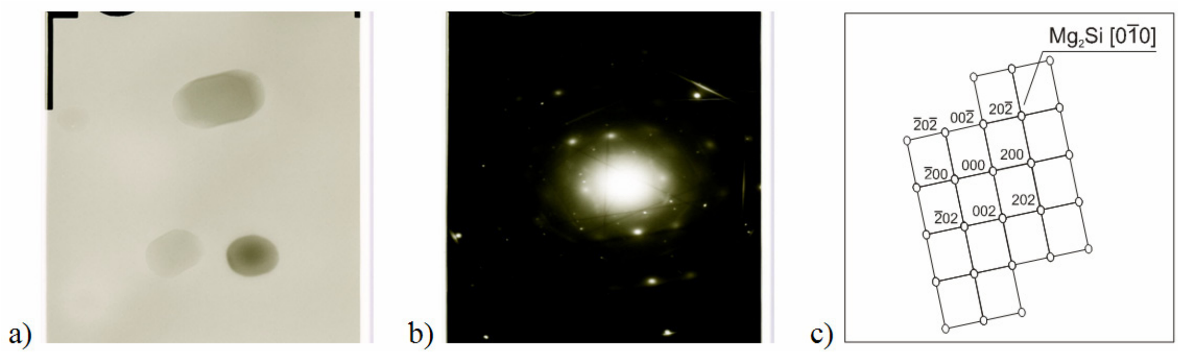

Fig. 7 a) Structure of the thin foil from AlMg1Si1 alloy after quenching at temperature 560°C and ageing at temperature 160°C/12h b) diffraction pattern from the area as in figure a, c) solution of the diffraction pattern from the figure b

Measured mechanical properties (tensile strength and Vickers hardness) correspond to structure investigations. It is observed that the highest strength and hardness was determine after quenching at 560°C temperature and ageing at 160°C/12h.

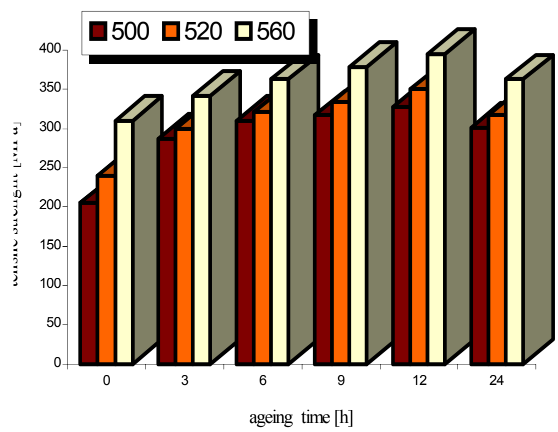

Fig. 8. The influence of quenching temperature and ageing time on tensile strength of AlMg1Si1

The main aim of the investigations was specification of the resistance to stress corrosion cracking of analyzed alloy. The investigations were carried out at the ambient temperature, with using INSTRON 1195, making possibility extension with constant speed.

Prolongation the ageing time to 24h causes decreasing all mechanical parameters values in each case (Fig. 8 and table 4).

Table 4.
The results of Vickers hardness tests

Ageing time	Hardness HV		
	Quenching temperature		
	500°C	520°C	560°C
quenching	51	68	81
3	56	82	94
6	65	93	104
9	72	99	110
12	87	113	117
24	73	105	108

The comparison criteria which characterized this resistance was coefficient k_σ, defined as proportion of maximal stresses in corrosion environment to maximal stresses in inert environment.

The results of corrosion tests are presented in figure 9. The crack resistance increases with ageing time, reach the maximum value in each case after ageing by 12h. Prolongation of the artificial ageing to 24h causes decrease of the coefficient k_σ value in each heat treatment cycles. The optimum resistance to stress corrosion cracking of investigated alloy was reached after quenching in temperature 560ºC /3h and after ageing in 160ºC/ 12h.

After corrosion tests were carried out fractography tests. Analyzed samples have typically ductile fracture (Fig. 10). There are also some samples where can be mixed fracture - ductile and brittle fracture.

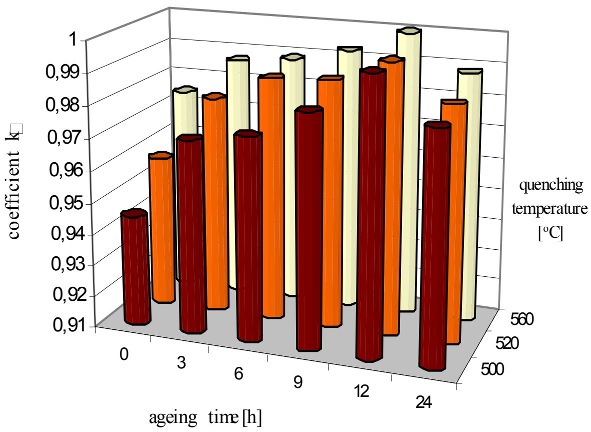

Fig. 9. The relationship of coefficient k_σ and temperature of quenching and ageing time

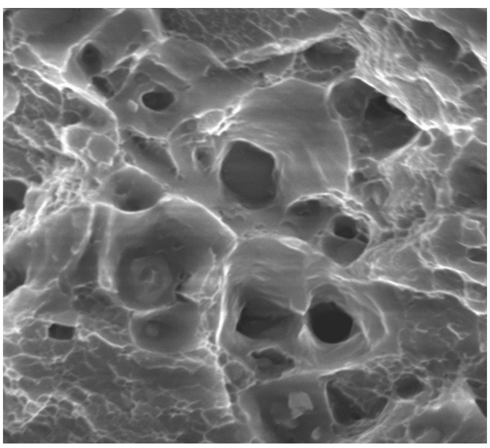

Fig. 10. Ductile fracture of AlMg1Si1 alloy after quenching at temperature 560°C and ageing at temperature 160°C/12h

5. Conclusions

In the paper it has been presented researches results of the influence of heat treatment on structure, mechanical properties and corrosion resistance of aluminium AlMg1Si1 alloy.

The researches included evaluation of the influence of applied heat treatment on some mechanical properties and structural analysis, which allow to define its optimum parameters so as to received the alloy resistant for stress corrosion cracking, within the limits of the corrosion factor i.e. sea water, in the conditions of the stress corrosion. It was the main aim of the researches.

Established, in the work, optimum parameters of the precipitation strengthening of the investigated alloy are following:

- for alloy AlMg1Si1 quenching in the temperature 560ºC in water and artificial ageing in temperature 160ºC during 12 hours. The value of the coefficient k_σ on the level 1.
- The crack resistance of analyzed aluminium alloy in the conditions of the stress corrosion, in sea water, in the particular stadium of artificial ageing has similar character adequate to mechanical properties.

Investigated aluminium alloy characterized high crack resistance in the analyzed conditions.

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