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Structure, mechanical properties and corrosion resistance of AlMg5 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: 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.
Practical implications: The range of possible uses the regard also increases from this, as materials on working constructions in the investigated aggressive environment.
Originality/value: Contributes to research on corrosion protection for aluminium and its alloys.
Keywords: Corrosion; Stress corrosion cracking; Aluminium; Mechanical properties

1. Introduction

The development of the many branches of national economy in the essential degree depends on the deliveries of non-ferrous metals, which create the more considerably varied set of alloys in the comparison with steel.

The main properties which make aluminium a valuable material are its low density, strength, recyclability, corrosion resistance, durability, ductility, formability and conductivity.

Due to this unique combination of properties, the variety of applications of aluminium continues to increase.

Aluminium and its alloys have been the prime material of construction for the aircraft industry throughout most of its history. Even today, when titanium and composites are growing in use, 70% of commercial civil aircraft airframes are made from aluminium alloys, and without aluminium civil aviation would not be economically viable [1-6].

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.

Today, ships are being designed and built for larger capacity, higher speeds and better manoeuvrability. That is, they must have as low a dead-weight as possible [5]. However, at the same time, due to safety and economical considerations, there should be no compromises either on quality or performance of the material used. In other words, the material must have the properties of high strength and excellent durability. Only innovative aluminium alloys and products can fully meet these demanding requirements [7].

2. Experimental procedures

The investigations were made using cylindrical specimens about diameter 1,98 mm from aluminium alloy AlMg5 containing 4.37% Mg, 0.18% Si, 0.42% Fe, 0.39% Mn, 0.03 Ni, 0.03 Zn, Cu-minute quantities, Al rest [8-11].

The heat treatment was consisted of quenching in water at temperatures: 480°C/12h, 520°C/12h, 560°C/12h and next artificial ageing at temperature 160°C/3, 6, 9, 12, 24h.

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 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.

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 dispersion 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) [12-13].

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.

3. Results and discussion

The selected typical structure of investigated alloy in initial state is shown in Figure 1a. The basic structure of aluminium AlMg5 alloy consists of the solid solution matrix on the Al base, Al_3Mg_2 precipitations and evenly distributed, dark precipitates of AlSiMnFe with characteristic anchor shape.

It is possible to observe similar differences in structures in samples after heat treatment. During quenching at temperatures 480°C, 520°C and 560°C phase β Al_3Mg_2 has dissolved in groundmass while dark etched precipitates of AlSiMnFe phase hasn't dissolved (Fig. 1b).

In the structure after artificial ageing at temperature 160°C it was found out very small precipitations of phase β Al_3Mg_2 and AlSiMnFe phase. Evident systems of dark precipitations as chains (Fig. 1c).

Investigations of the chemical composition in micro-zones suggested presence of intermetallic phase contained Al, Si, Mn Fe (light precipitations, Fig. 2c) 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 analysis 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. 2b).

In order to determine the kind of the precipitation it has been carried out X-ray qualitative analyse. As a result of qualitative X-ray analyses it was found only phase α (Al) (Fig. 3). 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.

a) b) c)

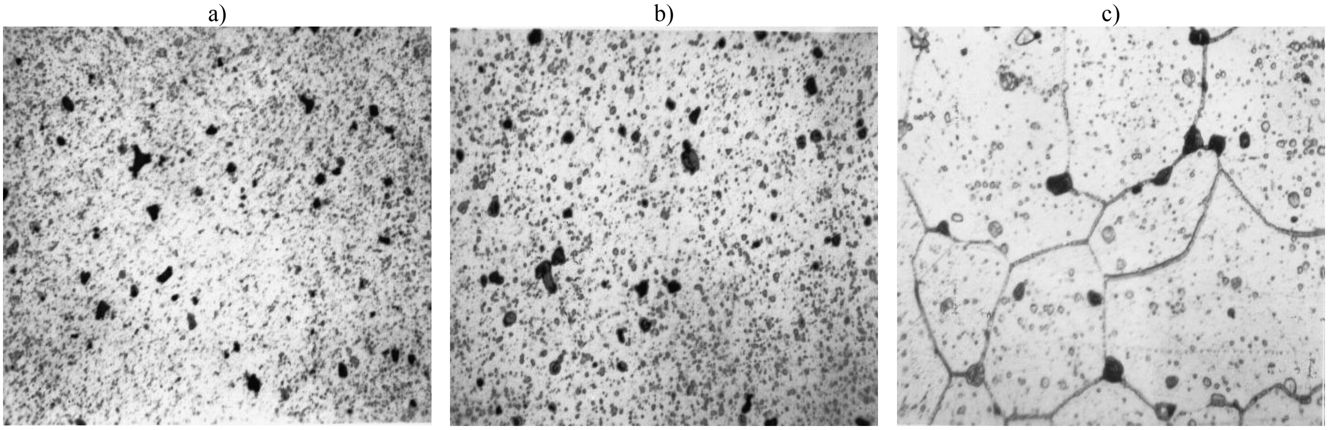

Fig. 1. Structure of the aluminium AlMg5 alloy, a) initial state, 600x, b) after quenching at 480°C temperature, 600x c) after quenching at 560°C temperature and ageing at temperature 160°C/12h, 600x

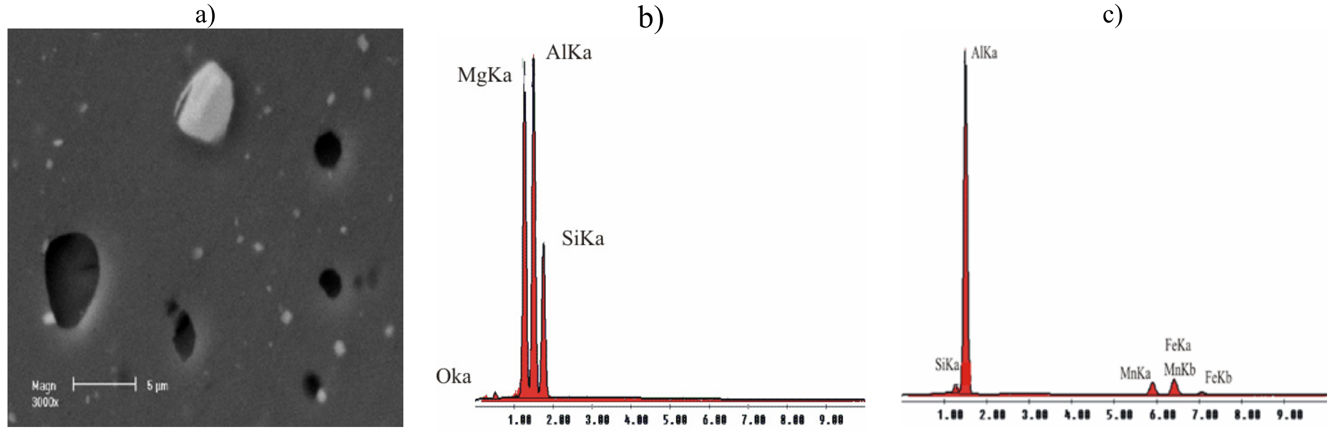

Fig. 2 a) Structure of AlMg5 alloy after quenching at temperature 520°C and ageing at temperature 160°C/12h, 3000x b) dark precipitations, c) light precipitations

It has been found out on the investigations of thin foils in transmission electron microscope, that the structure of the investigated alloy after quenching at temperature 560°C and ageing at temperature 160°C/12h consists of aluminium and phase Al_3Mg_2 which is hardening phase (Fig. 4).

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. Prolongation the ageing time to 24h causes decreasing all mechanical parameters values in each case (Fig. 5).

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. The comparison criteria which characterized this resistance was coefficient k_σ.

The results of corrosion tests are presented in Figure 6. The crack resistance increases with ageing time, reach the maximum value in each case after ageing by 12h.

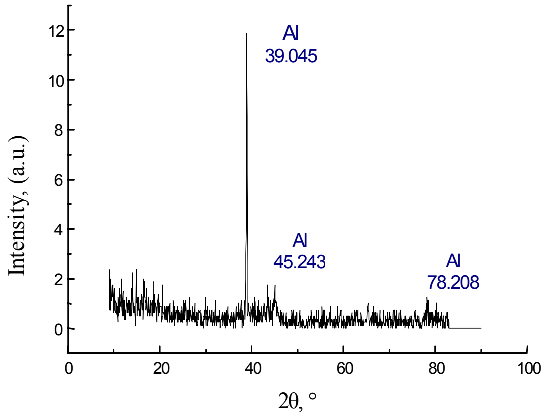

Fig. 3. X-ray diffraction of AlMg5 alloy after quenching at temperature 560°C and ageing at temperature 160°C/12h

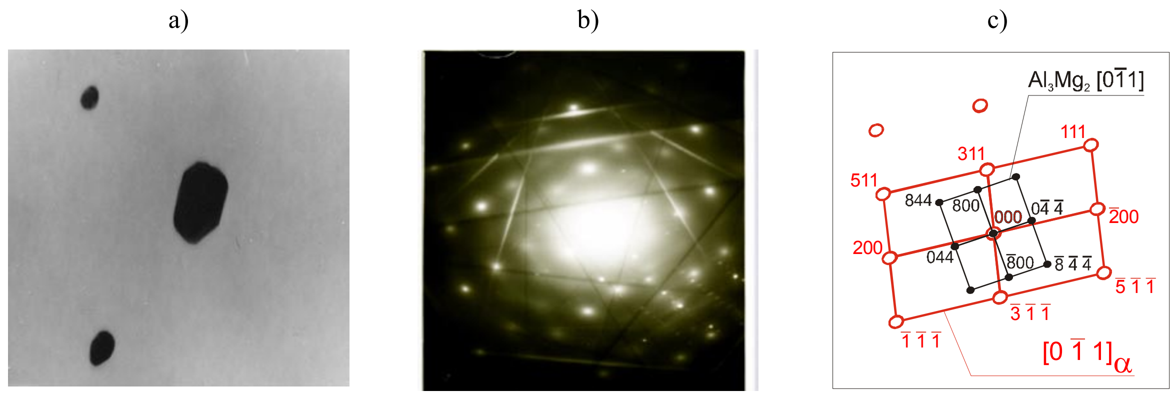

Fig. 4 a) Structure of the thin foil from AlMg5 alloy after quenching at temperature 560°C and ageing at temperature 160°C/12h, b) diffraction pattern from the area as in Figure a, c) solution of the diffraction pattern from the Figure b

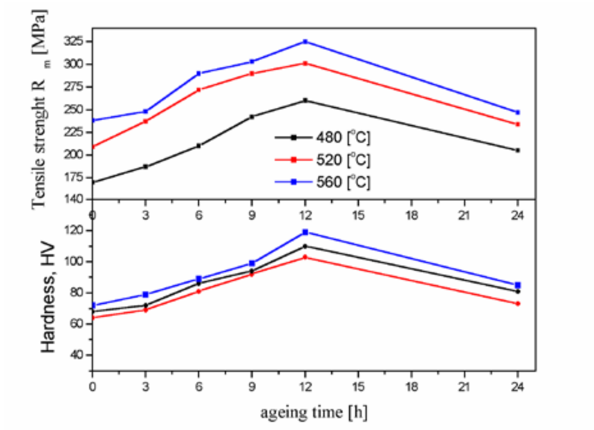

Fig. 5. The influence of quenching temperature and ageing time on tensile strength of AlMg5

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 at temperature 560°C /3h and after ageing at temperature 160°C/ 12h [8-10].

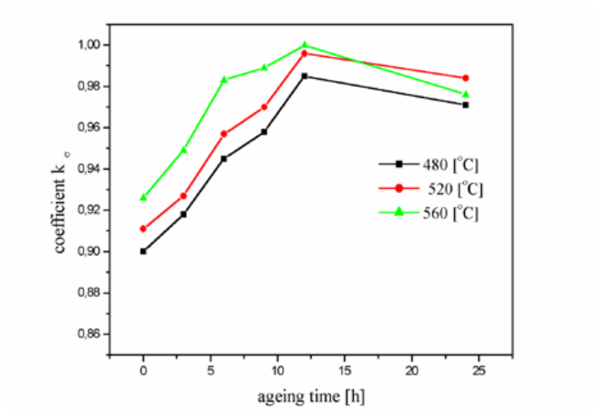

Fig. 6. The relationship of coefficient k_σ and temperature of quenching and ageing time

After corrosion tests were carried out fractography tests. Analyzed samples have typically ductile fracture. There are also some samples where can be mixed fracture - ductile and brittle fracture [14,15].

4. Conclusions

The researches included evaluation of the influence of applied heat treatment on some mechanical properties, structural analysis and resistant for stress corrosion cracking, within the limits of the corrosion factor, i.e. sea water, in the conditions of the stress corrosion.

Established, in the work, optimum parameters of the precipitation strengthening of the investigated alloy are following: quenching at the temperature 560°C in water and artificial ageing at temperature 160°C 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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