Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 21 ISSUE 1 March 2007

Structure, mechanical properties and corrosion resistance of AlMg5 and AlMg1Si1 alloys

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Received 16.10.2006; accepted in revised form 15.11.2006

Properties

ABSTRACT

Purpose: The main task of this work was to define the optimum heat treatment parameters so as to received the alloys resistant for stress corrosion cracking, within the limits of the corrosion factor, i.e. artificial sea water.

Design/methodology/approach: The mechanical properties were evaluated by tensile tests. 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, , 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 temperature 160ºC/12h) so as to received the alloys 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 growing demand for more fuel-efficient vehicles to reduce energy consumption and air pollution is a challenge for the automotive industry [1-6]. The characteristic properties of aluminium, high strength stiffness to weight ratio, good formability, good corrosion resistance, and recycling potential make it the ideal candidate to replace heavier materials (steel or copper) in the car to respond to the weight reduction demand within the automotive industry [7-9]. Aluminum owes its corrosion resistance to the barrier oxide film that forms immediately in a wide variety of environments. This oxide film is self-renewing and accidental abrasion or other mechanical damage of the surface film is rapidly repaired.

2. Experimental procedures

The investigations were made using cylindrical specimens about diameter 1,98 mm from aluminium 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 and AlMg1Si1 alloy containing 1,33% Mg, 1,07% Si, 0,38% Fe, 0,63% Mn, 0,3 Ni, 0,03 Zn, Cu- minute quantities, Al rest.

The heat treatment was consisted of quenching (in water) and next artificial ageing. The specification of different heat treatment cycles applied to the specimens is presented in Table 1.

Metallographic examinations of the material structure were made on Leica light microscope with magnification from 500 to 1300x.

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.

Table 1.
Specification of heat treatment

Alloy	Heat treatment			
	Quenching temperature/ quenching time [h]			Artificial ageing Temperature/ ageing time [h]
AlMg5	480°C/12h	520°C/12h	560°C/12h	160°C/3, 6, 9, 12, 24h
AlMg1Si1	500°C/3h	520°C/3h	560°C/3h	

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.

The corrosion tests were made on the INSTRON type 1195, making possibility extension of samples with constant speed until break [10]. 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 structures of investigated alloys in initial state are shown in Figure 1a and 1b. The basic structure of the researched aluminium alloys consists of the solid solution matrix on the Al base, Al_3Mg_2 precipitations (AlMg5), Mg_2Si (AlMg1Si1) and evenly distributed, dark precipitates of AlSiMnFe with characteristic anchor shape [11-15].

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. 1c).

In the case of AlMg5 alloy 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. 1d).

Investigations of the chemical composition in micro-zones suggested presence of intermetallic phase contained Al, Si, Mn Fe (light precipitations, Fig. 2c and Fig. 3c) 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 and Fig. 3b).

It has been found out, basing on the investigations of thin foils in transmission electron microscope, that the structure of the investigated alloy AlMg5 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).

On the ground of the investigations of diffraction and thin foils in transmission electron microscope it was found that the structure of aged alloy AlMg1Si1 consists of aluminium and Mg_2Si precipitations -which is hardening phase (Fig. 5).

Prolongation the ageing time to 24h causes decreasing all mechanical parameters values in each case (table 2).

The main aim of the investigations was specification of the resistance to stress corrosion cracking of analyzed alloys.

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. 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 alloys was reached after quenching at temperature 560ºC and after ageing at temperature 160ºC/ 12h.

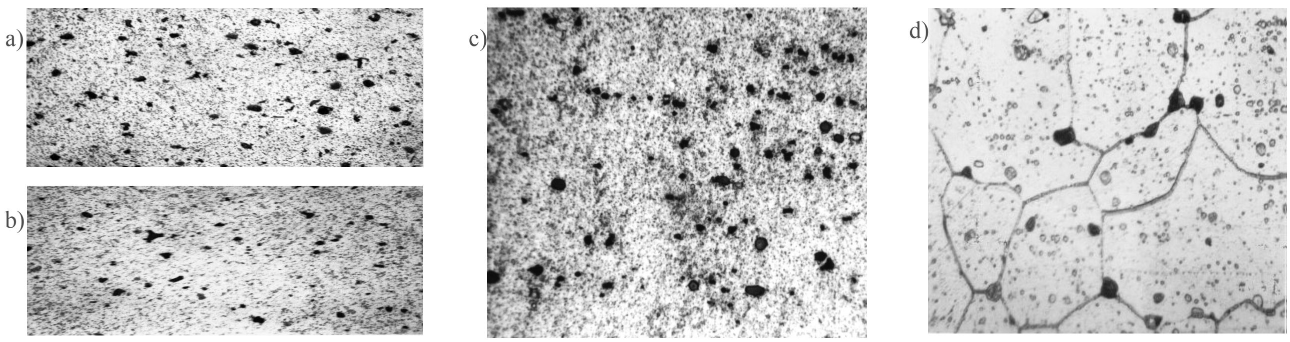

Fig. 1. a) Structure of the aluminium AlMg1Si1 alloy in initial state, 600x, b) Structure of the aluminium AlMg5 alloy in initial state, 600x, c) Structure of the aluminium AlMg1Si1 alloy after quenching at 560°C temperature and ageing at temperature 160°C/12h, 600x; d) Structure of the aluminium AlMg5 alloy after quenching at 560°C temperature and ageing at temperature 160°C/12h

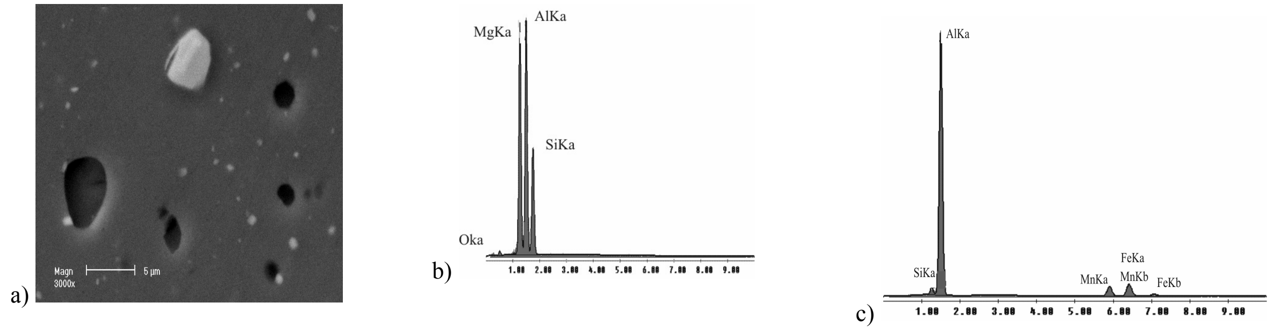

Fig. 2. a) Structure of AlMg5 alloy after quenching at temperature 520°C and ageing at temperature 160°C/12h, 3000x b) dark precipitations, c) light precipitations

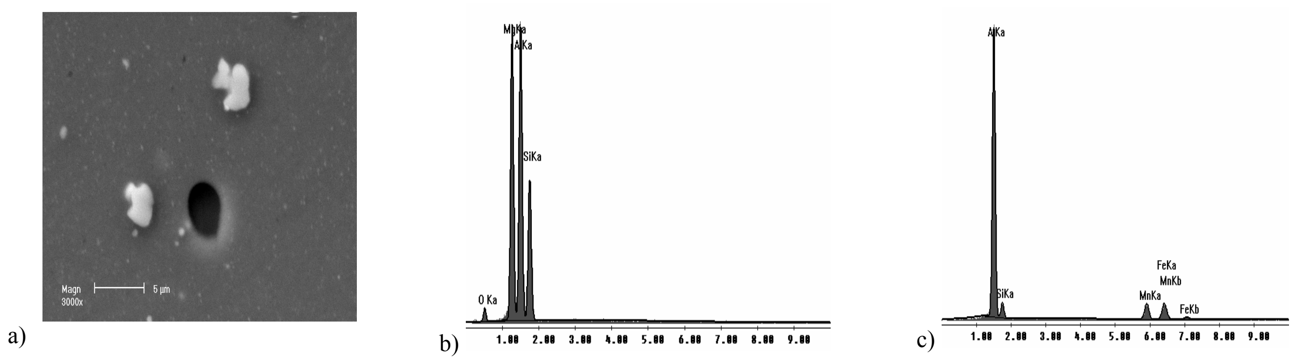

Fig. 3. a) Structure of AlMg1Si1 alloy after quenching at temperature 560°C and ageing at temperature 160°C/12h, b) dark precipitations, c) light precipitations

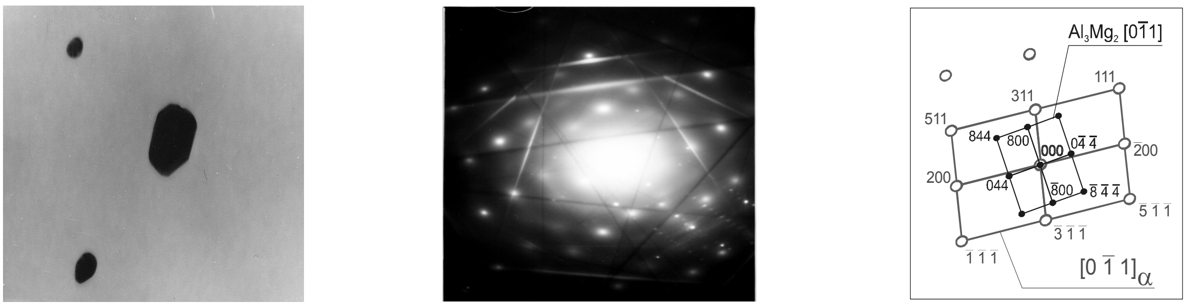

Fig. 4. a) Structure of the thin foil from AlMg5 alloy after quenching at temperature 560°C and ageing at temperature 160°C/12h, b) diffraction pattern from the area as in figure a, c) solution of the diffraction pattern from the figure b

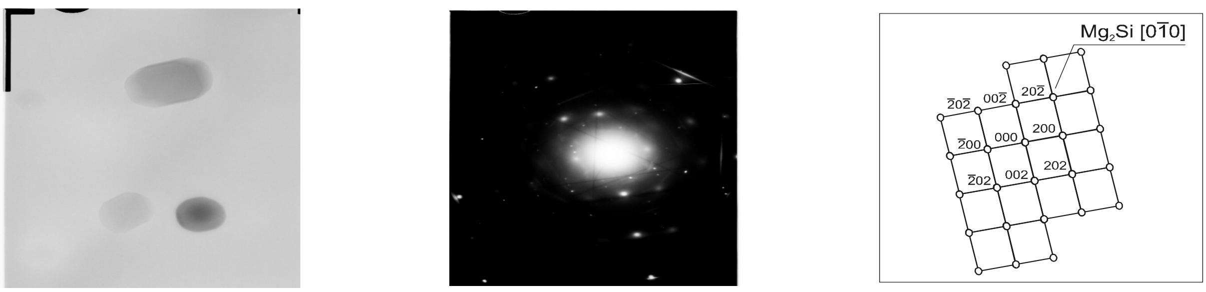

Fig. 5. a) Structure of the thin foil from AlMg1Si1 alloy after quenching at temperature 560°C and ageing at temperature 160°C/12h, b) diffraction pattern from the area as in figure a, c) solution of the diffraction pattern from the figure b

Table. 2.
The results of tensile tests

Alloy type	Ageing time [h]	Tensile strenght R_m [MPa]			
		Qquenching temperature			
		480°C	500°C	520°C	560°C
AlMg5	0	170		209	238
	3	187		237	248
	6	210		272	290
	9	242		290	303
	12	260		301	325
	24	205		234	247
AlMg1Si1	0		205	240	310
	3		287	300	342
	6		310	321	363
	9		317	334	379
	12		328	350	395
	24		301	317	363

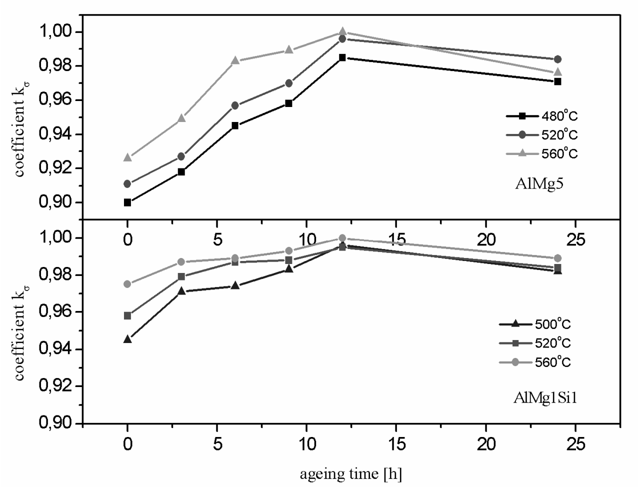

Fig. 6. The relationship of coefficient k_σ, quenching temperature and ageing time

4. Conclusions

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

- quenching at the temperature 560ºC in water,
- artificial ageing at temperature 160ºC during 12 hours.

In this conditions of the heat treatment the highest values of the tensile strength, are attained by the investigated alloys.

The crack resistance of analyzed aluminium alloys in the conditions of the stress corrosion, in sea water, in the particular stadium of artificial ageing has similar character adequate to mechanical properties. The value of the coefficient k_σ is on the level 1.Investigated aluminium alloys characterized high crack resistance in the analyzed conditions.

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