SHOT PEENING INFLUENCE ON CORROSION RESISTANCE OF AE21 MAGNESIUM ALLOY

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Abstract

Evaluation of the electrochemical characteristics of the AE21 magnesium alloy is presented in the article. The surfaces of tested alloys were treated by grinding and grinding followed by sodium bicarbonate shot-peening. The specimens were evaluated by electrochemical impedance spectroscopy method in combination with exposure tests in 0.1 NaCl solution. The exposition times were from 5 minutes to 168 hours. The measured data were analysed using equivalent circuits and polarization resistances of the various corrosion systems were determined. Results of the electrochemical measurements are complemented by metallographical evaluation of the tested alloy.

Keywords: Mg-Al-RE alloy, electrochemical characteristics, shot-peening, electrochemical impedance spectroscopy.

1. Introduction

Magnesium and its alloys are the lightest structural materials with relatively high value of specific strength, good machinability and castability and they can be full recycled [1, 2]. Listed advantages are very attractive mainly for automotive and aerospace. Weight reduction is one of the effective ways for reduction of fuel consumption and emission production. The car weight decreasing of about 100 kg influences the fuel consumption of about 0.4 litres per 100 km.

In present the requirements on appearance, quality and life-time of the parts is increasing. Shot-peening is one of the most important surface treatment and/or pre-treatment. This technology is mechanical type of a basic material surface treatment. Shot-peening medium (as main working tool) causes plastic deformation of surface layer after its impact on a treated material. Typical application of shot-peening is pre-treatment of the surfaces before deposition of organic or inorganic coatings. Other applications are creation of suitable morphology of the surface, surface hardening, increasing of fatigue and corrosion-fatigue resistance, etc. [3]. The positive influence of the shot-peening on fatigue resistance of magnesium alloys was published in [4, 5]. Shot-peening influence on corrosion resistance of magnesium alloys is questionable because of magnesium alloys high reactivity.

2. Experimental material

The AE21 magnesium alloy after extrusion from as cast state was used as an experimental material. The extrusion of material was performed in the laboratories of the University of technology in Clausthal, Germany at 370 °C with extrusion ratio of 22. The normalized chemical composition of AE21 alloy is in Tab. 1.

Tab. 1

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*ASTM chemical composition
of the AE21 Mg alloy*

Element	Al	RE	Mn	Mg
Content [wt.%]	2.0	1.0	0.3	balance

The surface treatment of the specimens was realized by shot-peening in the laboratories of Department of Technologies and Materials at University of Technology in Košice. Sodium bicarbonate ($NaHCO_3$) was used as shot – peening tool.

Microstructure of the AE21 EX alloy (Fig. 1) is created by polyedric grains of the solid solution of aluminium, rare earths metals, manganese and other additions in magnesium. In the microstructure are visible the areas of the Al_4RE phase [6, 7] and detail of this phase is in Fig. 2.
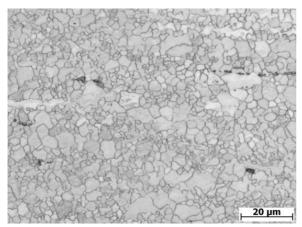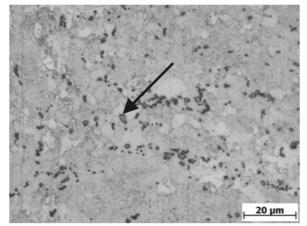

*Fig. 1. Microstructure of the AE21 EX
magnesium alloy, etch. picric acid [8]*

*Fig. 2. Al_4MM (Al_4RE) phase detail,
etch. picric acid [8]*

The electrochemical impedance spectroscopy method (EIS) was used for electrochemical characteristic determination and measurements were performed with Voltalab 10 corrosion measuring system (producer Radiometer Analytical SAS France) in the Laboratory of Metal Corrosion at Department of Materials Engineering, University of Žilina.

3. Experimental results and discusion

Measurements of polarization resistance were realized on grinded surfaces and on surfaces after shot-peening. The stabilization (exposition) times before electrochemical impedance spectroscopy measurement were 5 minutes and 1, 4, 8, 16, 24, 48, 96 and 168 hours. Frequency range of measurements was from 100 kHz to 50 mHz with frequency changing of 20 times per decade. Amplitude of AC voltage was 20 mV, measurement's temperature was 22 ± 1 °C and measured area was 1 cm^2. The specimens were fixed on rotating electrode and operating speed of the specimens was 70 min^{-1}. Connection and the measurement principle is described elsewhere [9, 10, 11].

The impedance – frequency plot (Bode magnitude plot) of the corrosion system of the AE21 Mg alloy in the 0.1M NaCl solution are resulting from EIS measurements. The Bode plots for grinded and soda shot-peened specimens are in Fig. 3 and Fig. 4, respectively. Analysis of the measured data were executed by EC Lab software (Bio-Logic SAS France) using equivalent circuits in Fig. 5. The type of equivalent circuits were selected on the basic of Bode plots shape. The circuits consist of several electrical parts. R_Ω is the resistance of electrolyte, CPE is constant phase element of a layer and R_p is polarization resistance of a layer [11, 12]. The equivalent circuit in Fig. 5a represents the situation on the surface of specimen when one layer of corrosion product exists (one inflection point on Bode magnitude plot). Fig. 5b represents the situation on the material surface when two layers of corrosion products exist (first layer is the double

layer and second layer is the layer of corrosion products) or two different areas (first one with good adhesion to the surface and second one as corrosion products at the broken places of the layer with good adhesion to the surface) are existed on the surface (two inflection points on Bode magnitude plots, first at the middle frequencies and second at the low frequencies).
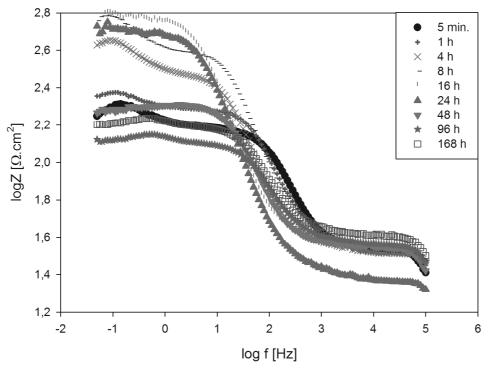

Fig. .3 Bode plots of the grinded surface of the AE21 Mg alloy in 0.1M NaCl after various exposure times
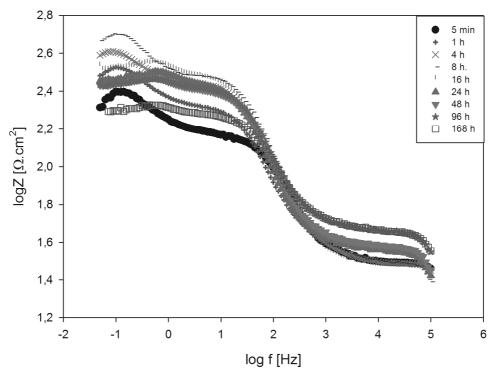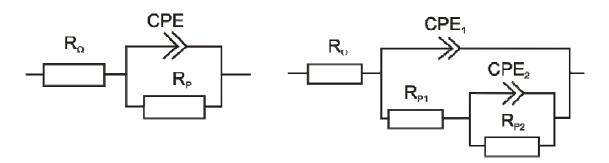

Fig. 4. Bode plots of the grinded surface of the AE21 Mg alloy in 0.1M NaCl after various exposure times

The curves obtained on grinded specimens after 16, 24 and 48 hours of exposition were analyzed using equivalent circuit in Fig. 5a. Other curves of grinded surfaces were analyzed by equivalent circuit in Fig. 5b. All surfaces after soda shot-peening were analyzed by equivalent circuit in Fig. 5a.

Main electrochemical characteristics obtained from measured curves by analysis are in Tab. 2. Total polarization resistance of the specimen's surface is the sum of the partial polarization resistances R_{p1} and R_{p2}.

a) one layer of corrosion products   b) two layers of corrosion products

Fig. 5. Equivalent circuits used for analysis of EIS data

Tab. 2

Electrochemical characteristics of grinded and shot-peened surfaces
after various exposure times in 0.1M NaCl

exposure time	grinded surface		soda shot-peened surface	
	$R_{p1}[\Omega.cm^2]$	$R_{p2}[\Omega.cm^2]$	$R_{p1}[\Omega.cm^2]$	$R_{p2}[\Omega.cm^2]$
5 min.	124 ± 18	50 ± 5	117 ± 13	100 ± 1
1 h.	164 ± 5	42 ± 8	181 ± 17	141 ± 14
4 h.	273 ± 3	143 ± 30	259 ± 10	139 ± 13
8 h.	361 ± 21	250 ± 4	271 ± 14	196 ± 12
16 h.	571 ± 53	0	276 ± 4	72 ± 14
24 h.	492 ± 17	0	243 ± 41	54 ± 24
48 h.	169 ± 36	0	232 ± 13	51 ± 8
96 h.	99 ± 2	19 ± 2	227 ± 22	46 ± 10
168 h.	120 ± 19	23 ± 5	155 ± 26	33 ± 4

Analyses of the Bode plots and measured polarization resistances show that polarization resistance of the grinded surface of AE21 EX alloy increases with incearsing of exposure time up to 8 hours. Polarization resistance of the surface after 8 hours of exposition is 3.5 time higher than total polarization resistance after 5 minutes of grinded surface exposition. Total resistance increasing is caused by increasing of both partial polarization resistances of corrosion system (R_{p1} and R_{p2}). The surfaces of the specimens are covered by corrosion products probably on the $Mg(OH)_2$ and/or MgO_2 base. The total polarization resistance is decreasing after more than 16 hours of exposition. It is caused by dropping out of corrosion

products that have protective character. Dropping out of corrosion products causes contact of corrosion enviroment with metal surface and futher active development of corrosion process. There were observed the change of the Bode's diagram shape after 16 hours of exposition. This change signalize losses of bilayer type of corrosion products and existence of mixed complex single layer (it is imposible to differ the double layer and layer of corrosion products).

The Bode plots of the soda shot-peened surfaces have the same shape after all tested exposure times (Fig. 4). It shows the existence of two different layers on the specimen's surfaces. The surface after soda shot-peening is covered by products that are formed during shot-peening process. Immediatelly after immersion of the specimens into the 0.1M NaCl solution the polariation resistance of the shot-peened surface is higher than polarization resistance of the grinded counterpart. It is probably caused by adherence of the blasting agent on the specimens surface. The corrosion resistance of double layer combined with shot-peening products layer is represented by R_{p2} value. This value was significantly changed after 16 hours of exposition which was probably caused by dissolution and/or dropping out of shot-peened products. The corrosion products on the hydroxide and/or oxide base represented by resistance R_{p1} are relatively stable and their resistance is decreasing after 168 hours. The maximum corrosion resistance of the soda shot-peened surfaces was reached after 8 hours of exposition with similar contribution of both layers on the specimen surface.

4. Conclusion

By the comparison of the maximum R_p values of grinded and shot-peened surfaces (after 8 hours of exposition of both types of the surfaces) we concluded that shot-peened surface has lower corrosion resistance. It is caused by higher reactivity of the surface after mechanical influence of the blasting agent.

After more than 8 hours of exposition the corrosion products were started dropping out. It shows the decreasing values of both parts of corrosion system (R_{p1} and R_{p2}). The decreasing of total polarization resistance of shot-peened specimens after more than 8 hours of exposition is more consistent than decreasing of R_p of grinded specimens. It is caused by better corrosion products adhesion to shot-peened surface and its restoration is faster after breaking of the corrosion products layer because of more nucleation places on the surface.

The results measured on the specimens exposed more than 48 hours suggest that grinded surfaces are fully degraded and they are not resistant against the corrosion processes in the 0.1M NaCl solution. The shot-peened surface is still corrosion resistant under 168 hours of exposition.

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