Influence of heat treatment on corrosion resistance of PM composite materials

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Properties

ABSTRACT

Purpose: of the project was evaluation of the effect of heat treatment and of the reinforcing Al_2O_3, Ti(C,N) and BN particles in the EN AW-AlCu4Mg1(A) aluminium alloy on the corrosion resistance in the NaCl water solution environment.

Design/methodology/approach: some of the composite materials were hyperquenched for 0.5 h at the temperature of 495ºC with the subsequent cooling in water, and were quench aged next for 6 h at 200°C. Corrosion tests were made in 5% water NaCl solution.

Findings: Besides visible improvement of heat treatment on the corrosion resistance of composite materials in 3% NaCl solution.

Practical implications: Tested composite materials can be applicate among the others in automotive industry but it requires additional researches.

Originality/value: It was demonstrated that the corrosion resistance of the sintered composite materials with the EN AW-Al Cu4Mg1(A) alloy matrix may be formed by the dispersion hardening with the Al_2O_3, Ti(C,N) and BN particles in various portions and by the precipitation hardening of the matrix.

Keywords: Corrosion resistance; Composites

1. Introduction

Metal composite materials with the light metals matrix are characteristic of the high mechanical properties and low density which makes it possible to use them for elements and subassemblies made so far from the traditional engineering materials [1-3].

Much attention is paid, in particular, to the composite materials reinforced with ceramic particles, called MMCs (Metal Matrix Composites) or to the metal-ceramics composites used in the aviation-, machine-, automotive-, space-, electronic, and military industries [2-5], first of all in the heavily loaded structures and with

the highest service parameters. Employment of the MMCs in the designs calls also the increased corrosion resistance from them [6-9]. Employment of the hard particles as reinforcement increases their hardness, Young's modulus and abrasion wear resistance; however, at also results in deterioration of their plastic properties [10-14]. Heat treatment is carried out consisting in hyperquenching and ageing to improve their mechanical properties. Composite materials precipitation hardening occurs due to hyperquenching and ageing as a result of precipitation of the hard dispersive particles of the intermetallic phases. The intermetallic phases occurring in the aluminium alloys matrix most often are: Al2Cu, Al2CuMg, Al2Mg, Al3Mg, Cu9Al4 , and Al2Cu3 [2,3].

Short paper

2. Experimental procedure

The investigations were made of the composite materials obtained with the powder metallurgy methods and by hot extrusion of the EN AW-AlCu4Mg1(A) aluminium alloy (0,20% Si, 0,30% Fe, 3,8-4,9% Cu, 0,30-0,9% Mn, 1,2-1,8% Mg, 0,10% Cr, 0,25% Zn, 0,15% Ti Al rest [15]) reinforced with the Al_2O_3 phases particles with the mass portions of 5, 10, and 15%. The initial size of the matrix material powder particles is smaller than 75 μm, of the reinforcement Al_2O_3 powder is smaller than 0.5 μm, Ti(C,N) and BN – 25 μm.

The weighed matrix and reinforcement powders were wet mixed together (methanol slurry) in the laboratory vibrating ball mill for 2 h to obtain the uniform distribution of the reinforcement particles in the matrix, and also to avoid development of the reinforcement particles clusters.

Aluminium containers were filled with the obtained mixtures. The powders mixtures in the containers were thickened initially (compacted) in the O.D. 26 mm die in the laboratory press with the computer load logging.

The following compacting process parameters were used:
- unidirexional, uniaxial compacting,
- room temperature,
- 350 kN load.

The selected compacting load was sufficient to obtain prepregs which would not crumble and at the same time would not be deformed too much, which would also have the adverse effect on their quality, as the excessive air pressure in the closed pores causes breaking the prepreg up when it is taken out from the die.

Aluminium containers filled with the compacted composite powders featured the charge for extrusion. These prepregs were heated to the temperature of 480-500˚C and were extruded at 500 kN load. The die walls were lubricated with the zinc stearate to attain slide during charge extrusion. The O.D. 8 mm bars were obtained as the final product, enclosed in a thin aluminium sheath.

To evaluate the heat treatment effect on properties and corrosion resistance some of the composite materials were hyperquenched for 0.5h at the temperature of 495ºC with the subsequent cooling in water, and were quench aged next for 6h at 200°C.

To determine the corrosion resistance of the EN AW-AlCu4Mg1(A) aluminium alloy and composite materials that differed with the reinforcement content percentage values, corrosion tests were made consisting in registering the anode polarisation curves using the measurement system consisting of the PGP-21 potentiostat working with the Radiometer Copenhagen VoltaMaster 1 software. Specimens of the composite materials featured the examined electrode that were ground and polished with the method used in the practical metallographic chemistry. The inspected surfaces of the specimens were washed with acetone immediately before the examinations. Specimens prepared in this way were tested in the 3% water NaCl solution. The electrochemical tests were carried out in the three-electrode glass electrolyser. The platinum electrode was the auxiliary one, and the reference electrode was the saturated calomel electrode. Basing on the potentiodynamical curves the corrosion current i_{cor} was determined, areas close to the equilibrium potential E_{cor} were used for that and Tafel's relationship was used for its evaluation. Making use of the determined values of the corrosion current and Rp were calculated for the investigated material in the NaCl environment, using the built-in software function - „1st Stern Method-Tafel extrapolation".

3. Results and discussion

As a result of the potentiodynamic tests carried out the anode polarisation curves (current density versus varying potential) were obtained for the matrix material and for the composite materials tested in the 3% NaCl water solution. The anode polarisation curves are composed of the anode branches, which correspond to the corrosion reaction course, and of the cathode branches, corresponding to the hydrogen depolarization. These curves confirm that the investigated materials are subjected to pitting corrosion, to which the aluminium alloys are most susceptible.

The best electro-chemical parameters, compared to the matrix material (for which the corrosion potential is -686.2 mV, current density in the passive range is 0.0154 mA/cm^2, and the polarization resistance value is 0.3828 $kΩ/cm^2$) are characteristic of the composite material reinforced with 5% of the Al_2O_3 particles which improved the investigated material's corrosion resistance when added to its matrix.

15% portion of the reinforcement particles causes the significant reduction of the determined corrosion quantities - corrosion potential is -693.5 mV; current density in the passive range is 0.0225 mA/cm^2 and the value of the polarization resistance is 0.13 $kΩ/cm^2$. In case of the composite materials reinforced with the Ti(C,N) particles the best electro-chemical properties are characteristic of the composite material with 5% portion of the reinforcement particles, which caused the slight reduction of the corrosion level of the investigated material in comparison to the matrix material. The corrosion potential of this composite is -678 mV; density of the corrosion current in the passive range is 0.0073 mA/cm^2, and the polarization resistance value 0.609 $kΩ/cm^2$. At 10 and 15% portions of the reinforcement with the Ti(C,N) particles a slight reduction occurs of the corrosion resistance compared to the matrix material; the corrosion potential values for these composites are -705.9 mV and -714.3 mV respectively, current density values in the passive range are 0.019 and 0.0235 mA/cm^2, and the polarization resistance values are 0.247 $kΩ/cm^2$ and 0.0875 $kΩ/cm^2$ respectively. The lowest corrosion resistance, and therefore the highest corrosion level is characteristic of the composite material with addition of the BN particles whose corrosion potential at 5, 10, and 15% portion values are respectively -695.7 mV; -704.8 mV, and -718.6 mV, corrosion current density values in the passive range 0.0251 mA/cm^2, 0.0262 mA/cm^2, and 0.0298 mA/cm^2, and the polarization resistance values are 0.24 $kΩ/cm^2$, 0.1944 $kΩ/cm^2$, and 0.188 $kΩ/cm^2$.

The same corrosion resistance tests of the matrix and composite materials were carried out after heat treatment which causes evident changes in behaviour of the investigated materials during anode polarisation in solution of chlorides, and therefore the increase of the measured quantities and improvement of the corrosion resistance of the investigated materials in the water solution of NaCl.

Corrosion potential of the matrix material after precipitation hardening grows to the value of -644.3 mV; current density in the passive range is 0.0019 mA/cm^2, and the polarisation resistance value is 5.85 $kΩ/cm^2$. At 5% portion of the Al_2O_3 reinforcement particles corrosion potential grows to the value of -633.2 mV, density of the corrosion current decreases to the value of 0.0001 mA/cm^2, and the polarisation resistance grows to the value of 33.67 $kΩ/cm^2$. At 15% portion of the reinforcement particles the

corrosion potential grows to the value of -661.9 mV, current density falls to the value of 0.0023 mA/cm^2, and the polarisation resistance grows to the value of 2.45 kΩ/cm^2. In case of the composite materials reinforced with the Ti(C,N) particles, at 5% portion of the reinforcement chase the corrosion potential grows to the value of -634 mV; current density falls to the value of 0.0017 mA/cm^2, and the polarisation resistance grows to 7,25 kΩ/cm^2. At 15% of the reinforcement portion in matrix the corrosion potential grows to the value of -683 mV, density of the corrosion current decreases to the value of 0.0047 mA/cm^2, and the polarisation resistance grows to the value of 1.67 kΩ/cm^2. Corrosion resistance of the composite material with the addition of the BN particles grows also – the corrosion potentials of the composite with the 5, 10 i 15% BN portions grow to -689 mV; -700.7 mV, and -707.7 mV respectively; density of the corrosion current values drop to 0.0027 mA/cm^2, 0.009 mA/cm^2 , and 0.0165 mA/cm^2, and the values of the polarisation resistance grow to 4.22 kΩ/cm^2, 3 kΩ/cm^2, and 1.80 kΩ/cm^2.

The pitting potential E_n value (Table 1) at which pits begin to develop on surfaces of the examined samples value and the value of the repassivation E_{cp}, (Table 1) one below which no active pits occur on the surfaces of samples, were determined from the flow of the potentiodynamic curves' flows.

Table 1. Electrochemical parameters of the matrix from the EN AW-Al Cu4Mg1(A) aluminium alloy and composite materials (A-before the heat treatment, B-after the heat treatment)

Material	Pitting potential, E_n, mV		Repassivation potential, E_{cp}, mV	
	A	B	A	B
EN AW-Al Cu4Mg1(A)	-646	-629	-712	-705
EN AW-Al Cu4Mg1(A)/5%Al$_2$O$_3$	-641	-619	-701	-695
EN AW-Al Cu4Mg1(A)/10%Al$_2$O$_3$	-644	-620	-707	-700
EN AW-Al Cu4Mg1(A)/15%Al$_2$O$_3$	-651	-636	-720	-714
EN AW-Al Cu4Mg1(A)/5%BN	-677	-655	-704	-704
EN AW-Al Cu4Mg1(A)/10%BN	-689	-677	-711	-721
EN AW-Al Cu4Mg1(A)/15%BN	-692	-690	-709	-721
EN AW-Al Cu4Mg1(A)/5%Ti(C,N)	-634	-630	-712	-707
EN AW-Al Cu4Mg1(A)/10%Ti(C,N)	-644	-633	-704	-717
EN AW-Al Cu4Mg1(A)/15%Ti(C,N)	-652	-637	-705	-725

Having compared breadth of the corrosion loops (i.e., parameters E_{cp} and E_n in the range in which new pits cannot develop; however, in those already existing corrosion processes may continue), and also the inclination angles and height of these loops, one can infer that that the worst corrosion loops compared to the material without the reinforcement are characteristic of the composite materials with the 15% Al$_2$O$_3$, BN or Ti(C,N) reinforcement particles portion. The pitting potential values increase along with the increase of the volume portion of the reinforcing particles in the matrix.

Breadth of these loops decreased after the heat treatment, just like the repassivation one E_n and the pitting potential E_{cp}, height and inclination angle of these loops decreased too, which also attests to the positive effect of the heat treatment on the corrosion resistance of the investigated materials (Fig. 1 a-c).

a)

b)

c)
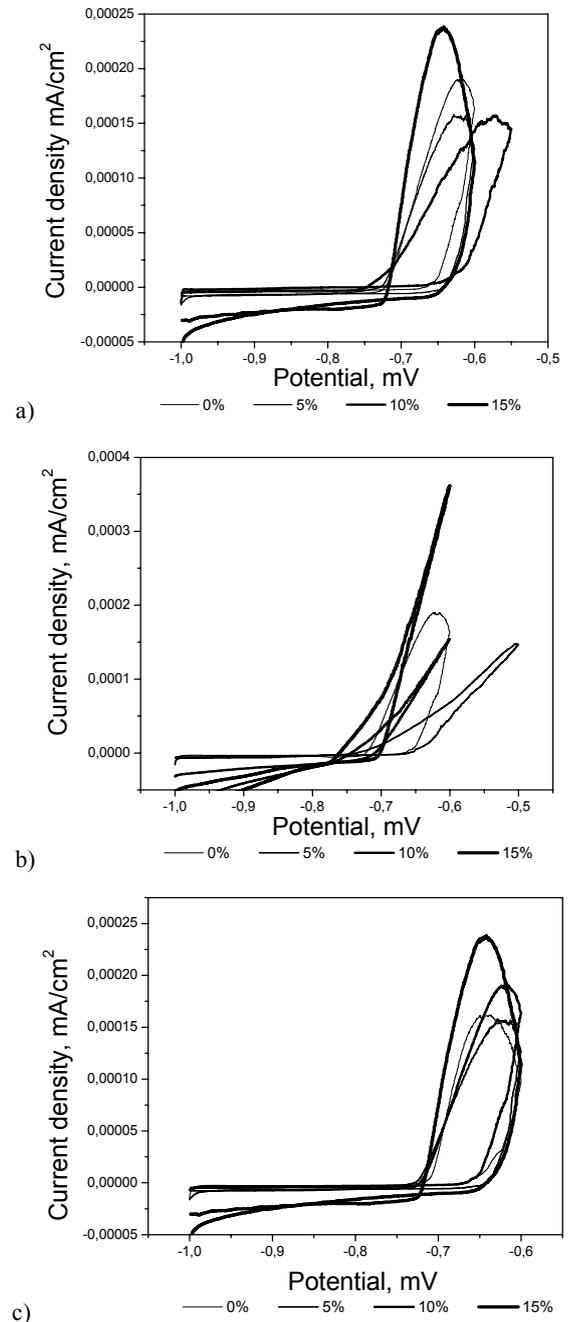
Fig. 1. Potentiodynamic curve for EN AW-Al Cu4Mg1(A) and aluminum alloy composite materials: a) Al$_2$O$_3$, b) BN c) Ti(C,N), after the heat treatment

The exemplary microphotographs of the examined specimens' surfaces after the corrosion test before and after heat treatment show pits developing around the reinforcement particles, which leads to discontinuity around the particles, and therefore to cracks in the vicinity of pits. Microscope observations confirm the results obtained after the corrosion test (Fig. 2 a-d).
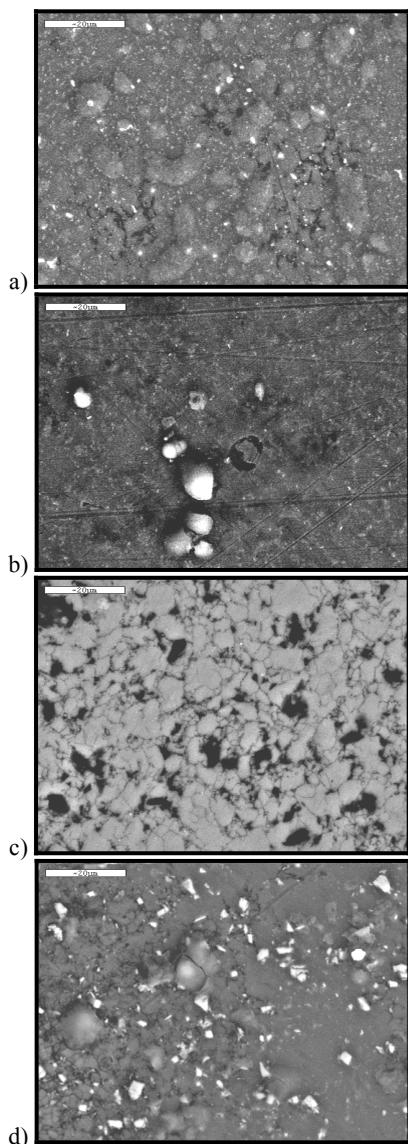
Fig. 2. Microstructure of the investigated materials after corrosion test :a) EN AW-Al Cu4Mg1(A), b) Al$_2$0$_3$, c) BN, d) Ti(C,N) after the heat treatment

4. Conclusions

The decline of the corrosion resistance of the composite material progresses along with the increase of the particles in the matrix from the aluminium alloy. The precipitation hardening process causes corrosion resistance growth of the investigated materials. The highest corrosion resistance compared with the matrix (corrosion wear after the test in 3% NaCl water solution) is characteristic of the composite materials reinforced by 5 and 10% Al$_2$O$_3$, with the corrosion rates of 0.002 mm/year and 0.013 mm/year respectively. The corrosion rate for the composite with 5% portion of the Ti(C,N) particles is 0.021 mm/year. The worst corrosion resistance is characteristic of the composite material reinforced with the BN particles.

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