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Influence of heat treatment on properties and corrosion resistance of Al-composite

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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 particles in the EN AW-AlCu4Mg1(A) aluminium alloy on the mechanical properties, abrasive and 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. Hardness tests were made on HAUSER hardness tester with the Vickers method at 10 N. Static compression and tensile tests of the fabricated composite materials were made on the ZWICK 100 type testing machine at room temperature. Abrasion resistance wear tests were carried out with the constant number of cycles of 5000 (120 m) at various loads: 4, 5, 6, 7, and 8 N. Test pieces were rinsed in the ultrasonic washer to clean them and next were weighed on the analytical balance with the accuracy of 0.0001 g to check the mass loss. Corrosion tests were made in 5% water NaCl solution.

Findings: Besides visible improvement of mechanical properties: hardness, compression strength and tensile strength, wear resistance there were also observed the influence 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 mechanical properties, as well as the wear and 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 particles in various portions and by the precipitation hardening of the matrix.

Keywords: Composites; Mechanical properties; Abrasive wear; Corrosion resistance

1. Introduction

Currently, the most widespread use have found the composite materials with the light metals matrix, and especially from the aluminium alloys, reinforced with the ceramic particles and carbides that can be employed in many industry branches, first of all in the automotive-, aircraft-, power industry, electronic-, engineering- or space industry. Aluminium and its alloys are characteristic of good mechanical properties, and the reinforcing particles are introduced to improve them further, e.g., ceramic particles, and the composite materials obtained in this way have much better mechanical properties than alloys [1,3,5,8,10,12,13]. Aluminium and its alloys are characteristic of high corrosion resistance in the standard atmospheric conditions and in the environment of many acids, thanks to the Al_2O_3 aluminium oxide layer developing on their surface. Therefore, the corrosion resistance of aluminium depends on the solubility of its protective layer. Its tightness and good adhesion to the substrate, determining the corrosion resistance, is dependant on purity of aluminium or its alloys [2,4,6,9,11,14].

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 [7]) 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.

Powders of the starting materials were wet mixed in the laboratory vibratory ball mill to obtain the uniform distribution of the reinforcement particles in the matrix. The mixed powders were then dried in the air. The components were initially compacted at cold state in a die with the diameter of ∅ 26 mm in the laboratory vertical unidirectional press–with a capacity of 350 kN. The obtained PM compacts were heated to a temperature of 480÷500˚C and finally extruded–with the extrusion pressure of 500 kN. 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.

Hardness tests of the fabricated composite materials were made on HAUSER hardness tester with the Vickers method at 10 N load, according to the Polish Standard PN-EN ISO 6507-1. Seven indentations were made on the transverse section diameter for specimens taken from bars obtained by extrusion, both for the EN AW-AlCu4Mg1(A) aluminum alloy and for the fabricated composite materials reinforced with the Al_2O_3 phases particles, to determine their average hardness.

Static compression and tensile tests of the fabricated composite materials were made on the ZWICK 100 type testing machine at room temperature. The examined test pieces in the compression tests have a height of 10 mm height and a diameter of 7 mm. Cylindrical tensile specimens of 5 mm diameter, 25 measuring and 18 mm gauge length according to PN-EN 10002-1+AC 1 were machined from the extruded bars while maintaining the tensile axis parallel to extrusion direction. Yield stresses (YS), ultimate tensile strength (UTS) and Young module (E) were determined employing at least two specimens for each material.

Abrasion resistance wear tests were carried out using the device designed at the Faculty of Mechanical Engineering of the Silesian University of Technology. Test pieces were 30 mm long. Preparation of the test pieces for tests consisted in grinding with the 1200 grit abrasive papers, to obtain four flat and even surfaces. Tests were carried out on surfaces prepared in this way using the steel balls with 8.7 mm diameter as the counter-specimens. Tests were carried out with the constant number of cycles of 5000 (120 m) at various loads: 4, 5, 6, 7, and 8 N. Test pieces were rinsed in the ultrasonic washer to clean them and next were weighed on the analytical balance with the accuracy of 0.0001 g to check the mass loss.

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 the corrosion rate $v_{cor,}$ 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

Examinations of the composite materials on the scanning electron microscope using the EDS add-on before their heat treatment made it possible to reveal occurrences of the Al-Cu-Mg-Mn intermetallic phases' precipitations (Fig. 1). Examinations of these materials in the heat treated state indicate to the reduction of the presence and size of the intermetallic precipitations. Due to the heat treatment performed the precipitations get dissolved in the solid solution in the hyperquenching process.

Hardness tests of the fabricated composite materials revealed its diversification depending on the weight ratios of the reinforcing particles in the aluminum matrix.

Mean hardness values of the aluminum alloy and of the fabricated composite materials reinforced with the Al_2O_3 ceramic particles with the weight ratios of 5, 10 and 15% are shown in Table 2. Investigated composite materials are characterized by an higher hardness compared to the non-reinforced material.

Hardness of composite materials increases with increasing content of the reinforcing material in the metal matrix.

Heat treatment carried out caused hardness increase and, like in case of the composite materials before their heat treatment, the hardness grows along with the volume portion increase of these particles in the matrix.

Introducing to the aluminum matrix reinforcement particles increase compression strength but with the growth of the portion of reinforcement the compression strength lowers (Table 1).

All examined composite material are characterized by lower tensile strength in comparison with matrix material. There was also found small decreasing tendency of the tensile strength with the growth of the reinforcement portion. Only in the case of 5% of Al_2O_3 portion the tensile strength is higher than the aluminum matrix.

Wear of the investigated materials versus load change at the constant distance is of a linear character. Many factors affect the mass loss after the wear tests of the composite materials: hardness of the obtained composite materials, shape and dimensions of the reinforcement particles, and also values of load between the test piece and the counter-specimen.

Reinforcement of the sotf aluminum matrix by hard Al_2O_3 particles influence of the hardness growth (Table 1) but deacrese the wear resistance of composite materials.

With the increase of the reinforcement portion in aluminum matrix the growth wear is observed because the particles are to small (≤ 0,5 µm) and quickly fall out during friction with counter-specimens.

Heat treatment carried out resulted in the wear resistance improvement of the matrix material and of the fabricated composite materials (Fig. 2) because of decreasing the presence and sizes of the intermetallic precipitations occurring in the structure of the investigated materials.

As a result of the potentiodynamic tests carried out curves of the current density versus varying potential were obtained.

The curves obtained at potential changes in the anodic and cathodic directions confirm that the investigated materials are subjected to pitting corrosion, to which aluminium and its alloys are susceptible. The best electrochemical parameters: E_{cor}, i_{cor} i Rp detemined using the Tafel method (Table 2) are characterisitc of the EN AW-AlCu4Mg1(A)/5%Al_2O_3 composite material. Also a portion of 10% of the reinforcing Al_2O_3 particles cause improvement of the corrosion resistance, compared with the material with no reinforcement. However, 15% reinforcement portion causes the significant decrease of the corrosion resistance.

The same corrosion resistance tests for the matrix material and composite materials were made after their heat treatment causing significant changes in the behaviour of the examined materials during the anode polarisation in the solution of chlorides, thereby increase of the measured values and improvement of the corrosion resistance of the investigated materials in the water solution of NaCl (Table 2).

The heat treatment carried out cause in the hyperquenching process solving in the solid solution of the big precipitations of the intermetallic phases, whereas during the ageing the homogeneous precipitation occurs of the dispersive intermetallic phases in the whole volume of the matrix grains. Such structural state adds to the significant reduction of the number of locations in which corrosion centres may form.

Having compared breadth of the corrosion loops (i.e., parameters E_n and E_{cp} 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_2O_3 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 pitting potential E_n and the re-passivation one 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. 3).

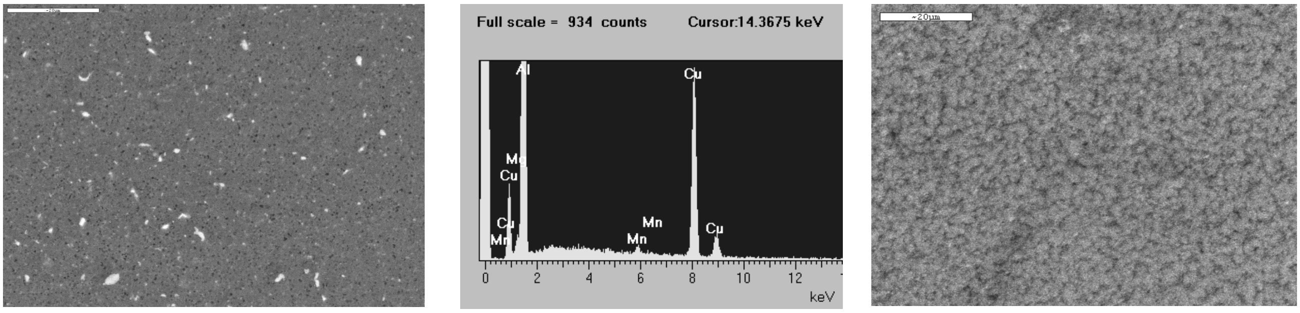

Fig. 1. Microstructure of aluminium alloy; before heat treatment, x-ray energy dispersive spectrum for intermetallic precipitations, after heat treatment

Table 1.
Properties of investigated composites material (A-before the heat treatment, B-after the heat treatment)

EN AW- AlCu4Mg1 (A)/Al_2O_3	Hardness HV1		Ultimate compressive strength, UCS (MPa)		Ultimate tensile strength, UTS (MPa)		Yield stresses, YS (MPa)		Young module E (GPa)	
	A	B	A	B	A	B	A	B	A	B
0%	8	97	523	724	419	492	261	410	76	68
5%	91	99	797	825	425	449	259	333	83	82
10%	106	110	762	779	406	418	245	281	78	76
15%	123	130	663	695	375	395	226	259	71	72

Table 2.
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	Corrosion potential, $E_{cor,}$ mV		Corrosion current, $i_{cor,}$ mA/cm^2		Polarization resistance, Rp, kΩ/cm^2		Pitting potential, $E_{n,}$ mV		Repassivatio n potential, $E_{cp,}$ mV		Corrosion rate v_{cor} mm/y	
	A	B	A	B	A	B	A	B	A	B	A	B
EN AW-Al Cu4Mg1(A)	-686	-644	0,015	0,0019	0,383	5,85	-646	-629	-712	-705	0,129	0,023
EN AW-Al Cu4Mg1(A)/5%Al_2O_3	-669	-633	0,009	0,0001	0,601	33,7	-641	-619	-701	-695	0,12	0,002
EN AW-Al Cu4Mg1(A)/10%Al_2O_3	-683	-638	0,015	0,0011	0,425	15,2	-644	-620	-707	-700	0,125	0,013
EN AW-Al Cu4Mg1(A)/15%Al_2O_3	-693	-662	0,022	0,0023	0,130	2,45	-651	-636	-720	-714	0,304	0,027

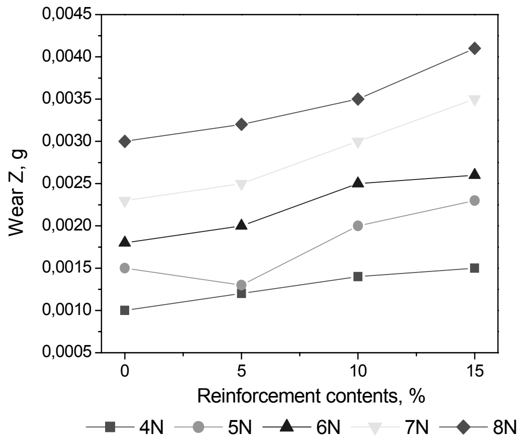

Fig. 2. Wear of the aluminium alloy and composite materials in the following states in the precipitation hardened state, at various load values, N

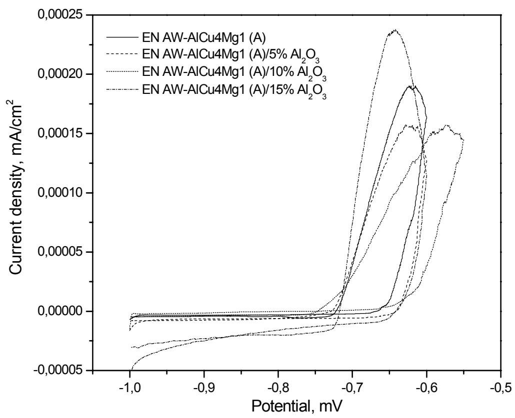

Fig. 3. Potentiodynamic curve for EN AW-Al Cu4Mg1(A) and aluminum alloy composite materials: after the heat treatment

4. Conclusions

Based on the structural examination of composite materials with EN AW-AlCu4Mg1(A) aluminum matrix reinforced by Al_2O_3 particles there was found that reinforcement particles are uniformy distributred in aluminum matrix. During extrusion directed structure is formed oriented with extrusion direction.

Heat treatment - age hardening – allows to decrease the size of intermetallic phase and as a consequence for the homogenisation of the matrix structure. Besides visible improvement of mechanical properties: hardness, compression strength and tensile strength, wear resistance there were also observed the influence of heat treatment on the corrosion resistance of composite materials in 3% NaCl solution. Reinforcement of aluminium matrix by Al_2O_3 particles causes the increase of corrosion resistance of composite materials.

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