



Composite materials based on EN AW-Al Cu4Mg1(A) aluminum alloy reinforced with the BN ceramic particles

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ABSTRACT

Purpose: the aim of the project was to evaluate of the effect of heat treatment and the reinforcing BN particles content on the mechanical properties, abrasive wear and corrosion resistance in the NaCl water solution environment on the EN AW-AlCu4Mg1(A) aluminium alloy matrix composite.

Design/methodology/approach: Some of the composite materials were hyperquenched for 0.5 h at the temperature of 495°C 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 applicative 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 extruded composite materials with the EN AW-Al Cu4Mg1(A) alloy matrix may be formed by the dispersion hardening with the BN particles in various portions and by the precipitation hardening of the matrix.

Keywords: Aluminum alloy; Composite materials; Powder metallurgy; Corrosion resistance; Polarisation curve; Abrasive wear

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MATERIALS

1. Introduction

Considerable attention is focused on metal matrix reinforced with strength and high modulus ceramic reinforcements because of their superior properties in comparison with most of conventional materials [8,9,12].

In last years the development of metal matrix composites (MMCs) is observed in many industry branches, among others in the aircraft industry, automotive-, and armaments ones, as well as in electrical engineering and electronics, etc. [1,3,4,6,7,11,13,14].

The metal matrix composite can be reinforced with particles, dispersoids or fibres. However, the biggest interest in composite materials is observed for those reinforced with hard ceramic particles due to the possibility of controlling their tribological-, heat- or mechanical properties by selection of the volume fractions, size, and distribution of the reinforcing particles in the matrix [18-21].

These materials should exhibit good corrosion resistance in the aggressive environment therefore determining of the corrosion resistance of composite materials with aluminium matrix reinforced with ceramic additives is very important [2, 5, 15, 16].

Aluminum based composite materials are leading ones in this area, they are fabricated using many methods, including powder metallurgy processes, and then formed, e.g., by hot extrusion. Powder metallurgy makes materials properties relatively easy to control by mixing materials with different properties in various proportion.

They are used more often, compared with the composite materials of other metals, due to the broad range of their properties, and also due to the possibility of replacing the costly and heavy elements made from the traditionally used materials [10,17].

The goal of the work is to investigate the structure, selected mechanical properties, abrasive wear and corrosion resistance of the composite materials with the EN AW-AlCuMg4 (A) aluminum alloy based matrix reinforced with the ceramic particles of the BN phases with various weight ratios.

2. Experimental procedure

Examinations were made of the composite materials with the EN AW- Al Cu4Mg1(A) (75 μ m) aluminum alloy matrix with the chemical composition specified in Table 1 [22], reinforced with the BN (25 μ m) ceramic particles with the weight ratios of 5, 10 and 15%.

Table 1.
Chemical composition of EN AW-AlCu4Mg1(A) aluminum alloy,% vol.[22]

Si	Cu	Fe	Mn	Mg	Cr	Zn	Ti	the others	Al
0.24	0.1	1.2-1.5	0.1-0.3	1.9-2.9	0.04	0.10	0.09	0.20	rest

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:

- unidirectional, uniaxial compacting,
-]room temperature,
- 350 kN load.

The selected compacting load was sufficient to obtain preregs 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 preregs 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 495°C with the subsequent cooling in water, and were quench aged next for 6h at 200°C.

Metallographic examinations of the composite materials with the EN AW- Al Cu4Mg1(A) aluminum alloy matrix reinforced with the BN particles were carried out on LEICA MEF4A optical microscope; metallographic photographs were taken of sections transverse and longitudinal in respect to the extrusion direction. The specimens were etched in 5% HF. However, morphology examination of the starting powders and measurement of the powder particles sizes were carried out on OPTON (SEM) DSM 940 scanning electron microscope.

Hardness tests of the fabricated composite materials were made on HAUSER hardness tester with the Vickers method at 10 N load, according to the 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- Al Cu4Mg1(A) aluminum alloy and for the fabricated composite materials reinforced with the BN phase 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”.

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.

3. Results and discussion

The metallographic examinations of the investigated composite materials make it possible to observe the homogeneous distribution of the reinforcing material in the matrix; however, banding of the reinforcing particles parallel to the extrusion direction was noted on the longitudinal microsections (Fig. 1 a, b).

Analysis of microphotographs from scanning electron microscopy (SEM) reveals pores and confirms previous results (Fig. 2 c,d).

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 BN ceramic particles with the weight ratios of 5, 10 and 15% are shown in Table 2. Investigated composite materials are characterized by a 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 2).

Based on the compression test results all composite materials are characterized by a lower compression strength compared with the non-reinforced material.

When the portion of reinforcement particles BN is bigger then, the ultimate compression strength of composite materials decreases. Compression tests made it possible to compare compression strength values of composite materials with various reinforcing particles.

Loss of cohesion of the composite materials demonstrated by cracking of test pieces corresponds with the sudden drop of their compression strength observed on the stress-strain curves. Based on the results all composite materials are characterized by lower compression strength compared with the non-reinforced material.

Observations of tensile fracture topography reveals that in all composites materials as well as in aluminum alloy - matrix material fracture is ductile. Fig. 2 shows fracture topography for composites with BN ceramic particles reinforcement. Decohesion between particle and matrix goes thru the interphase boundary indicating weak bonding between reinforcement and matrix finally affecting the stress transference between both components of the composites.

Additionally the reinforcement particles agglomeration and porosity discussed previously affects performance of this class of materials.

Results of tensile tests performed for each investigated material are presented at Table 2. From the analysis of the data following can be pointed out that EN AW-Al Cu4Mg1(A) aluminum alloy presents higher YS and UTS than composites materials with BN ceramic particles. Addition of BN decreases the tensile properties. The biggest concentration of reinforcing particles the lowest properties (Table 2).

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.

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. Increase of reinforcing BN particles contents result in composite materials wear rate increase. It is caused by weak interface strength of matrix and reinforcing particles (Fig. 3 and 4).

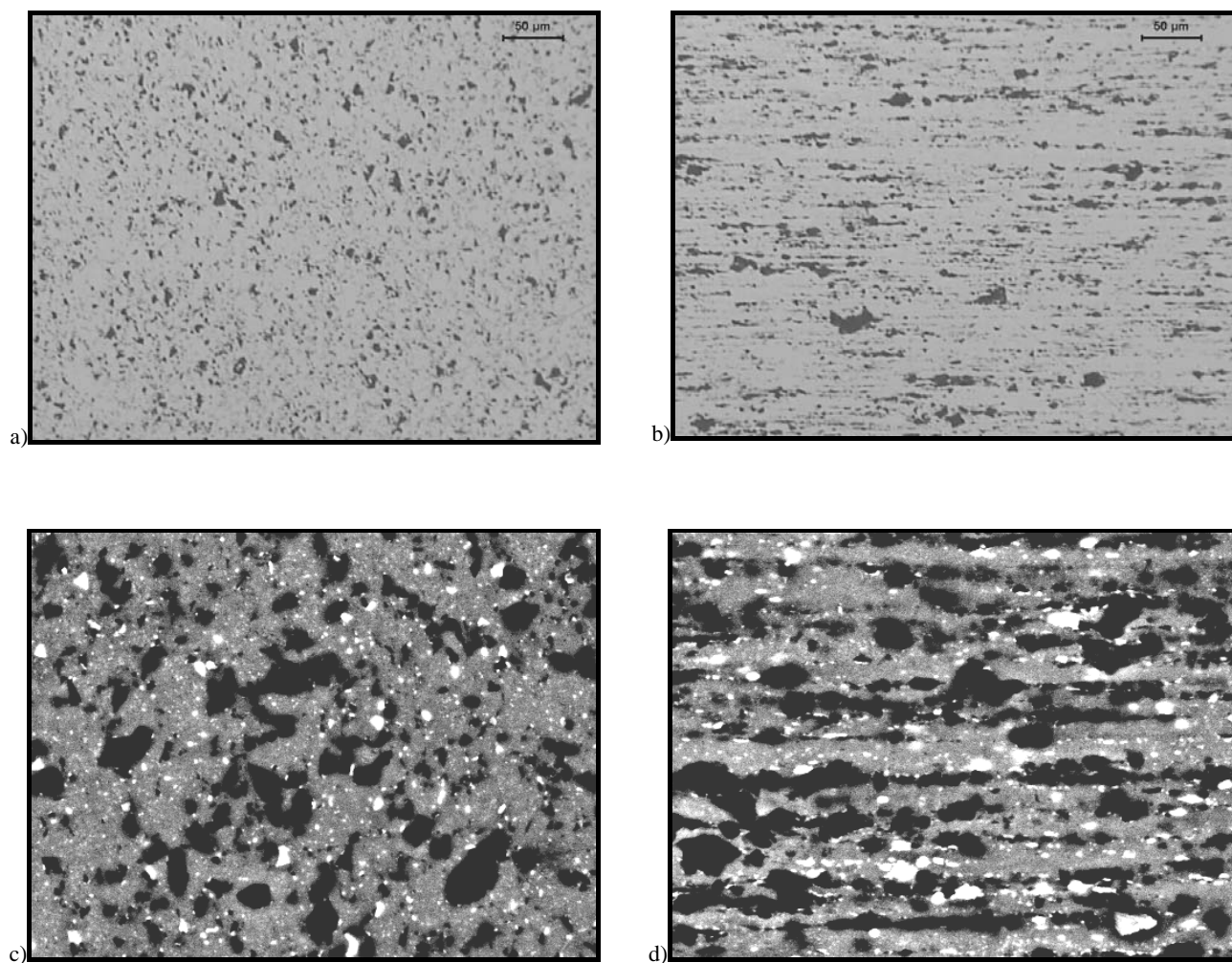


Fig. 1. Section of etched aluminum alloy matrix composite materials with BN particles: a) cross section, b) longitudinal section, LM, magnification 200x, c) cross section, d) longitudinal section, SEM

Table 2.

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

EN AW- AlCu4Mg1 (A)/BN	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%	89.3	97.7	523	724	419	492	261	410	76	68
5%	90	100	667	675	377	441	258	362	68	67
10%	91	102	560	622	311	372	221	309	62	59
15%	103.2	115	472	481	213	220	199	202	43	37

Table 3.

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)

EN AW- AlCu4Mg1 (A)/BN	Corrosion potential, E_{cor} , mV		Corrosion current, i_{cor} , mA/cm ²		Polarization resistance, R_p , kΩ/cm ²		Pitting potential, E_p , mV		Repassivation potential, E_{cp} , mV		Corrosion rate v_{cor} mm/y	
	A	B	A	B	A	B	A	B	A	B	A	B
	0%	-686	-644	0.015	0.0019	0.383	5.85	-646	-629	-712	-705	0.129
5%	-695	-689	0.025	0.0027	0.240	4.22	-677	-655	-704	-704	0.142	0.068
10%	-704	-700	0.026	0.009	0.194	3.01	-689	-677	-711	-721	0.260	0.090
15%	-718	-707	0.029	0.0165	0.188	1.80	-692	-690	-709	-721	0.295	0.102

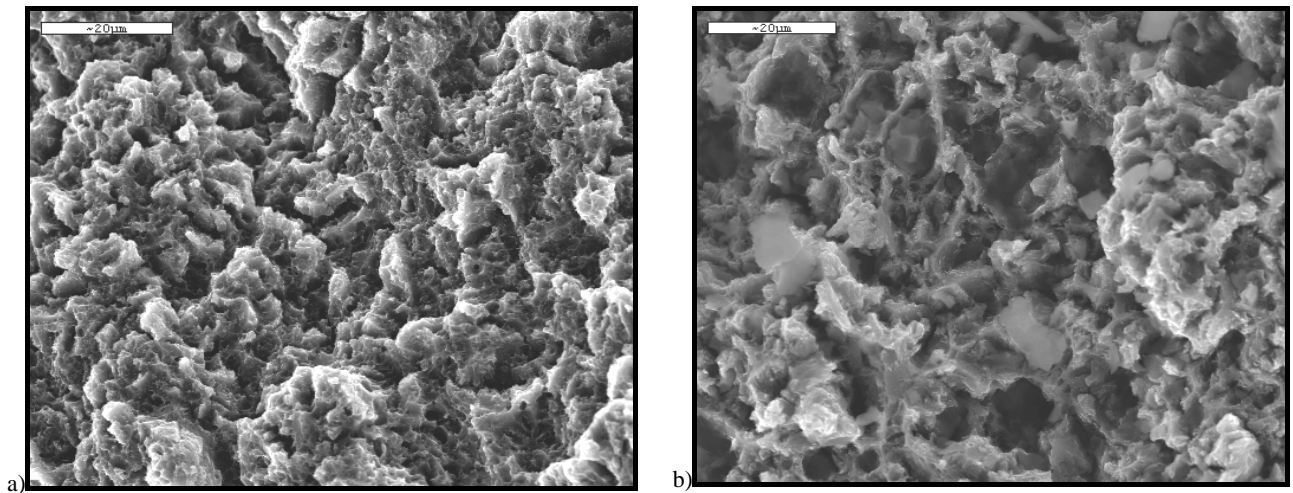


Fig. 2. Tensile test fracture topography of a) EN AW–Al Cu4Mg1(A) aluminium alloy, b) EN AW–Al Cu4Mg1(A) matrix composites reinforced with BN, after the heat treatment

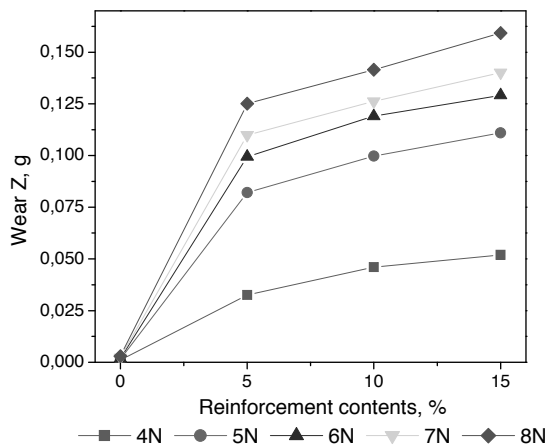


Fig. 3. Wear of the aluminium alloy and composite materials in the following states in the precipitation hardened state, at various load values, N

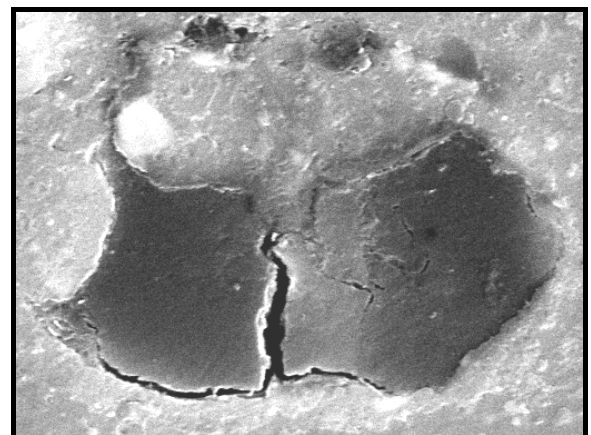


Fig. 4. The characteristic crack of particles

Heat treatment carried out resulted in the wear resistance improvement of the matrix material and of the fabricated composite materials 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

A slight deterioration of the corrosion resistance occurs compared to the matrix material at 5, 10 and 15% portion of the reinforcement with the BN particles; the corrosion resistance of these composites is -695,7 mV, -704,8 mV and -718,6 mV respectively, current density in the passive range 0,0251 mA/cm², 0,0262 mA/cm² and 0,0298 mA/cm², and the polarization resistance 0,2400 kΩ/cm², 0,1944 kΩ/cm² and 0,1880 kΩ/cm².

The composite material with addition of the BN particles whose corrosion potential at 5, 10, and 15% portion values are respectively -689,1 mV, -700,7 mV, and -707,7 mV, corrosion current density values in the passive range 0,0027 mA/cm², 0,009 mA/cm², and 0,0165 mA/cm², and the polarization resistance values are 4,22 kΩ/cm², 3,01 kΩ/cm² and 1,80 kΩ/cm². Corrosion rates of the composites with the 5, 10, and 15% portions of the BN reinforcement particles are 0,068 mm/year, 0,090 mm/year, and 0,102 mm/year respectively.

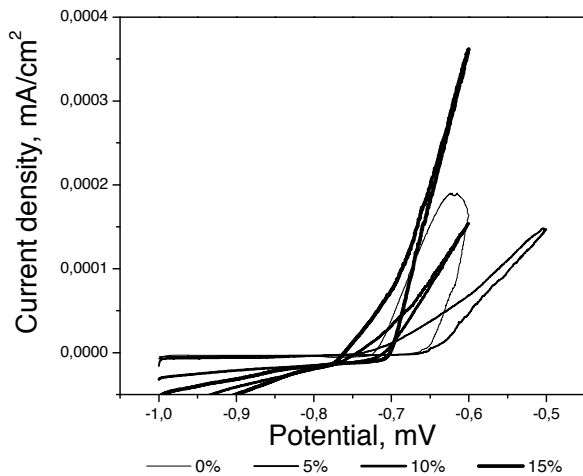


Fig. 5. Potentiodynamic curve for EN AW-Al Cu4Mg1(A) and aluminum alloy composite materials, after the heat treatment

New corrosion centres develop along with the increase of the portion of the reinforcing particles in the matrix of the investigated materials, both before their heat treatment and in the precipitation hardened state, which is connected with the failure progressing both into the material and on its surface when it is subjected to the corroding agent influence. This is equivalent to increasing the surface corrosion rate in the corrosive solution, which was determined basing on the values of the calculated

corrosion rate V_{kor} of the investigated test pieces, and also basing on the microscope observations of the corroded surfaces (Fig. 6).

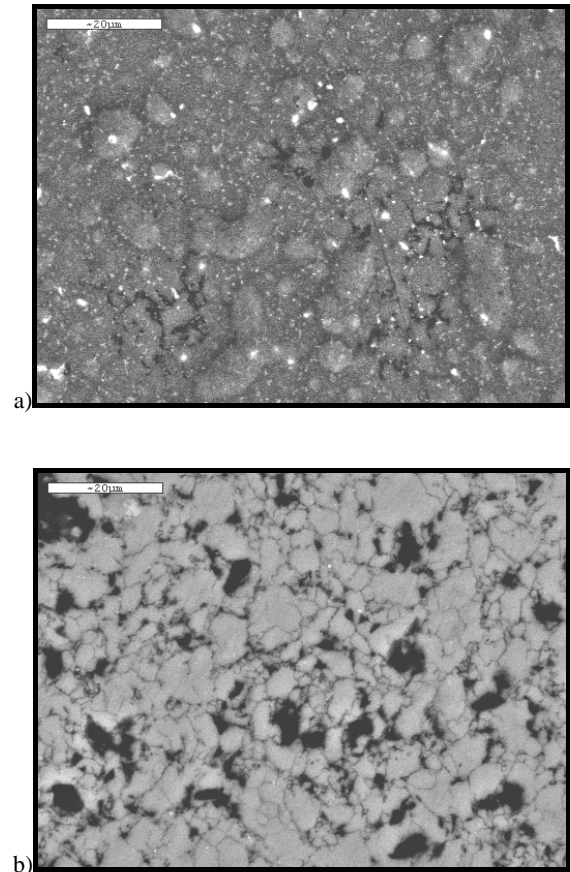


Fig. 6. Microstructure of the investigated materials after corrosion test: a) EN AW-Al Cu4Mg1(A), b) BN, after the heat treatment

Corrosion rate of the matrix material and of the composite materials after their heat treatment decreases significantly. Corrosion resistance falls along with the growth of the portion of the reinforcing particles in the matrix, which is supposedly dependant on the passive layer on the aluminium surface, separating the metal from the corrosive environment. Most probably the reinforcing particles act like impurities which locally prevent forming the adhering oxide layer.

The pitting potential E_{cp} value (Table 3), at which pits begin to form on surface of the investigated test pieces, and the re-passivation potential E_n value (Table 3), below which no active pits exist on the surface of test pieces were determined from the potentiodynamic curves flow.

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_{cp} and the re-passivation one E_n , 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. 5).

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. 6).

4. Conclusions

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

Introducing the hard BN particles into the soft matrix from the aluminium alloy causes hardness increase. Hardness of composite materials grows along with the increasing portion of the reinforcing material in the metal matrix. Precipitation hardening causes additional hardness increase of the investigated materials.

Moreover, basing on the tests carried out one can state that along with the BN particles portion in the aluminum matrix growth, compression strength and tensile strength of the composite material deteriorates. Addition of BN decreases the tensile properties - the biggest concentration of reinforcing particles the lowest properties. That in case of BN reinforcing particles decohesion between particle and matrix goes thru the interphases boundary indicating weak bonding between reinforcement and matrix finally affecting the stress transference between both components of the composites.

The weak bonding decided about wear resistance of investigated materials as well. Increase of reinforcing BN particles contents results in composite materials wear note increase. The wear resistant is slightly better when heat treatment is applied.

It was observed the influence of reinforcing particles on the corrosion resistance of the investigated materials. Introduction of BN particles cause decrease of corrosion resistance and with then concentration corrosion resistance decrease. Heat treatment of the composite materials by homogenization of the microstructure ameliorate the corrosion resistance.

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