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Structure, properties and corrosion resistance of PM composite materials based on EN AW-2124 aluminum alloy reinforced with the Al_2O_3 ceramic particles

L.A. Dobrzański, A. Włodarczyk, M. Adamiak

Division of Materials Processing Technology and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, Konarskiego 18a, 44-100, Gliwice, Poland, email: anna.wlodarczyk@polsl.pl

Abstract: Investigation results of composite materials based on the EN AW-2124 aluminium alloy reinforced with the Al_2O_3 particles with various weight ratios of 5, 10, and 15% are presented. Hardness tests and the ultimate compressive strength tests made it possible to demonstrate that both these properties change along with the reinforcing particles concentration change. Results of the corrosion tests, determined using the potentiodynamic method in the 3% water solution of NaCl indicate that corrosion of the investigated composite materials depends on the volume fraction of the reinforcing particles.

Keywords: Aluminum alloy; Cmposite materials, Corrosion resistance

1. INTRODUCTION

The development is observed in last years of metal matrix composites (MMCs) in many industry branches, among others in the aircraft industry, automotive-, and armaments ones, as well as in electrical engineering and electronics, etc. [1-7]. Considerable attention is focused on metal matrix reinforced with strength and high modulus ceramic reinforcements because of their superior properties in comparison with most conventional materials [6,8,9]. These materials should exhibit good corrosion resistance in the aggressive environment; therefore, determining the corrosion resistance of composite materials with aluminium matrix reinforced with ceramic additives is very important [10].

The goal of the work is to investigate the structure, selected mechanical properties, and corrosion resistance of the composite materials with the EN AW-2124 aluminum alloy based matrix reinforced with the ceramic particles of the Al_2O_3 phases with various weight ratios.

2. RESULTS AND DISCUSSION

Examinations were made of the composite materials with the EN AW-2124 aluminum alloy matrix (Table 1), reinforced with the Al_2O_3 ceramic particles with the weight ratios of 5, 10 and 15%. Powders of the starting materials were wet mixed (methanol slurry) in the laboratory vibratory ball mill to obtain the uniform distribution of the reinforcement particles in the matrix.

Table 1.
Chemical composition of EN AW-2124 aluminum alloy,% vol. [11]

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	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	remainder

The components were initially compacted at cold state in a die with the diameter of ∅ 26 mm in the laboratory vertical uniaxial 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. Bars with the diameter of 8 mm were obtained as the end product. Metallographic examinations of the composite materials with the EN AW- 2124 aluminum alloy matrix reinforced with the Al_2O_3 particles were carried out on LEICA MEF4A optical microscope; metallographic photographs were taken of the transverse and longitudinal sections in respect to the extrusion direction. Density of the extruded specimens was estimated with Archimedean principle, by determining the specimen mass and volume, and basing on the apparent loss of weight after immersing the specimen in water.

Hardness tests of the fabricated composite materials were made on HAUSER hardness tester with the Vickers method at 10 N load (PN-EN ISO 6507-1).

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. The yield point (YS), ultimate tensile strength (UTS) and Young's modulus (E) were determined employing at least two specimens for each material.

To determine the corrosion resistance of the EN AW-2124 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. 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. Potential change rate was 30 mV/min. 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".

On the contrary to the conventional casting processes the PM route of composite materials production makes possible to obtain wide range of reinforcement particles percentage addition without typical for them segregation. Metallographic examinations of the composite materials using optical microscopy revealed the uniform distribution of the Al_2O_3 reinforcing particles in the aluminum matrix. However, banding of the ceramic particles parallel to the extrusion direction was observed on the longitudinal microsections. In the final products of composites materials, depending on the reinforcement type, size and shape, type of matrix material, the density difference can occur, although the extrusion processes tends to minimize this problem. The reinforcement particles agglomeration and porosity is the most appointed cause of low performance of this class of materials.

Table2.
Properties of investigated composites material reinforced with Al_2O_3 ceramic particles

Material	Density [%]	HV1	UCS [MPa]	UTS [MPa]	YS [MPa]	E [GPa]
EN AW-2124	99,45	89,27	-	416	262	76
EN AW-2124/5%Al_2O_3	98,54	91,85	797,97	392	227	72
EN AW-2124/10%Al_2O_3	98,34	106,6	762,06	406	246	79
EN AW-2124/15%Al_2O_3	98,88	123,3	663,22	425	260	84

One can see that the density of all produced materials is close to the theoretical one but the existing differences indicate presence of porosity (Table 3). Analysis of microphotographs from scanning electron microscopy (SEM) reveals pores and confirms previous results.

Hardness tests of the fabricated composite materials revealed its diversification depending on the weight ratios of the reinforcing particles in the aluminum matrix. With the increase of volume portion of ceramics particles in matrix increase the hardness of composite materials.

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% (Table 3).

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. The effect of the reinforcing particles portion on the UCS (ultimate compression strength) values is presented in Table 3.

Loss of cohesion of the composite materials demonstrated by cracking of test pieces corresponds with the sudden drop of their compression strength. Based on the results all composite materials are characteristic of a lower compression strength compared with the non-reinforced material. Based on the compression test results all composite materials are characteristic of a lower compression strength compared with the non-reinforced material. When the portion of reinforcement particles Al_2O_3 is bigger, then the ultimate compression strength of composite materials decreases.

Curves obtained at potential changes in the anodic and cathodic directions confirm that the investigated materials are subjected to pitting corrosion. The highest pitting potential (-641 mV) is characteristic of the EN AW-2124/5%Al_2O_3 composite material, which indicates to its highest pitting corrosion resistance that may be caused by a good connection of the matrix particles with the reinforcement particles, and also by their small dimensions (0,5 μm). The lowest pitting potential (-651 mV) is characteristic of the composite material with the 15% volume portion of Al_2O_3. Having compared the hysteresis loop width (E_p i E_r), that is the range in which pits develop and they are growing, one can state that the highest corrodibility have the composite materials with the 15% reinforcement portion compared to the matrix. The pitting potential values increase along with the increase of the volume portion of the reinforcing particles in the matrix. The values of the E_{cor}, $I_{cor,}$ Rp, $v_{cor,}$ electrochemical parameters were determined using Tafel's method, and values of the $E_{p,}$ E_r parameters were determined from the runs of the potentiodynamic curves (Table 4).

However, the highest corrosion current value of 0.0225 mA/cm^2 was observed for the composite material reinforced with 15% Al_2O_3, which attests to its best pitting corrosion resistance. Also polarization resistance for this composite is the lowest (130 ohm/cm^2) which testifies it worst corrosion resistance in comparison with the others investigated composite materials.

Table 3.
Results of electrochemical corrosion investigation of the EN AW-2124 and composites material reinforced with Al_2O_3 ceramic particles in 3% NaCl

Material	E_{cor} [mV]	I_{cor} [mA/cm^2]	Rp [ohm/cm^2]	v_{cor} [mm/y]	E_p [mV]	E_r [mV]
EN AW-2124	-686	0,0154	382	0,129	-646	-712
EN AW-2124 / 5%Al_2O_3	-669	0,0089	601	0,120	-641	-701
EN AW-2124 / 10%Al_2O_3	-683	0,0148	424	0,125	-643	-706
EN AW-2124 / 15%Al_2O_3	-693	0,0225	130	0,304	-651	-720

4. CONCLUSION

Based on the structural examinations carried out the uniform distribution of the Al_2O_3 reinforcing particles in the EN AW-2124 aluminum alloy was revealed. Almost the theoretical density and directed structure, oriented corresponding to the extrusion direction were obtained during the extrusion process. The directed structure, oriented corresponding to the extrusion direction, developed during the extrusion process. Addition of the reinforcingAl_2O_3 particles to the aluminum matrix increased hardness of the composite materials obtained. The highest hardness was revealed for the composites reinforced with the 15% of Al_2O_3 particles. Moreover, basing on the tests carried out one can state that along with the Al_2O_3 particles portion in the aluminum matrix growth, compression strength of the composite material deteriorates. The highest UTS and YS were reveled for the composite reinforced with the 15% of Al_2O_3 particles. The presented corrosion resistance tests results for the investigated materials in the 3% NaCl solution indicate that the composite materials with the 5 and 10% volume portions of the ceramic particles are characteristic of the slightly higher corrosion resistance compared to the matrix material. However, along with the increase of the volume portion of the reinforcing particles in the matrix this resistance deteriorates, and at the 15% portion it reaches values higher than those of the matrix material.

REFERENCES

1. L.A. Dobrzański, A. Włodarczyk, M. Adamiak: Inżynieria Materiałowa, nr 6/137, 2003, (in Polish), p.609
2. J.W. Yeh, S.Y. Yuan, Ch.H Peng*:* Materials Science and Engineering A252/1998, p. 212
3. A. Włodarczyk: Composite materials with the AlCu4Mg1 (A) aluminium alloy matrix reinforced with the Ti(C,N), BN or Al_2O_3 ceramic particles, PhD thesis in progress.
4. A. Włodarczyk, L.A. Dobrzański, M. Adamiak: Inżynieria Materiałowa, Kraków-Krynica 7-10,October, (2003) (in Polish), p.369
5. L.A Dobrzański., A. Włodarczyk, M. Adamiak.: 12th Scientific International Conference "Achievements in Mechanical and Materials Engineering" AMME'2003, Politechnika Śląska, Gliwice-Zakopane (2003), p. 297
6. C.H. Gür: Materials Scince and Engineering A361 (2003), p.29
7. H.S.Chu, K.S. Liu, J.W. Yeh: Scripta Materialia 45 (2001), p.541
8. H. S. Hong, K.H. Chung: Materials Scince and Engineering A194 (1995), p.165
9. N.H. Kim, C.G. Kang, B.M. Kim: International Journal of Mechanical Scinces 43/2001, p.1507
10. H. Ughlig: Corrosion and its prevention, WNT, Warszawa 1976 (in Polish)
11. PN-EN 573-3, 1998 (Polish Standard – in Polish)