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Structure and properties of aluminium alloys reinforced with the Al_2O_3 particles

L.A. Dobrzański, M. Piec*

Institute of Engineering Materials and Biomaterials,
Faculty of Mechanical Engineering, Silesian University of Technology,
ul. Konarskiego 18a, 44-100 Gliwice, Poland

Investigation results are presented in the paper of composite materials with the EN AC - AlSi12(Cu) magnesium alloys matrix reinforced with the Al_2O_3 particles of 0.5 and 2 μm size and with the 50% volume fraction of ceramic particles, made by squeeze casting. Results of the metallographic examinations are presented and of the qualitative X-ray phase analysis of the obtained composites.

1. INTRODUCTION

The Al based composites reinforced with ceramic particles are used more and more widely, especially in transportation, manufacturing of the surface and air means of conveyance, in armaments industry and in astronautics. Publications appear since many years dedicated to manufacturing these materials and their investigation. There is a need to design properly the structures of composites, including the distribution of particles in their matrix to obtain their optimum functional properties.

Designing of composites on metal matrices reinforced with various ceramic particles makes it possible to obtain materials with very good mechanical properties (ratio of the mechanical properties to their specific density), functional properties, and with a significant increase of their abrasive wear resistance thanks to the effect of the reinforcing phase on the tribological surface - with maintaining the low part weight, resulting from using mostly the light metals for matrix [1, 3, 4].

However, improvement of the mechanical and tribological properties of composite materials compared to the matrix material alone is often dependant on many interlinked factors resulting from the particular aspects of design of these materials, beginning from selection of components, their manufacturing method, up to attaining the specific macro- and microstructure of the final element.

The unwanted reactions that may take place between the matrix and reinforcement may be limited or even eliminated by employment of barrier coatings (unreactive); however, this is an expensive method, or by minimizing the contact time of the reinforcement with the liquid metal by reducing the solidification time, as it is done in the squeeze casting method. Because of the occurrences of the phenomena mentioned above (wettability and reactivity),

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solidification processes in case of composite materials have found their application for metal matrices with the low melting point, like Al [2].

Mechanical properties of composite materials reinforced with ceramic particles depend on the matrix type, mutual wettability, amount of the reinforcing phase, and size of the reinforcing particles. Hardness of these materials depends on the contents of ceramic fibers in the matrix and grows with its increase. Therefore, an attempt was made in this paper to describe the meaning that the aluminium oxide particles have in these materials, being introduced into the EN AC - AlSi12(Cu) aluminium alloy matrix.

2. EXPERIMENTAL PROCEDURE

Examinations were made using the composite materials specimens with the EN AC - AlSI12(Cu) magnesium alloy matrix, reinforced with the Al_2O_3 ceramic particles. The chemical composition of the magnesium alloy is presented in Table 1.

Table 1
Chemical composition of the EN AC - AlSi12(Cu) magnesium alloy

Alloy type	Mass fraction of the element, [%]								
	Si	Cu	Mg	Mn	Fe	Ti	Zn	Ni	Pb
EN AC - AlSi12(Cu)	12	≤ 1	≤0.35	0.3	≤0.8	≤0.2	≤0.55	≤0.3	≤0.2

Table 2
Volume fraction of the reinforcing particles in the investigated specimens

Powder types	Volume fraction		
	Specimen 1	Specimen 2	Specimen 3
Al_2O_3 – Cl2500	55	41	0
Al_2O_3 – HPA0.5	23	17	79
Cellulose	20	40	20

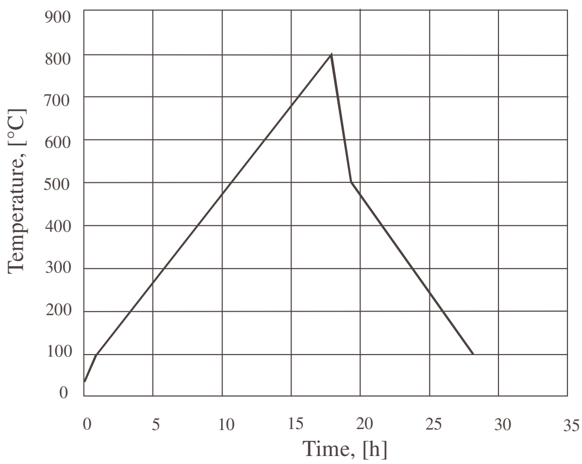

Fig. 1. Temperature versus time in the pyrolysis process

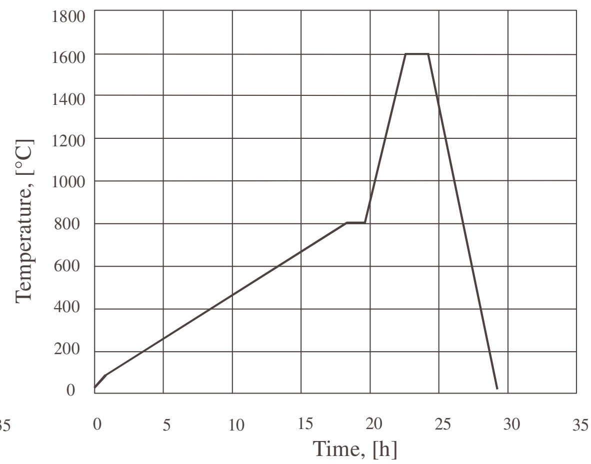

Fig. 2. Temperature versus time in the sintering process

The Al_2O_3 specimens were prepared in a special vessel 64.9 mm long, 45.9 mm wide, and 35.6 mm high. Two powder types were used for preparation of the powder, CL 2500 with the average grain size of 2 μm and HPA 0.5 with the average grain size of 0.5 μm. Organic material – cellulose – was used to provide the relevant volume fraction of the ceramic particles. The PVA-Mowiol 18/88 polyvinyl alcohol with 10% concentration was added as 1% fraction. Volume portions of the particular fractions in the prepared Al_2O_3 specimens are presented in Table 2.

Preparation process of the Al_2O_3 powder includes the following stages: weighing, grinding (5 minutes), freezing and drying (-10 ÷ +40°C), sifting (sieve 0.25 mm), sprinkling the powder with distilled water (3% volume), homogenization at the temperature of 21°C for 24h.

The powder, prepared in this way was one-side uniaxially pressed at the room temperature under the pressure of 100 MPa for 10 sec. The process of preparing the Al_2O_3 specimens included the following stages: forming of powder, pressing, pyrolysis of the organic materials, and sintering.

Parameters of the preparation process of the aluminium oxide specimens are presented in Figures 1 and 2. Sintering of specimens was carried out in the Gero furnace at the temperature of 1600 °C. The aluminium oxide specimens infiltration process with the EN AC - AlSi12(Cu) aluminium alloy was preceded by heating of the reinforcing material to the temperature of 900 °C in the Heraeus furnace, whereas the matrix material was heated to the temperature of 800 °C in the Degussa furnace.

Infiltration of specimens prepared in the above mentioned way was squeeze cast in the argon atmosphere under the pressure of 100 MPa for 120 seconds. The vessel in which the specimens were infiltrated was heated to the temperatures of 250 450 °C respectively.

Metallographic examinations were carried out on the Zeiss Axiophot light microscope at magnifications of 50 and 100 x. Metallographic pictures were taken of transverse sections perpendicular to the pressing direction of the composite materials.

Examinations of fractures of the composite materials with the EN AC - AlSi12(Cu) matrix reinforced with the Al_2O_3 ceramic particles were made on the DSM 940 scanning electron microscope at magnifications of 1000, 2000, and 3000 x.

Hardness tests were made on the Zwick / ZHR hardness tester with the load force of 98 N for 30 sec. The X-ray qualitative phase analysis was made using the Dron-2 diffractometer equipped with the cobalt anode lamp, powered with the current of 40 kV voltage, with the 20 mA heater current. The measurements were made in the 2θ angle range from 40 to 105°.

3. ANALYSIS OF EXPERIMENTAL RESULTS

All examinations described in this work were made on specimens with 20% fraction of organic material and 79% volume fraction of Al_2O_3, in proportions: 70% Cl 2500, 30% HPA 0.5 infiltrated with the aluminium alloy. Materials with the 40% volume fraction of cellulose were not infiltrated, as many defects in the form of laminar cracks were detected in them during sintering. Material with 80% Al_2O_3 – HPA0.5 and with 20% cellulose fraction was not infiltrated because of its excessive porosity.

The multiple hardness value growth of the composite material in respect to the matrix material was revealed as a result of hardness tests of the EN AC - AlSi12(Cu) aluminium alloy and the infiltrated material. Matrix material demonstrates hardness of 16.7 HRA, whereas the composite material attains hardness of 59.6 HRA.

a) b)

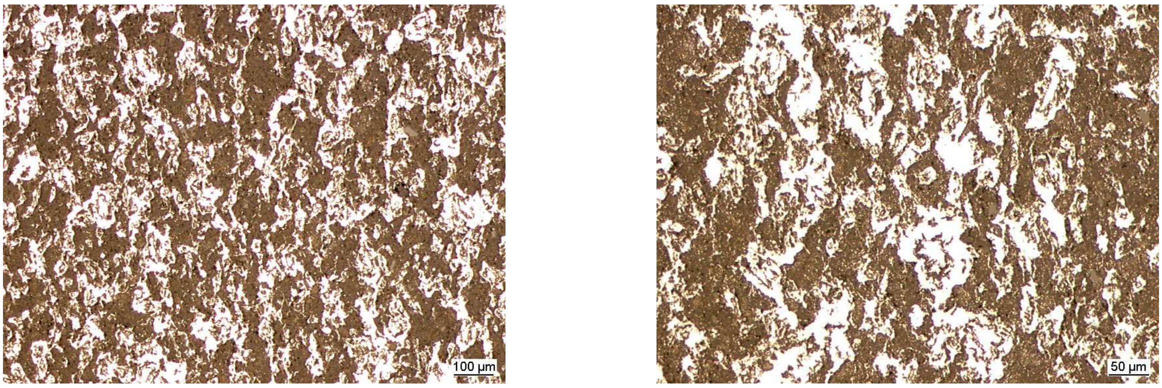

Fig. 3. Composite structure – infiltration temperature 800 °C, Al_2O_3 phase – dark areas, Al alloy matrix – light areas

It was observed during metallographic examinations of composite materials that the Al_2O_3 powder distribution in the matrix is homogeneous. Occurrence of the Al and Al_2O_3 solid solution was found in the structural examinations and basing on the X-ray qualitative phase analysis of the composite material with the EN AC - AlSi12(Cu) aluminium alloy matrix reinforced with Al_2O_3 (Figs. 3, 4). No other phases were detected in the investigated composite material.

It was found out in the experiments of infiltration of Al_2O_3 with the EN AC - AlSi12(Cu) alloy that the temperature of the vessel in which the infiltration was made had the significant effect.

All experiments made at the vessel temperature of 450 °C ended up with the complete infiltration, whereas, after lowering the vessel temperature to 250 °C incomplete infiltration was found.

a) b) c)

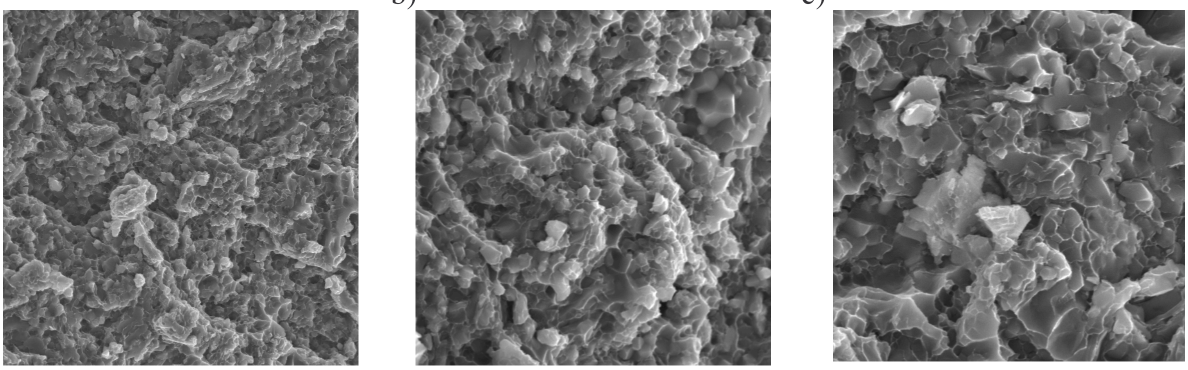

Fig. 4. Topography of composite materials fractures with the EN AC - AlSi12(Cu) matrix reinforced with the Al_2O_3 ceramic particles, a) magnification 1000×, b) 2000×, c) 3000x

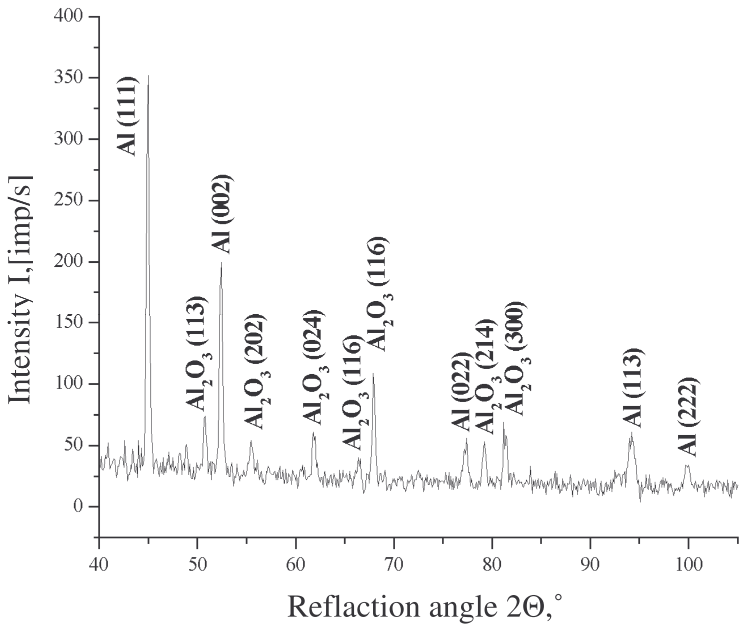

Fig. 5. X-ray diffraction pattern of the composite material with the EN AC - AlSi12(Cu) alloy matrix reinforced with the Al_2O_3 particles

4. SUMMARY

Metallographic examinations on the light and scanning microscopes revealed the homogeneous distribution of the Al_2O_3 particles in the matrix material. Basing on the X-ray qualitative phase analysis no reactions between matrix and reinforcement were revealed. Basing on hardness tests the composite material hardness was found to be nearly 4 times higher compared to the matrix material. It was found out that infiltration of the entire Al_2O_3 specimen with the EN AC - AlSi12 (Cu) alloy was not possible after lowering the infiltration vessel temperature to 250 °C.

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