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MECHANICAL PROPERTIES OF Al-Si COMPOSITE MATERIALS OBTAINED BY STIR CASTING

Alina Georgeta JUMOLEA, George ARGHIR

Abstract: *Particulate reinforced metal matrix composites were made with metallic matrix of aluminium (AlSi5Cu2Mg) reinforced with volume 3 %, 5 %, and respectively 7 % silicon carbide by stir casting. Control specimen (C) presented rounded aluminium-silicon dendrites in microstructure. By adding SiC the microstructure becomes finer, silicon carbide particles are uniform distributed, in grain boundaries, at 7 % SiC clusters appear. Mechanical tensile strength is increasing from 129 MPa of C to 159.5, 164, and respectivelly 158.8 MPa. Tensile yield strength is increasing, comparative to 100 MPa of C, at 119, 126.5, and respectively 117.5 MPa. Relative elongation, comparative to 0.75 % for C, increases at 1.2 %, 1.45 %, and respectively 1.1 %. Yield stress and elongation increase as silicon carbide increases, having both a slight drop at 7 % SiC. Elastic modulus decreases with increasing of silicon carbide content from 14,850 MPa at C to 9,923, 8,711, and respective 10,729 MPa. Modulus decrease of about 6 % by adding 3 - 7 % SiC in the metal matrix. HB hardness increases from 60 units for C to 87.05, 92, and respectively 86.5 units when reinforcing material is added. A decrease in hardness is noticed at 7 % SiC. The best mechanical properties are obtained at 5 % SiC added to the aluminium-silicon matrix.*
Key words: *Metal matrix composite, silicon carbide, mechanical properties.*

1. INTRODUCTION

The most important progress in the field of techniques have been conditioned to obtaining and use of new materials, which have always been a necessity that led to products with outstanding properties for a wide range of mechanical stress, with a low specific mass. Particular importance was given so to elaboration and research of composite materials in the last years.

The purpose of this study was to obtain a composite material possessing high mechanical properties at a low density using an aluminum matrix reinforced with 3 %, 5 %, and 7 % silicon carbide by stir casting. Interest in the scientific world is noted for producing aluminium matrix composite reinforced with silicon carbide particles [1-16]. All authors were occupied with reinforcement of 1 – 3 or 10, 15, and 20 % SiC.

2. MANUFACTURE OF ALUMINIUM MATRIX COMPOSITE MATERIALS REINFORCED WITH SILICON CARBIDE PARTICLES

It was used an AlSi5Cu2Mg alloy as metallic matrix for excellent properties of casting as high fluidity, relative low shrinkage, low susceptibility to hot cracking and pore-forming [17, 18]. It was used VORTEX technology for elaboration of AlSi5Cu2Mg/SiC materials [19, 20]. This technology consists in adding of silicon carbide particles in the vortex, created in melt through mechanical stirring by means of a shaft ended with metallic blades, driven by a variable speed electric motor. Liquid alloy, representing the matrix, is stirred vigorously, appearing a whirlpool in which particles are introduced by a dosing device [21].

Silicon carbide, hard and brittle, presents the advantages of its high refractory behaviour and hardness, as compared with other materials. It was used β-type silicon carbide added in volumetric 3 %, 5 %, and 7 % SiC.

The particles were introduced into the melt as uniform as possible to avoid their agglomerations and were preheated before introduction into the melt in order to improve mixing and reduce the agglomeration tendency.

Melting of the matrix alloy was done in a flame graphite crucible furnace, with a conical shape, having a height greater than the diameter, so that the angle of inclination of the shaft agitator is between 20 - 30 ^{o} to vertical [22-24]. This angle of inclination was selected to achieve a better mixing and avoid turbulences at the surface of the melt. Shaft with metallic blades has been preheated before stirring. Stirring time was set between 1 - 2 minutes for a better homogenization of the material [25].

Two percent of metallic magnesium was introduced into the melt to decrease surface tension for better wetting and improving fluidity in the matrix - particles system [26].

Casting was carried out at a temperature between 780 - 810 °C, because at temperatures exceeding 810 °C may appear rejection of the particles by the melt, as well as particle agglomeration due to chemical interaction between the particle and the melt [27, 28]. A metallic not preheated mould was used for casting for rapid solidification of material to avoid agglomeration, sedimentation, and segregation of particles.

3. RESULTS AND DISCUSSION

Micro-structural inspection was carried out on samples taken from the Al/Si composite, on optical microscope NEOPHOT 21.

Figure 1 shows the control specimen microstructure (AlSi5Cu2Mg) with no reinforcement particles in metallic matrix produced by casting.

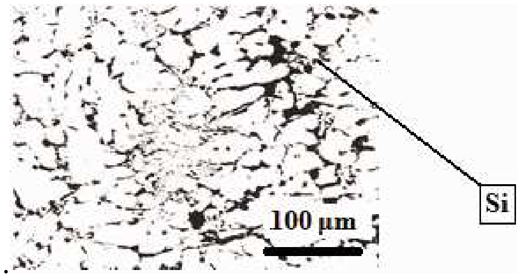

Fig. 1. Microstructure of AlSi5Cu2Mg.
Etchant: 0.5 % HF.

Silicon appears as points grouped in colonies growing from independent centres, having a fine distribution, at the edge of rounded dendrites, formed of Al-Si solid solution result of eutectic reaction, due to the high speed cooling during solidification, Figure 1. Microstructure is quite uniform and equaxial.

Figure 2 shows micrographs of Al/SiC composite material for silicon carbide particles of different volume percentages.

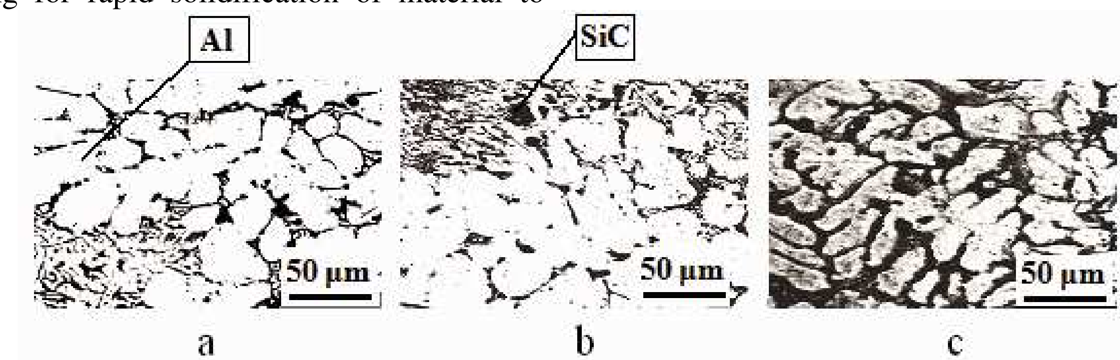

Fig. 2. Microstructure of Al/SiC with: a) 3 % SiC; b) 5 % SiC; c) 7 % SiC. Etchant: 0.5 % HF.

There is noticed aluminium – silicon dendrites, Figure 2a, surrounded by silicon carbide particles at their limits. Micrograph shows a uniform distribution of silicon carbide particles. No segregation of the particles is in composite material containing 3 % SiC.

The particles of silicon carbide are uniformly distributed (in 5 % SiC specimen) and they are located at the grain boundaries of the aluminium matrix, Figure 2b. Finer eutectic is seen in the sample.

It can see (the silicon carbide particles increases at 7 %) the microstructure is dense and dark, but the distribution of the reinforcing particles is still uniform and well-connected to the aluminium matrix, Figure 2c. Some SiC clusters are seen.

In all cases, the SiC particles are at aluminium-silicon dendrites limit.

With the increase of SiC the structure is becoming finer, and the presence of particle clusters are noticed, Figure 2c.

The material has a heterogeneous structure of castings, Figures 2a, 2b, and 2c.

Micro-structural analysis reveals that some SiC particles can remain free.

Increasing the content of 5 % SiC, the more uniform is their distribution in the matrix; structure becomes finer, resulting in a higher mechanical strength of the sample, Figure 2b.

Cylindrical test pieces were machined from the casts and then subjected to mechanical tensile and hardness tests. The main mechanical characteristics were determined:

- Tensile mechanical strength - Rm;
- Tensile yield strength - Rp0.2;
- Modulus of elasticity (Young) - E;
- Relative elongation - A;
- Hardness - HB.

A LOSENHAUSENWERK LOS 600 universal testing machine was used for tensile testing. The load is applied gradually to the specimen until breaking.

Table 1 shows the results of tensile tests.

The mechanical tensile strength of the control specimen (C) is of 129 MPa, Table 1. It is increasing to 159.5, 164, and respectively 158.8 MPa by adding 3 %, 5 %, and respectively 7 % SiC. Tensile strength, at 7 % SiC content, has a decrease due to silicon carbide saturation and the presence of agglomerations of particles in the sample. The addition of 3 – 7 % SiC to the aluminium-silicon matrix is 25 % breaking effort improving. Silicon carbide particles being at the aluminium – silicon dendrite limits are barriers opposing to their deformation, so the deforming effort and breaking strength are increased.

The tensile yield strength is increasing at 119, 126.5, and respectively 117.5 MPa at the content of 3 %, 5 %, and respectively 7 % SiC, comparative to 100 MPa of control specimen. Almost the same increase is noticed for relative elongation, that is 1.2 %, 1.45 %, and respectively 1.1 %, for 3 %, 5 %, and respectively 7 % SiC, comparative to 0.75 % for control specimen.

Yield stress and elongation increase as silicon carbide particles content increases, having both a slight drop at 7 % SiC. This is due to the presence of silicon carbide clusters at 7 % SiC, Figure 2c, causing casting defects.

The modulus of elasticity (E) is shown in Table 1.

Table 1

Tensile tests: Tensile mechanical strength – Rm, Tensile yield strength - Rp0.2, Modulus of elasticity (Young) – E, Relative elongation – A

Crt. Nr.	Specimen	d_0, mm	S_0, mm^2	Fr, N	Rm, MPa	Rm Average, MPa	Rp0.2, MPa	Rp0.2 average, MPa	A, %	A average, %	E, MPa	E Average, MPa
1	C	13.9	151.7	14,866.6	98	129	97	100	0.5	0.75	19,400	14,850
2	C	14	153.9	2,4624	160		103		1		10,300	
3	3 % SiC	13.9	151.7	23,665.2	156	159.5	110	119	1.1	1.2	10,000	9,923
4	3 % SiC	14	153.9	25,085.7	163		128		1.3		9,846	
5	5 % SiC	13.9	151.7	23,968.6	158	164	117	126.5	1.4	1.45	8,357	8,711
6	5 % SiC	14	153.9	26,163	170		136		1.5		9,066	
7	7 % SiC	13.9	151.7	23,604.5	155.6	158.8	108	117.5	0.97	1.1	11,134	10,729
8	7 % SiC	14	153.9	24,931.8	162		127		1.23		10,325	

C – Control specimen; d_0 – initial diameter; S_0 – initial area; Fr – maximum breaking tensile strength.

As it was expected, the elastic modulus decreases with increasing of silicon carbide content in the control specimen from 14,850 MPa to 9,923, 8,711, and respective 10,729 MPa, at contents of 3 %, 5 %, and 7 % SiC. Modulus decreases of about 6 % by adding 3 -

7 % SiC in the metal matrix. This decrease can be explained by the fact that the interface between the matrix and reinforcing material is weaker and reduced the load transfer from the matrix to the reinforcing material.

A universal testing machine MOHR and FEDERHAFF was used to hardness tests.

Hardness tests were carried out on the ends of the traction breakings, by Brinell method with 10 mm ball and 1000 kgf load for 30 seconds. The results of the hardness test are presented in Table 2.

Table 2

Hardness tests (HB)

Crt. Nr.	Specimen	Dprint, mm	HB, units	HB average units
1	C	4.67	55	60
2	C	4.32	65	
3	3 % SiC	3.88	85.4	87.05
4	3 % SiC	3.73	88.7	
5	5 % SiC	3.81	90.7	92
6	5 % SiC	3.75	93.3	
7	7 % SiC	3.94	85	86.5
8	7 % SiC	3.87	88	

Since the particles of silicon carbide have high hardness and surface coming in contact to testing ball will have a large number of particles, sample will resist to deformation, leading to an increase in the hardness of the samples containing silicon carbide over than 3 %, so from 60 units for C to 87.05, 92, and respectively 86.5 HB units, for 3 %, 5 %, and respectively 7 % SiC.

It is noted a slight decrease in hardness at a content of 7 % SiC due to high elaboration temperature and too long melt agitation which produces defects in castings.

4. CONCLUSIONS

There were made composite materials with metallic matrix of aluminium (AlSi5Cu2Mg) reinforced with 3 %, 5 %, and respectively 7 % silicon carbide particles by stir casting.

Control specimen (C) presented rounded aluminium-silicon dendrites in microstructure. Silicon appears grouped in colonies, growing from independent centres, having a fine distribution at the edge of dendrites. By adding 3 %, 5 %, and respectively 7 % SiC the microstructure becomes finer, silicon carbide particles are uniform distributed, in grain boundaries, at 7 % SiC clusters appear.

The mechanical tensile strength is increasing from 129 MPa of C to 159.5, 164, and respectively 158.8 MPa. Tensile strength, at 7 % SiC content, has a decrease due to silicon carbide saturation and the presence of agglomerations of particles in the sample.

The tensile yield strength is increasing, comparative to 100 MPa of C, at 119, 126.5, and respectively 117.5 MPa. The same increase is noticed for relative elongation, comparative to 0.75 % for C that is 1.2 %, 1.45 %, and respectively 1.1 %. Yield stress and elongation increase as silicon carbide increases, having both a slight drop at 7 % SiC, due to silicon carbide clusters.

The elastic modulus decreases with increasing of silicon carbide content from 14,850 MPa at C to 9,923, 8,711, and respective 10,729 MPa. Elastic modulus decrease 6 % by adding 3 - 7 % SiC in the metal matrix. The decrease is the result of weaker interface between matrix and reinforcing particles – which reduces the load transfer.

The HB hardness is increasing from 60 units for C to 87.05, 92, and respectively 86.5 units when reinforcing material is added. Decreases in hardness are noticed at 7 % SiC due to high elaboration temperature and too long melt agitation which produces defects.

The best mechanical characteristics are obtained at 5 % SiC added to the aluminium-silicon matrix.

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PROPRIETĂŢI MECANICE ALE MATERIALELOR COMPOZITE Al-Si OBŢINUTE PRIN TURNARE

Rezumat – Materiale compozite cu matrice metalică din aluminiu (AlSi5Cu2Mg) sunt armate cu particule din carbură de siliciu (SiC) în cantitate de 3, 5 şi 7 % prin amestecare în stare lichidă. Proba martor (C) a prezentat, în microstructură, dendrite de aluminium-siliciu rotunjite. Prin adaugare de SiC microstructura devine mai fină, particulele de SiC sunt mai uniform distribuite, la limita granulelor şi apar grupate la 7 % SiC. Rezistenţa mecanică la tracţiune creşte, comparative cu 129 MPa a probei C, la 159,5, 164 şi respectiv la 158,8 MPa. Rezistenţa de curgere la tracţiune creşte, comparativ de la 100 MPa a C, la 119, 126,5 şi respectiv 117,5 MPa. Alungirea relativă, comparată cu 0,75 % pentru C, creşte la 1,2, 1,45 şi respectiv 1,1 %. Rezistenţa de curgere la tracţiune şi alungirea relativă cresc pe măsura creşterii conţinutului de SiC, insă ambele au o cădere uşoară la 7 % SiC. Modulul de elasticitate scade cu creşterea conţinutului de SiC de la 14.850 MPa pentru C la 9.923, 8.711 şi respectiv 10.729 MPa. Modulul de elasticitate scade cam 6 % prin adăugarea a 3 – 7 % SiC matricei metalice. Duritatea HB creşte de la 60 unităţi pentru C la 87,05, 92 şi respectiv 86,5 unităţi când se adaugă material de armare. O scădere a durităţii se remarcă la 7 % SiC. Cele mai bune proprietăţi mecanice se obţin la adăugarea de 5 % SiC matricei de aluminiu-siliciu.

Alina Georgeta JUMOLEA, PhD Student, Eng., Technical University of Cluj-Napoca, Department of Materials Science and Technology, E-mail: jumoleaalina@yahoo.com.

George ARGHIR, PhD, Professor Emeritus, Technical University of Cluj-Napoca, Department of Materials Science and Technology, georgearghir@hotmail.com, Office Phone: +40 264401705, Home Address: Detunata 17/27, 400434 Cluj-Napoca 9, Home Phone: + 40 264414036.