THERMAL CHARACTERISTICS OF COMPOSITES WITH AN ALUMINIUM ALLOY MATRIX REINFORCED WITH SILICON CARBIDE AND GRAPHITE

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Abstract. The aim of the paper is to analyse the thermal stability of hybrid composites (MMCH) with AlSi7Mg03+10%SiC$_p$+3% Graphite, used in the automotive, aeronautic, microelectronic industries, by thermal analysis, type DIL (dilatometric analysis) and TGA (thermogravimetric analysis) correlated with techniques for structural investigation (SEM/EDS).

The results obtained, show that the reinforcing elements influencing the thermal expansion phenomenon and the phase transformations. The linear expansion coefficient (CTE), determined utilizing the Kerner model, extended for hybrid composites, is similar to the one determined through experiments, being influenced by the thermal characteristics, the volume fraction of the matrix and the reinforcing elements. A similar influence was recorded in the case of thermogravimetric analysis.

Keywords: composites, aluminium, SiC, graphite, thermal expansion

1. Introduction

The evolution of industrial branches such as auto, aeronautic and microelectronic engineering has led to the development of composite materials with a metallic matrix (MMC), with increased thermal conductivity and a reduced thermal expansion coefficient [1].

An optimum joining between the thermal, mechanical and tribological characteristics of the MMC composites was obtained through the development of hybrid composites (MMC) reinforced with a minimum of two components.

The thermo-physical characteristics of a material (expansion coefficient, thermal conductivity, diffusivity, specific heat) are evidenced through thermal analysis, defined by T. Hatakeyama, Liu Zhenhai [2] as being a group of techniques in which a physical property of a material is measured based on the temperature while the material is subjected to a programme of controlled variation of temperature.

In the presented paper, in order to analyse the thermo-physical characteristics and the dimensional stability of the hybrid composite MMCH (AlSi7Mg03 + 10% SiCp + 3% copper covered graphite) two methods were used: DIL (dilatometric analysis) and TGA (thermogravi-metric analysis).

Dilatometer studies show the way in which the composite materials responds to thermal variations.

The thermogravimetric analysis (TGA) highlights the mass stability and the structural transformations while the sample is subjected to controlled temperature variations. TGA also offers data regarding the upper limit for the operating temperature of the material [3].

Thermo-physical properties were affected by the nature of the matrix, nature and size of the reinforcing particles, coating elements and compounds formed, and residual porosity [1, 3].

A comparative analysis regarding the dimensional stability of the aluminium matrix, reinforced with silicon carbide particles and graphite. Introducing graphite and SiC particle (SiCp) into the metallic matrix with an aluminium base resulted in decreased thermal expansion of the composites, since SiC has a lower thermal expansion coefficient than that of aluminium matrix [3].

Higher dimensional stability values are obtained as long as the dimensions of the reinforcing particles decreases.

Addition of graphite and SiC, favours the formation of a compound Al_4C_3:

$$4Al(l)+3C(s) \rightarrow Al_4C_3(s),$$

$$4Al + 3\ SiC \rightarrow Al_4C_3 + 3\ Si.$$

This compound in the composite material structure leads to a degradation of the thermal properties [1].

Formation of hybrid composites by adding graphite together with SiCp, in the metallic matrix, generates a residual stress due to the difference between the thermal expansion coefficients of the components [3].

The residual porosity impairs the thermal conductivity (TC) of the composites. Increasing the concentrations of graphite in MMCH composite with SiC and graphite obtained by the Vortex method causes an increase in residual porosity (matrix porosity is 1.3233%, in the composite with 1.25% graphite is 8.8165% and in the composite with 3% graphite is 11.7884%) [4, 11].

2. The Studied Material

The chemical composition of the analysed material is presented in Table 1.

Table 1. The chemical composition of the composite material

Material	Matrix	SiC_p [%]	Graphite [%]
MMCH	AlSi7Mg03	10	3

2.1. The matrix material

Composites with metallic matrix (MMC) are characterized by a matrix formed of a material capable of incorporating the disperse component, that will not be destroyed through dissolving or melting, through chemical reactions or mechanical actions [5, 6].

The matrix is usually made from alloys of aluminium, magnesium, titanium or copper [5].

The usage of an alloy with an aluminium base (AlSi7Mg03) as a matrix in the studied composite is due to its characteristics, these are shown in Tables 2 and 3.

Table 2. Mechanical properties of matrix material [7]

Casting method	Tempe-rature	Yield strength $R_{p0.2}$ [MPa]	Tensile strength R_m [MPa]	Young modulus [GPa]	Hardness [HB]	Fatigue strength [MPa]
S	F	80-140	140-220	75	45-60	60-80

S - static cast, F - without treatment

Table 3. Physical properties of matrix material AlSi7Mg03 [7]

Density [g/cm^3]	Lin expansion coefficient (20-200 °C) [10^{-6}/K]	Thermal conductivity [W/mK]	Solidification range [°C]	Poisson coefficient ν
268.0	22	180	625-555	0.3499

2.2. Reinforcing elements

The reinforcing materials frequently used in MMCH include SiC, Al_2O_3, B_4C, TiC, graphite, because these provide an optimal rigidity, resistance and density.

The reinforcement of an aluminium alloy matrix with hard particulates (silica carbide) and soft particulates (graphite) imbues these materials with tribological characteristics.

In the assessed case the reinforcing element used was silicon carbide (SiCp) in powdered form in proportion of 10% and graphite in proportion of 3% covered with copper.

The choice of silicon carbide as a reinforcing element is justified by its physical-mechanical characteristics that are shown in table 4 as well as its physical and chemical compatibility with the aluminium alloy based matrix.

Table 4. Physical-mechanical characteristics of the SiC [8]

Material	Density [g/cm³]	Tensile strength [GPa]	Elasticity module [GPa]	Melting temperature [°C]	Linear expansion coefficient [x10^{-6}/°C]	Poisson coefficient ν	Thermal Conductivity [W/mK]
SiC	3.2	21	700	2730	4.3	0.19	180

Reinforcement with soft particles (graphite, talc) added to a metal matrix determine better lubricating properties accompanied by a reduction in density. In order to incorporate the graphite particles in the melted aluminium alloy matrix, these were covered with cooper [7].

Graphite is well known as solid lubricator and its presence in the aluminium alloy matrix favours auto lubrication.

The physical and mechanical characteristics of the graphite are presented in Table 5.

Table 5. The physical and mechanical characteristics of graphite

Material	Density [g/cm³]	Tensile strength [GPa]	Elasticity module [GPa]	Melting temperature [°C]	Linear expansion coefficient [x10^{-6}/°C]	Thermal conductivity [W/mK]
Graphite	2.2	19.6	680	3550	1.4- 6.0	150

2.3. Preparing the material

MMCHs composite synthesis was achieved by Vortex method during the course of MATRIB project and presented in previous works [5, 10]. The research has highlighted some issues relating to the minimum conditions for particle moistening by the molten aluminium alloy and mechanical, tribological, chemical, technological characteristics.

Covering copper graphite ensures a good wettability and embedding in the melted matrix.

3. Investigating techniques

3.1. Microstructural characterization

For microstructural characterization a Scanning Electron Microscope (SEM JOEL, JSM 840A) was used, equipped with dispersion spectrometer (EDS). Samples were polished using metallo-graphic practices and etched with Keller's regent prior to microstructure examination.

3.2. Thermal analysis

Thermogravimetric analysis (TGA) was carried out using a device for simultaneous thermal analysis (STA) type NETZSCH STA 449F3 STA 449F3A-0508-M. For experiments, a cylindrical sample was used, with a 5 mm diameter and height of 4 mm skimmed, washed and dried. The samples were heated to 700 °C with a heating speed of 30 °C/min and then cooled to room temperature with the same speed, in a nitrogen atmosphere at a flow rate for the gas of 20 ml/min as purging gas.

For determining the linear expansion coefficient (CTE) a LINSEIS type L75-230 dilatometer was used. The samples were heated at a rate of 15 °C/min to a temperature of 500 °C. The dilatometer is assisted by a specialized program which automatically calculates and draws the diagrams.

4. Results and discussions

4.1. Microstructural characterization

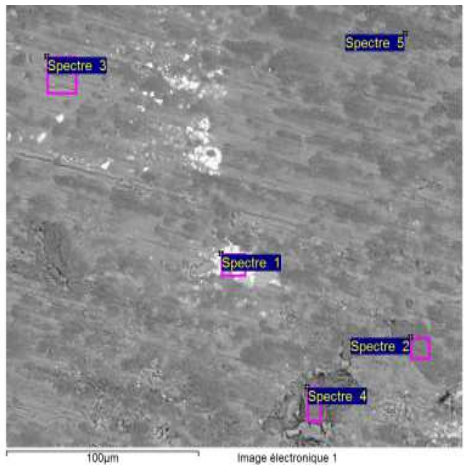
The microstructures of the hybrid composites AlSi7Mg03-SiC_p-copper coated graphite are shown in Figures 1 and 2.

SEM analysis highlights the embedded SiC particles in the matrix of AlSi7Mg03, the quasi dispersion of the graphite around the particles of SiC (Figure 1). It highlighted some areas where aluminium-silicon eutectic structures are arranged, carbide particles being dispersed at the limit of these areas (Figure 2).

The nature and composition formed structures, studied through Scanning Electron Microscopy with X-ray microanalysis (SEM/EDS), are shown in Figure 3. Analysis reveals the presence of copper introduced as wetting element, SiC, graphite, eutectic phase, α-Al solid solution, and compounds type Al_4C_3.

Figure 1. SEM image. Showing SiC particles embedded as well as the areas of quasi dispersion of the graphite in the SiC_p zones

Figure 2. SEM image. Area of the composite with eutectic solidification structures



Spectre	C	Mg	Al	Si	Cu
1	29.912	3.26	53.074	8.174	5.58
2	42.24		12.11	45.65	
3	9.15		86.55	0.97	3.93
4	62.26		1.98	34.45	1.31
5	21.45	0.27	68.612	9.42	0.16
Max.	62.26	3.26	86.55	45.65	5.58
Min.	9.15	0.27	1.98	0.97	0.16

Figure 3. SEM/EDS image for the composite material (AlSi7Mg03+10%Si+3%Gr)

4.2 Dilatometric analysis

Dilatometric analysis facilitates the detection of some phase transformations and of dimensional modifications as a result of heating the composite.

The variations of thermal expansion coefficient (maximum or minimum) in a short interval of temperature, marks the structural transformations in the composite material. Dilatometric analysis for the composite studied is shown in Figure 4.

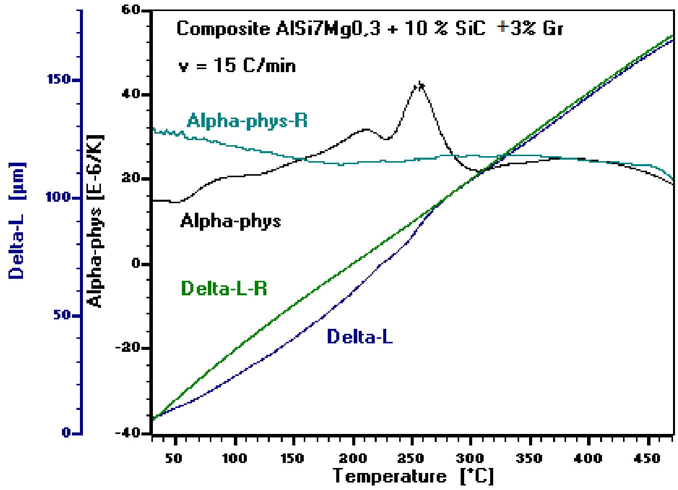


Figure 4. Dilatometric analysis for the composite AlSi7Mg03+10%SiC+3%graphite

In order to analytically determine the thermal expansion coefficient of the composite material, the Kerner, Schapery and Turner relations can be used. According to the Kerner model, the expansion coefficient of a composite material is determined with the following equation [9]:

$$\alpha_c = \overline{\alpha} + V_p(1-V_p)\cdot(\alpha_p - \alpha_m)\times \frac{K_p - K_m}{(1-V_P)\cdot K_m + V_p\cdot K_P + \dfrac{3K_p\cdot K_M}{4G_m}} \quad (1)$$

where:

$$:K = \frac{E}{3\left(3-\dfrac{E}{G}\right)} \quad (2)$$

$$\overline{\alpha} = (1-V_P)\cdot\alpha_m + V_p\cdot\alpha_p \quad (3)$$

where:

V_p is volume of the component fraction,

E and G – the longitudinal and transversal elasticity module of the matrix and of the reinforcing elements.

For the studied composite the Kerner model was extended, taking into consideration the double reinforcing (10% silicon carbide and 3% graphite).

The expansion coefficient, for the studied hybrid composite is 18.875×10^{-6}/°C.

4.3. Thermogravimetric analysis

In Figure 5, the thermogravimetric analysis for the composite AlSi7Mg03+10%SiC_p+ 3% graphite coated with copper, is shown.

The increase in mass in the first stage is explained by the absorption of particles from the heating environment due to porosity influenced by the processing technology and the concentric nature of the reinforcing elements. For the tested composite the porosity is 11.7884 % [5]. A mass reduction follows up to 100 °C, due to the loss of humidity. The peaks on the diagram represent a phase transformation during the heating and cooling cycle.

The exothermic peak registered at 544.8 °C is outside the range of solidification of the alloy matrix AlSi7Mg03 (625-555 °C). This small delay of the solidification process is due to the reinforcing elements that have a lower thermal conductivity (TC) than that of the matrix alloy.

The diagram shows an endothermic peak at 587.4 °C, that is within the 534-630 °C intervals and that represents the interval for state transformations from a solid state to a liquid state (melting).

V.K. Singh et al. [10] noted that the composite materials do not melt at a given temperature but in a temperature range and a small change in heat of fusion can be seen, due to presence of SiCp.

5. Conclusions

The distributions of SiCp and graphite particles in the MMCs were homogeneous.

A comparative analysis in terms of the coefficient of linear thermal expansion (CTE) of composites MMCH with an aluminium alloy based matrix reinforced with particles of silicon carbide and graphite, this highlights the fact that the expansion coefficients of composite materials stands at a level lower than the value of the alloy matrix.

The expansion coefficient (CTE) calculated has similar values with the one determined through experimentation.

The loss of mass during the heating cycle is limited.

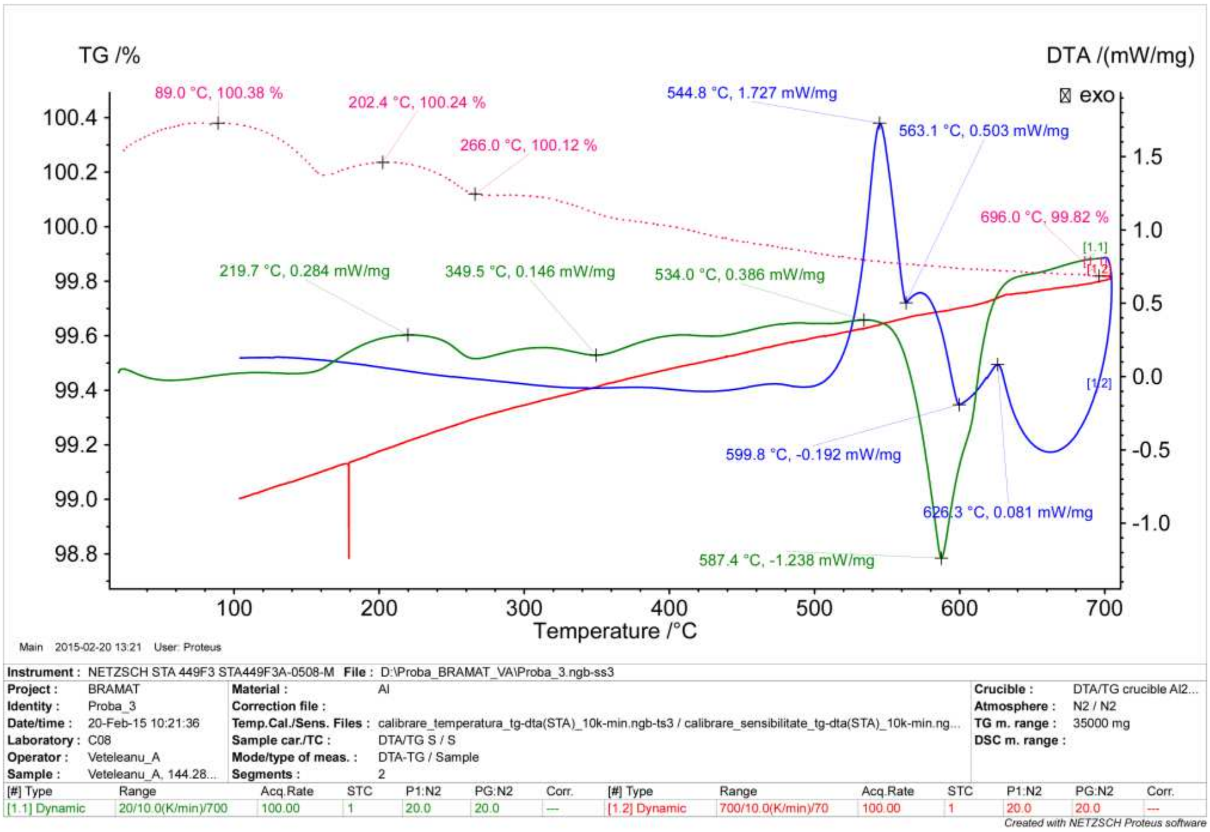


Figure 5. Thermogravimetric analysis of the composite AlSi7Mg03+10%SiC_p+3% Graphite coated with copper

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