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THE STRUCTURAL ANALYSIS OF COMPOSITE MATERIALS REINFORCED WITH SI-C PARTICLES

Abstract: The composite materials with particles consisting of a basic material (matrix) embedded particles of one or more materials. The particles can be metallic or nonmetallic, as the matrix can be, metalic or non metalic. Like a first step the composite mixing involves the embedded process analysis of SiC particles in molten metal. The main issues considered relate to some aspects of embedding additional material in molten metal and methods of achieving the best possible including it. From this point of view was used the overheat of metalic matrix. The experimental plan was followed by Taguchi and structural analysis made was focus on four from 16 completed experimental researches. Six parameters were used each one has two levels. Also the micrographs corresponding experimental tests are presented.

1. Introduction

The composite materials with particles are composed from basic material (matrix) embedded with particles of one or more materials. The particles can be metallic or nonmetallic, as the matrix can be metallic or nonmetallic as well [1].

The metallic particles in the nonmetallic matrix: such a composite solid fuel rocket is composed of aluminum oxide powder in a flexible organic link, as that polysulphide, polyurethane or rubber. Another example is the material obtained from a metal powder which is suspended in a thermosetting resin. The composite material obtained is durable, tough, good conductor of heat and electricity, is used for sealing cold.

The nonmetallic particles with nonmetallic matrix: an example of this category is the material consists of sand and rock particles in a mixture of cement with water that reacts chemically and hardens. Particles of nonmetallic materials can be glass, which forming a composite material when the gas is in a glass matrix or plastic one.

The metallic particles in metallic matrix: a highly alloy composite material is obtained from metallic particles located in a metallic matrix, but is without "dissolve" process. The plumbum particles are commonly used in copper alloys and steel as well. Some metals are

brittle at ordinary temperatures; the particles of these metals such as tungsten, chromium, molybdenum, can be included in a ductile matrix.

The nonmetallic particles in metallic matrix: nonmetallic particles, such as ceramics, may be embedded in a metallic matrix. The composite material obtained is called - cermet. Are known two classes such as:

-Oxide - based composite;

-Carbide - based composites.

The particles, large or small (micro), spherical form, flat or other configuration, is mainly used to produce composites with high wear resistance, ensuring the achieved product the following properties:

-reduced weight;

-remarkable fixed dimensional stability;

-high capacity of vibration damping.

The presence of particles leads to elongation decrease and therefore of material toughness (comparative with elongation and matrix toughness), which will minimize its use only to produce composites that are not required to excessive mechanical and thermal shock.

There are a wide variety of particles produced from SiC, graphite, Al2O3, mica, SiO2, boron nitride, glass, MgO, TiC, Si3N4, steel or iron shot, ZrO2, TiO2, Pb, Zn, with widely varying sizes from less than one micron (crystals) to 500 microns or larger.

2. The embedded of complementary metal inside of molten metal

The achieving of composite involves like a first step the embedded process analysis of SiC particles in molten metal with the following relations is necessary [2].

Resultant of involved forces in the transfer of the molten metal particle is dependent on the physical properties of the two components and wetting conditions in the system. For a spherical particle, the net force acting on its entry in the liquid alloy is:

$$F_r = F_i + F_\sigma + F_a, \tag{1}$$

where: F_i is the inertia force; - the variation force caused by surface energy; - buoyancy force. The silicon carbide particle will penetrate into the melt if $F_r > 0$.

The inertia force can be determined by the equation:

$$F_i = m_p a_p, \tag{2}$$

where: is the mass of particle; - particle acceleration.

The force caused by the variation of surface energy accompanying the process ( ), is obtained from the relationship:

$$F_\sigma = \frac{A_p \Delta E_\sigma}{2\mathrm{r}_p}, \tag{3}$$

where: A_p is the particle total surface $A_p = 4\pi r_p^2$; $\Delta E_\sigma = \sigma_{pg} - \sigma_{pl}$, σ_{pg} - particle-gas interphase tension; σ_{pl} - interphase tension solid-liquid alloy particle; $2r_p$ - the minimum distance that a solid particle to penetrate through the molten metal.
Since, at equilibrium, according to Young's equation:

$$\sigma_{pg} - \sigma_{pl} = \sigma_{lg} \cos\theta, \tag{4}$$

the force due to surface energy variation will be:

$$F_\sigma = 2\pi r_p \sigma_{lg} \cos\theta, \tag{5}$$

where σ_{lg} is the melt surface tension.
The buoyancy force is given by the equation:

$$F_a = -\rho_l V_p a_p, \tag{6}$$

where: is the density of metallic melt and - is the volume particles.
In these circumstances, the force required for particle to penetrate into the melt is:

$$F_r = m_p a_p \left(1 - \frac{\rho_l}{\rho_p}\right) + 2\pi r_p \sigma_{lg} \cos\theta. \tag{7}$$

If we note:

$$F_\rho = m_p a_p \left(1 - \frac{\rho_l}{\rho_p}\right), \tag{8}$$

the equation (7) becomes:

$$F_r = F_\rho + F_\sigma, \tag{9}$$

where, F_ρ is the force determined by the difference between particle density and liquid alloy.
In terms of wetting ($\theta < 90^\circ$ and $F_\sigma > 0$) could be the following conditions:
-for $\rho_p > \rho_l$, $F_\rho > 0$, so $F_r > 0$. Therefore, the particle will be incorporated into the melt.
-if $\rho_p < \rho_l$, $F_\rho < 0$, so $F_r = F_\sigma - F_\rho$. It follows that the particle will be embedded or not fused to the value of its acceleration.
-for $\rho_p = \rho_l$, $F_\rho = 0$, so $F_r > 0$.

Under these conditions the particle will penetrate into the melt. The particles dispersed in the matrix may lead to significant reduction of crystalline grain size if the nucleated process is increases.
In a composite material the dispersed phase is expected to affect the stability of the solidification front, as it is a diffusion barrier and the change in the solid-liquid interface as well. When dendrites appear in smaller spaces than the distance between the main dendritic branches (developed under conditions of free growth) will have side branches twisted.
Could be consider that the limit of solid-liquid separation is appropriate isothermal melting temperature of the matrix, [6, 7].
If the distance between the particle and the interface is d, the corresponding isothermal melting temperature will be given by the next relation [5]:

$$\frac{(R+d)\left(1+\frac{a}{b}\right)}{r\left[1+a\left(\frac{R}{r}\right)^3\right]}=\cos\theta, \tag{10}$$

where: $a=\frac{1-K}{2+K}$; $b=\left(1+\frac{d}{R}\right)^3$; K – the ratio of thermal conductivities of matrix and particle ($K=\frac{\lambda_m}{\lambda_p}$).
When the $K>1$, the forward speed of the solidification front will be slowed in the right particle, appearing solid during a recess in training and creating favorable conditions for embedding the particle in the crystalline grain.
In case of $K<1$, the particle located in front of the solidification front will reduce the local heat flux from the melt and liquid-solid interface in the right supplementary material will form a projection which will tend to push the particle in the liquid phase continuously.
In order to achieve a better incorporation of the additional material can take a series of measures leading to a decrease in wetting angle. Techniques used for this purpose are: a solid component coverage or non-metal film, alloy metal bath, bath superheat metallic thermal treatment of dispersed material to oxidize or remove adsorbed gas layer.

3. The methodology used and results

The general methodology used for testing and planning follow the Taguchi method [4] with two levels for input parameters (Table 1):

- G_r is the particles grain, [μm];
- T_{emp} the casting temperature, [oC];
- T_{imp} represents the mxing time, [min];
- A alloy type used;
- P is the mass percentage of particles, [%];
- V_a is the stirring speed of the mixing, [rot/min].

After the implementation the Taguchi planning results a total of 16 experimental researches.
The best mechanical properties of the composites were obtained in experimental researches 3, 7, 9 and 11.
The results on structural analysis of the samples are presented below (Table 2 and Figures 1-4). It was considered a cast alloy with the following composition: 90.12% Al, 3.46% Cu, 4.8% and 0.24% Mn, 0.22% Mg, 0.4% Fe.
Optical microscopy and SEM microscopy were used for structural analysis matrix alloys and composites with silicon carbide particles.
For optical microscopy was used an optical microscope XJP-6A equipped with image acquisition system and specialized software for metallographic image analysis (Material Plus v4.1). SEM microscopy was used for an electron microscope VEGA Tescani II LMH Detection and equipped with EDX detector for chemical analysis microareas.
Working conditions were:

-vacuum environment (10^{-2} Pa);
-voltage 30kV;
-tungsten filament.

4. Conclusions

After the analyzing the structures of the samples above presented can be formulated the following conclusions take into account the parameters used. The solidification velocity is different along the height of evidence, which supported the different size of dendrites α phase (metal matrix). The major granulation of ceramic particles avoid their agglomeration during mixing in metal matrix, which promotes better dispersion inside of liquid matrix volume favoring their obtaining a composite material with acceptable homogeneity. Concerning the low-speed mixing, due to less intense agitation causes a low porosity composite material which favors obtaining better mechanical properties. Other parameter, higher-temperature mixing, leads to a greater fluidity of the liquid alloy, which contributes to a better dispersion of ceramic particles. The mixing low-time matrix avoids contact with the air mixing chamber leading to a low porosity composite material. The percentages higher-mass particles contribute to the formation of a ceramic composite containing a higher volume ratio of ceramic particles influence on physical and mechanical properties of composite materials. Increasing and decreasing the Si content of Cu may promote wetting of ceramic particles which leads to increased volume fraction of ceramic component, and its better dispersion in the volume of liquid matrix with implications for physical and mechanical properties of composite materials.

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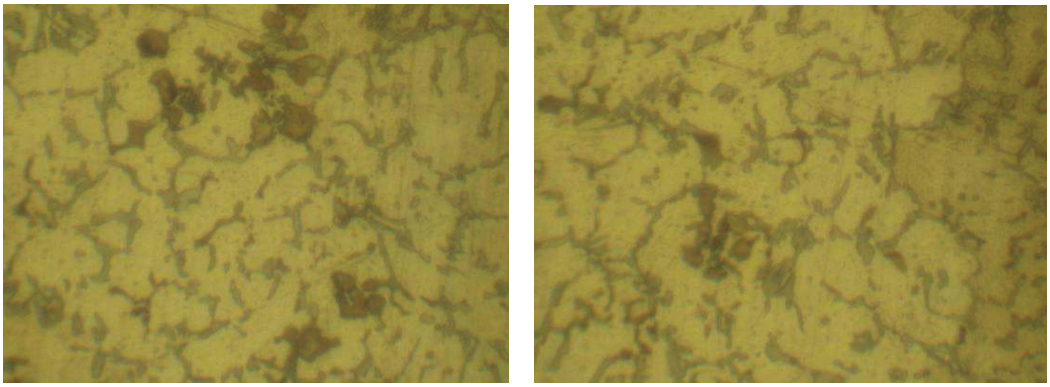
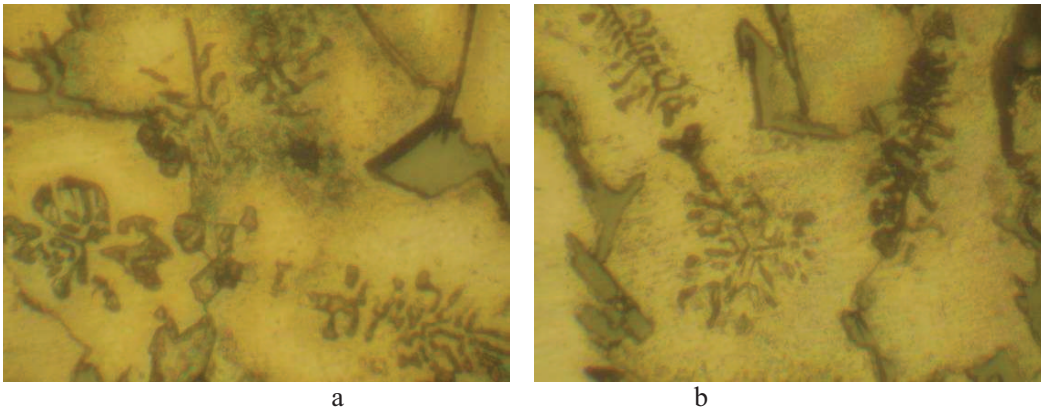
FIGURES



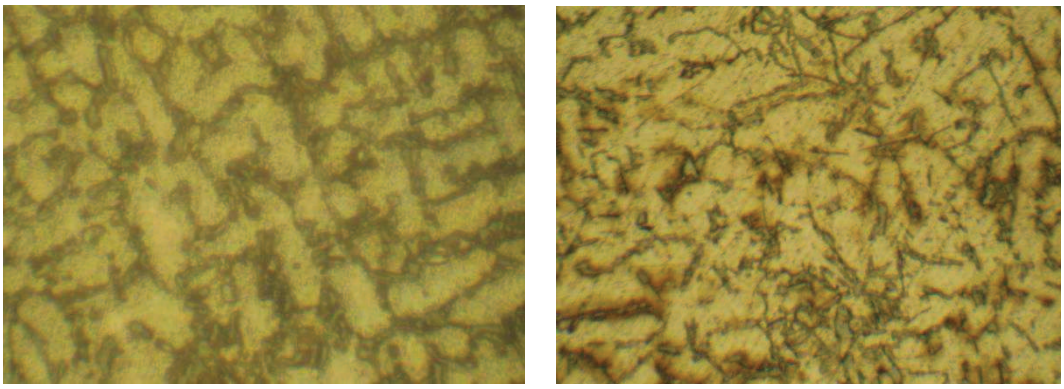
a b

Fig.1. The micropraphs for experimental testing no. 3
a-lower position; b-upper position



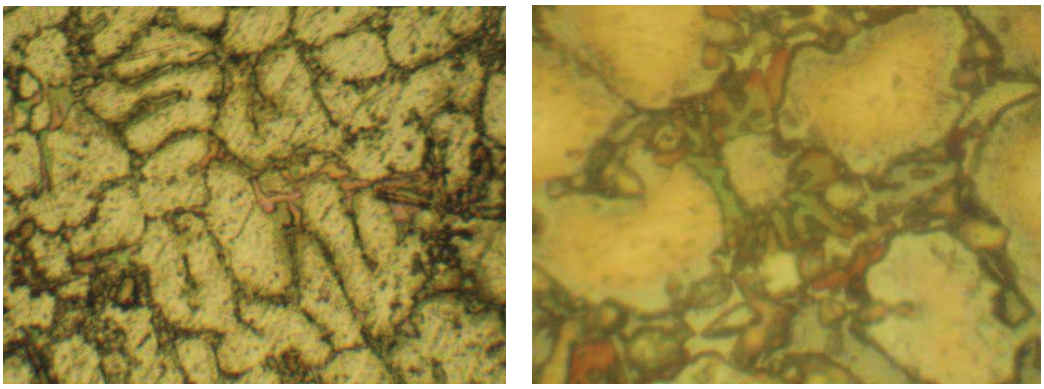
a b

Fig. 2. The micropraphs for experimental testing no. 7
a- lower position; b-upper position



a b

Fig. 3. The micropraphs for experimental testing no. 9
a-lower position; b-upper position



a b

Fig. 4. The micropraphs for experimental testing no. 11
a-lower position; b-upper position

TABLES

Table 1. The variation levels of input parameters

Input parameter *Levels*	Gr [μm]	T [^{o}C]	Time [min]	Alloy type, (European Standard)	P [%]	V, [rot/ min]
1 level	40	650	1	ENACAlSi5Cu3Mg	2	250
2 level	120	750	3	ENACAlSi7Cu2Mg	6	720

Table 2. Microstructural observations / sample position

No.	Upper and lower positions
3	Composit ENACAlSi5Cu3Mg+SiC: G_p = 60 μm, $Temp_{stirring}$ = 750 ^{0}C, $Time_{stirring}$ = 1 min, P_p = 6 % (mass), $V_{stirring}$ = 250 rot/min, Width of micrographs = 130μm
	There is a big difference between the sizes of dendrites α phase (metal matrix) from the lower and upper composite sample and contact with heat source at the top of the sample favors reducing the solidification rate of the composite material, the particles are positioned in space interdendritic, which shows a weak humectability inter-dendritics areas because it solidifies the end, after the expulsion of particles inside α dendritic phase (metal matrix); also observed in the inter-dendritic space the presence of intermetallic compounds of silicon and aluminum alloy characteristics of aluminum alloy used as matrix.
7	Composit ENACAlSi7Cu2Mg+SiC: G_p = 60 μm, $Temp_{stirring}$ = 750 ^{0}C, $Time_{stirring}$ = 1 min, P_p = 6 % (mass), $V_{stirring}$ = 250 rot/min, Width of micrographs = 130μm
	Could be observed the existence of separations due to increased percentage of Si eutectic alloy used as matrix.
9	Composit ENACAlSi7Cu2Mg+SiC: G_p = 60 μm, $Temp_{stirring}$ = 650 ^{0}C, $Time_{stirring}$ = 3 min, P_p = 2 % (mass), $V_{stirring}$ = 250 rot/min, Width of micrographs = 130μm
	Could be observed particles within dendrites phase α (metal matrix) which shows that increasing the Si content and decreasing the Cu particle wetting by favoring the metal matrix.
11	Composit ENACAlSi7Cu2Mg+SiC: G_p = 40 μm, $Temp_{stirring}$ = 750 ^{0}C, $Time_{stirring}$ = 1 min, P_p = 6 % (mass), $V_{stirring}$ = 250 rot/min, Width of micrographs = 130μm
	It notes the existence of separations due to increased percentage of Si eutectic alloy used as matrix. Contact with heat source at the top of the sample favors reducing the solidification rate of the composite material.