THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI.
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N^0. 1 – 2013, ISSN 1453 – 083X

METALLIC MATRIX COMPOSITES WITH CERAMIC PARTICLES. WETTING CONDITIONS

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ABSTRACT

The paper presents the main aspects regarding the mixtures obtained made up from aluminium melts and different kinds of ceramic particles (silicon carbide and boron carbide). Synthetically discussed are the wetting conditions and the wetting coefficient and the possibilities to improve it insisting on the alloying metal bath, its overheating and the heat treatment of the particles with the aim to remove gases from the superficial layer. The critical acceleration necessary for the incorporation of particles into the melt for different temperatures was determined.

KEYWORDS: aluminium, silicon carbide particles, boron carbide particles, wettability, minimum acceleration

1. Introduction

In recent years the production of metallic composites has expanded the use of additional material in the form of particles due to some important advantages: much cheaper compared to fibres; isotropic materials or materials with controlled heterogeneity can be obtained; simple technologies can be used to incorporate the complementary material.

Compared to the organic matrix, metallic materials are used for the need to obtain composites that can be used at relatively high temperatures. For castings destined to be used at smaller temperatures than 400°C, aluminium and its alloys are used as matrix due to a sum of advantages (low cost, small density, acceptable mechanical properties, electrical and thermal conductivity, corrosion resistance, workability). Titanium used as alloying element improves the behaviour of aluminium at high temperatures [1].

Mechanical, thermal and electric properties of metallic composites depend, inter alia, on the type, quantity, size, shape, and complementary material distribution.

Generally, particles of graphite, ceramic metallic materials or glass are used to produce metallic composites with low density, high specific properties, dimensional stability, and, especially wear resistance.

Silicon carbide particles (cubic or hexagonal elementary cells) are frequently used to produce composites due to the low cost, small density, high specific mechanical properties, low thermal expansion coefficient, resistance to thermal shock, hardness etc.

Although less used, boron carbide is also an attractive material for the production of metallic composites. In aluminium-based composites boron carbide particles provide low density, thermal stability, hardness, wear resistance [2].

Due to the close values of densities (ρB4C=2.52g/cm^3), the intensity of the settling process is diminished in aluminium melts (ρ_{Al}=2.369g/cm^3 at the melting point) [3].

Gravitational casting is still the simplest and least expensive method of producing metallic composites. Therefore, to produce aluminium particles mixtures remain a matter of general interest.

2. Wetting conditions

The wettability parameter, $\sigma_{lg}\cos\theta$ where σ_{lg} is the surface tension at the aluminium melt-gas interface and θ is the contact angle, allows analysing the wetting conditions in aluminium – silicon or boron carbide [4]. Positive values of this parameter indicate wetting conditions in the system. Evidently, non-wetting occurs when $\sigma_{lg}\cos\theta < 0$.

The values of the wettability parameter in different aluminium-based systems are presented in Table 1 and Figure 1. The calculations were made based on the values of the surface tension and the wetting angle, as presented by Rohatgi [5]. The wettability parameter values determined confirm non-wetting conditions in the two systems reported, in different conditions [2-3, 6-10].

It should be noted that the layer of alumina formed due to the high affinity of aluminium for oxygen prevent a correctly estimation of the contact angle.

Table 1. *Wettability parameter values*

System	T, [°C]	Wettability parameter, $\cdot 10^3$, [N·grd/m]	
		SiC	**B$_4$C**
Al	700	-238.85	- 425.5
	800	-178.95	- 362.95
	900	-161.21	- 275.69
Al-2Cu	700	-242.24	- 378.78
	800	-197.05	-342.38
	900	-145.56	-282.49
Al-4.5 Cu	800	-186.93	- 323.36
Al-2Mg	700	-193.34	- 325.36
	800	-147.04	- 117.12
	900	-120.72	- 66.40
Al-4.5Mg	800	-136.67	- 32.99

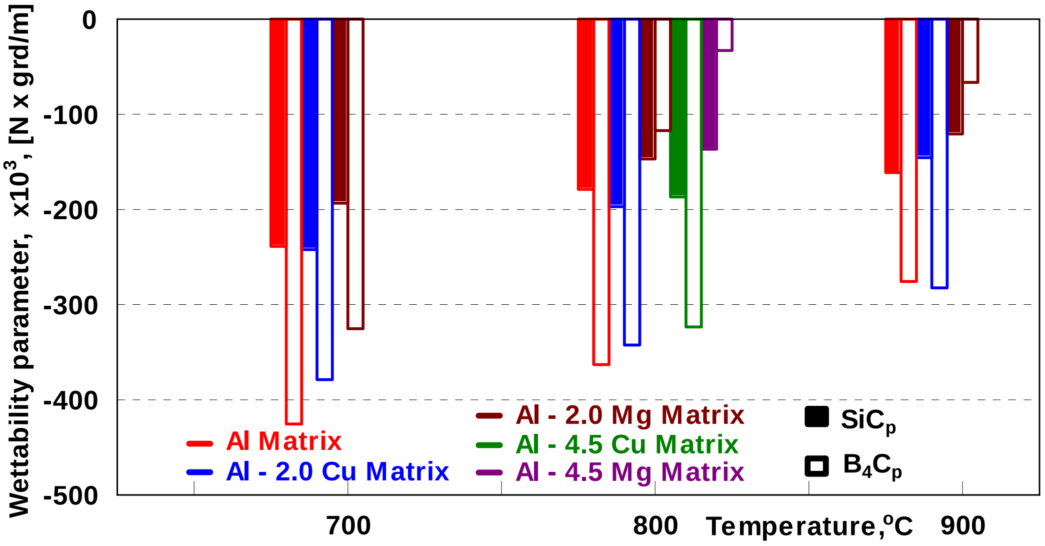

Fig. 1. *Wettability parameter*

The transfer of a silicon or boron carbide particle from the gaseous phase into the aluminium melt is complete when the gas - particle interface is replaced by a particle - liquid interface [11].

In the particular case of a cubic particle (l_p) moving with gravitational acceleration g, the total force that acts during its penetration into the metallic bath is:

$$F_t = G_p + F_\sigma + F_a , \qquad (1)$$

where: G_p is the gravitational force; F_σ - the force determined by the superficial energy; F_a - Archimedes force.

If *Y* axis of an xOy coordinate system associated to the particle has the positive direction towards the melt surface, the particle will be incorporated when $F_t > 0$ [12].

The gravitational force can be determined by the equation:

$$G_p = m_p g , \qquad (2)$$

where m_p is the mass of the particle.

In order to determine the force caused by the superficial energy ΔE_σ, it is necessary to take into account the following relationship:

$$F_\sigma = 6 l_p \sigma_{lg} \cos\theta , \qquad (3)$$

Archimedes force is given by the following equation:

$$F_a = -\rho_l V_p g = -m_p g \frac{\rho_l}{\rho_p}, \qquad (4)$$

where: ρ_l is the density of the liquid aluminium, V_p - the volume of the particle; ρ_p - the particle density.

Therefore, the necessary force for a particle to penetrate the metal bath is:

$$F_t = m_p g\left(1-\frac{\rho_l}{\rho_p}\right) + 6 l_p \sigma_{lg} \cos\theta . \qquad (5)$$

In non-wetting conditions, when $\rho_p < \rho_l$, for the two analysed systems it results that:

$$m_p g\left(1-\frac{\rho_l}{\rho_p}\right) + 6 l_p \sigma_{lg} \cos\theta < 0 , \qquad (6)$$

and the particle will float.

Therefore, to penetrate the melt, the particle needs a minimum acceleration:

$$a_p = -6\frac{\sigma_{lg}}{l_p^2(\rho_p - \rho_l)}\cos\theta \cdot \qquad (7)$$

Different values of this parameter for aluminium melts are presented in Table 2. The calculations were performed by using Rohatgi’s data and the following relations [13]:

$$\rho_{Al} = 2.369 - 3.11 \cdot 10^{-4}(T - T_{top}), \qquad (8)$$

$$\rho_{Al-Mg} = 2.376 - 0.009\%Mg . \qquad (9)$$

Table 2. *The values of minimum acceleration*

System	***T*,** [°C]	$a_p \cdot 10^4$, [m/s^2]			
		SiC		**B$_4$C**	
		l_p=10^{-4}, [m]	l_p=2·10^{-4}, [m]	l_p=10^{-4}, [m]	l_p=2·10^{-4}, [m]
Al	700	16.79	4.2	156.2	39.05
	800	12.14	3.03	111.94	27.99
	900	10.56	2.64	73.31	18.33
Al-2Mg	700	13.62	3.4	120.5	30.13

3. Improvement of wetting

The high values calculated for the minimum acceleration impose the necessity to apply some methods to improve the wetting conditions. The simplest methods are:

- overheating of the melt. The presence of an oxide film at the aluminium melt surface drastically reduces the wetting angle. For pure aluminium the oxide layer formed at the surface of the melt, due to the small solubility of oxygen, is γ-Al2O3 [14].

The wetting becomes possible at higher temperatures when the oxide layer can be removed by a chemical reaction [15]:

4 Al (l) + 3 Al2O3 (s) = 3 Al2O (g) (10)

For aluminium and its alloys the effect of temperature on the superficial tension is to decrease it. In this way, the wetting angle between the melt and the complementary material reduces.

Some empirical relationships, such as those proposed by Keene or Shen, can be used to study the effect of temperature on the surface tension [16, 17]:

$$\sigma_{lg} = 985 - 0.19(T - 933)\ [\text{mJ/m}^2] \qquad (11)$$

$$\sigma_{lg} = 890 - 0.182(T - 933)\ [\text{mJ/m}^2] \qquad (12)$$

Generally, a longer time of contact at high temperatures improves the wetting conditions.

In an Al-SiCp system, at usual temperatures of the melts, the following reaction:

4Al + 3SiC ⇔ Al4C3 + 3Si (13)

causes the appearance of an undesirable compound [7].

Silicon, used as alloying element, may prevent the formation of this compound.

Boron carbide reacts with both solid and liquid aluminium. In solid state or for an overheating degree of the melt up to 110°C, it forms Al3BC or AlB2 compounds. Over this temperature Al3BC and Al3B48C2 are produced [18]. The appearance of these compounds is also undesirable because it leads to decomposition of complementary material

On the other hand, increasing temperature a reduction of apparent dynamic viscosity of the mixture occurs.

- heat treatment of dispersed material. A gas film exists on the surface of particles and blocks direct contact between the two components. Also this fine film favours ascension movement of the particles although $\rho_{Al} < \rho_p$ [19, 20].

- alloying or flux treatment of the melt. Some elements introduced in aluminium-based melts assure wetting conditions by:
  - reducing of melt surface tension;
  - lowering the interfacial energy between the melt and the particle;

- chemical reactions (reactive wetting).

Elements with high affinity to oxygen (lithium or magnesium for example) avoid the appearance of the oxide layer on the surface of the complementary material and diminish interfacial tension.

Introduced in the melt, magnesium creates also advantageous wetting conditions by the diminution of the melt surface tension. Such as, in accordance with Lang’s equation, 1 wt% Mg reduces the aluminium surface melt by 5% approximately. Magnesium does not react with silicon carbide. Compared with magnesium tin has a much smaller effect [7, 19].

Titanium improves the wettability of silicon carbide due to the strong affinity for the complementary material constituting TiC, TiSi2 and Ti3SiC2 compounds [7].

Titanium presence in K2TiF6 favours improvement of wetting in Al-B4C system by the appearance of TiB$_2$ and TiC compounds at the surface of particles [A.R. Kennedy, 2001, Kertli, 2008).

4. Conclusions

Aluminium-silicon or boron carbide composites have low density, high specific properties, hardness and good wear resistance.

Gravitational casting is a simple and inexpensive method to be used for obtaining metallic composites parts.

Non-wetting conditions exist in the two-systems.

The high values calculated for minimum acceleration impose the necessity to apply some simple methods to improve the wetting conditions: overheating of the metallic bath, alloying or flux treatment of the melt.

Titanium leads to the improvement of wetting conditions as a result of the chemical reactions in the melt.

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