

# Solidification and structure of heterophase composite

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## Materials

### ABSTRACT

**Purpose:** In this paper, the structure and solidification curves are presented for a homo- and heterophase composite. The results of research on the solidification process are compared for the applied aluminium alloy matrix (AlSi12CuNiMg2) and for composites containing one type of particles ( $Al_2O_3$ ) and heterophase reinforcement (mixture of  $Al_2O_3$  particles + glassy carbon - Cg).

**Design/methodology/approach:** The course of the solidification process was recorded by means of a system which enabled continuous control and measurement of the metal temperature during solidification of the composite suspension. The system was equipped with a thermoelectric cup core QC4080, with an incorporated thermocouple of K type (NiCr-Ni). The application of disposable thermoelectric cup cores of identical heat abstraction coefficient and known, standardized dimensions, ensured identical conditions and rate of heat abstraction during the cooling of the castings.

**Findings:** The research has shown, glassy carbon particles have an influence on both temperature change and the time of composite castings solidification. The changes results, first of all, from disparate physical properties of the glassy carbon particles used (thermal conductivity, mass density), compared to aluminium oxide particles ( $Al_2O_3$ ).

**Practical implications:** Glassy carbon particles decrease shrinkage of the casting and change the nature of its crystallization.

**Originality/value:** Employment of heterophase reinforcement allows to get segregation and sedimentation in the matrix, which results in the occurrence of a gradient structure.

**Keywords:** Composites; Solidification; Ceramic particles; Glass carbon particles

## 1. Introduction

Composites reinforced with ceramic particles (i.e. SiC,  $Al_2O_3$ ) are most often fabricated by casting methods with the use of suspension forming processes. Economical reasons have contributed to a wide application of the method of mechanical stirring of components [1-4]. Many authors link the forming of the structure of Al alloy-ceramic particles composites with the use of casting techniques with two problems. The first one refers to particles' behaviour in a liquid metal until crystallization commencement (floating, sedimentation and agglomeration), where wetting of ceramics by a liquid matrix is a significant and predominant factor. The other one is the description of

factors connected with direct action of the growing crystallization front with reinforcing phase particles [3-15]. From the moment of crystallization and solidification commencement, the crystalline phase begins to grow. Its growth proceeds in a direction opposite to the particles' movement. Thus, apart from the geometric factor, i.e. the type, volume fraction and size of reinforcing particles, it is the crystallization rate and the casting's solidification time that determine the structure obtained and particles' distribution in the matrix.

The study aimed at determining and comparing the cooling curves obtained for the matrix (AlSi12CuNiMg2) and for composites containing one type of reinforcing particles ( $Al_2O_3$ ) and heterophase composites, where two types of ceramic particles, a mixture of aluminium oxide and glassy carbon, were used as the reinforcement.

## 2. Research methodology

As the matrix material, a casting alloy of aluminium AlSi1212, modified with a 2% magnesium addition, was used. In single-phase composites, aluminium oxide ( $\text{Al}_2\text{O}_3$ ) of 15% fraction and a  $25\mu\text{m}$  particle size was used for reinforcement. In heterophase composites, two types of ceramic particles were applied in the form of a mixture of  $25\mu\text{m}$  aluminium oxide and glassy carbon of  $100\mu\text{m}$  size. For that group of materials, a 10% fraction of each powder was applied. Composite suspensions fabricated by the traditional stirring method, described in detail in paper [3], were then subjected to degassing and homogenization under lowered pressure. A testing stand designed and built at the Institute of Composites and Powder Metallurgy, Silesian University of Technology, was used to this end. As former research has shown [16,17], the application of vacuum technology with simultaneous homogenization of a composite suspension changes the properties of the liquid suspension, including first of all its castability, and allows removal of gassy regions formed during composite production.

The course of the solidification process was recorded by means of a system which enabled continuous control and measurement of the metal temperature during solidification of the composite suspension (Fig. 1).

The system was equipped with a thermoelectric cup core QC4080, with an incorporated thermocouple of K type (NiCr-Ni). The cup core was placed on a tripod and permanently connected via a contactor unit and a thermoelectric conductor with an analog-digital measuring system based on the MC201 module, configured to operate with a PC [18]. The application of disposable thermoelectric cup cores of identical heat abstraction coefficient and known, standardized dimensions, ensured identical conditions and rate of heat abstraction during the cooling of the castings. Thereby, the influence of the mould material on the solidification of the investigated composites was eliminated, which allowed an evaluation of the influence of the

reinforcing particles' type on the course of cooling curves for the systems applied.

The structure of composite ingots was examined on an MeF-2 Reichert light microscope and a Hitachi S-4200 electron microscope, applying properly made preparations.

## 3. Research results and their analysis

The data obtained allowed plotting of cooling curves for the matrix and composites which, after numerical processing, are presented in Fig. 2. The differences in the course of composite materials' curves are particularly well visible for the heterophase composite, where apart from aluminium oxide particles, amorphous glassy carbon particles were used. The differences refer to both time and temperature of the crystallization beginning. The matrix material solidified during 20s in the temperature range of  $559\text{--}558^\circ\text{C}$ . The composite containing a mixture of  $\text{Al}_2\text{O}_3$  + glassy carbon particles solidified in the temperature range of  $574\text{--}571^\circ\text{C}$ , in the time of 7s. The temperature of crystallization beginning of the composite containing aluminium oxide particles was  $557^\circ\text{C}$ , with the composite solidifying for 18s in the temperature range of  $557\text{--}556^\circ\text{C}$ .

As results from the data obtained, glassy carbon particles considerably increase the temperature at the beginning of crystallization and shorten its time, both when compared to the composite containing one type of particles ( $\text{Al}_2\text{O}_3$ ) and when compared to the matrix. This testifies to a significant influence of glassy carbon particles on the solidification process course and thereby, to the disparate nature of the heterophase composite crystallization. The differences in composites' solidification time and temperature may be determined by different thermal conductivity coefficients applied for the particles, which amount for  $\text{Al}_2\text{O}_3$  -  $35\text{W}/(\text{mK})$ , for glassy carbon -  $200\text{W}/(\text{mK})$ , and for the AlSi12CuNiMg2 matrix -  $180\text{W}/(\text{mK})$  [15].

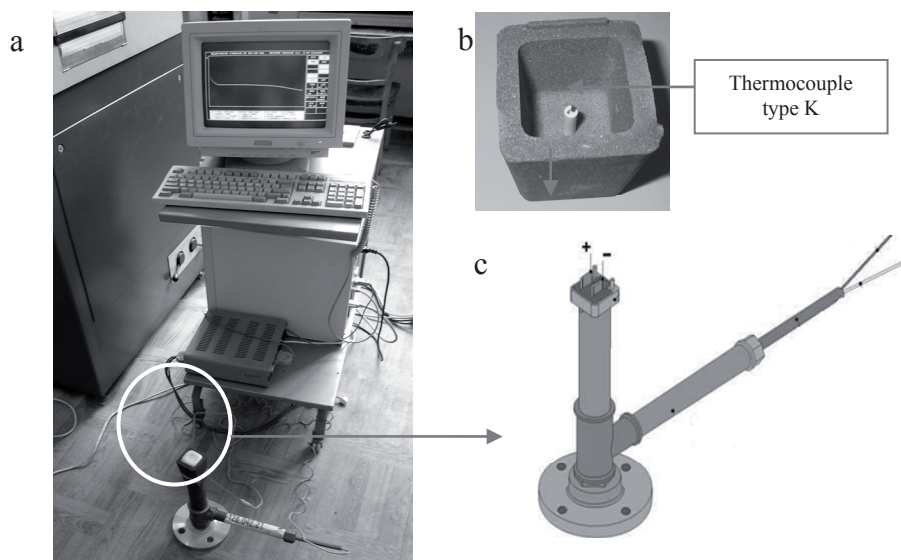


Fig. 1. Measurement system used for register of solidification curves a), thermo-electric cup with thermocouple type K b), column c) [18]

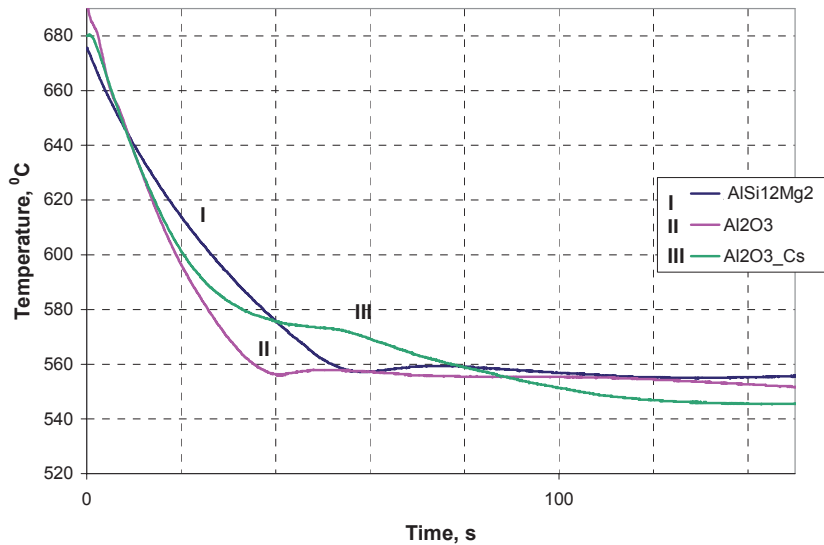


Fig. 2. Solidification of matrix and composites: I-AISi12CuNiMg2, II- AISi12CuNiMg2+10% Al<sub>2</sub>O<sub>3</sub> 25µm, III- AISi12CuNiMg2/10% Al<sub>2</sub>O<sub>3</sub> 25µm + 10 % Cg

On the cross-section of a heterophase composite ingot, sedimentation and segregation were found (Fig. 3b), which in consequence, enabled the formation of a gradient structure. The lower part of the ingot does not contain particles and the matrix-composite interface is flat and parallel to its base. The microstructure of the matrix-reinforcement interface area and of the region from the upper part of the ingot, with visible reinforcement, is shown in Fig. 4. In addition, the heterophase composite is characterized by much lower shrinkage in the riser head region and lack of casting defects, which were identified in the composite with one reinforcing phase (Fig. 3a).

#### 4. Conclusions

As the research has shown, ceramic particles in the form of amorphous glassy carbon have an influence on both temperature change and the time of composite castings solidification. They also have influence on the casting properties of composites suspension, reducing they castability. The changes results, first of all, from disparate physical properties of the glassy carbon particles used (thermal conductivity, mass density) [19-21], compared to aluminium oxide particles (Al<sub>2</sub>O<sub>3</sub>). Moreover, glassy carbon particles decrease shrinkage of the casting and change the nature of its crystallization. Their low mass density (1,4 g/cm<sup>3</sup>) contributes to segregation and sedimentation in the matrix, which results in the occurrence of a gradient structure in the heterophase composite. The presented research results represent a preliminary study and they require completing. The on-going research refers to the influence of the type, size and volume fraction of reinforcing particles on solidification and crystallization of heterophase composites [22].

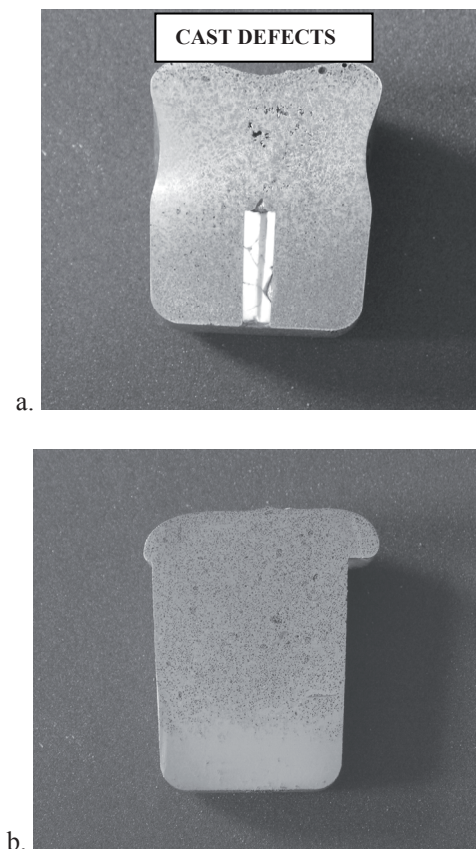


Fig. 3. Macrostructure of composites with particles displacement visible in the matrix: a) AISi12CuNiMg2+10% Al<sub>2</sub>O<sub>3</sub> 25µm, b) AISi12CuNiMg2/10% Al<sub>2</sub>O<sub>3</sub> 25µm + 10 % Cg



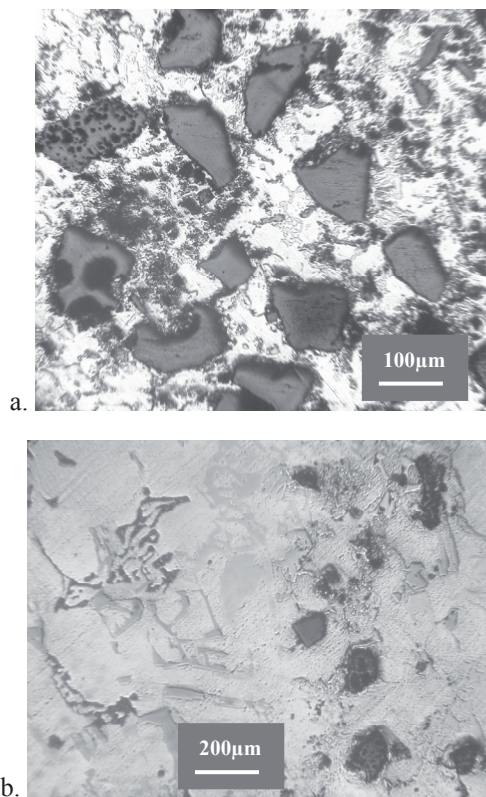


Fig. 4. Microstructure of AlSi12CuNiMg2/10% Al<sub>2</sub>O<sub>3</sub> 25µm + 10 % Cg, OM; a) reinforced area, b) matrix-reinforced interface area.

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