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The solidification process of the AK12/SiC+C composite suspension in various heat exchange conditions

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ABSTRACT

Purpose: In the research work the result of the structure and solidification analysis for aluminium cast composite with ceramic particles in different solidification conditions have been presented. The results of research on the solidification process for heterophase composite have been shown.

Design/methodology/approach: The solidification process of the AK12/SiC+C composite suspension in various heat abstraction conditions was recorded using the ThermaCAM^{TM}E25 photometer system for temperature control and measurement. The system, equipped with a thermovision camera, LCD display and a laser pointer, was connected to a SPIDER 8 recorder and used to monitor, record and, simultaneously, to visualize the temperature changes which take place during composites' solidification. The structure analysis for composite casts was performed by means of optical microscopy.

Findings: As the research has shown, moulds which abstract heat quickly, like a graphite or permanent mould, ensure obtaining a uniform distribution of ceramic particles in the matrix. A longer time of composite suspension solidification facilitates floatation and segregation of the reinforcing particles. Therefore, application of materials which prolong the solidification process, e.g. a sand mould, enables obtaining a gradient or laminar structure in heterophase composites.

Practical implications: The mould's material changes the nature of composite crystallization.

Originality/value: It was found that the has a significant influence on the distribution of heterophase reinforcement in the matrix. By applying an appropriate mould material it is possible to shape the cast structure and the distribution of particles in the cast.

Keywords: Composites; Solidification; Thermovision; Structure

MATERIALS

1. Introduction

In recent years, Metal-matrix composites (MMC) have emerged as a promising class of materials. Especially, Aluminum composites with their unique thermal properties have enormous space and avionics prospects. The problem of casts' solidification has been the subject of research conducted in various scientific and research centers within the country and abroad [1-19]. Cast solidification is accompanied by a crystallization process that is a stage at which the cast's primary structure is being formed. It consists of the formation of crystal nuclei and their growth, accompanied with segregation of components. At the same time; there is a risk of the occurrence of structure defects. Incorporation of ceramic particles in a liquid alloy additionally disturbs this difficult to describe process and causes a change to a majority of factors. First and foremost, the thermophysical properties and viscosity of the liquid suspension are changed. Reinforcement particles influence the nucleation, whereas their interaction with the crystallization front results in a diverse structure of the cast [2-4]. Therefore, getting acquainted with the specificity of the composite casts' solidification process and the accompanying phenomena allows shaping the diversified structure of particles' distribution in the matrix.

Based on the authors' own research, it has been found that the structure and distribution of reinforcement, formed during solidification of composite casts, are in correlation with the size, volume fraction, type and properties of the reinforcement applied [9-19]. As the conducted tests have shown, the properties of the particles used are particularly significant in heterophase composites, where the reinforcement applied has various physicochemical characteristics. They have a significant influence on the change of temperature and time of matrix solidification, which has its consequences in the composite's structure. It has been found that in the same conditions of heat abstraction, it is possible to mould a diversified structure of the cast through appropriate selection of phase composition of the reinforcement [16-19].

The process of cooling of a liquid alloy in a mould and the final structure, which in turn determines the final properties of the product, are influenced by many factors, including the mould material.

2. Rresearch methodology

The process of formation of the particles distribution structure in the matrix was analyzed in various conditions of heat abstraction for a heterophase composite, where a mixture of silicon carbide particles, size 25μm, and glassy carbon particles, size 100μm, were used as reinforcement. For the matrix, a casting alloy of aluminium with silicon, AK12, was used. Volume fraction of the reinforcement amounted to 20%. In order to obtain different solidification conditions, two moulds were used: graphite and a sand one (Fig. 1). Composite suspensions were produce via a well-known method described in the literature, consisting of mechanical stirring of a liquid alloy, into which appropriately prepared reinforcing particles were being introduced [10,11]. The composite suspensions were subjected to degassing and homogenization under lowered pressure and afterwards, to gravity casting into previously prepared moulds.

The solidification process of the AK12/ SiC+C composite suspension in various heat abstraction conditions was recorded using the ThermaCAM^{TM}E25 photometer system for temperature control and measurement. The system, equipped with a thermovision camera, LCD display and a laser pointer, was connected to a SPIDER 8 recorder and used to monitor, record and, simultaneously, to visualize the temperature changes which take place during composites' solidification (Fig.2). During the tests, the temperature and time of composite solidification as well as the mould temperature were recorded. The data obtained allowed determining the solidification curves, which are shown in Figs. 3 and 7.

Additionally, thermal images with a 10s time interval were recorded, based on which it is possible to determine the temperature distribution on the mould's cross-section at each stage of the solidification process. In this paper, only some selected images and temperature distribution on the mould wall are shown, for the beginning and the end of the composite suspension solidification. The macrostructure and microstructure of the composite ingots solidifying in various conditions of heat abstraction are shown in Figs. 6 and 10. 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.

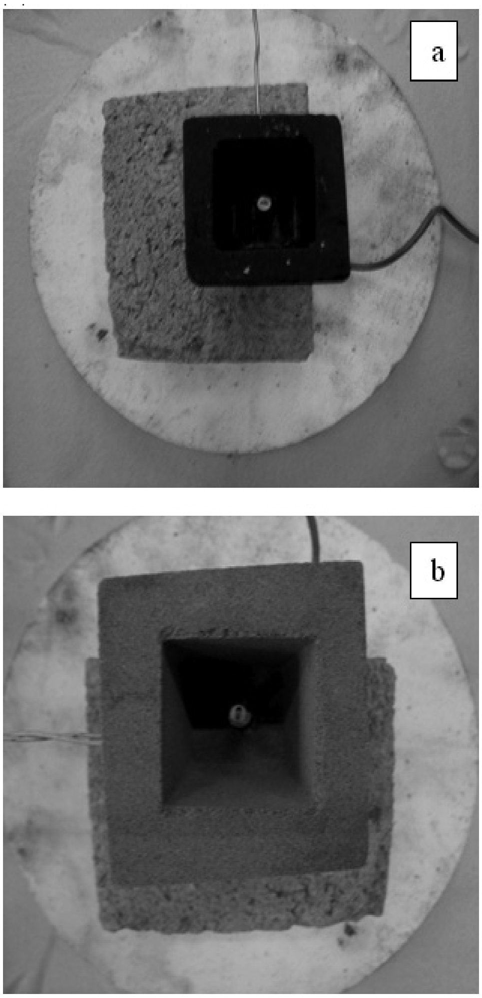

Fig. 1. View of the moulds used in the solidification analysis: a) the graphite mould, b) the sand mould

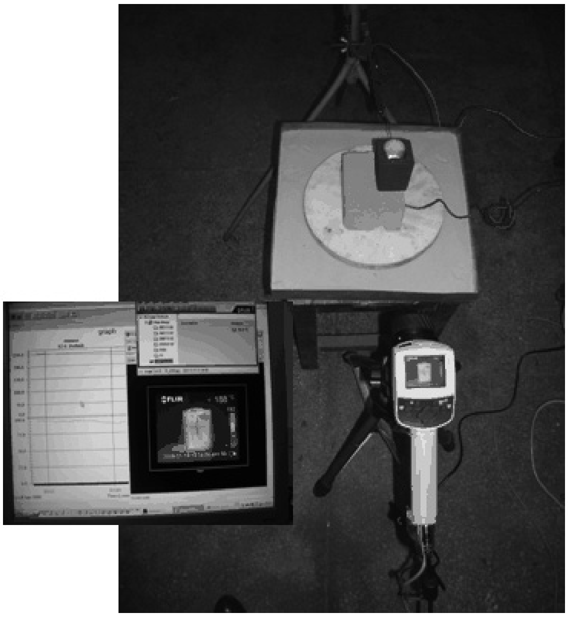

Fig. 2. View of the ThermaCAM^{TM}E25 photometer system for temperature control and measurement

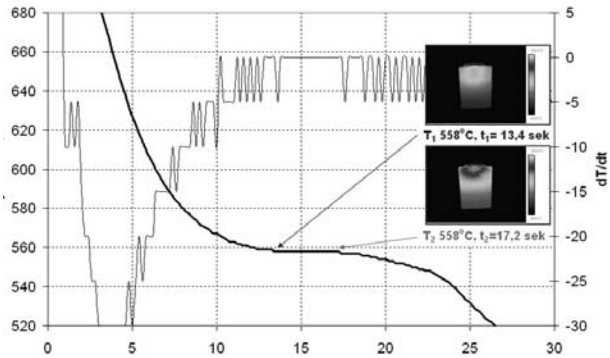

Fig. 3. The solidification curve of AK12/ SiC+C composite solidify in a graphite mould, [19,20]

3. Research results and analysis

As the research results have shown, the solidification of AK12/ SiC+C composite in a graphite mould proceeds in a very short time of 4.2 s at a temperature of 558°C (Fig. 3).

By analyzing the distribution of temperatures of the wall of a graphite mould during solidification of a composite ingot, it can be confirmed that the mould was fairly uniformly overheated. The difference in temperatures between points SP01 and SP03 at the moment when the solidification process started equaled 92°C and after the solidification equaled 122°C, (Figs. 4, 5).

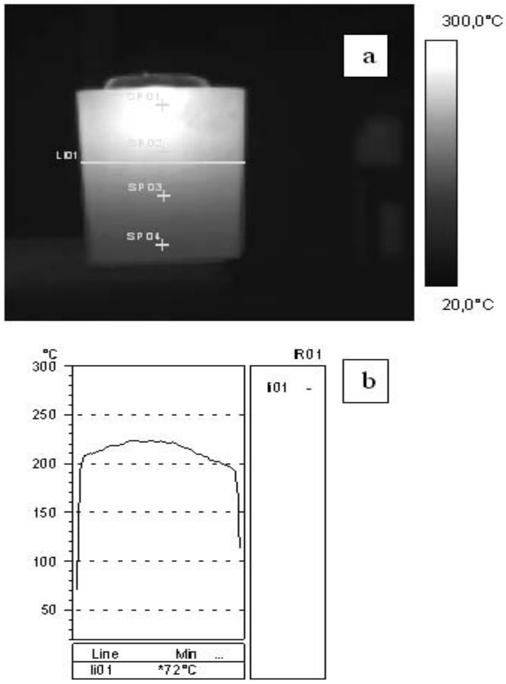

Fig. 4. The AK12/ SiC+C composite: a) thermal image and b) temperature profile on the outside surface of graphite mould; start of solidification: T_1 = 558^{o}C,t_1=13.4 s

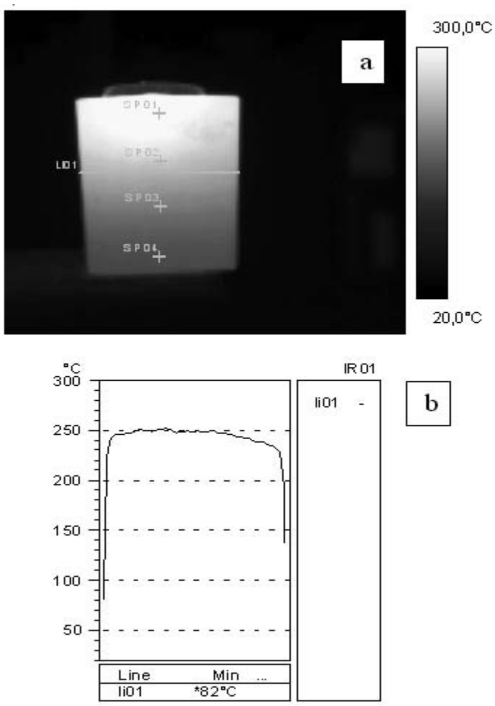

Fig. 5. The AK12/ SiC+C composite: b) thermal image and temperature profile on the outside surface of graphite mould; finish of solidification: T_1 = 558^{o}C, t_1=17.2 s

During the solidification process, the temperature of the mould's external wall increased by 63°C in point SP01 and by 33°C in point SP02. Such conditions of heat abstraction by a mould made of graphite lead to obtaining a structure with a uniform distribution of particles throughout the cross-section of the composite ingot (Fig. 6).

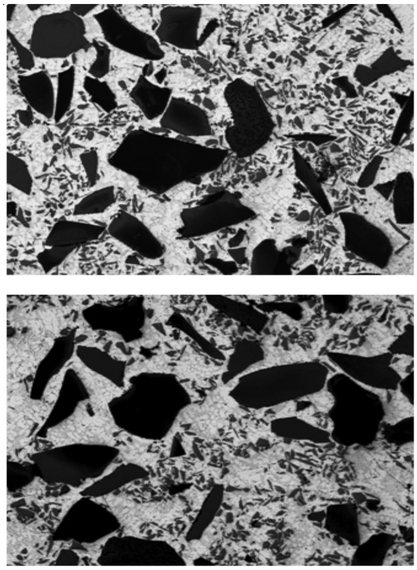

Fig. 6. The microstructure of AK12/ SiC+C composite solidifies in graphite mould, mag. 250x, OM

At the same time, the composite suspension AK12/ SiC+C, which was cast into a sand mould, solidified in the temperature range of 565°C-559°C for 150 s (Fig. 7). The distribution of temperatures in the wall of the sand mould during the composite ingot's solidification shows directional heat abstraction (Figs. 8, 9)

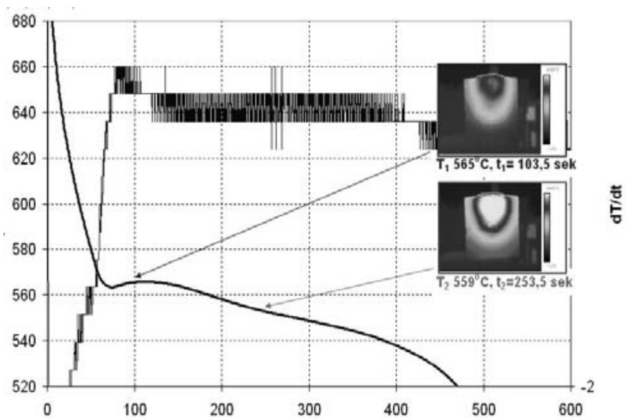

Fig. 7. The AK12/ SiC+C composite: a) solidification curve of composite solidify in a sand mould, b) thermal image and temperature profile on the outside surface of sand mould; start of solidification: T_1 565°C, t_1= 103.5 s, [19, 20]

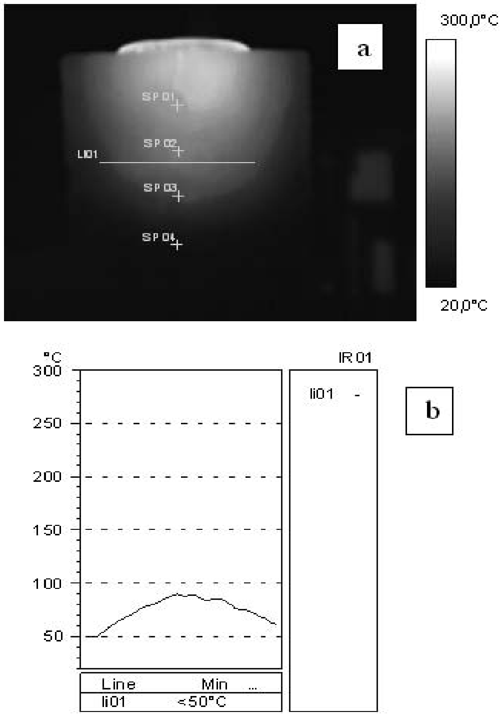

Fig. 8. The AK12/ SiC+C composite: a) thermal image and b) temperature profile on the outside surface of sand mould; start of solidification: T_1 = 565°C, t_1=103.5 s

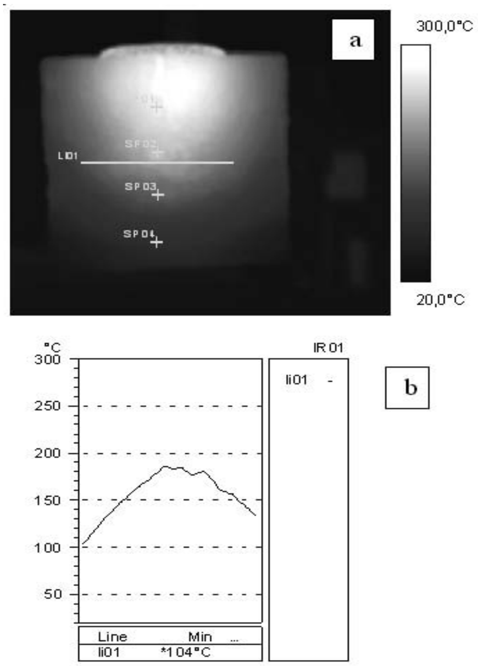

Fig. 9. The AK12/ SiC+C composite: a) thermal image and b) temperature profile on the outside surface of sand mould; finish of solidification: T_1 = 559°C, t_1=253.5 s

The difference in temperature between points SP01 (117°C) and SP03 at the moment the solidification process started equaled 57°C (Fig. 8b) and after the solidification, 98°C (Fig. 9b).

At the same time, the composite suspension AK12/ SiC+C, which was cast into a sand mould, solidified in the temperature range of 565°C-559°C for 150 s (Fig. 7). The distribution of temperatures in the wall of the sand mould during the composite ingot's solidification shows directional heat abstraction (Figs. 8, 9). The difference in temperature between points SP01 (117°C) and SP03 at the moment the solidification process started equaled 57°C (Fig. 8b) and after the solidification, 98°C (Fig. 9b). During the solidification process, the temperature of external wall of the mould in point SP01 increased by 113°C, whereas in point SP02, by 103°C, and in point SP03, by 72°C. Both, a long period of solidification and the conditions of heat abstraction by the sand mould led to obtaining a laminar structure (Fig. 10).

Fig. 10. The macrostructure of AK12/ SiC+C composite solidifies in sand mould; the layered displacement of ceramic particles in the matrix is visible on the picture [19,20].

4. Conclusions

Based on the analysis of the obtained results of tests concerning composite suspensions' solidification, it has been found that the mould's material has a significant influence on the distribution of heterophase reinforcement in the matrix. By applying an appropriate mould material it is possible to shape the cast structure and the distribution of particles in the cast. As the research has shown, moulds which abstract heat quickly, like a graphite or permanent mould, ensure obtaining a uniform distribution of ceramic particles in the matrix (Fig. 6). A longer time of composite suspension solidification facilitates floatation and segregation of the reinforcing particles. Therefore, application of materials which prolong the solidification process, e.g. a sand mould, enables obtaining a gradient or laminar structure in heterophase composites, (Fig. 10).

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