EFFECT OF SELECTED CASTING METHODS ON MICROSTRUCTURAL CHARACTERISTIC OF PARTICLE REINFORCED ALUMINIUM MATRIX COMPOSITES

A. J. Dolata[1*], M. Dyzia[2]

[1] *Faculty of Materials Engineering and Metallurgy, Department of Materials Technology, Silesian University of Technology, Katowice 40-019, KrasiŒkiego St 8, Poland*
**e-mail address: anna.dolata@polsl.pl*

Keywords: AlMMC, casting methods, hybrid reinforcement, structure.

Abstract

In the presented work two methods of casting: gravity casting and centrifugal casting have been described. The main aim of the study was development procedures for producing the AlSi/SiC+C hybrid composite. Selection of reinforced particles was made on their tribological characteristics. SiC particles in the matrix alloy for its high abrasion resistance and hardness, glassy carbon particles for obtaining a low coefficient of friction. Composite suspensions with the same phase composition were cast into molds with different coefficients of thermal conductivity. This allowed to determine the influence of thermal conditions on the formation of the structure and distribution of particles in the matrix. The structure of cast composites was examined by light and electron microscope, applying properly made preparations. In the paper the conditions of casting, macro-and microstructure and selected properties of the casts have been presented.

1 Introduction

Aluminium alloy matrix composites represent a new casting material characterised by casting properties similar to those of conventional Al alloys, but significantly differing in properties. Al/SiC and Al/Al_2O_3 composites have been being manufactured on an industrial scale and used for various structural components for several years now [1]. Their manufacturing process includes the introduction of ceramic particles into liquid metal, formation of composite suspension, its homogenisation and casting into ingots [2,3].

The conditions of composite suspension casting have a significant impact on the particles distribution structure within the cast and thus shape its properties. This paper only presents the selected results of the works carried out under the comprehensive programme of research concerning the development of processing procedures for manufacturing and shaping the structure and properties of AlMMC composites. This paper presents the structure of aluminium alloy matrix composites reinforced by silicon carbide (SiC) and glassy carbon (C) particles, shaped in different casting processes. Al/SiC+C hybrid composites are a new material with specific tribological properties [4]. As shown by previous research, the presence of SiC particles in aluminium alloy ensures obtaining high abrasion resistance and hardness, while the presence of C (glassy carbon) particles ensures obtaining the material with controlled coefficient of friction [4,5].

2. Subject and research materials

The chemical composition of matrix alloy is one of the main factors that determine the possibility of introduction of particles into liquid metal and structure stability of obtained material. The main indicator for Al alloys reinforced by silicon carbide and carbon particles is the silicon content. Based on the investigations of thermodynamic stability it has been found that aluminium alloys reinforced by such particles must include at least 7% of Si. Lower silicon content results in formation of chemically instable aluminium carbide at the interface area as an effect of chemical reaction of aluminium and carbon. Therefore, the eutectic aluminium alloy (AlSi12CuNiMg), additionally modified by 2% of magnesium and 0,03% of strontium, was selected for the composite matrix. The introduction of Mg improves the ceramic particle surface wettability, reduces the Al_2O_3 oxide film tightness and allows the metal-ceramics joint to be obtained as a result of formation of a spinel layer at the interface [6]. The alloy modification with strontium affects the refinement of its structure.

The silicon carbide SiC with size of up to 25μm and glassy carbon with particle size of up to 80μm were used as the hybrid reinforcement. In this work, the gravity casting with different heat abstraction conditions and the centrifugal casting were used. The casting conditions and the structure of obtained casts were presented.

3. Solidification of hybrid composite suspensions under various heat abstraction conditions

One of the elements of the assessment of technology for manufacturing composites is their behaviour during solidification. In this paper, the selected investigation results of the composite suspension solidification process under various heat abstraction conditions recorded using the photometer system ThermaCAM™E25 for temperature control and measurement were presented [7]. In order to determine the impact of variable heat abstraction conditions on the process of shaping the particles distribution structure within the matrix, composite suspensions with the same phase composition were cast into moulds with different thermal conductivity coefficients. The investigations were made for hybrid composite reinforced by the mixture of silicon carbide SiC and glassy carbon C with 20% share of the mixture (15%SiC+5%C).

Three moulds were used in the investigations: graphite, sand and self-curing phosphate mass ones. During the investigations, the temperature, composite solidification time and mould temperature were recorded. In addition, thermal images with 10s time interval were recorded, based on which temperature distribution on the mould surface can be determined. The selected images for the moulds used are shown in Figures 1-6. The solidification of composite in a graphite mould proceeds in a very short time of 4.2 s, at 558°C (Fig. 1).

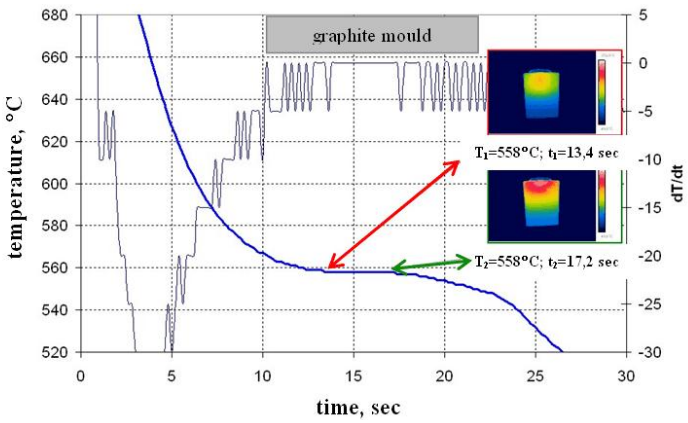


Figure 1. The solidification curve of AlSi12CuNiMg/SiC+C composite - graphite mould.

By analysing the distribution of temperatures of the wall of a graphite mould during the solidification of composite ingot, it can be confirmed that the mould was fairly uniformly overheated. The difference in temperatures between points SP1 and SP3 at the moment when the solidification process started was 92°C and after the solidification it was 122°C. During the solidification process, the temperature of the mouldôs external wall increased by 63°C in point SP1, by 27°C in point SP2 (Fig. 2a) and by 33°C in point SP3. Such conditions of heat abstraction by a graphite mould resulted in obtaining a structure with uniform distribution of particles over cross-section of the composite ingot (Fig. 2b).

a

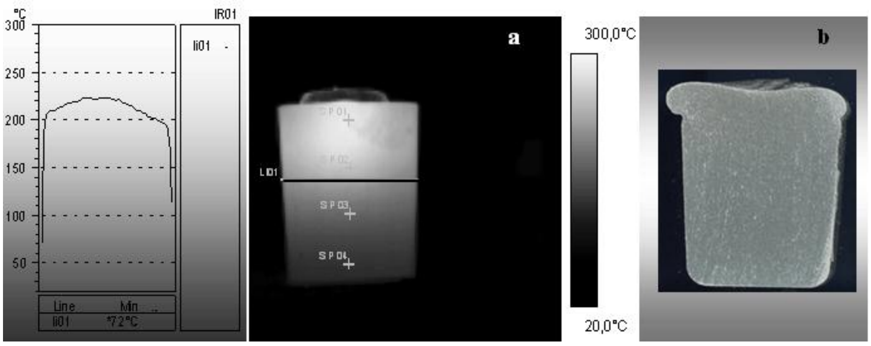


Figure 2. a) Temperature profile and thermal image on the outside surface of graphite mould, start of solidification: T_1 = 558°C, t_1=13,4sec; b) macrostructure.

For a self-curing phosphate mass mould, the increase in wall temperature during the solidification of AlSi12CuNiMg /SiC+C composite ingot was slower (Fig. 3) as compared to the graphite mould, however the overheating of the mould was also uniform. The difference in temperatures between points SP1 and SP3 (Fig. 4a) at the moment when the solidification process started was 81°C and after the solidification it was 99°C. During the solidification process, temperature of the mouldôs external wall increased by 160°C in point SP1 and by 155°C in point SP2. In point SP3, the increase was 142°C. Such conditions of heat abstraction by a self-curing phosphate mass mould resulted in obtaining a gradient structure over cross-section of the ingot. For macrostructure of the composite, see Figure 4b.

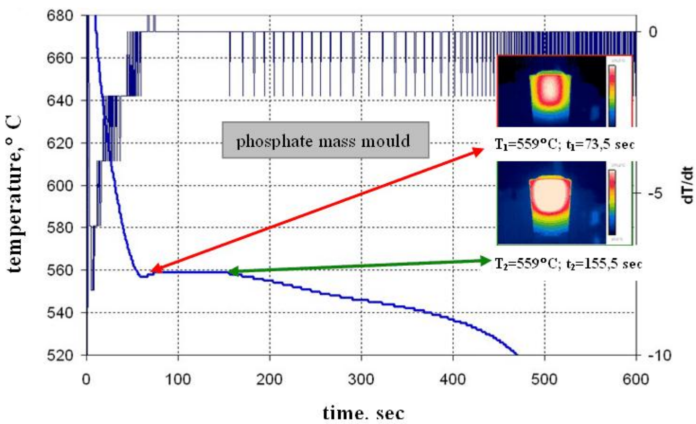


Figure 3. The solidification curve of AlSi12CuNiMg/SiC+C composite in a self-curing phosphate mass mould.

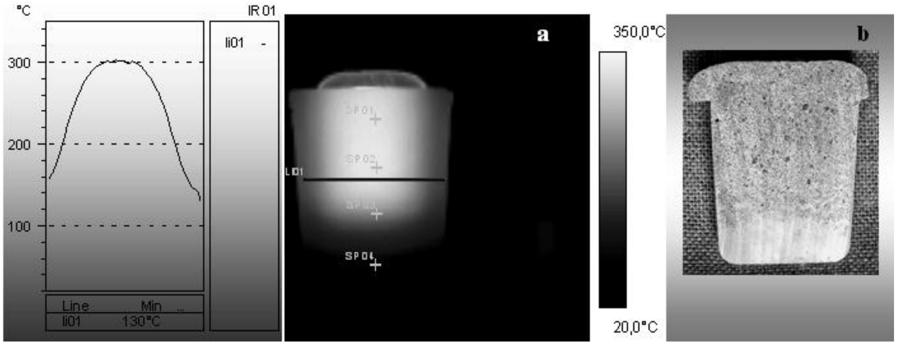


Figure 4. a) Temperature profile and thermal image on the outside surface of a self-curing phosphate mass mould, start of solidification: T_1 = 559°C, t_1=73,5sec; b) macrostructure.

In turn, the composite suspension AlSi12CuNiMg /SiC+C, which was cast into a sand mould, solidified in the temperature range of 565°C-559°C for 150 s (Fig. 5). The distribution of temperatures in the wall of a sand mould during the solidification of composite ingot shows directional heat abstraction. The difference in temperatures between points SP1 (117°C) and SP3 at the moment the solidification process started was 57°C and after the solidification it was 98°C. During the solidification process, the temperature of external wall of the mould increased by 113°C in point SP1, by 103°C in point SP2 and by 72°C in point SP3. Both, the long period of solidification and the conditions of heat abstraction by the sand mould resulted in obtaining a laminar structure (Fig. 6b).

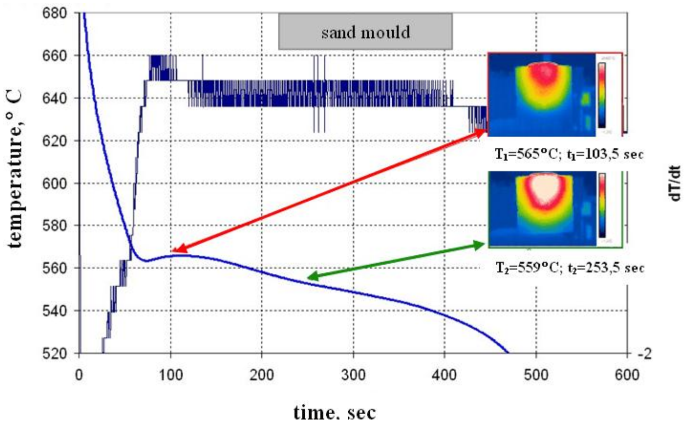


Figure 5. The solidification curve of AlSi12CuNiMg/SiC+C composite in a sand mould.

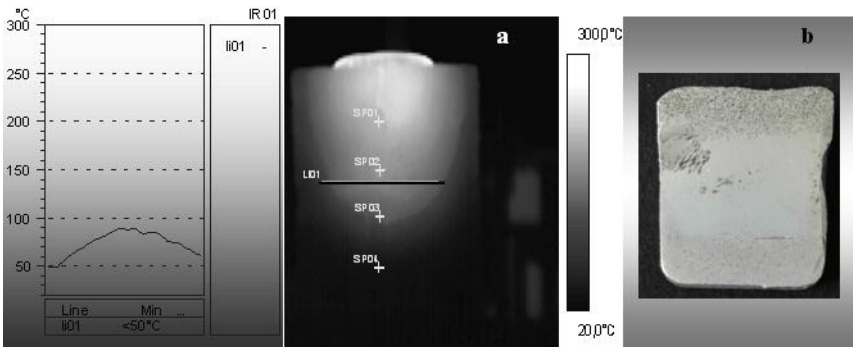


Figure 6.a) Temperature profile and thermal image on the outside surface of a sand mould, start of solidification: T_1 = 565°C, t_1=103,5sec; b) macrostructure.

As the research has shown, moulds which abstract heat quickly, like a graphite or permanent metal mould, ensure obtaining a uniform distribution of ceramic particles in the matrix (Fig. 1), whereas the materials that extend the time of solidification allow obtaining a gradient or laminar structure in hybrid composites. Figures 2a, 4a, 6a show a clear difference in distribution of temperatures on a sampler surface at the beginning of the solidification of composites. A significantly higher ability to accumulate heat by graphite allows fast heating over practically its entire volume, whereas in case of a sand mass sampler, a distinct directional heat absorption occurs, which is visible even after 250s (temperature around 180°C), as opposed to the graphite sampler where practically the whole sampler obtains the temperature of 220°C as quickly as within 15 s. The changes in the solidification curve are also clear (Figs. 1,3,5). On one hand, this can be caused by the mould material (differences in coefficients of heat accumulation, thermal conductivity and heat abstraction) and on the other hand by the effects that occur in metal (solidification, particles segregation). Therefore, it can be confirmed that the structure of particles distribution (SiC and C) in the matrix can be shaped not only by the heat abstraction rate, but also by the orientation of such abstraction.

4. Centrifugal casting of hybrid composite suspensions

The composite suspensions were cast into a centrifugal casting mould, using the centrifugal casting process with vertical axis of rotation. The casting parameters, such as mould temperature, pouring temperature and centrifugation speed, were selected based on simple calculations and verified experimentally. As a result of the difference in density of matrix and particles, it is possible to obtain a diverse distribution of particles in the centrifugal casting process. In particular, for AlSi12CuNiMg /SiC+C hybrid composite it is possible to obtain gradient or three-layer casts (Fig. 7).

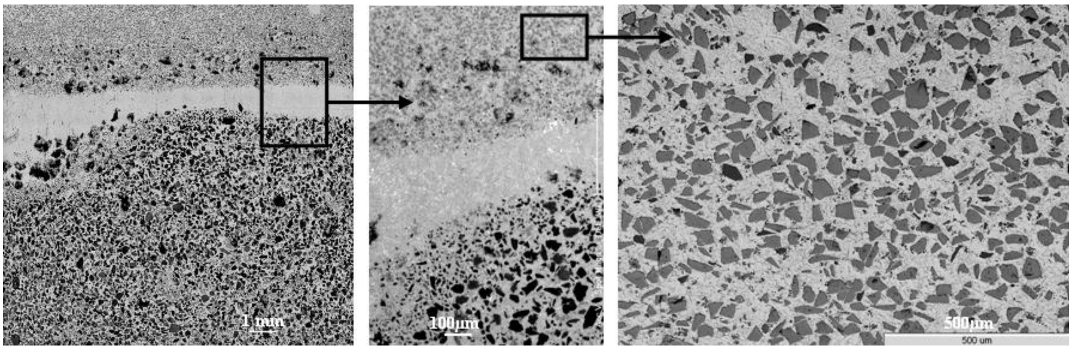


Figure 7. Microstructure of Al/SiC+C hybrid composite obtained by centrifugal casting process.

On the basis of experimental works, it has been found that the mould temperature of T=450ºC ensures the formation of composite layers. The centrifugation speed is of less importance here, nevertheless it has a significant impact on the formation of layers containing SiC or C particles. The basic parameters of centrifugal casting for which the investigations were made are presented in Table 1.

Table 1. Parameters of centrifugal casting

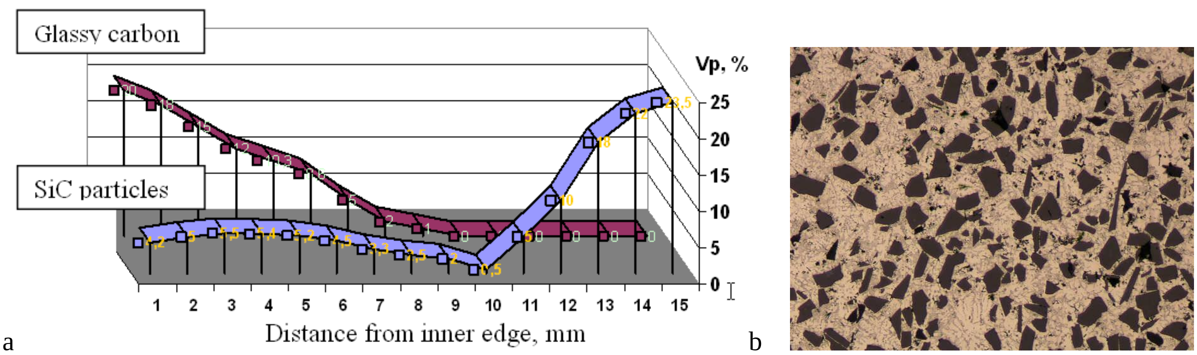
Axis of rotation	vertical
Centrifugation speed	1500 [rpm]
Material forms	steel
Inner diameter form	60 [mm]
Temperature mold before pouring	450 [°C]
Casting temperature	720 [°C]
Mass of casting composite suspension	0,8 [kg]

Using the casting parameters in Table 1, the sleeve casts of 60mm in diameter and 90mm in height were made. Then, rings were cut out of the obtained sleeves to be used for investigations of the structure of ceramic particles distribution over cross-section of the cast as well as for tribological tests, the detailed results and analyses of which are shown in [3,4].

4.1 Quantitative description and stereological characteristics of selected casts

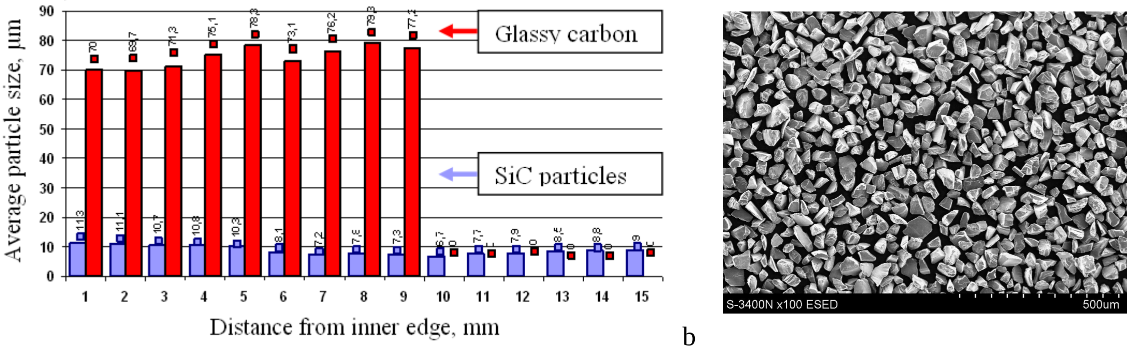
The computer program Met-Ilo was used for quantitative image analysis. In accordance with the assumed methodology, a number of geometric parameters were determined, out of which the following ones were selected for analysis of the impact of applied centrifugal casting technology on distribution of ceramic reinforcement in the produced composite sleeves: volume fraction Vp and average size of the particle reinforcement used. The measurements were taken on the binary images of real photographs taken with a light microscope integrated with a high-resolution camera and high-output PC. The image analysis was made on the fields of $1mm^2$, bordering each other and located along the cast radius. The results of quantitative analysis are presented in graphs for selected groups of casts with 10% and 20% volume of hybrid reinforcement (SiC+C).

Figure 8a presents the curves characterize the distribution of hybrid reinforcement over the surface of a sample under investigation. Two series of values are shown in the graph ï the first one concerns silicon carbide (SiC) and the latter relates to glassy carbon (C). Two distinct layers were obtained in the composite. The external layer with thickness of approx. 4mm is characterised by the increased volume of SiC particles, from 10 to 20%, while in the external layer with thickness of approx. 6mm the average volume fraction of SiC particles maintains at the level of 5%. In the internal layer, the highest content of reinforcement is shown by glassy carbon and its amount decreases from 20% to 8.6%, in outward direction of the sample under investigation. In the external layer, no presence of carbon particles was found. Of course, it is connected with a significant difference in density of SiC (ρ=3.2g/cm^3) and carbon (ρ=1,8g/cm^3) particles. The area of approx. 2mm with slight share of SiC and C particles is also visible. These results confirm the measurements of average diameters taken for silicon carbide and glassy carbon particles, which are shown in Figure 9. For silicon carbide (SiC), the average size of particles over the entire length was 9.1 µm. The biggest glassy carbon grains were observed in the external layer of the sleeve and their average size was 74 µm.



a b

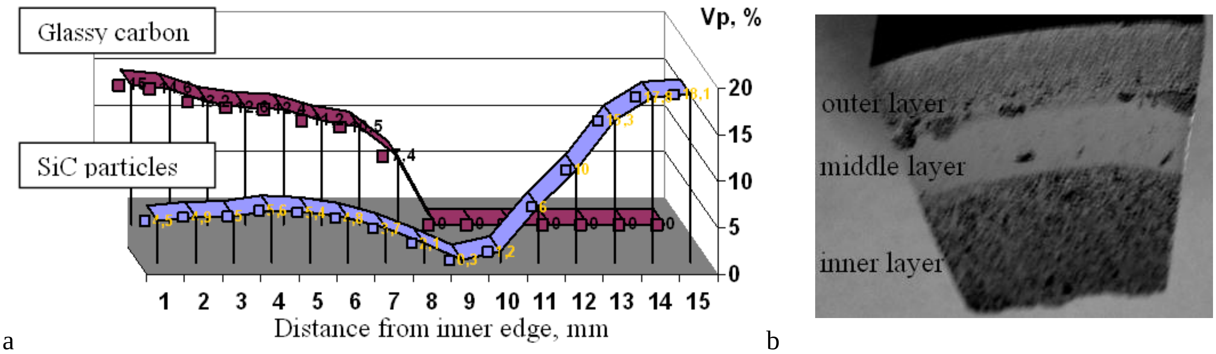
Figure 8. Composite AlSi12CuNiMg /20% (SiC+C): a) distribution of hybrid reinforcement over cross-section of cast, b) microstructure from the outer layer enriched in SiC particles.



a b

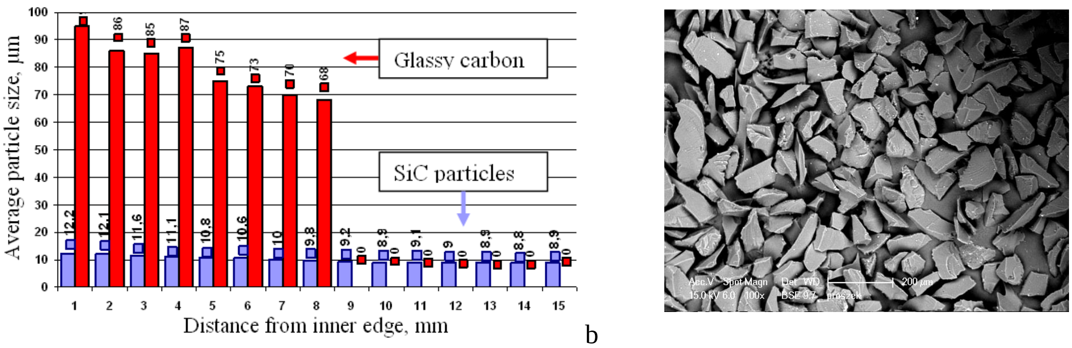
Figure 9. Results the measurements of average diameters for silicon carbide and glassy carbon particles over cross-section of the cast, b) silicon carbide particles.

The macrostructure of AlSi12CuNiMg/(SiC+C) composite with 10% volume of hybrid reinforcement is shown in Figure 10a. Based on the counting made during the quantitative analysis of composite, the graph was made for the volume of reinforcement over cross-section of the composite (Fig. 10b). Figure 11a, in turn, presents the distribution of average diameter for reinforcing particles. The investigations confirm the diversification of distribution of hybrid reinforcement (SiC+C) over cross-section of the composite and its close correlation with the size and volume of the particles used.



a b

Figure 10. Composite AlSi12CuNiMg /10% (SiC+C): a) distribution of hybrid reinforcement over cross-section of cast, b) macrostructure with visible layers.



a b

Figure 11. Results the measurements of average diameters for silicon carbide and glassy carbon particles over cross-section of the cast.

The graph shows two series of values ï the first one concerns the surface fraction of silicon carbide and the latter relates to glassy carbon C. The internal layer of 7mm is characterised by the average 5% volume of silicon carbide particles and three times higher 15% volume of glassy carbon C. On the external layer, with thickness of 4mm, the volume of SiC particles smoothly decreases from 18.1% to 10%. This area is free of glassy carbon particles. The carbon particles are prevailing, in turn, in the internal area and their amount decreases in gradients from 15% to 10.5%, while the share of silicon carbide particles does not exceed 5.6%. Similarly to the previous investigated material, the composite includes the area of 4mm with slight volume of SiC particles, not exceeding 2.5%, and with no glassy carbon particles. The average size of particles for silicon carbide SiC is 13 µm and for glassy carbon C ï 70 µm (Fig. 11b).

The above results of the analysis of SiC and C particles distribution in hybrid composites are typical of this group of particles material. In the investigations presented in [9,10], it has been found that carbon particles are always located in the internal part of the centrifugal casting, while SiC particles ï in its external part. However, the appropriate selection of casting parameters may affect the thickness of obtained composite layers, and thus the usable properties of the product, especially the tribological ones.

Summary

The results of described investigations revealed a wide range of possibilities of shaping the structure of developed hybrid composites in the gravity and centrifugal casting processes. Various conditions of composite suspension casting, and so different specificity of the cast solidification process, have a significant impact on the particles distribution structure within the cast, thus increasing the possibility of designing its properties, especially the tribological ones. The selection of the hybrid reinforcing system of SiC+C type provides the possibility of shaping both the abrasion and sliding properties of obtained composites. Of course, these features are affected by both the size and quantity of particles, and in case of hybrid composite by the appropriate proportion between the silicon carbide and glassy carbon particles.

Acknowledgements

Scientific work financed from funds allocated for National Science Center, Project No. N N508 630 540

References

[1] Miracle D.B. Metal matrix composites. From science to technological significance, *Composites Science and Technology*, Vol. 65, pp. 2526ï2540, 2005.

[2] Hashim J., Looney L., Hashmi M.S.J. Metal matrix composites: production by the stir casting method., *J. Mater. Process. Technol.*, Vol. 92/93, pp. 1ï7, 1999.

[3] Dolata A.J., M. Dyzia: Aspects of fabrication aluminium matrix heterophase composites by suspension method, *IOP Conference Series: Materials Science and Engineering*, Vol. 35 012020, 2012.

[4] Wieczorek J., ś leziona J., Dolata-Grosz A., Myalski J.: Influence of material of friction partner on tribological properties of heterophase composites, *Kompozyty (Composites)*, Vol. 8/1, pp. 5-10, 2008.

[5]. Dyzia M.: AlSi7Mg/SiC and Heterophase SiC_p+C_g Composite for Use in Cylinder-Piston System of Air Compressor, *Solid State Phenomena*, Vol. 176, pp. 49-54, 2011.

[6]. Dolata-Grosz A.: Interaction of Al-Si alloys with SiC/C ceramic particles and their influence on microstructure of composites, Solid State Phenomena, Vol. 176, pp. 55-62, 2011.

[7] Dolata-Grosz A., Dyzia M., ś leziona J.: The formation of the structure of cast composites in different solidification conditions, *Archives of Materials Science and Engineering*, Vol. 31/ 1, pp. 13-16, 2008.