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COMPOSITES THEORY AND PRACTICE

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SiC PARTICLE DISTRIBUTION IN CASTINGS MADE FROM COMPOSITE SUSPENSION A359/SiC$_p$ WITH VARIOUS CASTING CONDITIONS

The paper presents results of an evaluation of the reinforcing phase particles in identical test castings of small overall dimensions, obtained from a composite suspension in diversified casting conditions. The composite suspension behavior has been studied in different casting conditions: gravitational, gravitational aided by subatmospheric pressure and under centrifugal force. The beneficial influence of the factors intensifying the process of filling mold cavities with a composite suspension was found. Gravitational casting of the composite suspension is limited by the size of the casting modules - in the analyzed experiment conditions they cannot be lower than 1.4 mm. In the castings obtained using subatmospheric pressure, uniform distribution of the reinforcing phase particles was found. Additionally, highly diversified particle distribution was observed in castings from a suspension subjected to centrifugal forces.

Keywords: metal matrix composite, microstructure, gradient structure, casting composite

ROZKŁAD CZĄSTEK SiC W ODLEWACH Z ZAWIESINY KOMPOZYTOWEJ A359/SiC$_p$ PRZY RÓŻNYCH WARUNKACH ODLEWANIA

Przedstawiono wyniki oceny rozkładu cząstek fazy zbrojącej w identycznych odlewach próbnych o małych gabarytach, uzyskanych z zawiesiny kompozytowej w zróżnicowanych warunkach jej odlewania. Zbadano zachowanie się zawiesiny kompozytowej w warunkach odlewania: grawitacyjnego, grawitacyjnego wspomaganego podciśnieniem oraz pod działaniem siły odśrodkowej. Stwierdzono korzystny wpływ czynników intensyfikujących proces wypełniania wnęk form zawiesiną kompozytową. Grawitacyjne odlewanie zawiesiny kompozytowej ograniczone jest wielkością modułów odlewów, które w analizowanych warunkach doświadczeń nie mogą być mniejsze niż 1,4 mm. Stwierdzono równomierny rozkład cząstek fazy zbrojącej w odlewach uzyskanych z wykorzystaniem podciśnienia, a ponadto bardzo zróżnicowany rozkład cząstek w odlewach z zawiesiny poddanej działaniu sił odśrodkowych.

Słowa kluczowe: kompozyty metalowe, mikrostruktura, struktura gradientowa, kompozyty odlewane

INTRODUCTION

Castings made from Al/SiC composite suspensions, as distinct from classic aluminum alloys, are characterized by high abrasion resistance. However, because of containing hard SiC particles, certain problems arise with their finishing [1-4]. For manufacturing castings from composites reinforced with SiC particles, methods which limit the amount of necessary machining to a minimum are usually chosen. These methods include pressure casting and investment casting, among others. Pressure casting, due to high tooling costs, is usually applied in large series and mass production. Additionally, a composite suspension acts as an abrasive paste - it significantly reduces the durability of the used molds. A second method which allows the manufacturing of thin-walled, precise castings of any shape complexity, also reducing the need for their machining to a minimum, is investment casting. This method, also due to high tooling costs (e.g. dies or injection molds for model preparation) is used mostly in mass production, but the development of 3D printing technologies in recent years has also made it possible to use this method in small series production [5, 6]. When manufacturing castings out of a composite suspension, besides precise re-creation of the mold cavity shape, it is important to obtain a desired distribution of the SiC particles (gradient or uniform) in a solidified casting. Distribution of the particles in a casted suspension will be affected by two factors: the method of filling the mold and the solidification conditions [7-10].

PREPARATION AND COURSE OF STUDY

Studies of the influence of the mold cavity filling method on the SiC particles distribution in a casting were performed using a standard composite material, designated as A359/20SiC_p (F3S.20S DurAlcan™), whose chemical composition is presented in Table 1. The size of the SiC particles in the tested composite was approx. 20 μm.

TABLE 1. **Chemical composition of A359/20SiCp composite**
TABELA 1. **Skład chemiczny kompozytu A359/20SiC_p**

Chemical composition [% by mass]								SiC [% vol.]
Si	Fe	Cu	Mn	Mg	Zn	Ti	Al	
9.2	0.14	0.01	-	0.6	0.02	0.11	rest	≈ 20

For the tests, the precise method of investment casting was used. Three model sets were produced using Kerr wax, of the dimensions presented in Figure 1. The calculated solidification modules are presented in Table 2.

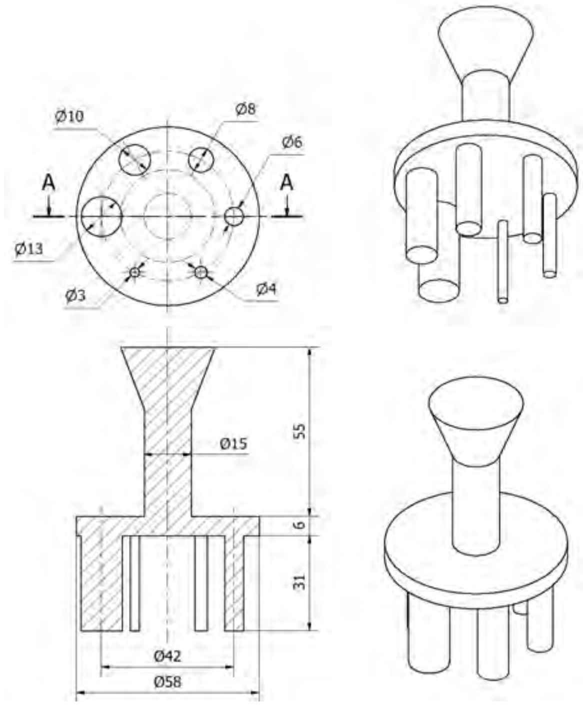

Fig. 1. Diagram of casting model used for tests
Rys. 1. Schemat modelu odlewniczego użytego do prób

TABLE 2. **Dimensions of mold cavities and casting modules**
TABELA 2. **Wymiary wnęk form i moduły odlewów**

Sample size [mm]	Sample casting modules [mm]
Ø 3 x 31	0.7
Ø 4 x 31	0.9
Ø 6 x 31	1.4
Ø 8 x 31	19
Ø 10 x 31	2.3
Ø 13x 31	2.9

The models were placed in metal sleeves and cast with a previously degassed gypsum molding sand Super Cast 20, from the KERR company. After the sand bonded, the models were melted out, then the molds were dried and burned at a temperature of 720°C, in a cycle lasting for 12 hours. Melting of the fragments of a composite pig was conducted without the use of a fluxing agent, in a laboratory crucible furnace K4/13 from the NABERTHERM company. Identically prepared molds (Fig. 2), which were chilled to a temperature of 300°C after annealing, were filled with the composite suspension gravitationally, using subatmospheric pressure (vacuum) and a centrifugal force. The temperature of the poured suspension was 720±10°C, the estimated pressure values for the casting conditions are presented in Table 3.

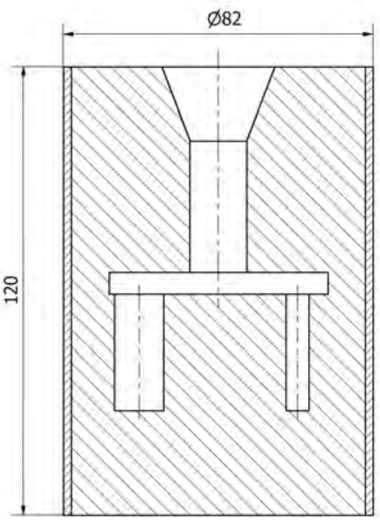

Fig. 2. Diagram of casting mold section
Rys. 2. Rysunek przekroju formy odlewniczej

TABLE 3. **Estimated values of pressure for mold pouring conditions**
TABELA 3. **Oszacowane wartości ciśnienia dla warunków zalewania form**

Mold cavity diameter [mm]	Resulting pressure value [Pa]		
	Gravitational casting $\Delta P_1 = P_m - P_k$	Subatm. pressure casting $\Delta P_2 = P_m + P_p - P_k$	Centrifugal casting $\Delta P_3 = P_{odś} - P_k$
3	105	80105	1010
4	395	80395	1300
6	685	80685	1590
8	830	80830	1735
10	917	80917	1822
13	998	80998	1903

where: $P_{1,2,3}$ - correspondingly: resulting pressure (gravitational, subatmospheric, centrifugal), P_m - metallostatic pressure, P_p - subatmospheric pressure, P_k - capillary pressure depending on casting diameter, $P_{odś}$ - pressure resulting from centrifugal force
For the calculations, the following assumptions have been made:
- density of composite suspension - 2550 kg/m^3
- surface tension of liquid suspension 1 N/m
- wetting angle of mold material by suspension - 150°
- value of subatm. pressure recorded on suction ferrule of applied installation.

For the centrifugal mold casting, a casting machine from F.lli Giacetti company was applied, where the mould was placed and clamped on the crucible on its vertical axis. At the start of centrifugation, the set (crucible+mould) was placed in the horizontal position and the casting process was started.

The angular velocity was 270 rpm and the radius connecting the spinning axis of the crucible-mold set was equal to 130 mm. The spinning time of the set was 5 minutes and it exceeded the total solidifying time of the casted suspension. A mold prepared for casting in subatmospheric pressure conditions had venting holes drilled in the sleeves, and a sealing ring. The mold was placed in a workstation, the vacuum pump was turned on and then the mold was filled with the composite suspension. The pump was turned off after the casting solidified. Gravitational filling was realized using standard procedures.

Each of the three molds used for the studies allowed obtaining 6 samples, which were evaluated using two criteria:
1) degree of filling of particular mold cavities which form the casting,
2) metallographic structure observed on polished sections prepared for individual castings in planes crossing the symmetry axes of each casting.

Evaluation of the degree of mold cavity filling was performed visually and on the basis of geometrical measurements (lengths of the composite samples - test castings). Samples of castings used to determine the distribution of the reinforcing phase were cut in a way as to make it possible to conduct metallographic evaluation of axial sections of the samples, along with a fragment of the base of each sample. Metallographic evaluation was conducted on all the polished sections, in various areas. For the metallographic evaluation of the structure of the sample materials, a NIKON Optiphot-100 optical microscope was used. Distribution of the reinforcing phase particles was examined using a picture analysis method (ImageJ 1.42q software) in three areas of each casting, by taking photographs in three randomly selected areas of the analyzed polished section: in the central part of the casting, 5 mm from its upper and lower edge, and its fractions were determined from the surface occupied by grains on the metallographic specimen surface.

STUDY RESULTS AND THEIR EVALUATION

According to the predictions resulting from the previous calculations of the resulting pressure, the cavities of molds ø3 and ø4 mm cast gravitationally were not filled with the composite suspension. The cavities of molds filled with subatmospheric pressure and centrifugally did not have defects in the form of misruns. Figure 3 graphically presents the distribution of the SiC reinforcing phase in castings obtained using different methods of mold filling, depending on the casting diameter.

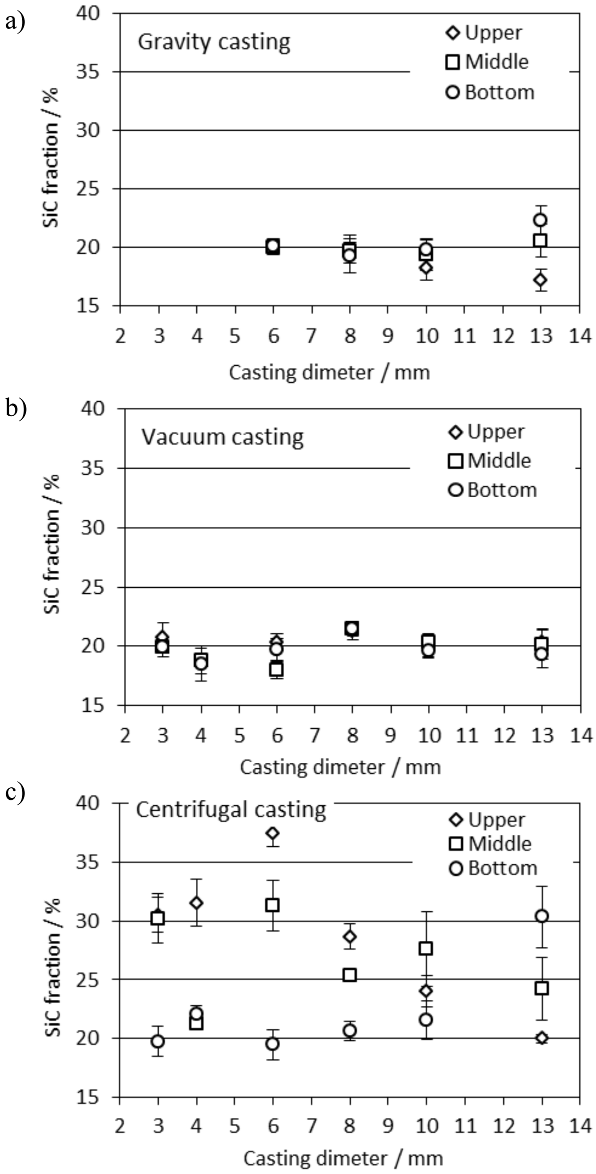

Fig. 3. Distribution of SiC particles depending on diameter of casting for molds filled: a) gravitationally, b) with subatmospheric pressure, c) centrifugally

Rys. 3. Rozkład cząstek SiC w zależności od średnicy odlewu dla odlewów wypełnianych: a) grawitacyjnie, b) podciśnieniowo, c) odśrodkowo

The diagram in Figure 3a allows one to conclude that in the castings of diameters ø6 and ø8 mm filled gravitationally, the portion of SiC particles in the observed areas is uniform and equals approx. 20%. An increase in the diameter of the subsequent castings causes a change in the particle portion. The distribution of the reinforcing phase particles in the obtained test castings indicates that in the case of gravitational casting, a longer period of solidification of the composite suspension (increase in casting modules) favors particle sedimentation. For the casting with the greatest module (ø13 mm), distribution of the SiC particles was: in the upper area - approx. 17% (Fig. 4a), in the central area - approx. 20% (Fig. 4b) and in the bottom part of the sample, the fraction of the reinforcing phase was approx. 22% (Fig. 4c).

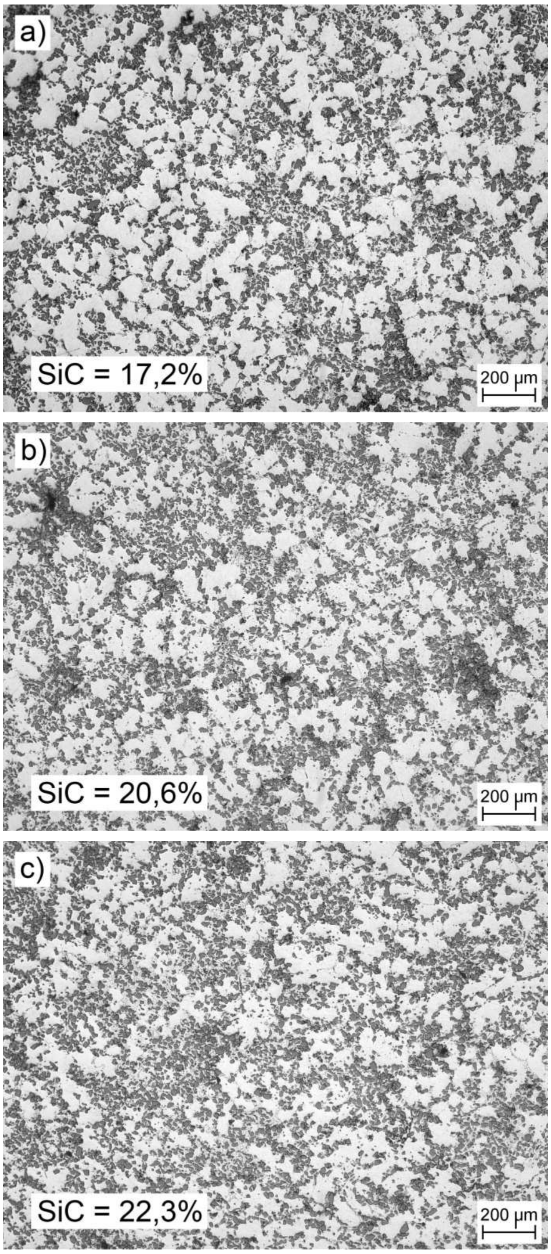

Fig. 4. Microstructure of ø13 mm casting obtained gravitationally: a) upper area, b) central area, c) bottom area

Rys. 4. Mikrostruktura odlewu ø13 wypełnianego grawitacyjnie: a) obszar górny, b) obszar środkowy, c) obszar dolny

A similar effect was not found when observing structures of castings obtained during casting intensified by subatmospheric pressure. The distribution of the reinforcing phase particles in all the analyzed casting areas was approx. 20% of the volume (Fig. 3b). No variability in the SiC distribution can be a result of inertial forces working on a particle in the suspension at the moment of pouring. When the suspension stream accelerates, increased density of the particles causes their additional relative movement in the matrix. The uniformity of the reinforcement distribution is a result of sedimentation preceding solidification of a casting in the existing thermal conditions.

The most diversified distribution of the reinforcing phase particles in the structure of the obtained castings was found for the casting aided by centrifugal force (Fig. 3c). In the castings of diameters in between 3÷10 mm, the greatest fraction of the reinforcing particles occurs in their upper areas and the lowest - in their lower areas (Fig. 5).

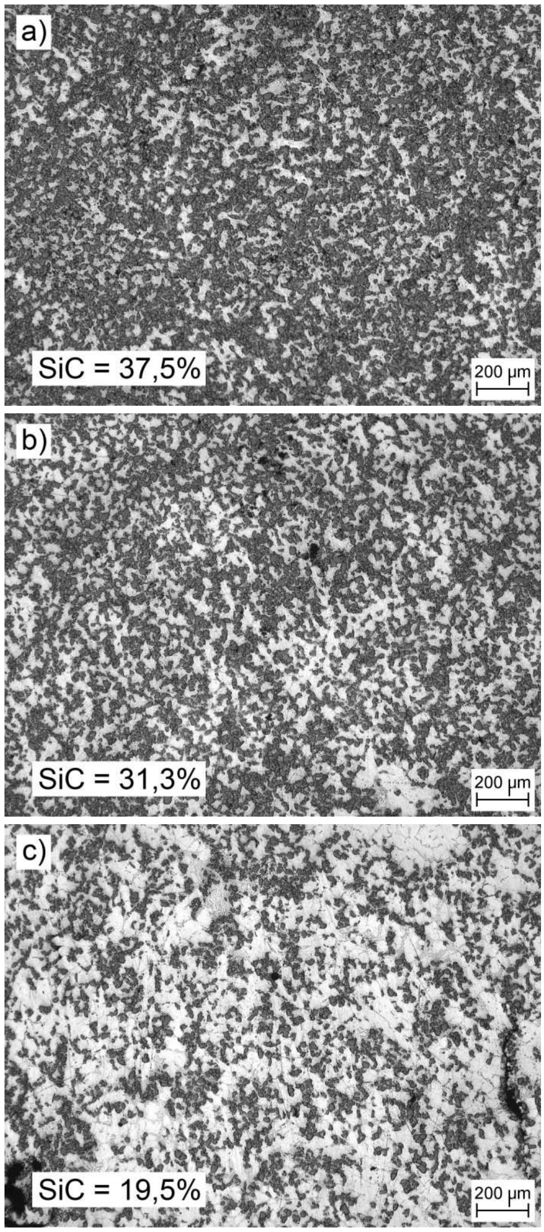

Fig. 5. Microstructure of ø6 mm casting obtained using centrifugal force: a) upper area, b) central area, c) bottom area

Rys. 5. Mikrostruktura odlewu ø6 wypełnianego odśrodkowo: a) obszar górny, b) obszar środkowy, c) obszar dolny

Reversed distribution of the particles in castings of lower modules is most likely caused by mutual blocking of particles (formation of agglomerates at the root of the running gate) in a stream of rapidly flowing and solidifying suspension, which can be concluded on the basis of analyzed pictures of polished sections (Fig. 6).

The concentration of SiC particles in the lower parts of castings of the greatest module value (Fig. 7) can be explained by the undisturbed work of the inertial forces on the sedimenting particles.

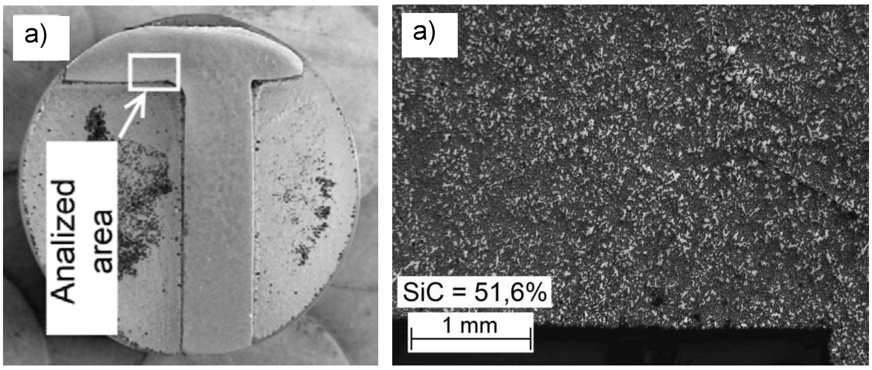

Fig. 6. Distribution of particles in running gate of ø6 mm casting filled using centrifugal method: a) location of analyzed area, b) microstructure

Rys. 6. Rozkład cząstek we wlewie doprowadzającym odlewu ø6 mm wypełnianego metodą odśrodkową: a) miejsce analizowanego obszaru, b) mikrostruktura

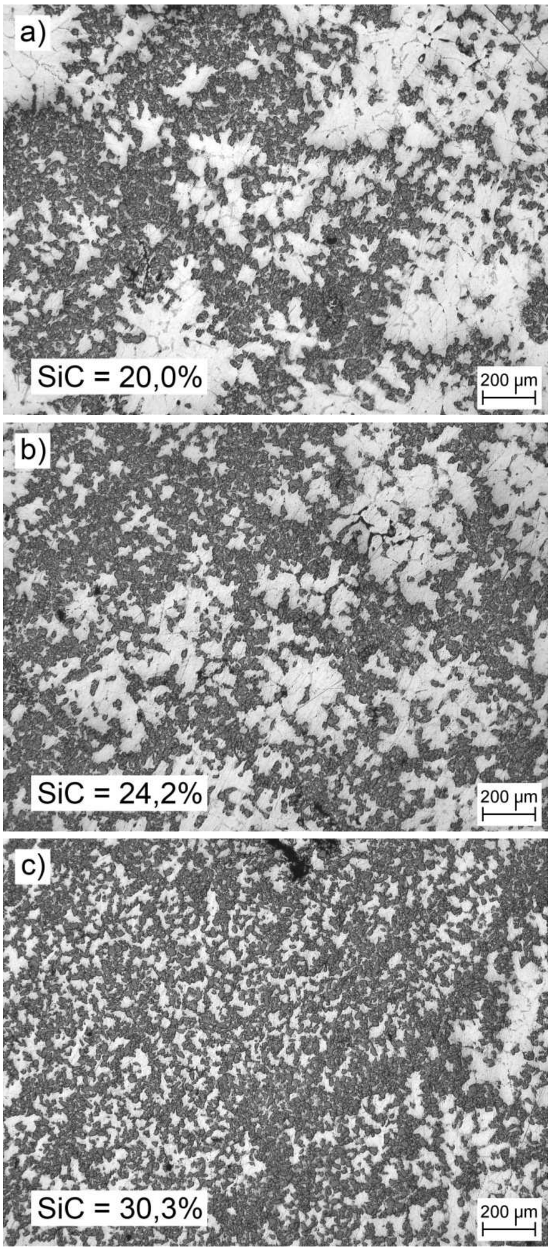

Fig. 7. Microstructure of ø13 mm casting obtained with centrifugal force: a) upper area, b) central area, c) bottom area

Rys. 7. Mikrostruktura odlewu ø13 mm wypełnianego metodą odśrodkową: a) obszar górny, b) obszar środkowy, c) obszar dolny

In all the analyzed samples (filled by the centrifugal method), the average volume fraction of SiC particles is above 25%. The increased agglomeration of reinforcement phase resulted from SiC particles flowing from the gaiting system (Fig. 8) in the centrifugal force direction.

Fig. 8. Micrographs of gaiting system with visible reinforcement-matrix interface

Rys. 8. Mikrografia systemu wlewu z widoczną wzmocnioną przestrzenią

SUMMARY

The conducted studies have proven the occurrence of variable structures of the material of composite castings with non-complex geometry, obtained from an identical suspension. The results of the studies indicate that diversified conditions of filling the casting molds strongly affect the behavior of the reinforcing phase particles in a casted suspension. Highly-desired factors that facilitate obtaining precise castings out of the composite suspensions also cause additional (except sedimentation) movement of the particles in relation to the matrix, which causes significant variability of the fraction of a granular reinforcing phase in the structure of the obtained castings. Controlled diversification of the distribution of the reinforcing phase in the composite castings allows one to obtain, for example, castings of a gradient structure, but achieving this effect in each individual case requires experimental verification. It must be acknowledged as advisable to continue studies on the behavior of composite suspensions in various casting conditions.

REFERENCES

[1] Alakesh Manna, Bhattacharayya B., Influence of machining parameters on the machinability of particulate reinforced Al/SiC-MMC, The International Journal of Advanced Manufacturing Technology 2007, 9-10, 25, 850-856.

[2] Przestacki D., Szymański P., The influence of laser beam on structure surface layer of composite A359/20SiC_p Composites Theory and Practice 2012, 12(3), 155-158.

[3] Przestacki D., Szymański P., Metallographic analysis of surface layer after turning with laser assisted machining of composite A356/20SiC_p, Kompozyty (Composites) 2011, 11(2), 102-106.

[4] Qiguo Zhang, Jianxun Qiu, Yi Wang, Mingyuan Gu, Studies on machinability of Al/Si_p + SiC_p composite materials, Journal of Materials Science 2007, 42, 6, 5845-5850.

[5] Oczoś K.E., Rosnące znaczenie Rapid Manufacturing w przyrostowym kształtowaniu wyrobów, Mechanik 2008, 81, 4, 241-257.

[6] Mager A., Moryson G., Cellary A., Marciniak L., Zastosowanie technik Rapid Prototyping do wytworzenia wyrobów metalowych, Postępy Nauki i Techniki 2011, 8, 174-182.

[7] Dolata-Grosz A., Śleziona J., Wieczorek J., Dyzia M., Struktura strefowa kompozytów AK12-Al_2O_3 i AK12-SiC kształtowana w procesie odlewania odśrodkowego, Kompozyty (Composites) 2002, 5(2), 305-308.

[8] Dolata-Grosz A., Dyzia M., Śleziona J., Rozmieszczenie cząstek zbrojących w kompozycie Ak12/SiC+C kształtowane podczas krzepnięcia odlewu, Kompozyty (Composites) 2008, 8(3), 296-301.

[9] Dolata-Grosz A., Wieczorek J., Dyzia M., Śleziona J., Struktura kompozytowych odlewów otrzymanych odśrodkowo, Kompozyty (Composites), 2001, 1(2), 141-143.

[10] Jackowski J., Szymański P., The structure of centrifugally cast composite casting, Composites Theory and Practice 2012, 12(1), 66-71.

