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SEGREGATION REINFORCED PHASE IN AlSi/Cr_xC_y COMPOSITE PRODUCED UNDER ELECTROMAGNETIC FIELD

In this paper, the technology of AlSi12Cu2Fe/Cr_xC_y in/ex-situ composites produced with Cr30Fe8C ex situ particles is described. The composites were gravity cast, applying simultaneously an electromagnetic field. The purpose of the investigation was to analyse the influence of the frequency of an electromagnetic field on the segregation, quantity and morphology of the reinforcement phase in an aluminum matrix. The technological concept is based on the assumption that the added chromic-iron particles dissolves in the aluminum matrix and the carbide phase becomes the reinforcement of the composite with a variable portion of Al-CrFe intermetallic phases. On the basis of microstructure observation, the quantity, segregation effect, morphology and the volume fraction of the different phases in the composite material was assessed by microscopical analysis.

Keywords: composite, segregation, morphology, electromagnetic field

SEGREGACJA FAZY WZMACNIAJĄCEJ W KOMPOZYCIE AlSi/ Cr_xC_y WYTWARZANYM W POLU ELEKTROMAGNETYCZNYM

W pracy przedstawiono technologię otrzymywania kompozytów in/ex situ AlSi12Cu2Fe/Cr_xC_y z użyciem cząstek ex situ Cr30Fe8C zawierających fazę węglikową Cr_xC_y w osnowie CrFe. Kompozyty odlewano grawitacyjnie w polu elektromagnetycznym. Celem badań była ocena wpływu zmiany częstotliwości prądu zasilającego wzbudnik pola elektromagnetycznego na segregację, liczbę i morfologię wydzieleń fazy wzmacniającej w aluminiowej osnowie kompozytu. Koncepcja technologiczna przeprowadzonych badań oparta została na założeniu, że chromowo-żelazowa osnowa wprowadzanych do ciekłego stopu aluminium cząstek ulegnie rozpuszczeniu, a pozostałe fazy węglikowe Cr_xC_y stanowić będą rzeczywiste wzmocnienie kompozytu, przy zmiennym udziale faz międzymetalicznych Al-CrFe występujących na granicy kontaktu komponentów. Na podstawie obserwacji mikrostruktur kompozytów dokonano ilościowej analizy segregacji, morfologii oraz udziału powierzchniowego fazy wzmacniającej w osnowie kompozytu.

Słowa kluczowe: kompozyt, segregacja, morfologia, pole elektromagnetyczne

INTRODUCTION

The present research was inspired by an analysis of the available literature [1-4] and the authors experiences [5-11].

An important question for the production of metal matrix composites is the way to obtain a homogeneous distribution of the reinforcing phase. Problems which are to be solved during the concept and manufacturing of composites reinforced with particles, are for example: the wettability of the particles, interaction between the different phases, effect of the particles on the solidification process of the composite and the selection of appropriate process parameters.

The approach in the present study was the use of forced convection in the melt to control the solidification process. For many years different devices have been used to generate the motion of molten metal. Firstly they are mechanical stirrers used in order to homogenise the molten metal. The positive impact of convection forced by an electromagnetic field on the solidification process and on the resulting cast structure led to a series of experimental studies in this area [12--18].

PURPOSE AND SCOPE OF RESEARCH

The aim of the present study is to determine the effect of changes in the frequency of the current power inductor on the gravitational segregation and morphology of the reinforcing phase in an aluminum matrix.

The concept is described in [5] and is based on the assumption that a chromium-iron matrix of CrFe30C8 particles dissolves and residual carbide phases will substantially strengthen the composite.

Scope of the research:
1. casting of aluminium composite samples
2. study of microstructure obtained in composite castings
3. determination of correlation between structure refinement and distribution of reinforcing phase and frequency of supply current.

METHODS OF INVESTIGATION

To perform the test castings, the aluminum alloy AlSi12Cu2Fe (Table 1) and CrFe30C8 particles (Table 2) were used.

The preparation of the particles included:
- Screening on a set of sieves. In the study particles 200 μm in size were used.
- Mixing of particles with a solution of surfactant at temperature of 80°C. Surfactant was an aqueous solution of boron and sodium oxides.
- Heat treatment at 380°C for 3 h.

To produce the AlSi/CrFeC composites, the experimental set up as schematically shown in Figure 1 was used.

A suspension containing 10% by weight of Cr30Fe8C particles was produced by using mechanical mixing. The electromagnetic field was generated by using a current of 10 A and a maximum of 65 mT magnetic induction. The frequency of the supply current (50, 75, 100 Hz) was adjusted by an inverter, to control the electromagnetic field rotation speed.

TABLE 1. **Chemical composition of AlSi12Cu2Fe used in investigation according to norm PN-EN 1706:2001**
TABELA 1. **Skład chemiczny stopu osnowy AlSi12Cu2Fe wg PN-EN 1706:2001**

EN AC - AlSi12Cu2Fe (AK132)	
Chemical composition	Element content in [%]
Si	12.42
Cu	2.01
Mg	0.18
Mn	0.16
Fe	0.89
Ti	0.04
Zn	0.42
Ni	0.05
Pb	0.05
Sn	0.02
Cr	0.01

TABLE 2. **Chemical composition of CrFe30C8 participles**
TABELA 2. **Skład chemiczny cząstek CrFe30C8**

	Chemical composition [%]					
	Cr	Fe	C	Si	P	S
CrFeC	61.07	30.16	7.88	0.85	0.02	0.02

The technological production parameters of the composite samples are shown in Table 3.

a) b)

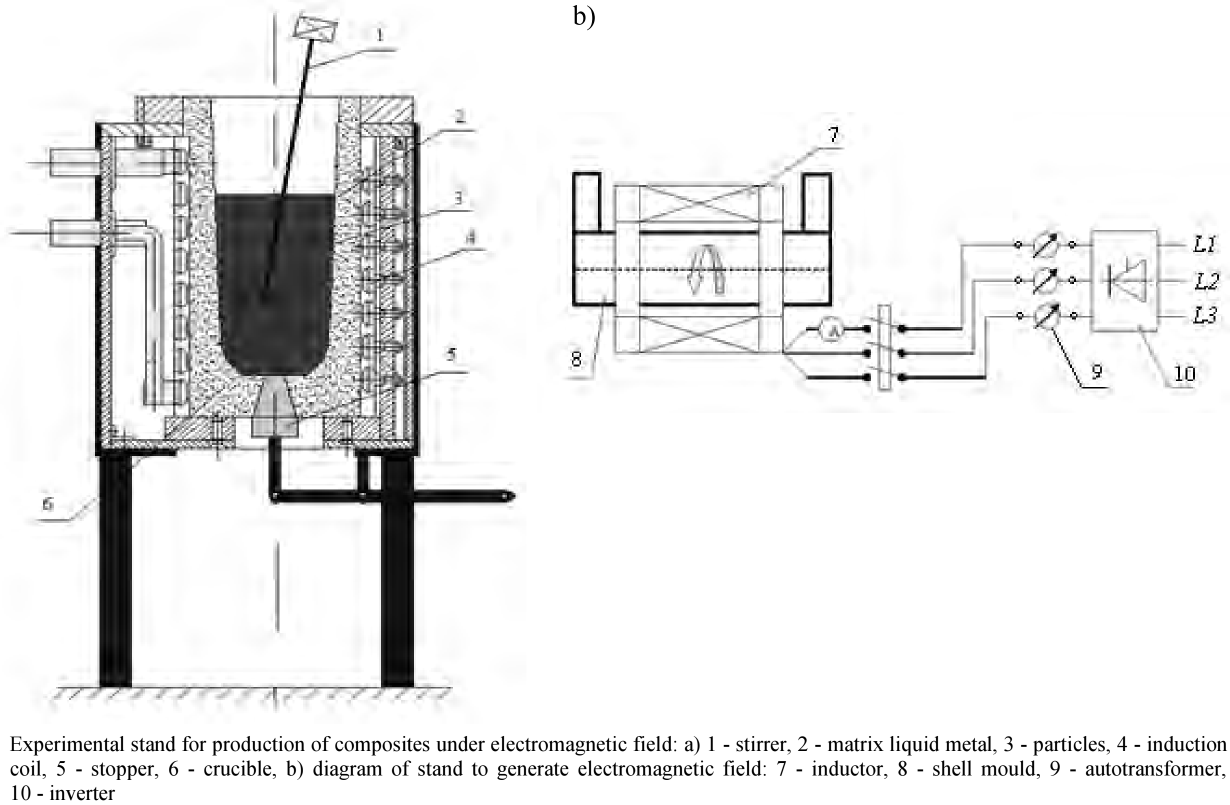

Fig. 1. Experimental stand for production of composites under electromagnetic field: a) 1 - stirrer, 2 - matrix liquid metal, 3 - particles, 4 - induction coil, 5 - stopper, 6 - crucible, b) diagram of stand to generate electromagnetic field: 7 - inductor, 8 - shell mould, 9 - autotransformer, 10 - inverter

Rys. 1. Stanowisko do wytwarzania kompozytów w polu elektromagnetycznym: a) 1 - mieszadło, 2 - ciekły metal osnowy, 3 - cząstki, 4 - cewka indukcyjna, 5 - zatyczka, 6 - tygiel, b) schemat urządzenia do wytwarzania pola elektromagnetycznego: 7 - induktor, 8 - forma, 9 - autotransformator, 10 - falownik

TABLE 3. **Production technological parameters of AlSi/CrFeC experimental composite casts**
TABELA 3. **Parametry technologiczne wytwarzania próbnych odlewów kompozytowych AlSi/CrFeC**

Cast number	Parameters supply and labor inducer					Other generation parameters			
	Frequency f [Hz]	Voltage U [V]	Current intensity I [A]	Power P* [kW]	Time of field influence t_p [s]	Pouring temp. T_z [°C]	Time stirring the particles in crucible t_m [s]	Angular velocity of field rotation ω [rad/s]	Maximum theoretical speed of movement of metal in the form V [m/s]
1	50	50	10	0,43	120	580	120	157.1	1.2
2	75	70		0,60				235.5	1.8
3	100	80		0,69				314.0	2.4
4	Without electromagnetic field.			-				-	-

* - factor of phase shift, cosφ = 0.86
p - number of pole pairs in inductor, p = 2

TEST RESULTS

The cast composite samples were metallographically examined. The morphology and distribution of the reinforcing phase in the metal matrix were analyzed. From each casting, 10 samples were cut with a thickness of about 1 cm thick, as shown in Figure 2b. On each metallographic specimen 13 symmetrical points were determined.

a) b)

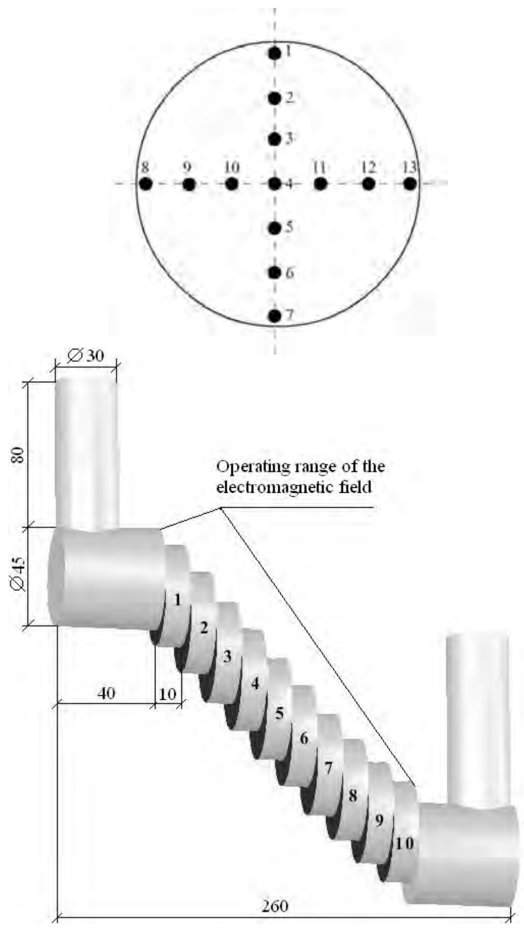

Fig. 2. Preparation method of samples for metallographic testing: a) measurement points on samples, b) method of sample excision used in tests (1÷10 sample number)

Rys. 2. Sposób przygotowania próbek do badań metalograficznych: a) punkty pomiarowe na próbce, b) sposób wycięcia próbek do badań (1÷10 nr próbki)

In Figure 3, the micrographs of specimens from the surface of the sections located in the axis of the composite castings are shown. The most preferred composite structure was obtained at a frequency of electromagnetic field of 75 Hz, (Fig. 3b). Large, gray reinforcing phases are relatively evenly distributed over the entire sample. Most of them have the characteristic shape of a hexagonal carbide phase. Some zones contain incompletely dissolved Cr30Fe8C particles. The composite structure made without the use of a electromagnetic field was totally different (Fig. 3d): due to lower diffusion, the new reinforcing phases were smaller, not fully developed and grouped in interdendritic spaces.

Using a computerized image analyzer, both the content and the distribution of the reinforcing phase in the matrix composite is determined. Quantitative analysis revealed differences in the volume fraction of the reinforcing phase changing along the horizontal axis of the casts. In Figure 4, the dependence on the volume fraction of the reinforcing phase along the longitudinal axis as a function of the frequency of the supply current is shown. The largest volume fraction of the strengthening phase is measured at a frequency of 75 Hz whereas the lowest fraction occurs in the sample made without the use of an electromagnetic field (0 Hz).

In Figure 5, the mean value fraction of the reinforcing phase for all the measurement areas as a function of the frequency of the supply current is shown. The largest share of the strengthening phase was obtained at a frequency of an electromagnetic field of 75 Hz (average 15%), whereas the lowest - in the sample made without the use of an electromagnetic field (average 2.76%). The distinct influence of the current frequency on the dimension of the surface of the strengthening phase was observed. Increasing the current frequency to above 75 Hz resulted in a decrease in the surface area of the reinforcing phase. The reason was a reduction of the transition zone phase at the expense of increasing the participation of Cr and Fe in the α solution in the aluminum matrix of the composite.

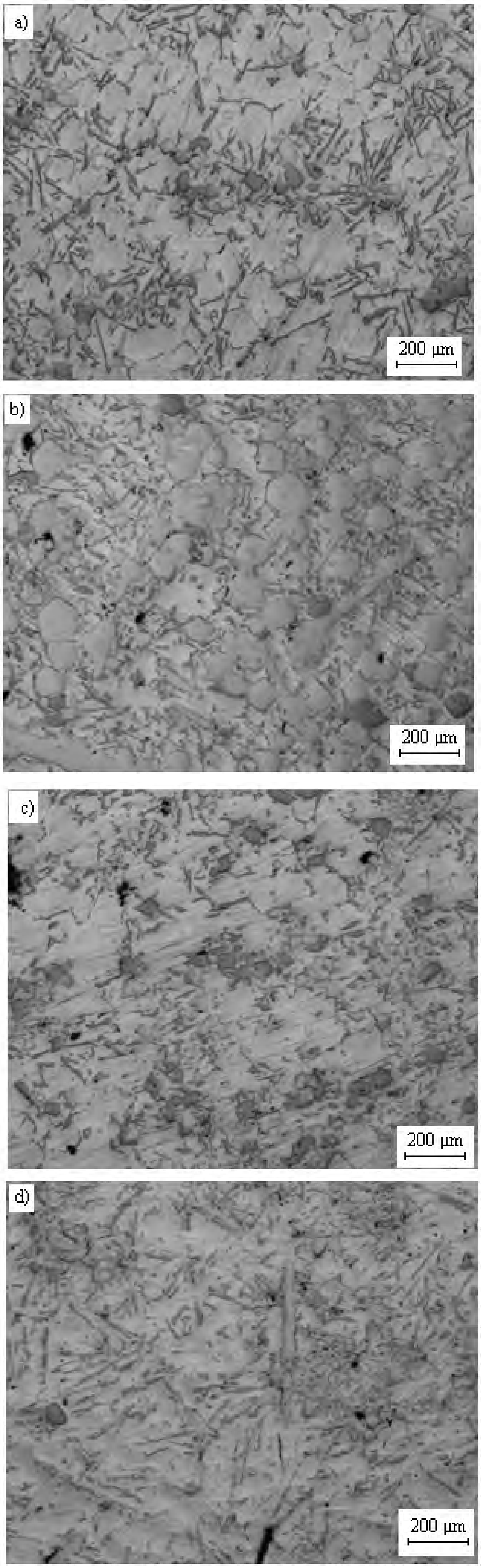

Fig. 3. Micrograph of central point in cast section for different current frequency: a) 50, b) 75, c) 100, d) without electromagnetic field

Rys. 3. Mikrografie centralnej części odlewów kompozytowych o różnej częstotliwości prądu: a) 50 Hz, b) 75 Hz, c) 100 Hz, d) bez pola elektromagnetycznego

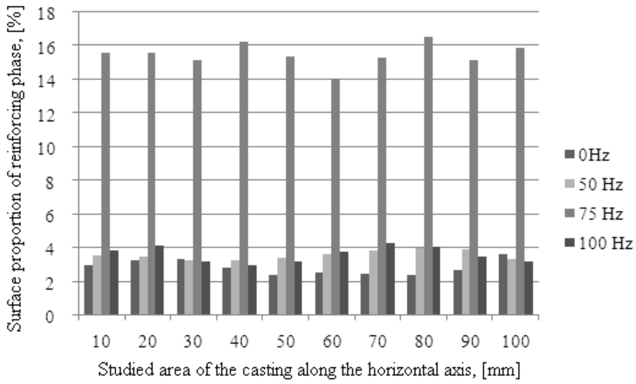

Fig. 4. Areal fraction of reinforcement phase along horizontal axis of casts for variable frequency electromagnetic field (0, 50, 75, 100 Hz)

Rys. 4. Udział powierzchniowy fazy wzmacniającej wzdłuż osi poziomej odlewów dla zmiennej częstotliwości pola elektromagnetycznego (0, 50, 75, 100 Hz)

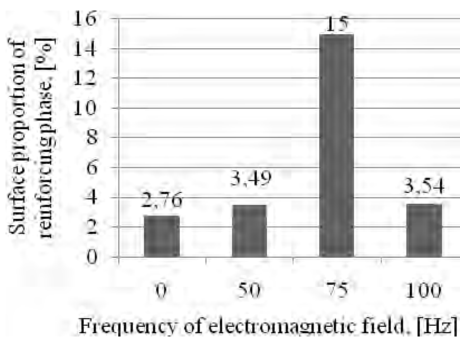

Fig. 5. Mean surface portion of reinforcement phase from all measurement areas on castings section for different frequency of current inductor supply

Rys. 5. Średni udział powierzchniowy fazy wzmacniającej z wszystkich obszarów pomiarowych na przekroju odlewów przy różnej częstotliwości prądu zasilającego induktor

The distribution of the surface strengthening phase along the vertical axis in the composites was determined. The gravitational segregation of the strengthening phase for measurement points (1 to 7) was analyzed. In Figures 6 and 7 the results of the analysis are shown.

In consequence, in the analysis of the volume fraction of the reinforcing phase, different characteristics of segregation are observed:

- In cast made without use of electromagnetic field, largest volume fraction of reinforcing phase in the lower area of samples is observed (gravitation effect).
- For 50 Hz, the largest volume fraction of reinforcing phase is observed in the middle of the casting (in horizontal axis - about 40000 μm^2) and smallest in outer layer.
- For 75 Hz, in all analyzed area, similar values were characterized (about 130000 μm^2).
- For 100 Hz, lowest surface portion was observed in horizontal axis of cast. Other regions were characterized by similar values.

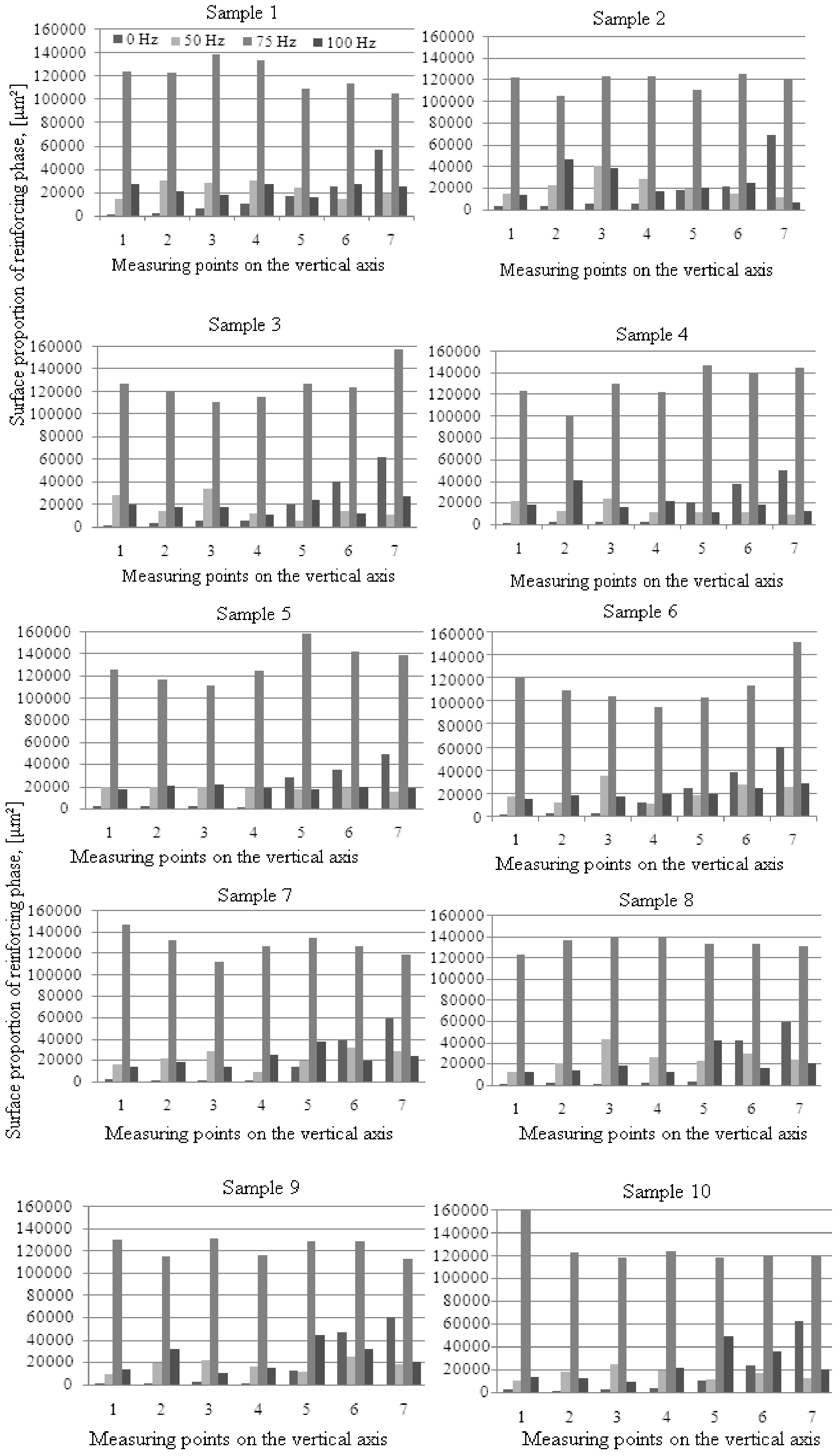

Fig. 6. Gravity segregation of reinforcement phase along height of cast (10 samples) equal to diameter of casting trial for different frequency inductor current

Rys. 6. Segregacja grawitacyjna wydzieleń fazy wzmacniającej wzdłuż wysokości odlewu (10 próbek) równej średnicy odlewu próbnego przy zmiennej częstotliwości prądu induktora

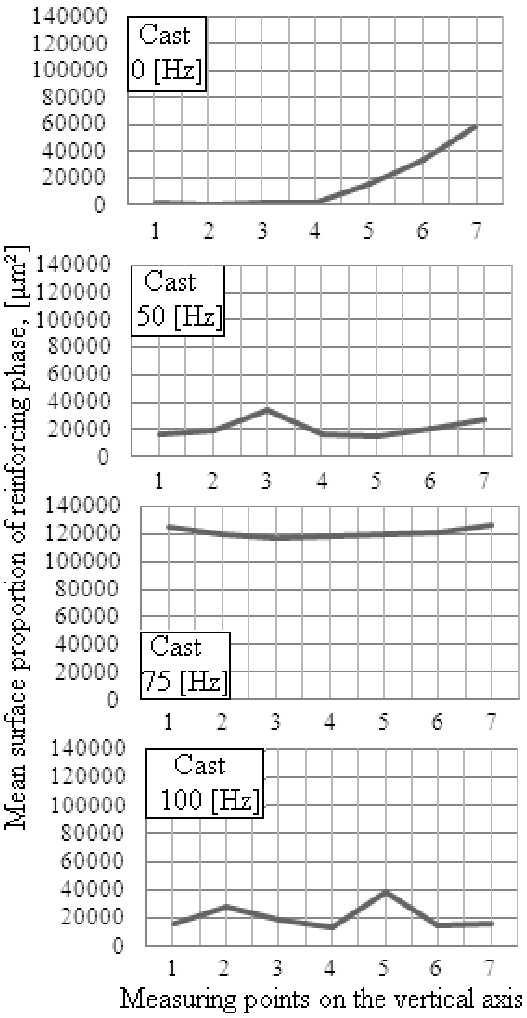

Fig. 7. Mean surface reinforcement phase along horizontal axis for trial composite casts

Rys. 7. Zestawienie średniej powierzchni wydzieleń fazy wzmacniającej wzdłuż osi poziomej próbnych odlewów kompozytowych

RESULTS

The most preferred composite structure and the largest volume fraction of the reinforcing phase was obtained at a frequency of electromagnetic field of 75 Hz.

Based on the analysis results, it was found that by choosing appropriate parameters of the electromagnetic field, the volume fraction of the transition reinforcing phase in the surroundings of the particles could be regulated. Already for a small rotation speed of electromagnetic field (157.1 rad/s), when the amount of motion between the components is small, the beginning of the diffusion phenomena of the chromium-iron matrix of CrFe30C8 particles into the aluminum matrix was noted. It resulted from the difference of concentrations at the contact boundary of the components. With an increased rotation speed caused by an increase in current frequency supplying the inductor to 75 Hz, a growth of transition phase precipitates (by about 12% higher than in other test castings) in the entire analyzed surface was observed. It could be the cause of such a segregation effect caused by angular acceleration. For these parameters of the electromagnetic field, a maximum increase of new phases was observed, which was the result of diffusion phenomena between the components. Further increasing the current frequency to 100 Hz again caused a decrease of volume fraction of the transition reinforcing phase in the surroundings of the particles. As a result of the diffusion phenomena of the chromium-iron matrix of the particles to the aluminum matrix, the reinforcing phase in the transition zone, which was created at a frequency of 75 Hz by increasing the speed rotation of the electromagnetic field to 100 Hz, underwent partial dissolution in the aluminum matrix. It resulted in a reduction of the volume of these phases. This also explains the lower uniformity in the distribution of the reinforcing phase obtained at 100 Hz compared to the effect obtained at 75 Hz.

As a result of these studies, the best parameters of the electromagnetic field due to the ability to control the diffusion and segregation phenomena in solidifying the AlSi12Cu2Fe/CrFe30C8 composite was isolated. It was found that the best ability to control the volume fraction of the transition reinforcing phase had casts made at a frequency of supply current inductor 75 Hz. The best speed rotation of electromagnetic field (235.5 rad/s) was determined, for which the best results of diffusion in the surroundings of the particles were obtained. The possibility to control the volume fraction and distribution of the reinforcing phase with use of an electromagnetic field was determined, which can be used for example in the control of the utility properties of wear-resistant materials with a high coefficient of friction such as brake discs.

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