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Influence of selected parameters of AlSi/CrFeC composite castings manufacturing on the resulted structure

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Materials

ABSTRACT

Purpose: The main aim of studies was to determine influence: size of reinforcing particles, frequency and the current intensity on the morphology of reinforcing phase precipitates in AlSi11/CrFe30C8 composites castings produced of rotating electromagnetic field.

Design/methodology/approach: In this paper the technology of AlSi11/Cr_xC_y composites produced with Cr30Fe8C ex situ particles is described. Technological conception of investigations was based on assumption that Cr-Fe matrix of particles dissolved in Al-Si composite matrix and carbide phases became actual reinforcement of the composite.

Findings: The results of investigations and their analysis shown, that contribution of these variables parameters essentially influence on the morphology of reinforcing phase. On the basis of analysis results determined the most effective technological parameters to produced composite casting.

Research limitations/implications: In the further research, authors of this paper are going to extend the scope of research about the another shape of the trial composite casting. Presented the technological process of composites producing created the possibility selection of different reinforcing particles depending on the technological and commercial properties.

Practical implications: Determined possibility to control of volume fraction and distribution of reinforcing phase with used of the electromagnetic field, it can be used for example in the control of utility properties wear-resistant materials with a high coefficient of friction such as brake discs.

Originality/value: The work presents the use of the electromagnetic field to shaping the structure and distribution of reinforcing phase in composite matrix. Within the range of this investigation created the new experimental stand to production of composites under electromagnetic field.

Keywords: Composites; Reinforcing phases; Structure; Electromagnetic field

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1. Introduction

The present research was inspired by an analysis of the available literature [1-13] and the authors experiences [14-15]. Fabrication and microstructure of the AlSi11 matrix composite containing 10% volume fraction of CrFe30C8 particles were presented in this paper.

At present materials engineering becomes more and more important branch of technical sciences and selection of suitable materials seems to be one of the most significant problems. As the consequence of a creative approach to those problems many new materials appear. High expectations posed nowadays constructive materials contribute to large increase the interest of composites.

Modern industry especially engineering and automotive looking for new materials about the much higher durability and better commercial properties than traditional construction materials. One of the directions of research are composites with the aluminum matrix (*AlMCs*) and reinforced by particles. In general, these materials exhibit good wear and erosion resistance, higher stiffness, hardness and strength, at a lower density when compared with the unreinforced material [1,2,8]. Particulates reinforced aluminum matrix composites are generally used on frictional couples working under technically dry fraction conditions [1,8].

Aluminum - based composites reinforced with particles of alien phases are considered products of the advanced technology. The distribution of particles, their size, shape and volume fraction together with metod production determinates the structure and properties of composites. The problems on soldification of castings are the last stage of composite suspension production. A description and understanding of the phenomena that accompany those processes allows the forming of a varied structure of the materials produced, which strictly determines the properties of the final product. The process of forming the structure during soldification of the composite cast is depending on many factors: size and volume fraction of the reinforcing phases as well as the kind and the properties of the using reinforcement [1,3]. The results of examination presented in this paper shown that forced movement of liquid suspension and influence of electromagnetic field during soldification process are also important.

Solidification of castings under electromagnetic field it is an interesting range of knowledge which became the object of interest for many authors [16-18]. Forced convection of liquid metal in the mould has a significant influence on the crystallization process of castings. Magnetic field strength affecting the liquid metal during crystallization process forming the phenomenon of mixing which is responsible for positive change occurring in the structure of the cast. For many years, the device whose main purpose is to generate movement of the liquid metal were used. The influence of electromagnetic fields in order to homogenization the structure has been successfully applied in the casting of aluminum materials [16,17] and composites [14,15]. This paper presents the possibility of influence of the electromagnetic field on the solidifying composite suspension to morphology and distribution of reinforcing phase in aluminum matrix. It is anticipated that this procedure will allow to obtain more favorable properties as compared to composites without forced convection at the time of its solidification.

2. Purpose and scope of researches

The aim of the present study is to determine the effect of changes: frequency of the current supplied to the inductor, the size of reinforcing particles and intensity of the current on the morphology of the reinforcing phase in aluminum matrix. The concept is based on the assumption that a chromium-iron matrix of CrFe30C8 particles dissolves in the AlSi matrix and residual carbide phases (mainly Cr_xC_y) will substantially strengthen the composite. The diffusion phenomena in the vicinity of particles entering depending on the variables parameters of composites production was analyzed.

Scope of the researches:

- preparation of CrFeC particles;
- formation the composite suspension;
- casting of the aluminum composite samples according to the plan of the Hartley experiment;
- study of the microstructure obtained in composite castings.

3. Methodology of the researches

To perform the test composite casts was used casting aluminum alloy AlSi11 (Table 1). Reinforcing phase was CrFe30C8 particles (Table 2) about 100, 200 and 315 μm granularity.

Table 1.
Chemical composition of AlSi11 used in investigation according to norm PN-EN 1706:2001

EN AC - AlSi11 (AK11)	
Chemical composition	Mass contents in [%]
Si	10.05
Cu	0.24
Mg	0.23
Mn	0.16
Ni	0.02
Fe	0.58
Zn	0.08
Ti+Zr	0.05
Inne	0.05

Table 2.
Chemical composition of CrFe30C8 participles

CrFe30C8	
Chemical composition	Mass contents in [%]
Cr	61.07
Fe	30.16
C	7.88
Si	0.85
P	0.02
S	0.02

The main factor taken into account during the selection of the chemical composition of aluminum matrix was minimum number of alloying elements affecting both the castability and the quantity of forming new phases in the structure of the casting.

High carbon ferrochromium particles characterized by, for example: high melting point (about 1630ºC), relatively good thermal conductivity (in 20ºC - about 22 W/mK), high hardness (about 30 HRC). However, their main advantage decisive for the choice of this study was the fact that these particles can easily succumb to diffusion phenomena on the matrix/reinforcement contact boundary. Based on this the concept of technological studies was defined.

In the study Hartley's plan to the experiment was used (Table 3). Three variable factors were selected:

- particles size Z (100, 200, 315 μm);
- intensity of the current I (5, 7.5, 10 A);
- frequency inductor supply current f (50; 75; 100 Hz).

The plan of the experiment implies the adoption of three levels of controlling factors X:

- the minimum (-);
- the central (0);
- the maximum (+),

and their normalization by the following relations:

$$\breve{X} = \frac{X-\bar{X}}{\Delta X} = \frac{2\alpha\cdot(X-\bar{X})}{X_{max}-X_{min}} \qquad (1)$$

$$\Delta X = \frac{X_{max}-X_{min}}{2\alpha} \qquad (2)$$

$$\bar{X} = \frac{X_{max}+X_{min}}{2} \qquad (3)$$

were:
X - the factor in real scale,
ΔX - step change of controlled factor,
$\breve{X}$ - the control factor for normalizing,
$\bar{X}$ - The central value of the factor in real scale,
α = 1 - for the plan based on the hypercube.

The central values for particles size Z, intensity of the current I and current frequency f were calculated, by the following relations:

$$\bar{X}Z = \frac{315[\mu m]+100[\mu m]}{2} = 207.5\ \mu m \qquad (4)$$

$$\bar{X}I = \frac{10[A]+5[A]}{2} = 7.5\ A \qquad (5)$$

$$\bar{X}f = \frac{100[Hz]+50[Hz]}{2} = 75\ Hz \qquad (6)$$

Variability units for particles size Z, intensity of the current I and current frequency f were calculated, by the following relations:

$$\bar{X}Z = \frac{315[\mu m]-100[\mu m]}{2\cdot 1} = 107.5\ \mu m \qquad (7)$$

$$\bar{X}I = \frac{10[A]-5[A]}{2\cdot 1} = 2.5\ A \qquad (8)$$

$$\bar{X}f = \frac{100[Hz]-50[Hz]}{2\cdot 1} = 25\ Hz \qquad (9)$$

Coding factors for particles size Z, intensity of the current I and current frequency f was done, by the following relations:

$$\breve{X}Z = \frac{X-207.5\,[\mu m]}{107.5\,[\mu m]} = x_1 \qquad (10)$$

$$\breve{X}I = \frac{X-7.5\,[A]}{2.5[A]} = x_2 \qquad (11)$$

$$\breve{X}f = \frac{X-75[Hz]}{25[Hz]} = x_3 \qquad (12)$$

The technological process production of trial composite castings were conducted in two stages. In the first stage the suspension containing 10% by weight of Cr30Fe8C particles was produced by using mechanical mixing. The mixing time was 90 s. Before the introduction of the molten metal matrix the particles were mixing with a solution of surfactant at temperature of 80ºC. Surfactant was an aqueous solution of boron and sodium oxides. In the second stage received composite suspension were cast to shell mould under electromagnetic field (Fig. 1). The time of field influence was 120 s. The electromagnetic field was generated by using a current of 5, 7.5, 10 A. The frequency of the supply current (50, 75, 100 Hz) was adjusted by an inverter, to control the electromagnetic field rotation speed.

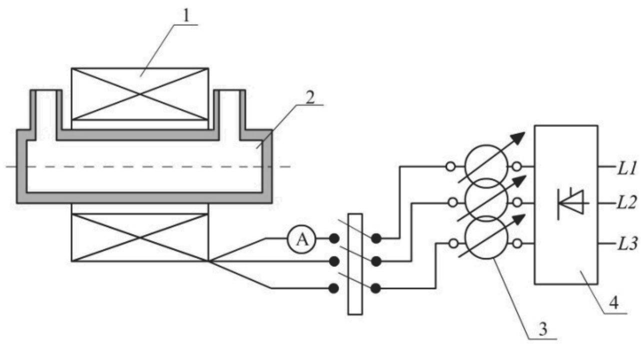


Fig. 1. Experimental stand for production of composites under electromagnetic field: 1 - inductor, 2 - shell mould, 3 - autotransformer, 4 - inverter

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 10 mm, as shown in Fig. 2. On each metallographic specimen 13 symmetrical points were determined. Darker faces were analyzed (Fig. 3).

Experiment planning matrix and the technological production parameters of the composite samples were shown in Table 3. The basic plan of the experiment included the performance of 11 experiments. Trial AlSi11/CrFe30C8 composite castings without influence of electromagnetic field also were produced.

Table 3.
Production technological parameters of AlSi/CrFeC experimental composite castings

Technological parameters production of experimental composite casts	Cast number according to the Harley's experiment design											Casts without elestromagnetic field		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Particles size, Z[μm]	100	100	315	315	100	315	200	200	200	200	200	100	200	315
Frequency, f [Hz]	100	50	50	100	75	75	75	75	50	100	75		-	
Voltage, U [V]	60	50	40	80	60	60	50	70	50	70	60		-	
Current intensity, I [A]	5	10	5	10	7.5	7.5	5	10	7.5	7.5	7.5		-	
Active power, P* [kW]	0.26	0.43	0.17	0.69	0.39	0.39	0.22	0.60	0.32	0.45	0.39		-	
The angular velocity of field rotation, ω[rad/s]	314.0	157.0	157.0	314.0	235.5	235.5	235.5	235.5	157.0	314.0	235.5		-	
The maximum theoretical speed of movement of metal in the form, V [m/s]	2.4	1.2	1.2	2.4	1.8	1.8	1.8	1.8	1.2	2.4	1.8		-	
The time of field influence, t_p[s]	120												-	
Matrix temperature during particles introducing, T_{cz}[°C]	680											680		
The time of components mixing in crucible, t_m [s]	90											90		
Pouring temp. T_z[°C]	580											580		

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

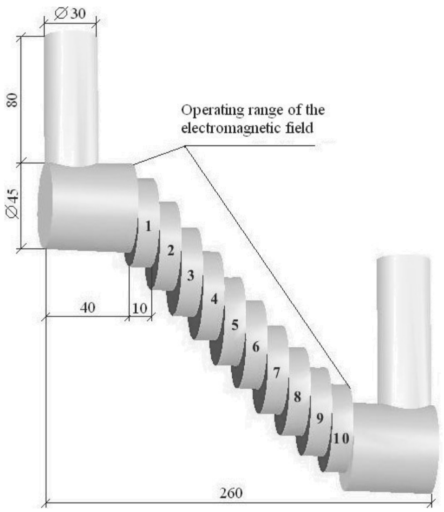


Fig. 2. Preparation method of samples for metallographic testing

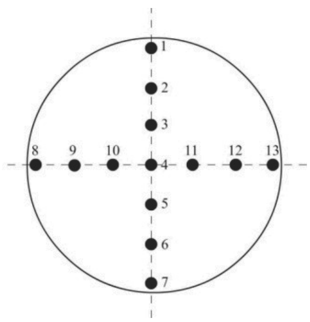


Fig. 3. Measurement points on composites samples

4. The results of researches

Using a computerized image analyzer NIKON Nis Elements, both the content and the distribution of the reinforcing phase in the matrix composite was determined. Quantitative analysis revealed differences in the volume fraction of the reinforcing phase changing along the axis of the casts. In the Figure 4 the mean values share surface reinforcing phase from all areas of measurement the cross section of obtained castings was shown. The smallest percentage of reinforcing phase was noted for casts performed without electromagnetic field (average of 1.74%). Whereas the largest for casts: 8 (200 μm, 75 Hz; 10 A - 11.38%), 7 (200 μm; 75 Hz; 5 A - 6.31%) and 11 (200 μm; 75 Hz; 7.5 A - 9.18%). Other casts were characterized by similar shares of surface of the reinforcement.

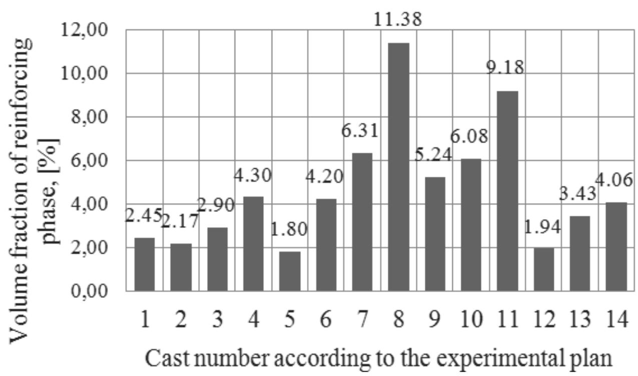


Fig. 4. Areal fraction of reinforcement phase in obtained composite castings

Clear effect of the electromagnetic field parameters on the surface of the reinforcing phase precipitates and their distribution in the matrix was observed. Increasing the current frequency above 75 Hz resulted in a decrease in surface area reinforcing phase. The reason for this was the reduction of transition zone phases at the expense of increasing the participation of Cr and Fe in the α solution in aluminum matrix of composite.

Using a computerized image analyzer mean values of stereological parameters in composite castings were defined (Table 4).

Table 4.
Mean values of stereological parameters in AlSi11/CrFe30C8 composite casts

Cast number	W/L [1/1]	P/S [1/μm]
1	0.45	0.01
2	0.41	0.02
3	0.49	0.03
4	0.59	0.02
5	0.44	0.03
6	0.40	0.02
7	0.33	0.02
8	0.24	0.01
9	0.39	0.02
10	0.38	0.02
11	0.29	0.02
12	0.42	0.04
13	0.42	0.03
14	0.40	0.06

By the aspect ratio W/L (width/length) surface development of reinforcing phase was determined (Fig. 5). The lower the value of this ratio defined more developed surface of reinforcing phase. Factor P/S (perimeter/surface) also was calculated.

The average factor P/S (perimeter/surface) achieved similar values for all castings (about 0.02 1/μm).

The lowest average value of the aspect ratio W/L (width/length) was achieved for casts:

- 8 (0.24 - 200 μm; 75Hz; 10A),
- 11 (0.29 - 200 μm; 75Hz; 7.5A),
- 7 (0.33 - 200 μm; 75Hz; 5A),
- 10 (0.38 - 200 μm; 100Hz; 7.5A),
- 9 (0.39 - 200 μm; 50Hz; 7.5A).

On the basis of the calculated stereological parameters confirmed that for casts with CrFe30C8 particles size 200 μm the highest average fraction surface transition phase was noted. Depending on the applied frequency *f* surface transition reinforcing phase had a different form in these castings, what is shown in the Figure 6.

In order to identify the phase composition in obtained materials point analysis (Fig. 7, Table 5) and analysis by X-ray on the diffractometer were realized. Phase identification to help with the PCSIWIN computer program by using databases in the form of files JCPDS - International Centre for Diffraction Data 2000 was performed. Sample results of X-ray analysis in Figure 8 was shown.

As a result of phase analysis revealed the presence of carbide phases mainly Cr_3C_2 in all received composite castings. The technological concept which was based on the assumption that a Cr-Fe matrix of particles dissolves in the Al-Si matrix and residual carbide phases (mainly Cr_xC_y) will substantially strengthen the composite was confirm in this study. Intensity of the various phases were similar for all tested samples.

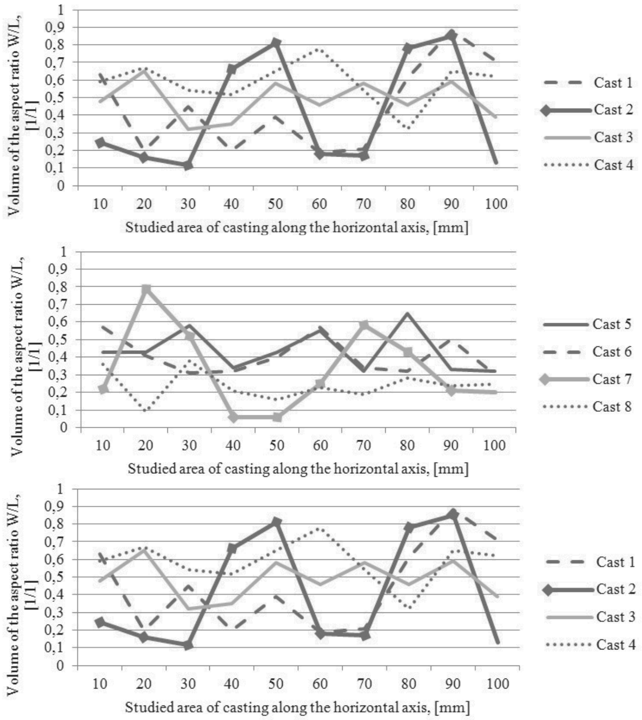
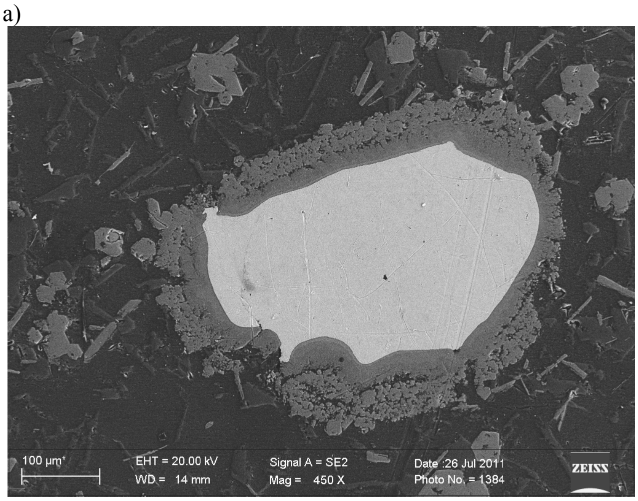


Fig. 5. The average value of the aspect ratio along the horizontal axis in AlSi11/CrFe30C8 composite castings produced under electromagnetic field

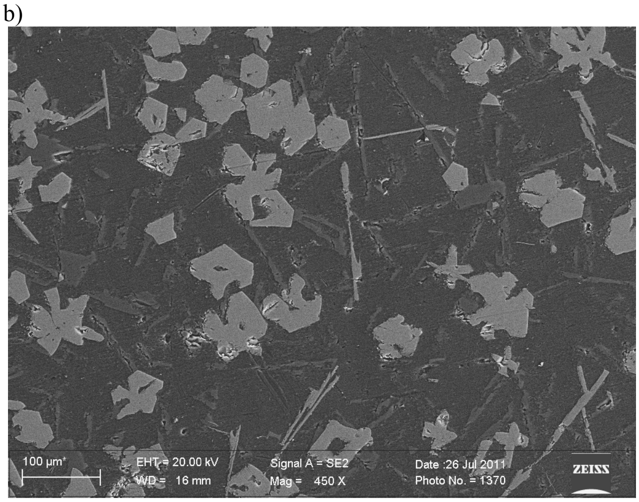
Table 5.
The analysis points in the received composite castings

Point number		Element content of weight and atomic, [%]				
		Al	Si	Cr	Fe	Mn
1	Wt%	100.00	-	-	-	-
	At %	100.00	-	-	-	-
2	Wt%	57.52	16.93	-	25.55	-
	At %	66.78	18.88	-	14.33	-
3	Wt%	-	100.00	-	-	-
	At %	-	100.00	-	-	-
4	Wt%	60.38	10.47	08.25	18.14	02.75
	At %	71.17	11.86	05.05	10.33	01.59
5	Wt%	02.10	97.90	-	-	-
	At %	02.19	97.81	-	-	-
6	Wt%	33.16	51.30	-	15.55	-
	At %	36.86	54.79	-	08.35	-
7	Wt%	62.24	09.73	06.86	21.18	-
	At %	72.90	10.94	04.17	11.98	-
8	Wt%	00.44	-	52.31	34.18	-
	At %	00.62	-	38.32	23.31	-
9	Wt%	-	01.38	26.65	64.00	-
	At %	-	02.07	21.62	48.33	-

a)



b)



c)

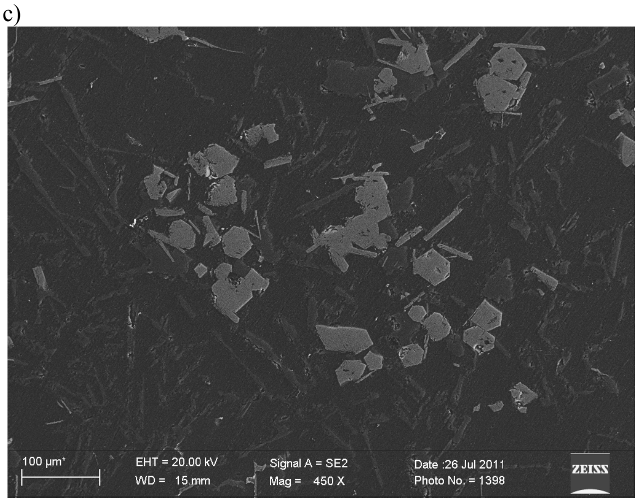


Fig. 6. Example of microstructure of AlSi11/CrFe30C8 composite samples with particles size of 200 [µm] for different frequency: a) 50 [Hz], b) 75 [Hz], c) 100 [Hz]

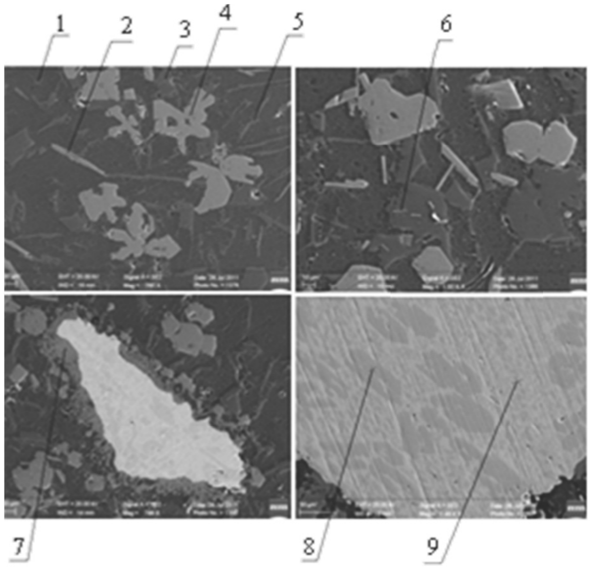


Fig. 7. Example of microstructures obtained AlSi11/CrFe30C8 composites with CrFe30C8 particles size 200 µm with specified characteristic points to the analysis

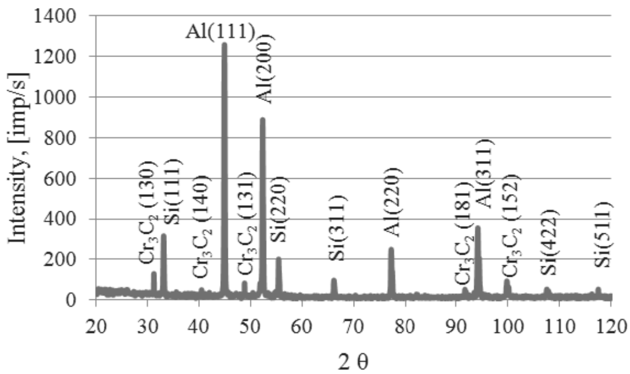


Fig. 8. The result of X-ray phase analysis of the AlSi11/CrFe30C8 composite castings

5. Conclusions

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 AlSi11/CrFe30C8 composite was isolated.

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 with the size of 200 µm 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 6% 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.

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 and particle size of 200 μm. 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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