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The Influence of the Forced Movement of Components on the Structure in Fabricated AlSi/Cr_xC_y Composite Castings

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Abstract

Fabrication and microstructure of the AlSi11 matrix composite containing 10 % volume fraction of CrFe30C8 particles were presented in this paper. Composite suspension was manufactured by using mechanical stirring. During stirring process the temperature of liquid metal, time of mixing and rotational speed of mixer were fixed. After stirring process composite suspension was gravity cast into shell mould. The composites were cast, applying simultaneously an electromagnetic field. The aim of the present study was to determine the effect of changes in the frequency of the current power inductor on the morphology of the reinforcing phase in the aluminum matrix. The concept is based on the assumption that a chromium-iron matrix of CrFe30C8 particles dissolves and residual carbide phases will substantially strengthen the composite. The microstructure and interface structure of the AlSi11/CrFe30C8 composite has been studied by optical microscopy, scanning microscopy and X-ray diffraction.

Keywords: Diffusion, Composites, Reinforcing phase

1. Introduction

During the last two decades a lot of research has focused on aluminum metal matrix composites (*Al MMCs*). A wide variety of fabrication techniques has been explored for Al *MMCs*, which include vapour state methods, liquid phase methods (infiltration of preforms, rheocasting/thixoforming, melt stirring and squeeze casting) and solid state methods (powder forming and diffusion bonding) [2][4]. Recently, the preponderance of research studies on *Al MMCs* has been aimed at developing particle reinforced aluminum matrix composites (*PR-AlMCs*), based on liquid methods, because they can be used to produce components by casting processes. The fabrication of *PR-AlMCs* using casting techniques is particularly attractive because it permits a low-cost and net-shape fabrication, adaptability of casting processes to existing production practices and flexibility in designing the structure through controlled solidification. However, it has some restrictions due to the matrix alloy and density of the reinforced phases. Therefore the volume fraction and the size of the reinforcements that can be added are very limited [1-8].

MMCs containing hard or/and ceramic particles offer superior operating performance. Al based discontinuous reinforced *MMCs* are of great scientific and technological interest and have received much attention in recent years because of their good mechanical and thermal properties. *PR-AlMCs* potential applications come mainly from established automotive, aerospace and high performance sectors (production of engine parts, brake components, transmission beams and, stiffeners and sporting equipment), because of the high stiffness, strength and wear resistance that these materials have [1-10].

Interface is a very general term used in various fields of science and technology to denote the location where two entities meet. The interface in composites refers to a bounding surface between the reinforcement and matrix across which there is a discontinuity in chemical composition, elastic modulus, coefficient of thermal expansion, and/or thermodynamic properties such as chemical potential. The interface (particle/matrix) is very important in all kinds of composites. This is because in most composites, the interfacial area per unit volume is very large. Also, in most metal matrix composite systems, the reinforcement and the matrix will not be in thermodynamic equilibrium, i.e., a thermodynamic driving force will be present for an interfacial reaction that will reduce the energy of the system. All these items make the interface have a very important influence on the properties of the composite. Interfacial characteristics in metal matrix composites reinforced play a significant role in determining the mechanical properties, such as strength, ductility, toughness, fatigue, etc. To achieve superior mechanical properties in *MMCs*, it is essential to form adequate interfaces, which not only do not degrade the reinforcement during fabrication, but also retain the structural stability [7-8].

The present research was inspired by an analysis of the available literature [1-8] and the authors experiences [9-10].

The aim of the study was to determine the effect of changes in frequency of the current power inductor on the form the transitional phase in the contact boundary of matrix/reinforcement in produced composites.

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

2. Experimental procedures

Composition of the reinforcement and the matrix used in the present study are shown in Tables 1 and 2, respectively.

Table 1.
Chemical composition of CrFe30C8 participles

	Chemical composition, [%]					
	Cr	**Fe**	**C**	**Si**	**P**	**S**
CrFe30C8	61,07	30.16	7,88	0,85	0,02	0,02

Reinforcement used in this study were CrFe30C8 having an average particle size 200 [µm]. Particle surfaces before the introduction of the molten matrix sodium and boron compounds were prepared. CrFeC particles were annealed at 360 [ºC] for 3h directly before introduction into the crucible.

The composite samples were prepared in two stages. In the first stage composite suspension about 10% particle mass participation by mechanical mixing in crucible was produced (Fig. 2). The mixing time was 90 [s]. In the second stage received composite suspension to shell mould under electromagnetic field were casted. Moulds from operating outside, rotating electromagnetic field was performed (Fig. 1). The time of field influence was 120 [s]. By inverter the frequency adjusted (50, 75, 100 Hz), what caused regulation of electromagnetic field rotation speed.

Table 2.
Chemical composition of AlSi11 used to investigation according to norm PN-EN 1706:2001

EN AC - AlSi11 (AK11)	
Chemical composition	Element content 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

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

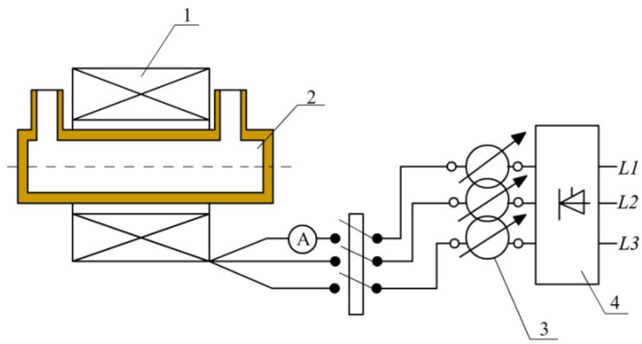


Fig. 1. Diagram of stand to generation of electromagnetic field: 1 – inductor, 2 – shell mould, 3 – autotransformer, 4 - inverter

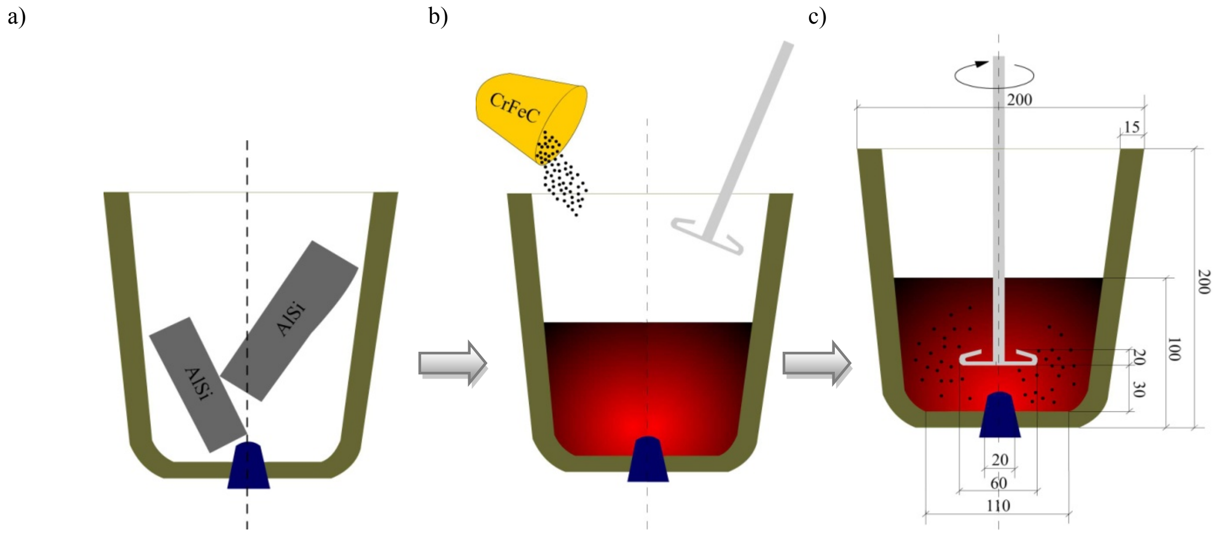


Fig. 2. Experimental stand for production of composites suspension: a) melting of metal matrix, b) addition of CrFe30C8 particles, c) mixing the components

Table 3.
Technological parameters production of AlSi11/CrFe30C8 experimental composite casts

Cast number	Parameters supply and labor inducer					Other parameters generation			
	Frequency f [Hz]	Voltage U [V]	Current intensity I [A]	Power P* [kW]	The time of field influence t_p [s]	Pouring temp. T_z [°C]	The time mixing particles in crucible t_m [s]	The angular velocity of field rotation ω [rad/s]	The maximum theoretical speed of movement of metal in the mould V [m/s]
1	50	50		0,43				157,1	1,2
2	75	70		0,60				235,5	1,8
3	100	80	10	0,69	120	580	90	314,0	2,4
4	Without electromagnetic field.			-				-	-

** - factor of phase shift, cosφ = 0,86*
p – number of pole pairs in the inductor, p=2

3. Results and discussion

To analyze the morphology of the CrFe30C8 particles (Fig. 3) the confocal laser scanning microscope (CLSM 5 Exciter by Zeiss) with emitting 405 [nm] wavelength was used. Results of analysis in Table 4 were shown. In the Figure 4 sample particles tested were shown.

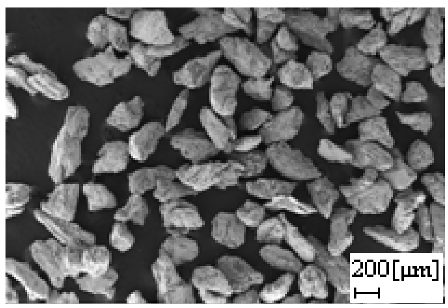


Fig. 3. Particles CrFe30C8 used in tests with size 200 [μm]

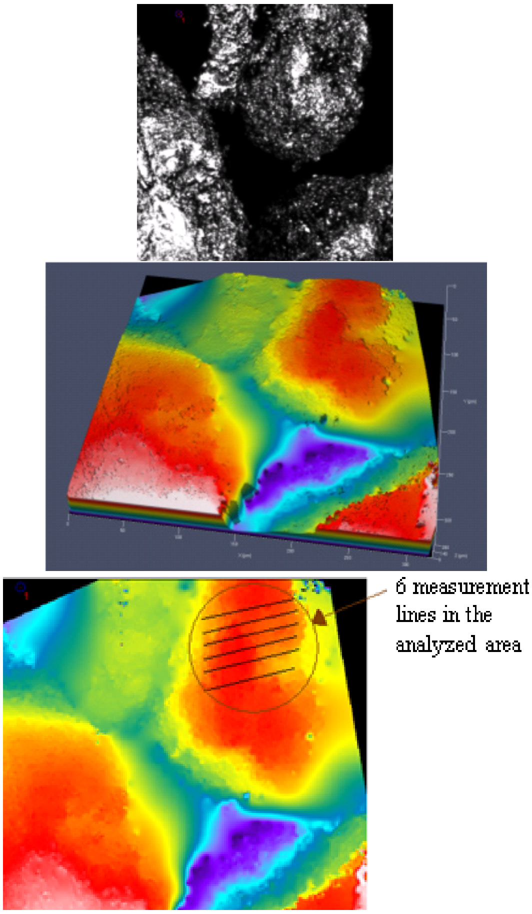


Fig. 4. Analysis of the CrFe30C8 particle surface with the size 200 [μm]

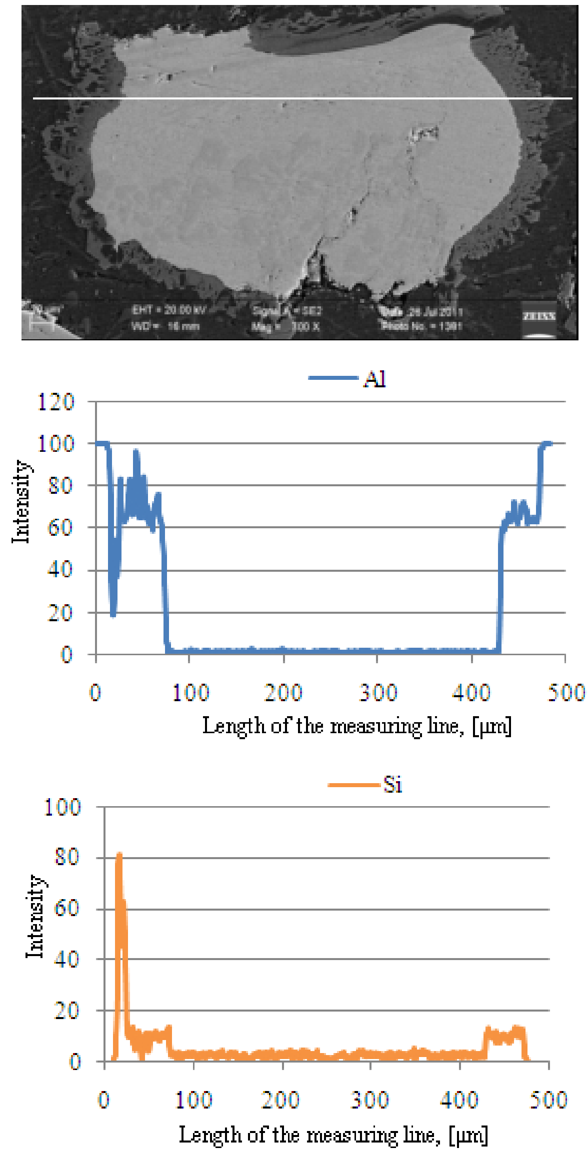
Table 4.
The results of the development area of CrFe30C8 particles

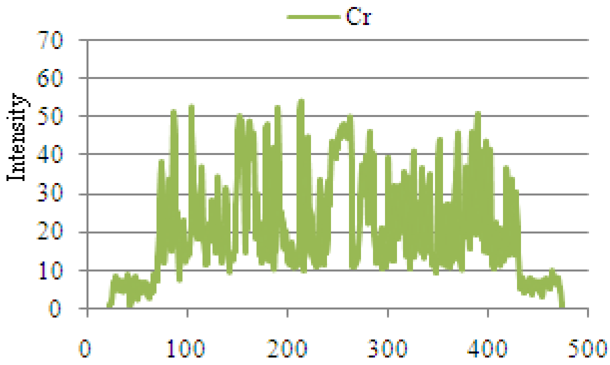
Line number	The calculated parameter, [μm]				
	The average height	Min height	Max height	The height difference	The standard deviation
1	346,81	290,10	364,63	74,53	18,15
2	335,91	285,82	389,73	103,91	17,22
3	319,73	266,61	358,96	87,64	21,23
4	311,24	252,61	358,96	106,35	22,56
5	352,77	267,70	371,07	103,37	21,79
6	369,59	339,42	374,98	35,56	6,41
The mean values	**339,34**	**252,61**	**389,73**	**85,23**	**6,01**

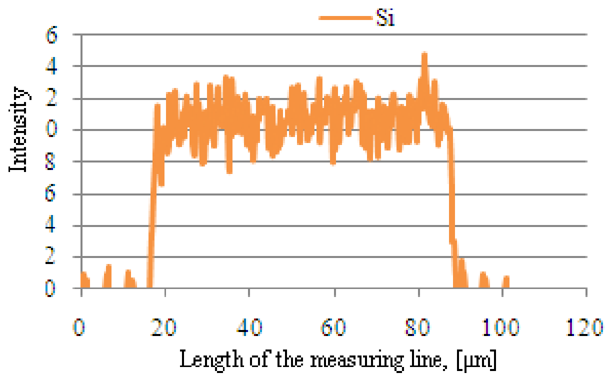
The results of measurements of particle surface development showed that the particles had extensive area of development (average 85,23 [μm]). This had a significant impact on the diffusion phenomena in the AlSi11/CrFe30C8 obtained composites.

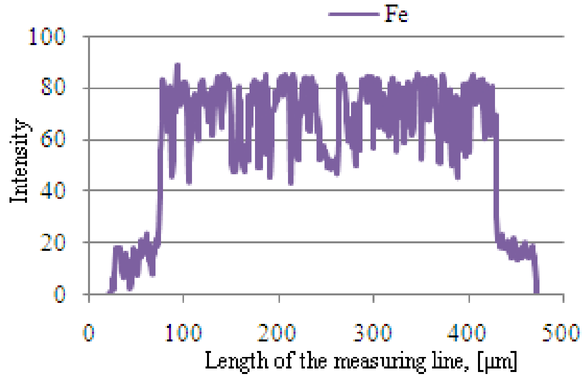
Depending on the maximum theoretical speed of movement of metal in the mould *V* 1,2; 1,8; 2,4 [m/s] obtained for frequency *f* 50, 75, 100 [Hz] adequately surface transition reinforcing phase had a different form in AlSi11/CrFe30C8 composite castings, what is shown in the Figure 5. Obtained composite samples examination of the microstructure by the DSM 940 by OPTON scanning electron microscope equipped with X-ray microanalyzer were performed. Point and linear analysis were executed (Fig. 5, 6, Table 5).

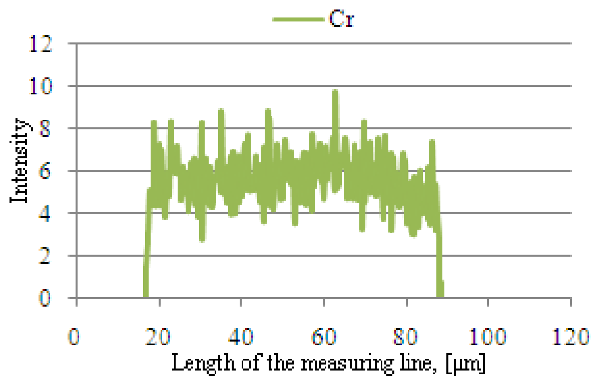
a)



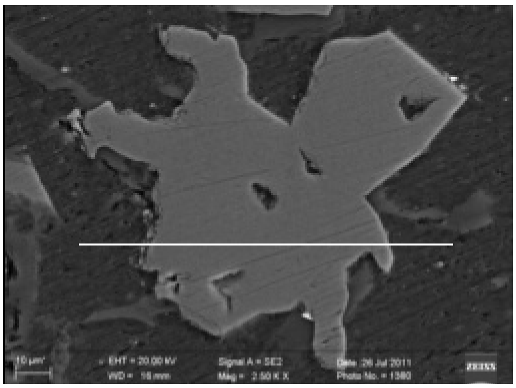

Cr
Intensity
70
60
50
40
30
20
10
0
0
100
200
300
400
500

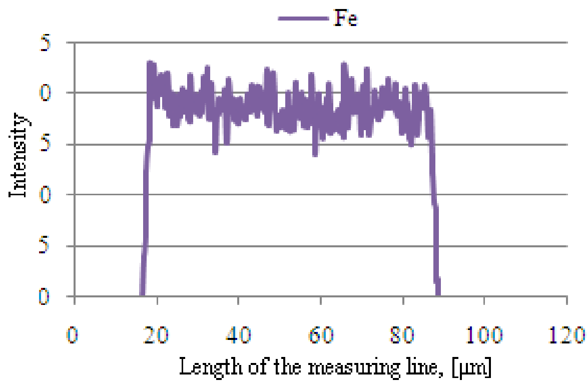

Si
Intensity
Length of the measuring line, [µm]
0
20
40
60
80
100
120

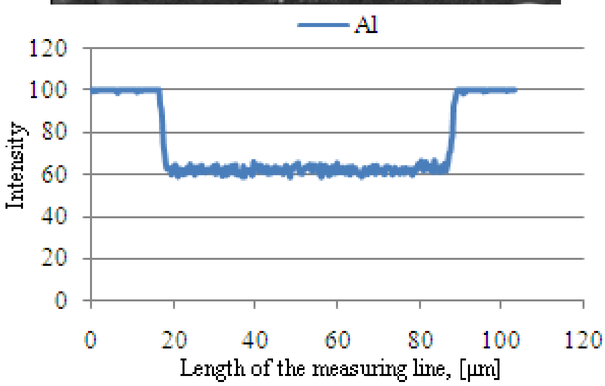

Fe
Intensity
100
80
60
40
20
0
0
100
200
300
400
500
Length of the measuring line, [µm]


Cr
Intensity
12
10
8
6
4
2
0
0
20
40
60
80
100
120
Length of the measuring line, [µm]

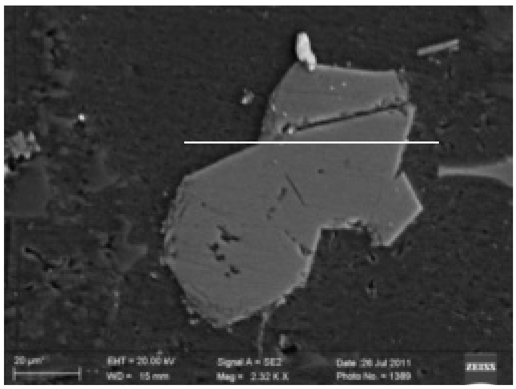
b)




Fe
Intensity
Length of the measuring line, [µm]
0
20
40
60
80
100
120


Al
Intensity
120
100
80
60
40
20
0
0
20
40
60
80
100
120
Length of the measuring line, [µm]

c)



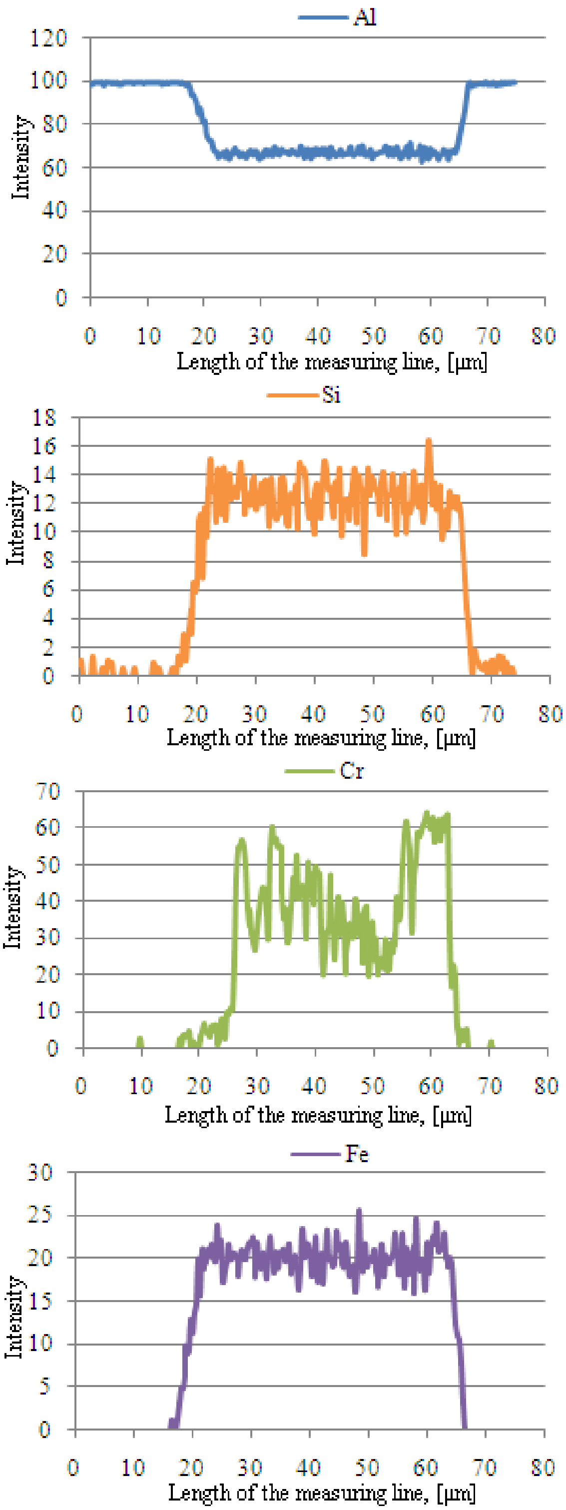


Fig. 5. Line analysis along the characteristic separation of reinforcing phase in AlSi11/CrFe30C8 composites for different frequency: a) 50 [Hz], b) 75 [Hz], c) 100 [Hz]

In the Figure 5 characteristic phases in obtained composite castings produced under electromagnetic field were presented. The most favourable structure of the composite were obtained for cast where used the frequency f 75 [Hz], what was shown in the Figure 5b. Transitional phases separation were relatively large uniformly distributed over the entire surface and were multifaceted. In the structure of the composite executed for the frequency f 50 [Hz] when the traffic intensity between the components is small beginning of the diffusion phenomena was observed, what was shown in the Figure 5a. Increasing the frequency of the current above 75 [Hz] resulted in change in the shape and size of the transitional phase precipitates. Most had the hexagonal shape typical of the carbide phase but newly formed phases were smaller and their distribution in the matrix of the composite was less uniform.

In order to identify the phase composition obtained materials point analysis (Fig. 6, 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 7 was shown.

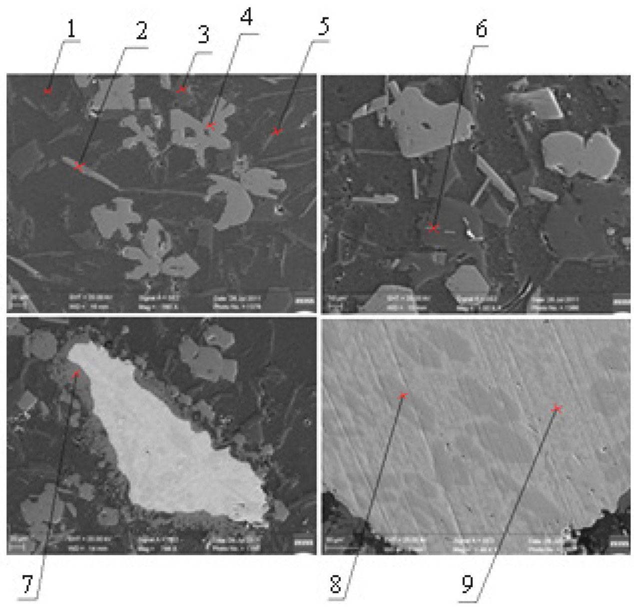


Fig. 6. Example of microstructures obtained AlSi11/CrFe30C8 composites with CrFe30C8 particles size 200 [µm] with specified characteristic points to the analysis

Table 5.
The analysis points in the received AlSi11/CrFe30C8 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	-

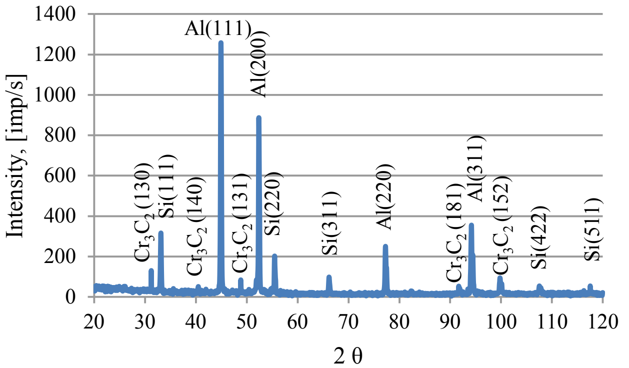


Fig. 7. The result of X-ray phase analysis of the AlSi11/CrFe30C8 composite castings

As a result of phase analysis revealed the presence of carbide phases mainly Cr_3C_2 in all received composite castings. Intensity of the various phases were similar for all tested samples.

As the complementary test microhardness measurements on the Microhardness tester FM – 700 was performed. In the Table 6 the results of microhardness tests were shown. In the Figure 8 the characteristic tested phases were shown.

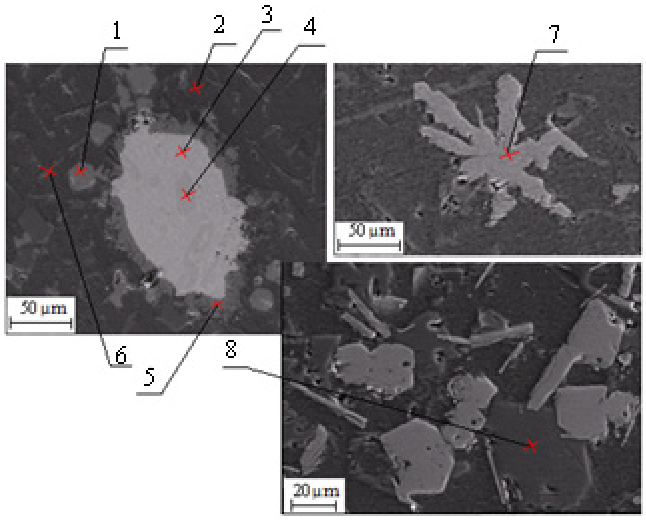


Fig. 8. Example of microstructures obtained AlSi11/CrFe30C8 composites with specified characteristic points to the microhardness tests

Table 6.
The results of microhardness tests in obtained composite castings

Measurement point number	Cast number			
	1 *f* 50[Hz]	2 *f* 75[Hz]	3 *f* 100[Hz]	4 without electrom. field
	[µHV]			
1	1456	2670	2150	1189
	1679	2534	2560	1208
	1590	2789	1985	1300
2	121	134	120	89
	127	130	117	90
	124	122	123	92
3	1346	1820	1350	1134
	1570	1790	1540	1190
	1413	1790	1250	1094
4	1300	1340	1342	1120
	1187	1379	1309	1278
	1299	1349	1314	1280
5	1550	2034	1800	-
	1890	2769	2150	
	1378	2490	2300	
6	1547	1680	1709	1480
	1600	1590	1689	1500
	1609	1698	1603	1324
7	2700	2912	2603	-
	2856	2894	2189	
	2802	2971	2307	
8	1005	1240	994	1145
	1120	1090	1050	1009
	1003	1145	1014	992

On the basis of the analysis of the results of microhardness tests determined that for cast produced under electromagnetic field with frequency *f* 75 [Hz] the largest values of reinforcing phases (average 1356 [μHV]) and phase of the transition zone (average 2431 [μHV]) were achieved. For composite casting produced without electromagnetic field newly formed phases transitions (measurement points 5 and 7) were not observed which could be due to less diffusion resulted from the smaller mutual movement between the components.

4. Conclusions

Based on the analysis results, it was found that by choosing suitable the relative velocity of components, the shape of the transition reinforcing phase in the surroundings of the CrFe30C8 particles could be regulated. Already for the small relative velocity of components (1,2 [m/s]) with 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 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 and the relative velocity of components 1,8 [m/s] a maximum increase of new phases was observed, which was the result of diffusion phenomena between the components. Separation of the transition phase have a very extensive form (multiform). Further increasing the current frequency to 100 [Hz] again caused a decrease 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 and changed in the shape of the transition phase precipitates.

Acknowledgements

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