

# 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-AMCs*), based on liquid methods, because they can be used to produce components by casting processes. The fabrication of *PR-AMCs* 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-AMCs* 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 of 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 particles

|                 | Chemical composition, [%] |       |      |      |      |      |
|-----------------|---------------------------|-------|------|------|------|------|
|                 | Cr                        | Fe    | C    | Si   | P    | S    |
| <b>CrFe30C8</b> | 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 [°C] 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<br>(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.

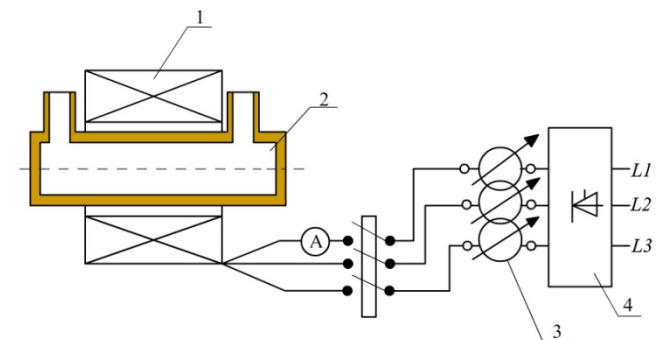


Fig. 1. Diagram of stand to generation of electromagnetic field:  
1 – inductor, 2 – shell mould, 3 – autotransformer, 4 - inverter

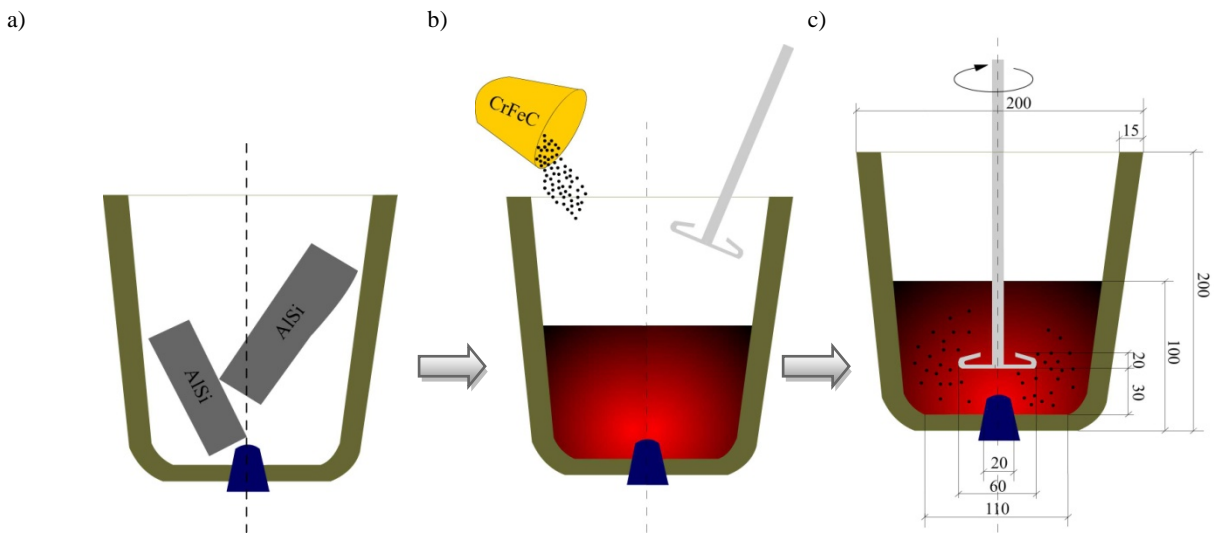


Fig. 2. Experimental stand for production of composites suspension: a) melting of metal matrix, b) addition of CrFe30C8 particles, c) mixing the components

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 $\omega$ [rad/s] | The maximum theoretical speed of movement of metal in the mould $V$ [m/s] |
| 1           | 50                                  | 50              | 10                        | 0,43             | 120                                   | 580                         | 90  | 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,  $\cos\varphi = 0,86$

$p$  - 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.

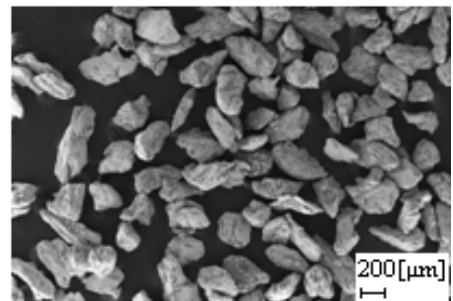


Fig. 3. Particles CrFe30C8 used in tests with size 200 [μm]

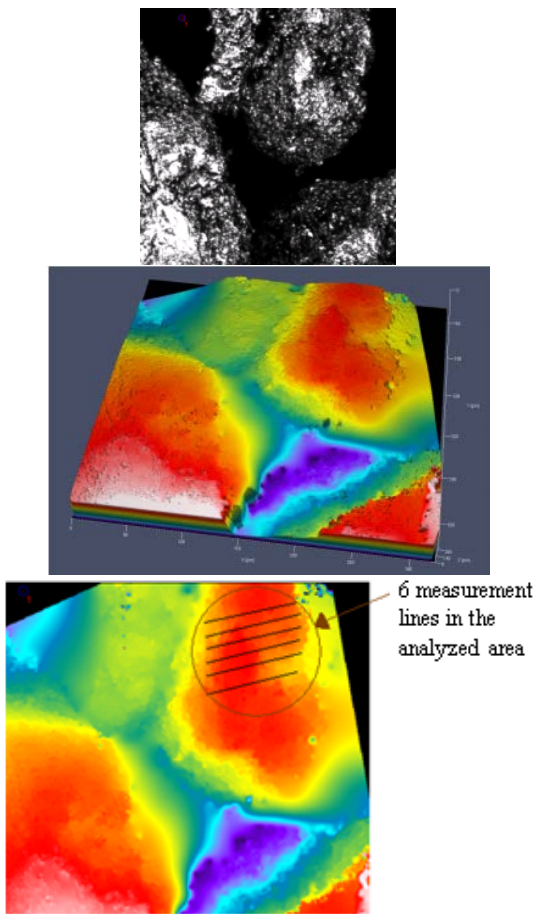


Fig. 4. Analysis of the CrFe30C8 particle surface with the size 200 [μm]

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

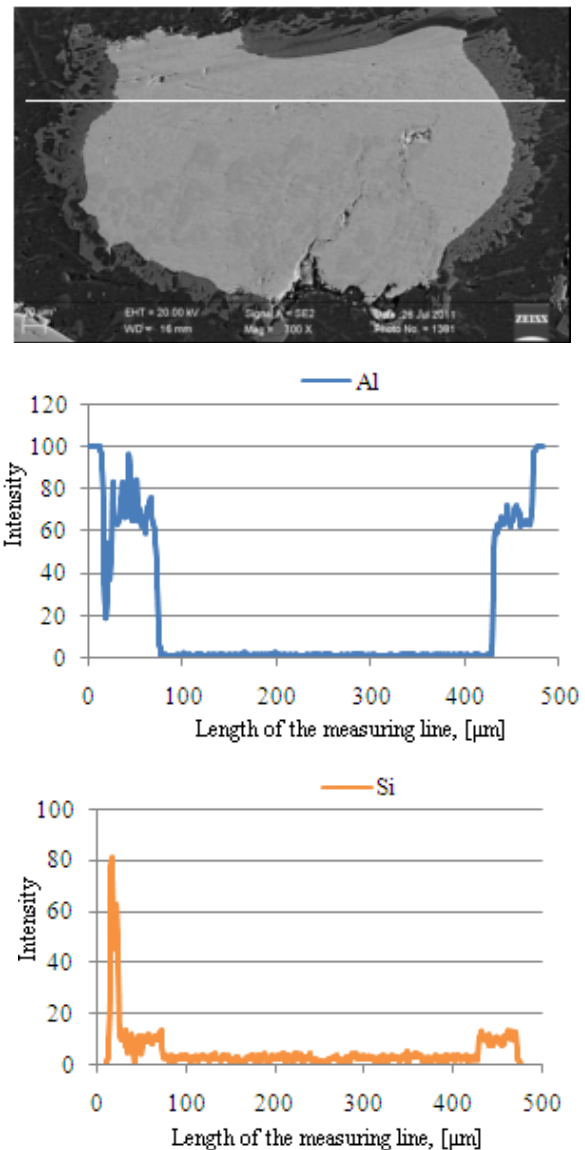
| Line number            | The calculated parameter, [μm] |               |               |                       |                        |
|------------------------|--------------------------------|---------------|---------------|-----------------------|------------------------|
|                        | 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                   |
| <b>The mean values</b> | <b>339,34</b>                  | <b>252,61</b> | <b>389,73</b> | <b>85,23</b>          | <b>6,01</b>            |

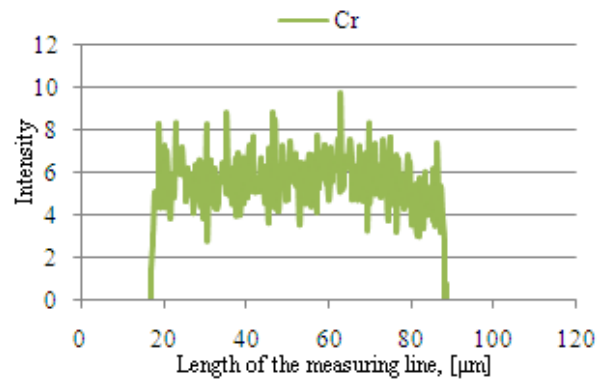
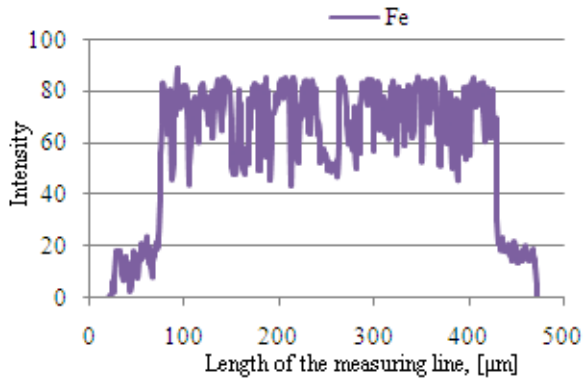
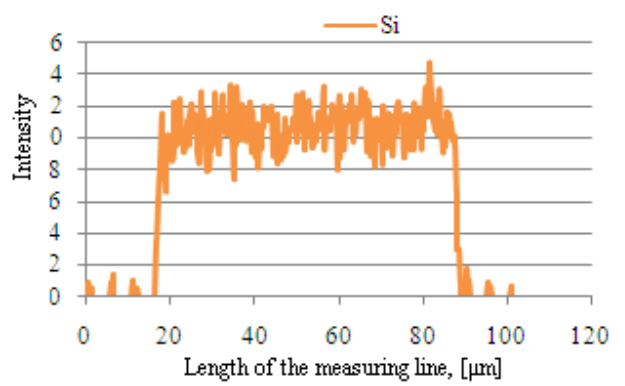
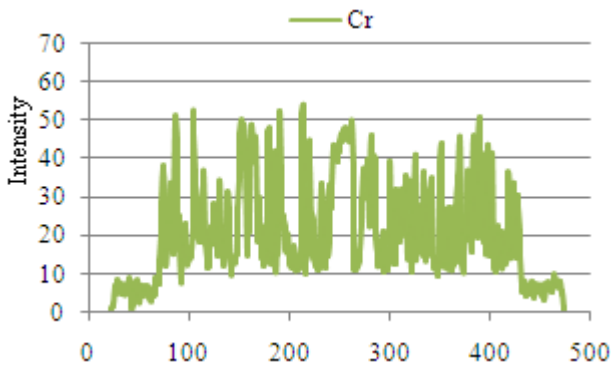
The results of measurements of particle surface development showed that the particles had extensive area of development (average 85,23 [μm]). This had a significant impact on the

diffusion phenomena in the AlSi11/CrFe30C8 obtained composites.

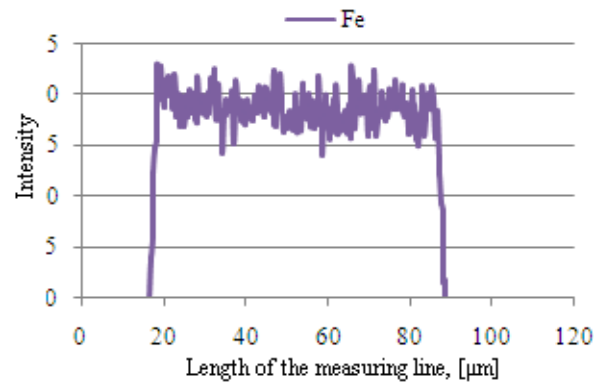
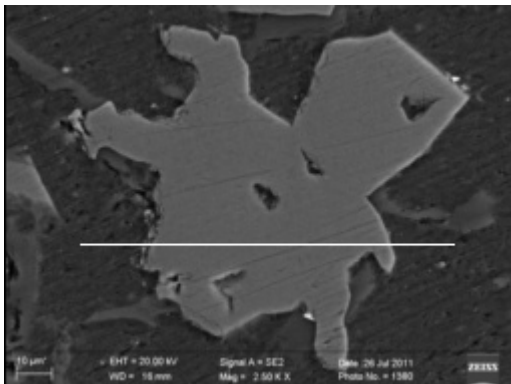
Depending on the maximum theoretical speed of movement of metal in the mould  $V$  1,2; 1,8; 2,4 [m/s] obtained for frequency  $f$  50, 75, 100 [Hz] adequately surface transition reinforcing phase had a different form in AlSi11/CrFe30C8 composite castings, what is shown in the Figure 5. Obtained composite 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)

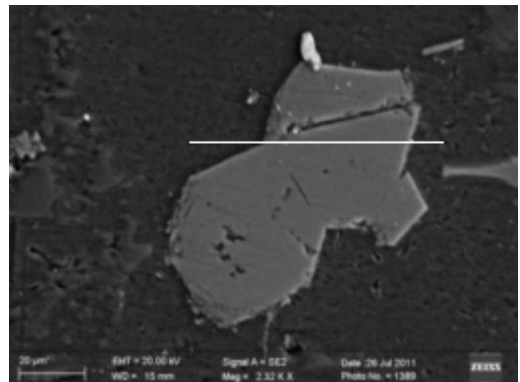
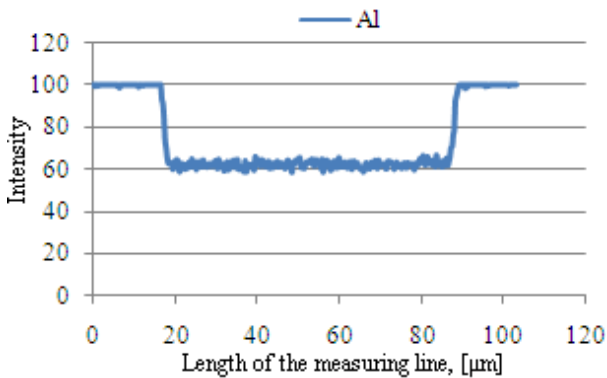




b)



c)



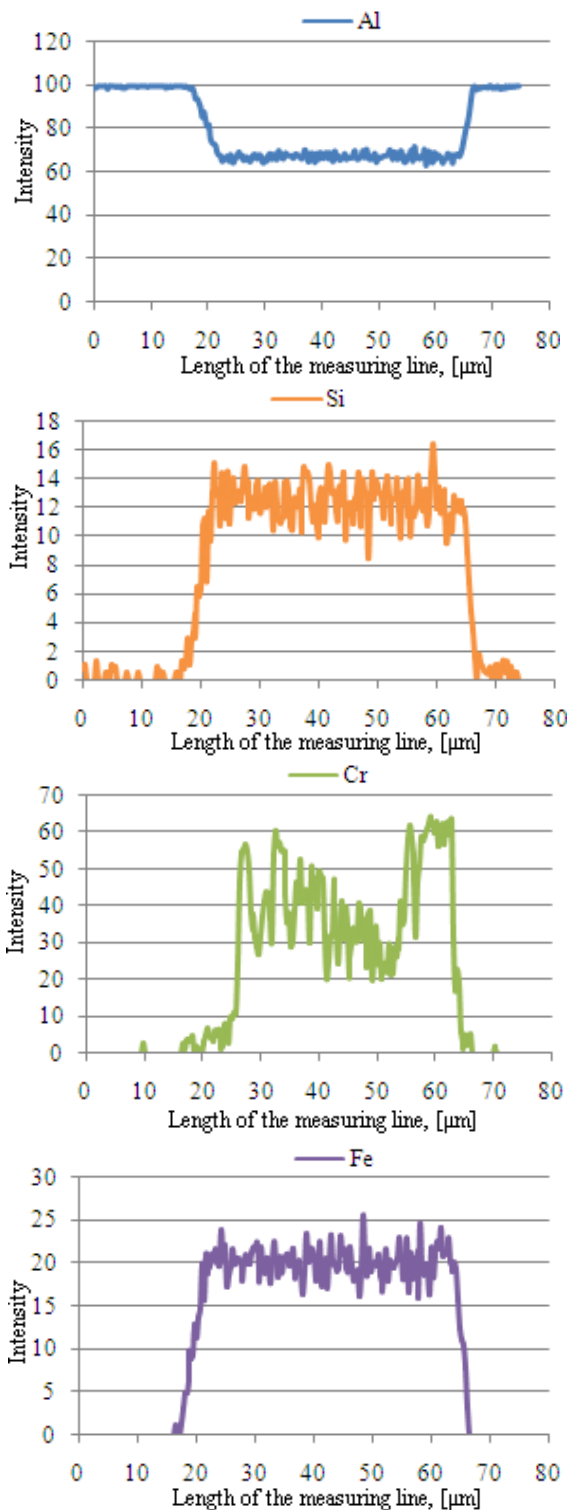


Fig. 5. Line analysis along the characteristic separation of reinforcing phase in AlSi11/CrFe30C8 composites for different frequency: a) 50 [Hz], b) 75 [Hz], c) 100 [Hz]

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.

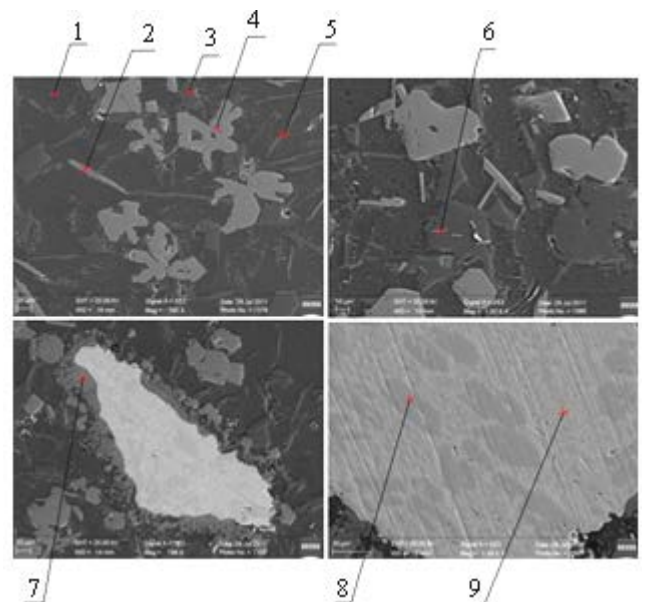


Fig. 6. Example of microstructures obtained AlSi11/CrFe30C8 composites with CrFe30C8 particles size 200 [μm] with specified characteristic points to the analysis

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 | -     |

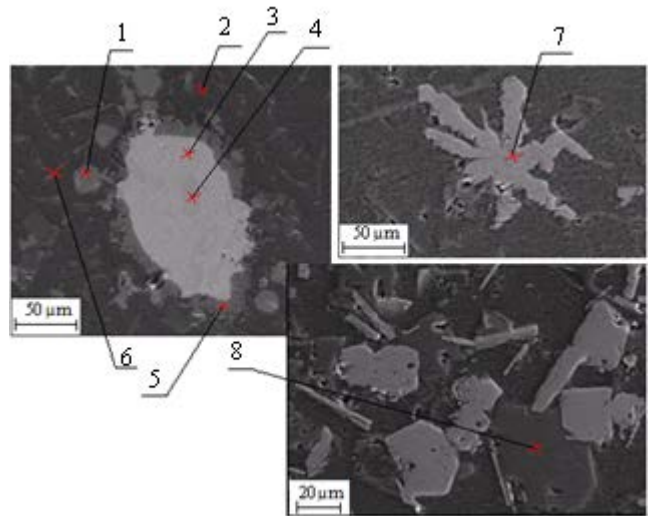


Fig. 8. Example of microstructures obtained AlSi11/CrFe30C8 composites with specified characteristic points to the microhardness tests

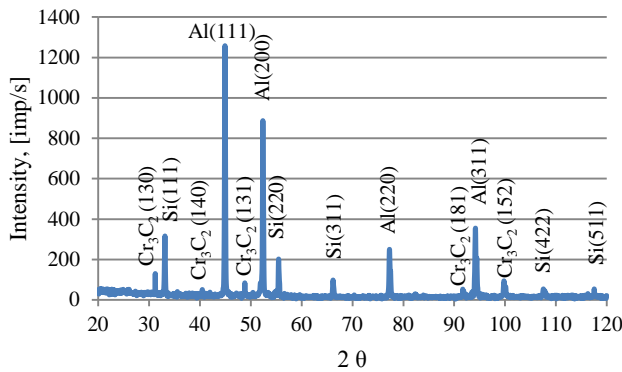


Fig. 7. The result of X-ray phase analysis of the AlSi11/CrFe30C8 composite castings

As a result of phase analysis revealed the presence of carbide phases mainly Cr<sub>3</sub>C<sub>2</sub> 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.

Table 6.

The results of microhardness tests in obtained composite castings

| Measurement point number | Cast number |             |              |                               |
|--------------------------|-------------|-------------|--------------|-------------------------------|
|                          | 1           | 2           | 3            | 4                             |
|                          | f<br>50[Hz] | f<br>75[Hz] | f<br>100[Hz] | without<br>electrom.<br>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 [ $\mu$ HV]) and phase of the transition zone (average 2431 [ $\mu$ HV]) 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.

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