

# Structure evaluation of cast dispersive AlSi-Cr<sub>x</sub>C<sub>y</sub> composites

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## Abstract

In this work author showed the diversification of structure for cast dispersive AlSi-Cr<sub>x</sub>C<sub>y</sub> composites. Wide possibilities of properties control and optimization were described, through microstructure of the matrix and the transition zone shaping. Utility castings were prepared with use of traditional casting techniques, ceramic and metal moulds. The influence of technological conditions and cooling rate on the composite structure was studied. The main factor of structural changes was the diffusion at matrix – reinforcement interface. Divers structure was observed in particle close neighborhood. Possibilities of diffusion control were indicated through application of factors assisting the crystallization.

**Keywords:** Diffusion, Transition zone phases, Microstructure, Cast composite, Al-Si

## 1. Introduction

Manufacturing of composite castings with high wear resistance characterized by high friction factor [1÷4], often requires compromise between technological and operation properties. High content of reinforcing particles disables obtaining casting with complicated shape, because of low castability of liquid composite dispersion. Reduced castability of composites [5÷7] compared to traditional alloys [8÷15] (to 40% [5, 6]) limits the application of typical casting techniques. Moreover, the methods of castability determination are burden with significant standard deviation. This is caused by complexity of metal flowing process. The alternative way of increasing the wear resistance is to maximize this property by selecting the matrix containing phases resulting from alloy additions with high hardness and dispersion. This is necessary, when using traditional reinforcing particles, ensuring favorable tribological properties. The selection of alloy additions should be based on advantageous properties of novel Al-Si alloys used for matrices with additions of e.g. Cr, Mo, W and Co [16]. Examples of such alloys are shown in table 1.

Modified and refined alloys were precipitate strengthened. In fig. 1 typical microstructure of alloy 1 with distribution of Cr and Mo was shown.

Tensile strength ( $R_m$ ) and hardness (HB) in ambient temperature for as-cast condition and after the heat treatment are shown in table 2.

Both mechanical properties increased after the heat treatment. Mechanical tests at elevated temperature (150°C and 300°C) are shown in table 3.

Presented alloys are characterized by lower mechanical properties at temperature of 300°C than for 150°C [16].

Table 1.  
Examples of chemical composition of novel Al-Si alloys [16]

No.	chemical composition [%mass.]								
	Si	Mg	Cu	Ni	Fe	Cr	Mo	W	Co
1	12,02	1,24	4,45	3,89	0,43	0,67	0,55	-	-
2	12,65	1,38	4,21	3,67	0,49	0,72	0,63	0,44	0,62

Such conclusion implicates information that even for advanced aluminum alloys, the construction of brake disc and material selection of elements consisting the kinematic pair should be so, that operating conditions will not exceed the temperature of 300°C.

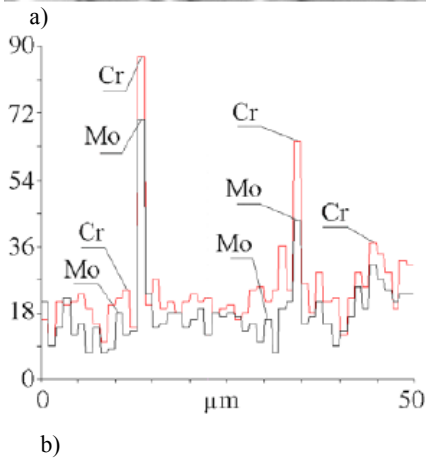
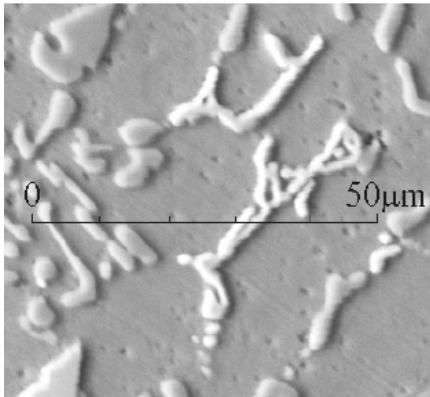


Fig. 1. Microstructure a) with linear distribution of Cr and Mo b) [20]

Table 2. Mechanical properties of Al-Si alloys presented in table 1 [16]

No.	state			
	as-cast		strengthened	
	HB	R <sub>m</sub> [MPa]	HB	R <sub>m</sub> [MPa]
1	121	369	137	486
2	154	420	172	535

Table 3. Mechanical properties at elevated temperature [16]

	150		300	
	HB	R <sub>m</sub> [MPa]	HB	R <sub>m</sub> [MPa]
	1	118	462	85
2	127	488	108	205

This work concerned the use of metallic particles liable to diffusion phenomena at matrix-reinforcement interface producing phases which increased the mechanical properties of the metal matrix and thus minimized the leap in structural and mechanical

characteristics of the interface. Unlike the composites with ceramic reinforcement in studied dispersions after the wetting of reinforcing particles intensive physical and chemical reactions occur. Progressing diffusion of particle components and proceeding reactions cause increase of liquidus temperature, what results in increase of dispersion viscosity. Control of diffusion processes is based mainly on chemical composition selection, morphological modulus, activation of particle surface, time and temperature of technological process.

Preliminary studies results for tribological and technological properties obtained in precision and permanent mould casting techniques [18, 19, 22] encouraged author to analyze the possibility of composite microstructure control. Moreover, composites designed in such way would enable heat treatment resulting in higher operating properties of composite castings omitting the unfavorable rheological properties of liquid composite dispersions.

## 2. Studies results description

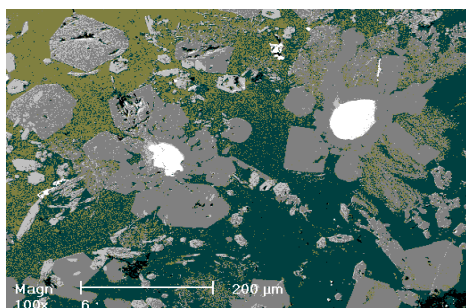
A comparison of structural properties for castings manufactured at extremely different heat flow conditions was conducted. For castings manufacturing two methods were used: the investment casting technique, characterized by pouring to heated ceramic moulds with use of vacuum equipment and permanent mould casting. Evaluation of technical aspects of casting process was preceded by model studies, which aim was to maximize the diffusion phenomena at components interface. In experimental studies particles of normalized iron preliminary alloys (FeCr) were used, which price and availability is favorable than ceramics typically used for wear resistant composites. In studied composite dispersions desirable diffusion processes together with chemical composition changes progress with time causing occurrence of components concentration gradient directed to particle micro-region. The actual reinforcing component is the chromium carbides introduced in form of ferrochromium. Intermetallic phases occurring in the matrix cause desirable gradual changes of mechanical properties in wide transition zone. Applied were the particles with size of hundredths and tenths of millimeter, to determine the possibility of diffusion phenomena control during liquid composite dispersion manufacturing and casting solidification. Polycrystalline particles, according to assumptions, due to diffusion should change from polyhedral to ovalized, more favorable form, changing the value of morphological modulus. It can result in increase of structural and operating properties. The ovalization of particles causes decrease of average local gradient of temperature occurring at matrix-reinforcement interface resulting in minimization of thermal stresses and more stable system. Moreover, oval shape is preferable during wear of kinematic pairs characterized by high friction factors. Base material was the composite AlSi11 – (CrFe33C7)<sub>p</sub> manufactured in temperature range of 690÷740°C with use of mechanical stirring for 20÷180 s with particles activated with use of boron and sodium compounds [19, 20]. The composite was poured into sand mould with resinoid bond. As a consequence of reinforcing particles introduction the increase of iron content is observed in direct neighborhood of the particles. The iron content in matrix micro-regions is directly connected

with diffusion rate in the transition zone. In alloys containing iron unfavorable needle-shaped iron phase is observed. Chromium, especially in the transition zone changes the morphology of iron-rich phases. In fig. 2 a-e examples of microstructure with CrFe33C7 particles in EN AC-ALSi11 matrix were shown. CrFe33C7 particles were also introduced, with satisfactory results to AlMg5Si and AlSi21 containing other dispersive in situ particles. In these composites positive effect of cobalt addition was observed, eliminating negative effect of iron. Conditions of composite formation in liquid state are related to temperature and time of stirring. With increase of both parameters kinetics of proceeding reactions increases, as well as the quantity of reactions products in the matrix. In conducted studies the influence of temperature was stronger. In fig. 2 microstructure and additions distribution were shown for characteristic structural components.

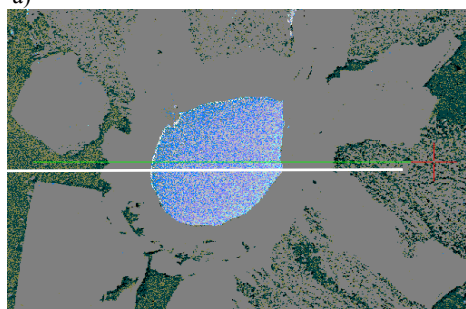
Presented samples show maximal, directional growth of phases in transition zone. Such morphology is unfavorable when phases are less plastic than the reinforcement.

Potential morphology of these phases can be controlled with use of chemical and physical factors, e.g. electromagnetic stirring, modifying additions, heat treatment and combinations of these techniques.

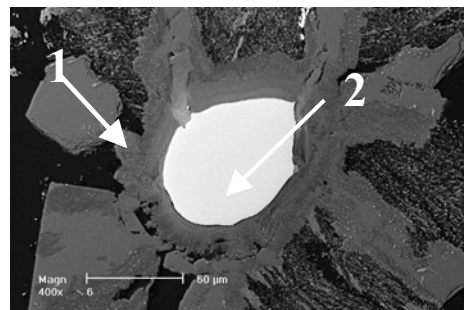
Next, some efforts were made to maximize the solubility of ferritic matrix of CrFeC particles for investment casting conditions. Detailed descriptions of these studies can be found in [17, 18]. The analysis was based mainly on the example of ventilated brake disc casting.



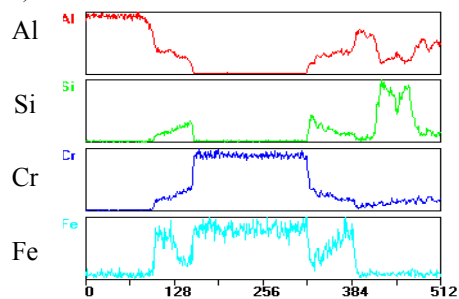
a)



b)



c)



d)

Element 1	Volume fraction [%]	Atom fraction [%]
Al	57.29	69.76
Si	7.32	8.57
Cr	19.43	12.28
Fe	15.96	9.39

e)

Element 2	Volume fraction [%]	Atom fraction [%]
Cr	86.65	87.46
Fe	13.35	12.54

f)

Fig. 2. SEM microstructure (a – c) and elements distribution in structural components ( d – f) of studied composites

Composites were prepared with use of EN AC-ALSi11 alloy. Double reinforcement was used in form of particles with two different granularities. Castings were prepared with use of ceramic and metallic particles. Main reinforcing function fulfilled the metallic particles  $(CrFe25C10)_p$  responsible for tribological properties improvement, with granularity of 0,3 [mm]. Such particles can be classified as ex situ reinforcement. Function of additional fine-dispersive reinforcement fulfilled the phases:  $(Cr_3C_2)_p$  and  $(Cr_3C_2+TiC)_p$  in form of reactive composite powders (table 4). Powders with fine-dispersive phases were obtained with use of powder metallurgy techniques.

Reinforcing phases contained in introduced powders are characterized by granularity of single microns, even nanometers. Other sort of additional reinforcement was the oxides, mainly

(Al<sub>2</sub>O<sub>3</sub>)<sub>p</sub>, resulting from ozone treatment of the liquid matrix. Total content of reinforcement in the manufactured composites was 43%<sub>mas.</sub>. To improve the wetting addition of 0,4 % Sb was introduced. Liquid dispersion was poured into the shell moulds. The process of mould cavity filling was aided, because of high viscosity and low castability, with use of external factors affecting the mould and internal factors affecting the liquid metal.

Table 4.  
Powders containing fine-dispersion phases reinforcing composite introduced into liquid matrix of EN AC-*AlSi11* alloy

Matrix 75% <sub>mas.</sub>	reinforcing phase 25% <sub>mas.</sub>	powder granularity [μm]	mass fraction of powder to metal matrix ratio EN AC- <i>AlSi11</i> [% <sub>mas.</sub> ]
FeCr	TiC	45÷90	20
NiCr	Cr <sub>3</sub> C <sub>2</sub>	20÷45	18
NiCr	Cr <sub>3</sub> C <sub>2</sub> TiC	20÷56	23

During pouring the mould was mechanically vibrated (MW), with vibration amplitude of 2 mm and at frequency of 6 Hz. Mechanical effect on liquid metal was obtained with use of linear, reversing electromagnetic field (LRPE<sub>h</sub>), with induction in range 20÷50 mT at reversing frequency of 0,5 Hz. Structure of the cast composites is shown in fig. 3. For composite shown in fig. 3 a) the reinforcing particles were the CrFe25C10 particles in quantity of 20% and NiCr/Cr<sub>3</sub>C<sub>2</sub> – TiC in quantity of 23%, what gave the 43% total content of reinforcement. Preliminary metallographic analysis revealed silicon eutectic crystals on α phase background and bright irregular particles of CrFe25C10 (1) together with dark equiaxed, fine-dispersive particles – probably Cr<sub>3</sub>C<sub>2</sub> carbides (2) originating from composite powders and phase AlCrFeSi (3). Compared to composite *AlSi11*+O<sub>3</sub> + CrFe25C10 the effect of modification is weaker what was concluded on basis of silicon crystals morphology. Fine-dispersive particles occurred as the individuals or in groups. Primal metallic particles of CrFe25C10 practically entirely dissolved. Changes in morphology of the matrix in compare to non-modified *AlSi11* alloy are rather small. Level of dendritic refinement of α phase is also negligible. The mechanism of structural changes and conclusions connected with the influence of reinforcing components are, at this stage ambiguous. Presented observation are hypothetical.

To compare the influence of technological conditions of liquid dispersion preparation and cooling rate on composite microstructure for *AlSi*-Cr<sub>x</sub>C<sub>y</sub> composites, additional experiments were conducted with use of permanent mould casting technique and composites *AlSi12Cu2Fe*-(CrC14)<sub>p</sub> and *AlSi11*-(CrFe25C10)<sub>p</sub> [22].

Reinforcing particles, preliminary activated were introduced in quantity of 18÷22%<sub>mas.</sub>, with granularity in range 71÷500 μm. In both cases the addition of 0,3% Sb was used to lower the surface tension and oxidation, what should improve the castability of liquid dispersions and slightly modify the structure. Comparison of obtained results showed significant influence of iron on possibility of liquid dispersion preparation. *AlSi11*-(CrFe25C10)<sub>p</sub> composite in compare to *AlSi12Cu2Fe*-(CrC14)<sub>p</sub> in spite of comparable iron content showed better final results in form of wider range of technological conditions of dispersion preparation.

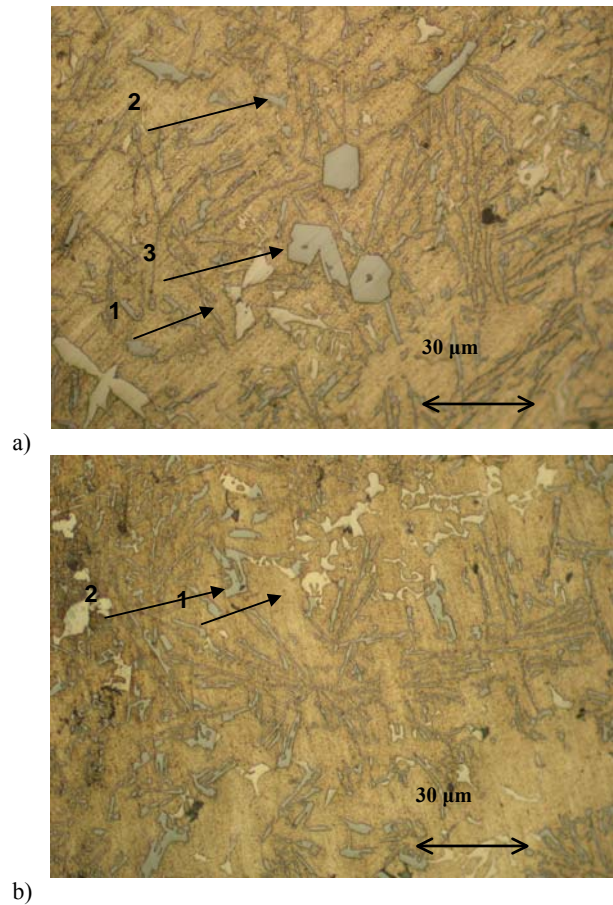
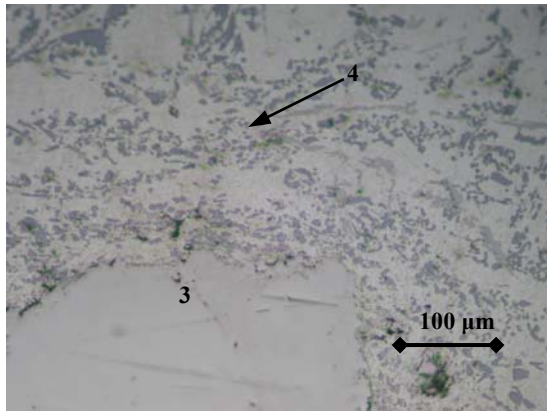


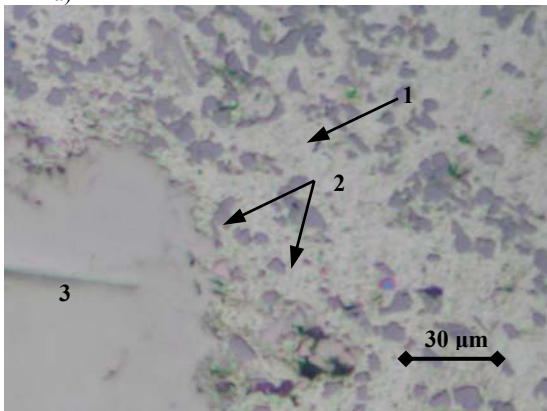
Fig. 3. Microstructure of cast composite brake disc prepared with use of investment casting method; a) *AlSi11*-(Cr<sub>3</sub>C<sub>2</sub>+TiC)<sub>p</sub>+ (CrFe25C10)<sub>p</sub> composite – casting aided with use of mechanical vibration (MW), b) *AlSi11*-(O<sub>3</sub>)<sub>g</sub>+(CrFe25C10)<sub>p</sub> composite – aided with use of linear, reversing electromagnetic field (LRPE<sub>h</sub>)

Time of stirring was significantly shorter, with higher quantity of introduced reinforcement. Such state is caused besides the iron influence also by the reinforcing particles granularity, which assumed diversification worked on *AlSi11*-(CrFe25C10)<sub>p</sub> composite advantage. In case of composite reinforced with ex-situ ceramic particles described difficulties are negligible. Similar phenomena have to expected in process of composite containing reactive particles manufactured with use of powder metallurgy. In case of double or several kind of reinforcement application technological difficulties would be similar. Comparison of technological properties of both kinds of studied composites indicated *AlSi11*-(CrFe25C10)<sub>p</sub> composite advantage. In fig. 4 micrographs were shown, which indicated the diversification of structural components, compared to fig. 2 and 3. In matrix background large CrFe25C10 particles can be seen, indicated with (3). As assumed larger particles observed in the structure indicate that diffusion processes in the transition zone are limited. Nevertheless, ovalization of the particles is observed. Products of physical and chemical reactions in form of AlCrFeSi phases (2) can be seen in close neighborhood of the particles (3). At the same time, probably because of higher cooling rate and thermal

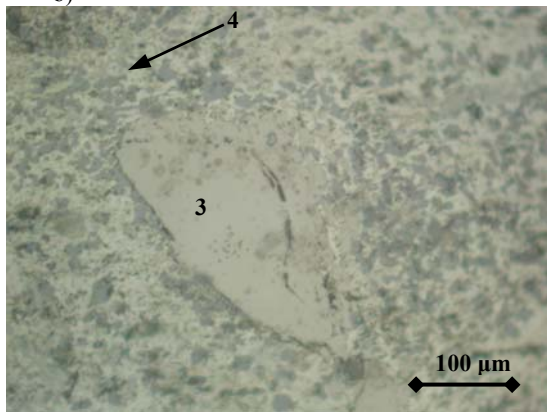
interactions caused by the particles, the silicon crystals refinement is observed, with change in the morphology from needle-shaped to globular. Heat treatment applied besides the transition zone development caused also refinement of silicon crystals in  $\alpha$  phase (4). Both effects are desirable and expected, but constitute a compromise, because of growth of eutectic silicon in compare to as-cast structure.



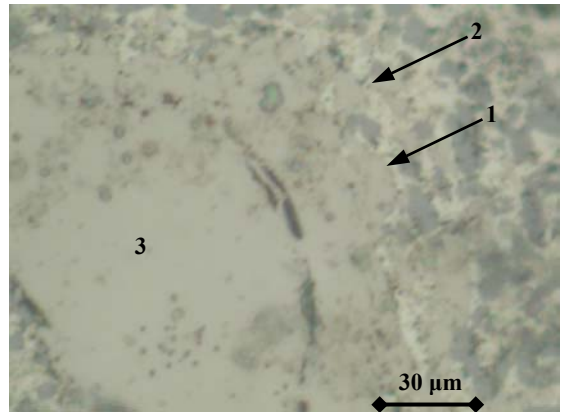
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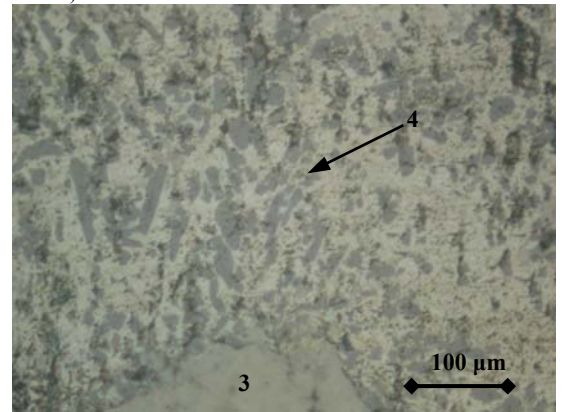
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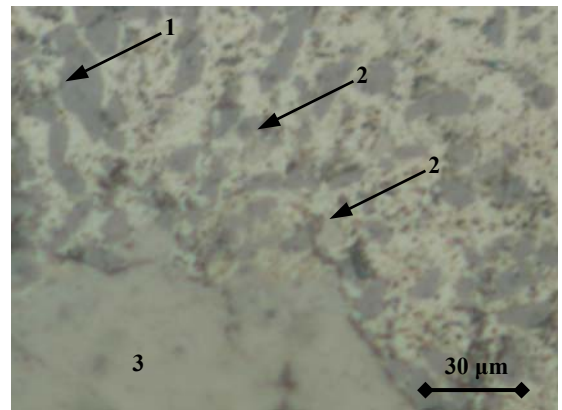
c)



d)



e)



f)

Fig. 4. Microstructure of test castings for  $\text{AlSi11-(CrFe25C10)}_p$  composite prepared with use of permanent mould casting; a), b) as-cast, c), d) after solution heat treatment, e), f) after ageing. Heat treatment parameters: 510°C/8h, water 20°C; 210°C/8h furnace cooling

Nevertheless, on mechanical properties the main influence has the  $\alpha$  phase dendrite secondary arm spacing, what suggests that there are another possibilities of structure control and optimization.

### 3. Summary

In presented studies utility castings were prepared with use of traditional casting techniques, which modification is possible even in small lot production. The results showed possibilities of diffusion phenomena control in the transition zone and as a consequence control of composite structure in particle close neighborhood and matrix. Key factors are here the way of dispersion components preparation and thermal conditions in casting mould during pouring and solidification. Crystallization process should be aided by factors causing the relative motion of dispersion components. Final structural properties can be shaped with use of heat treatment directed toward the matrix and transition zone modification. Presented AlSi-Cr<sub>x</sub>C<sub>y</sub> composites relative to diffusion process kinetics can be classified in both basic groups of *in situ* and *ex situ* composites.

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