ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 10
Special Issue
4/2010

95 – 99

18/4

Cast composites with Al-matrix reinforced with intermetallic carbide phases

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Received 31.08.2010; accepted in revised form 03.09.2010

Abstract

In this work authors presented collected results from studies concerning the manufacturing of metal matrix composites with reinforcement of intermetallic phases, mainly carbides, with use of different casting techniques. For composite matrix different Al-Si alloys were used. Presented results include microstructural studies, quantitative analysis, phases description and their chemical composition. In this part of the work authors characterized the transition zone between the reinforcing particles and metal matrix, showing the possibilities of controlling the properties of the transition zone and type of occurring transition phases.
During the studies two casting methods were used: permanent mould casting and lost wax casting. Authors indicated restrictions and possibilities of these methods in dispersive composite elements reinforced with metallic particles. The characteristic feature of such particles is their physical and chemical reactivity, which deteriorates the rheological properties of the liquid dispersion. Selection of technological parameters for manufacturing and casting was aimed on proper filling of the mould with liquid dispersion.
Both methods of casting were used for manufacturing of elements which technical application requires special tribological properties, eg. brake discs. Operating properties of all obtained composites were studied and analyzed. Authors showed the analysis of tribological studies connected with the composite structure and type and quantity of the reinforcement used.

Keywords: Al alloys, Composites, Intermetallic phases, Carbides

1. Introduction

Manufacturing of composite castings resistant to wear characterized by high friction coefficient [1 ÷ 4], often requires a compromise between the technological and operation properties. In general, a significant content of reinforcing particles reduces the possibility of obtaining castings with complicated shape due to reduced fluidity of liquid composite dispersion. Unfavorable castability of liquid composites [5 ÷ 7] as compared to conventional casting alloys [8 ÷ 15] (up to 40% [5, 6]) significantly reduces the possibility of applying standard techniques of casting. Difficult machining of wear resistant composites limits the use of casting techniques to use of precise casting techniques. Besides the selection of particle material, providing favorable tribological properties also the matrix selection provides an alternative in the search for increased resistance to wear. Solution to this problem may be to use matrices containing hard phases formed by alloy additions, with high dispersion of structural components. An example of the beneficial properties of matrices may be group of AlSi alloys with additions such as: Cr, Mo, W and Co [16]. The study is an attempt to answer the question: is it possible to obtain beneficial technological and operating properties of cast composites with Al matrix reinforced with metallic phases containing carbides and alloy additions improving mechanical properties mainly in the transition zone? The most important factor in this case is the diffusion between the particle and the matrix.

2. Technological assumptions

The concept of technology is based on the introduction of particles of metallic phases containing carbides with the desired high hardness and alloy components favorably affect the mechanical properties of composite matrix. Carbide phases of recognized positive effect on tribological properties are mainly chromium carbides. An example of material containing chromium carbides at maximum level is high carbon FeCrC primary alloy. Fragmented material activated with surface – actants is introduced into the liquid matrix to produce a stable suspension. Due to the progressive diffusion, which may in extreme cases lead to the complete dissolution of particles in the matrix, the time to prepare a liquid dispersion, pouring and crystallization time should be as short as possible, and particle size significant - even at the level of fractions of a millimeter.

3. Aim and scope of studies

The aim of this study was to manufacture castings with developed shape – typical for potential composite applications in die-casting and lost wax, which in addition to great technological and mechanical properties, ensure minimizing machining and are characterized by extremely diverse cast metal crystallization rates. The composition of alloy for reinforcing forming particles reinforcing material was determined. For designed technological conditions of casting carried out was the structural analysis of reinforcement and composite matrix. Tribological studies of composites produced in accordance with the accepted concept of technology was conducted.

4. Studies results

Evaluation of the technical aspects of the research was preceded by model studies, whose purpose was to determine the diffusion phenomena in the transition zone at cooling rates typical for sand moulds. Analyzed was a composite AlSi11 - (CrFe33C7) p produced in the temperature range 690 ÷ 740oC by mechanical stirring for 20 ÷ 180s using a surface activation of particles with use of boron and sodium compounds [13, 14]. In preliminary studies, the composite was poured into sand moulds with phenol-formaldehyde binder. As a consequence of particles introduction an increase of iron content in close neighborhood of particles is observed, whose participation in matrix micro regions is related to the diffusion rate in the transition zone. In iron-containing alloys a negative phase can occur in shape of complex, needle-shape inclusions. Particularly in the transition zone, chrome change unfavorable morphology of iron phases.

Tests of maximum dissolution of CrFeC particles was conducted with use of lost wax technique and ceramic moulds. A detailed description of the tests can be found in [12]. During selection of components for particles ThermoCalc software was used for numerical modelling of physicochemical reactions. Trial castings were prepared with composites: AlSi12Cu2Fe-(CrC14)p and AlSi11-(CrFe25C10)p. Presented composites were additionally reinforced with dispersion of fine particles obtained by powder metallurgy and the reactive gas treatment [13 ÷ 15]. In the presented study aspects of polymodal reinforcement was omitted. Surface-activated particles were introduced in quantity of 18 ÷ 22%wt. and granularity of 71 ÷ 750 mm. Castings diameter was in range of 255 to 285 mm and weight of 1.9 ÷ 2.3kg. In both cases, the additives were used to lower the surface tension and reduce oxidation, which improved castability of liquid dispersion. Composite suspension was pured into self-supporting ceramic moulds. Due to the large viscosity and low castability the cavity filling process was aided by mechanical vibration (MW) or the linear, reversible electromagnetic field (LRPEh). Composite structure obtained was shown in fig. 1.

a)

b)

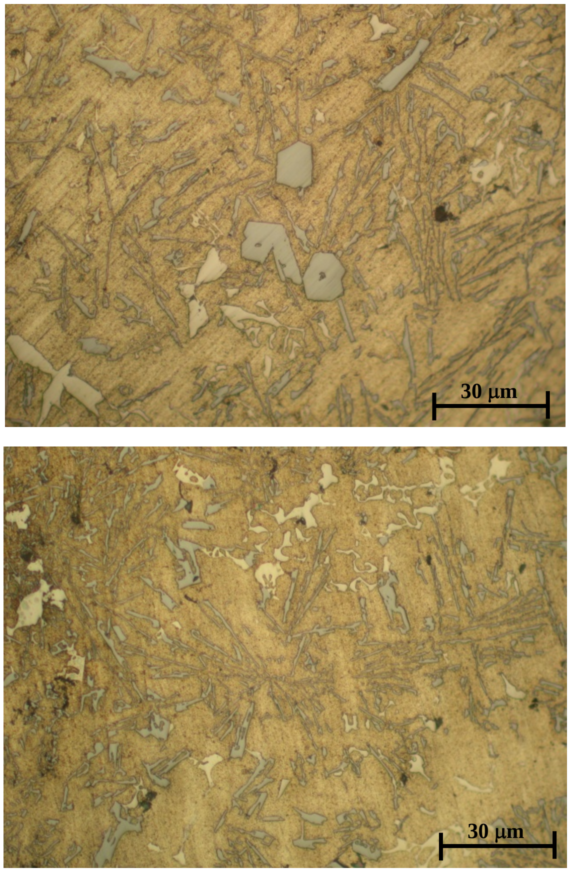
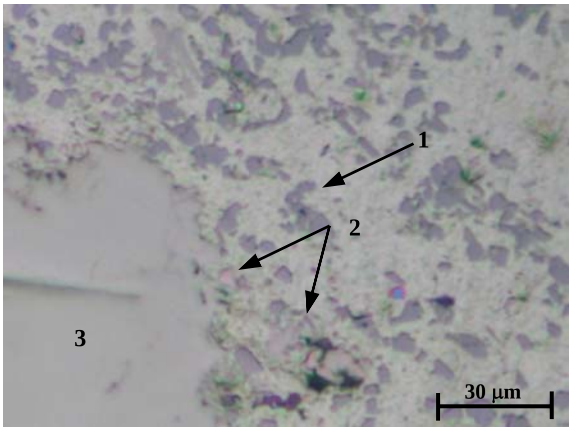


Fig. 1. Microstructure of cast composite brake discs prepared with use of ceramic moulds. a) composite AlSi11-(Cr3C2 + TiC)p + (CrFe25C10) p – pouring aided with use of mechanical vibration (MW), b) composite AlSi11-(O3)g + (CrFe25C10)p – pouring aided with linear, reversible electromagnetic field (LRPEh)

On the background of the gray α solution eutectic silicon can be seen together with bright equiaxed carbide phases and fine dark particles - probably carbides Cr3C2 resulting from composite powders. In comparison to the composite AlSi11+O3+CrFe25C10 visible structure is less fragmented. In the structure particles can be found separately or in form clusters. CrFe25C10 primary metal particles have dissolved completely. The degree of fragmentation of the dendritic α solution is small.

To compare the impact of the conditions on preparing the liquid dispersion and cooling rate on microstructure of the AlSi-CrxCy composites a die-casting technique was used [16]. Trial castings were made of composites: AlSi12Cu2Fe-(CrC14)p and AlSi11 (CrFe25C10)p. Surface-activated particles were introduced in quantity of 18 ÷ 22%wt. and granularity of 71 ÷ 500 mm. Comparison of results obtained on the basis of standardized eutectic alloys showed a significant effect of iron in the process of creating a liquid dispersion. Composite AlSi11-(CrFe25C10)p compared to AlSi12Cu2Fe-(CrC14)p, despite similar overall iron content allowed a much better final results expected in the form of a wider range of technological parameters of production. Component mixing time was much shorter and the amount of reinforcement entered at the time was greater. This state is due to the influence of iron and the size of particles, which diversity works for the benefit of composite AlSi11-(CrFe25C10)p. Comparison of technological properties of both investigated composites falls in favor of the composite AlSi11-(CrFe25C10)p. Fig. 2 shows the microstructure of composites obtained during die casting. In the matrix large particles of CrFe25C10 are visible, marked in micrographs (3).

a)



b)

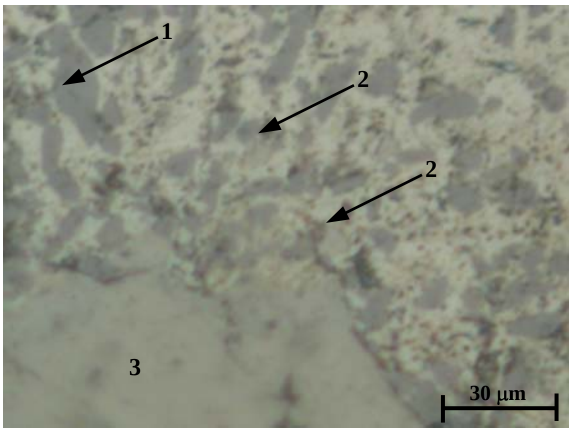


Fig. 2. Microstructure of cast composite brake discs AlSi11-(CrFe25C10)p obtained during die casting: a) as cast, b) after heat treatment. Processing parameters: 510ºC/8h water 20^{o}C, 210ºC/8h cooled with the furnace [16]

In agreement with assumptions large size of particles shows a limited contribution of diffusion processes in the transition zone. of the border area. However, observed particles have more oval shape. Products of physical and chemical reactions in the form of phases AlCrFeSi (2) can be seen in the close neighborhood of particles (3). At the same time, probably due to rapid cooling and thermal effects of reinforcing particles a clear fragmentation of eutectic silicon (1) ca be seen together with the favorable change in the morphology. Heat treatment besides expansion of the transition zone phases led to α solution dendrites fragmentation. Both effects are desirable and expected. There are however a compromise, namely in relation to the as cast structure; an increase in the dimensions of eutectic silicon is observed. However, the mechanical properties are mainly affected by the DAS of α solution, which suggests further opportunities to develop and optimize the morphology of the structural components of the matrix.

In order to obtain polymodal carbide in situ phases together with the introduction of beneficial alloying elements for the composite matrix, a reinforcing material was used containing in addition to carbide phases chemically unbound Cr, Co, Mo and Ni. Trial castings were prepared providing a full diffusion of particles introduced. In fig. 3 examples of microstructure were shown for composite containing 5%wt. of reinforcing particles.

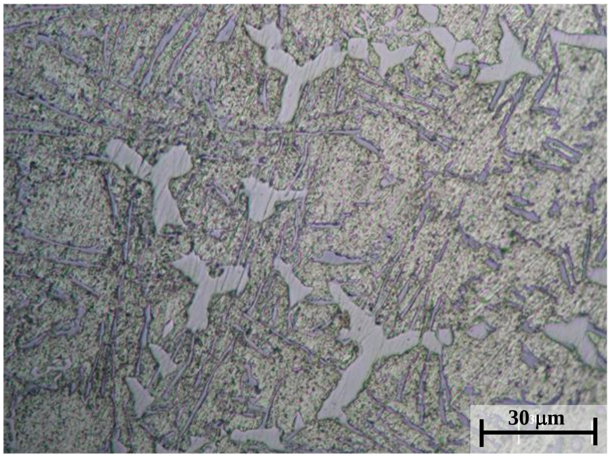
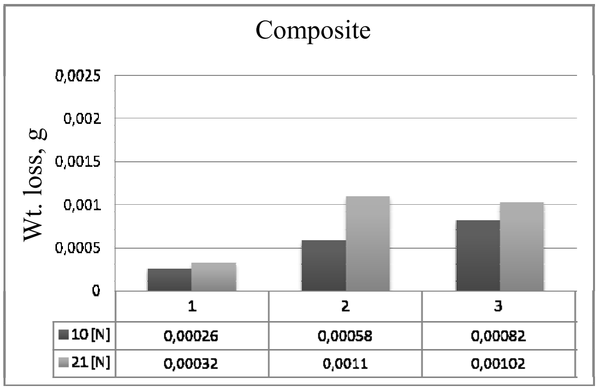


Fig. 3 Composite microstructure reinforced with intermetallic phases

Observed were three forms of intermetallic phases formed in situ in the AlSi matrix: equiaxed, ramified and tri-arm. Max. hardness was observed for the ramified phases (up to 2900μHV). The equi-axed precipitants showed hardnes of up to 900μHV and the tri-arm up to 700μHV.

In the matrix non-modified eutectic silicon and complex intermetallic phase can be seen. Determining the presence of carbon and registered a high microhardness of 1700 ÷ 2000 or even 2900 μHV indicates the presence of carbide phases.

On the basis of technological practices comply with the trial cast brake discs, and the structure of the obtained composites, die-casting technology was selected as the forward-looking. Samples for tribological tests were taken from brake disc castings. Samples tested were marked with the numbers 1, 2 and 3 The share volume of reinforcement was respectively 36, 26 and 16%. The average microhardness of the matrix and the reinforcement based on the 10 measurements was 61 and 1690 μHV, respectively. Test parameters were as follows: technically dry friction, to-and-fro motion , the friction distance 600m, load 10 and 21 N, test velocity 0.1 m/s. For counter-specimen material a typical brake pad was selected with a maximum working temperature of 400°C, hardness min. 150 MPa, slip speeds up to 15 m/s, density 2.1 g/cm^3 and a maximum unit pressure of 2.0 MPa. In fig. 4 the weight loss of composite samples and counter-specimen after the test was shown.



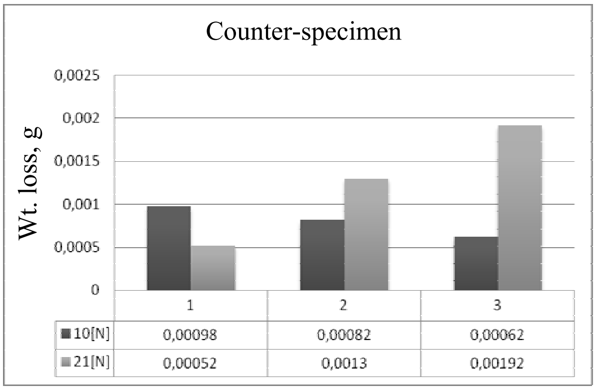


Fig. 4. Weight loss of cast composite samples counter-specimen FOR 715 FOMAR after tribological tests. Where: 1 - 36% reinforcement; 2 - 26% and 3 - 16%

In all tested samples the coefficient of friction stabilized at around 0.45 on the way of friction up to 100 m. The smallest value being (0.4) recorded for the samples with the highest content of reinforcing particles.

5. Conclusions

Intermetallic phases occurring in the matrix give gradient changes in structural properties of the transition zone with its range controlled by the diffusion. It is possible to control the diffusion phenomena with use of technological parameters. Particles shape due to diffusion is improved from multilateral to more oval. This results in change of morphological modulus, with beneficial influence on the structural and operating properties of the composite casting. Particles ovalization decreases the average local temperature gradient, occurring in the transition zone reinforcement – matrix, thereby improving the thermal and mechanical stability of the system in liquid and solid state. Die casting technique can be used in the production of geometrically complex parts resistant to frictional wear.

In obtaining the required microstructure essential are: processing of components for manufacturing a stable liquid dispersion and crystallization conditions in the mould. The final structural properties can be shaped by heat treatment aimed at modifying both the matrix and the transition zone, thereby also the morphology of particles. Presented AlSi- CrxCy composites depending on the diffusion kinetics shaping the microstructure of the matrix and the transition zone may be classified in two basic groups: in situ and ex situ, or on their border.

Acknowledgements

The studies were partially prepared under POKL AERO, Innovative material technologies applied in aerospace industry (POIG 01.02.-0015/08).

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