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Technological aspects of AlSi-Cr_xC_y composite casting manufacturing with use of permanent moulds

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Abstract

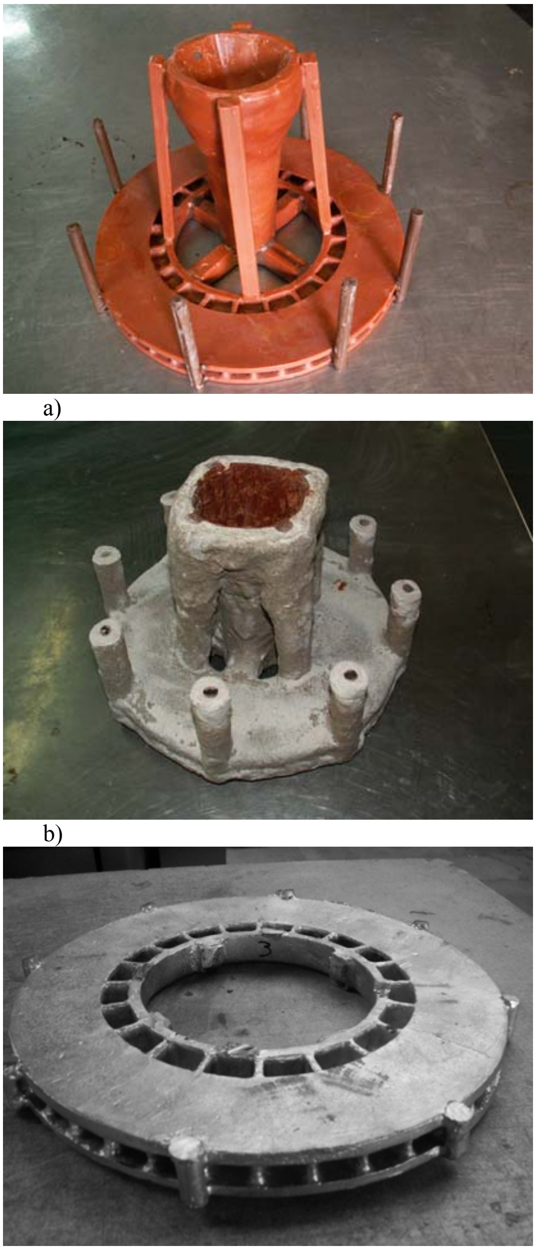
In this work authors presented the restrictions and possibilities of permanent mould casting technique in manufacturing dispersive composite elements reinforced with metallic particles. The characteristic feature of such particles is their physical and chemical reactivity, which deteriorates the rheological properties of the liquid dispersion. Selection of technological parameters for manufacturing and casting is aimed on proper filling of the mould with liquid dispersion. For comparison, the results of similar experiments with use of investment casting were shown. Basic constructional requirements connected with brake discs manufacturing were presented, together with the concept of moulding materials selection, influencing the flow of liquid dispersion. As the results of conducted studies technological parameters of brake disc manufacturing with use of AlSi-Cr_xC_y composites were determined.

Keywords: Permanent mould casting, Al-based composite, Metallic reinforcement, Chromium carbides

1. Introduction

Manufacturing of cast composite elements with developed shape requires application of geometrically complicated moulds. Unfavorable castability of liquid composites [1, 3, 4, 8] in compare to alloys [5÷7] (even of 40% [2, 3]) restricts the use of traditional casting techniques. Moreover, the methods of castability determination are burden with significant standard deviation. This is caused by complexity of metal flowing process [3, 4, 8], what indicated a need for development of new, individual methods of castability for different composites. Also in this range the simulation software refers only to traditional alloys [9÷13]. A certain alternative to this problem can be a search for improvement of mould cavity filling with liquid composite. This work is mainly an attempt to find right technological parameters and methods which enable omitting of typical difficulties in composite casting. Majority of manufactured composites is characterized by high wear resistance and friction factor [14÷17]. Such materials are difficult to machine. In such cases to minimize or omit the machining precision methods of casting are emplyed [18, 19].

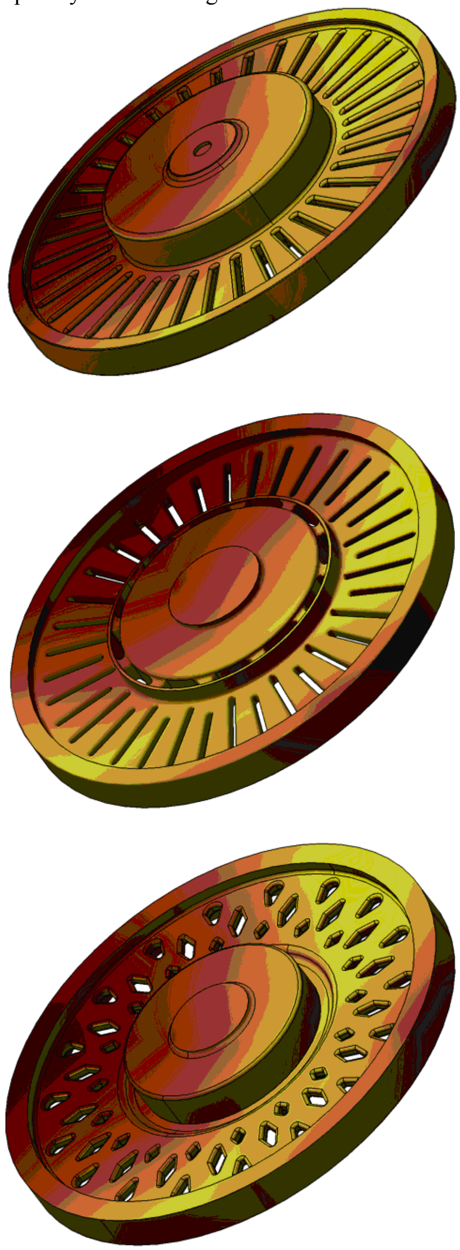
The aim of the studies was to verify the concept of typical casting manufacturing with complicated geometry using permanent mould casting and to continue the work presented in [18, 19]. In these works technical restrictions and potential possibilities of investment casting method for composite castings production was shown. As an example of such casting the ventilated brake disc casting was used, shown in fig. 1 c) with dimensions of ø(255/123)x22 [mm]. For composite metal matrix the aluminum alloy EN AC-AlSi11 was selected. As the reinforcement with two different granularities was used. For test castings the reinforcing particles were metallic and ceramic. Composite dispersions were poured into shell mould prepared according to investment casting technique (fig. 1 a, b).


a)
b)
c)
Fig. 1. a) wax model system; b) shell mouldc) brake disc casting, composite: AlSi11- 20%CrFe25C10 + 23%NiCr/Cr_3C_2-TiC

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. During pouring the mould was mechanically vibrated (**MW**). Mechanical effect on liquid metal was obtained with use of linear, reversing electromagnetic field (**LRPE$_h$**).

The studies concluded that the investment casting method was suitable for composite utility casting production, characterized by low castability, high viscosity and difficult machining. It was also confirmed, that external factors aiding the filling and crystallization was helpful. For used in the studies composites and technological conditions the parameters of mechanical vibrations and electromagnetic field parameters were determined. These are: electromagnetic field with induction of 20÷50 mT, with reversion frequency of 0,5 Hz and the mechanical horizontal and vertical vibrations amplitude of 2 mm at frequency of 6 Hz.

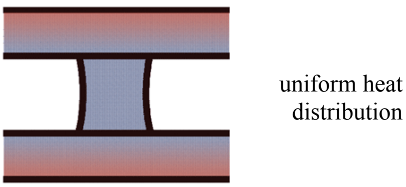
Regardless of liquid dispersion components selection there is always a need for compromise between the castability and the shape complexity of the casting.


a)
b)
c)
Fig. 2. Examples of sand cores for brake disc castings; a) and b) rectilinear, radial ventilating elements, c) ventilating elements with post shape and variable cross-section

For different brake discs there are always differences in ventilating channels construction. For composite brake discs in compare to traditional brake discs, the diameter is larger and distance between working surfaces is average two times larger, what results in higher air flow between the channels and better cooling. In traditional brake discs elements described above have similar dimensions. In fig. 2 examples of sand cores for brake disc were shown. In case of more sophisticated designs of ventilating channels there is one common feature – the geometry of surface forcing the heat exchange. In early solutions the ventilating elements were asymmetrical with respect to working surface, what was shown in fig 3 a). Such design was improper. In fig. 3 b) the correct section of ventilating element was shown.

In fig. 4 examples of brake disc novel designs were shown. Grooves enable carry-off the gasses which create the cushion between the disc and the pad during braking. They minimize the effect of water damp condensation and improve cooling of the disc. Similar effects are observed in case of drilled holes. Such solutions are applied for composite brake discs [21].

a)



b)

Fig. 3. Construction of ventilating element, a) improper; b) correct

Presented examples indicate possibilities of precision casting techniques employment in brake discs production omitting the mechanical machining.

2. Studies

The main aim of presented studies is the determination of technological parameters of permanent mould casting of brake disc castings with use of composite dispersion. The test casting shape – break disc – was selected as an example of utility casting with complicated shape and developed surface of heat exchange and required high dimensional precision. Compared to investment casting the permanent mould casting technique enables the possibility of large-lot production with needed repeatability and surface quality. Additional advantage is the high cooling rate which may have the positive influence on alloy modification.

Constructional assumptions for the mould design enclosed two main aspects:

1. Possibility of brake discs casting with different diameter, by using sand core to shape all surfaces of the disc, except of the working surface.
2. Application of thermo-insulating materials for the gating system.

a)

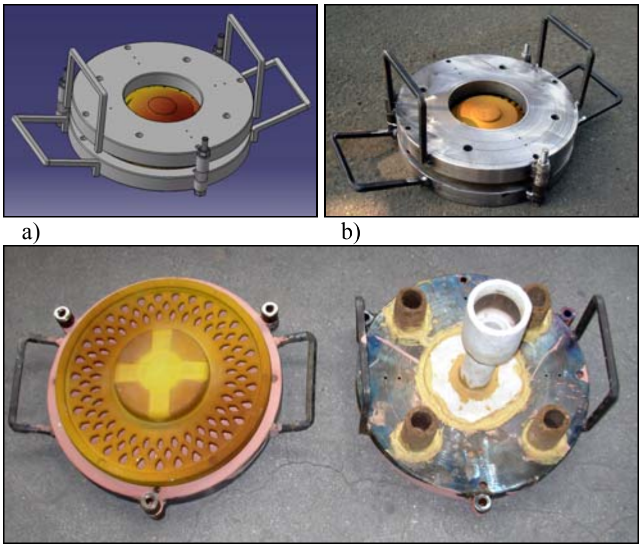
b)

c)

Fig. 4. Examples of cooling improvement solutions for brake discs; a) shape of ventilating elements; b) grooves, c) drilled holes [21]

Selection of the technological parameters of the casting were assumed in respect to one parameter – the temperature of liquid composite dispersion preparation, which was also the pouring temperature for the composite. To minimize the shrinkage and to improve the dispersion preparation process the temperature should be low and was assumed in range 670÷690 ^{o}C. To improve the flow of the dispersion through the mould cavity the mould was coated with ceramic coating and heated up. In fig. 5 a virtual model of designed mould and real photograph of mould prepared for casting was shown.

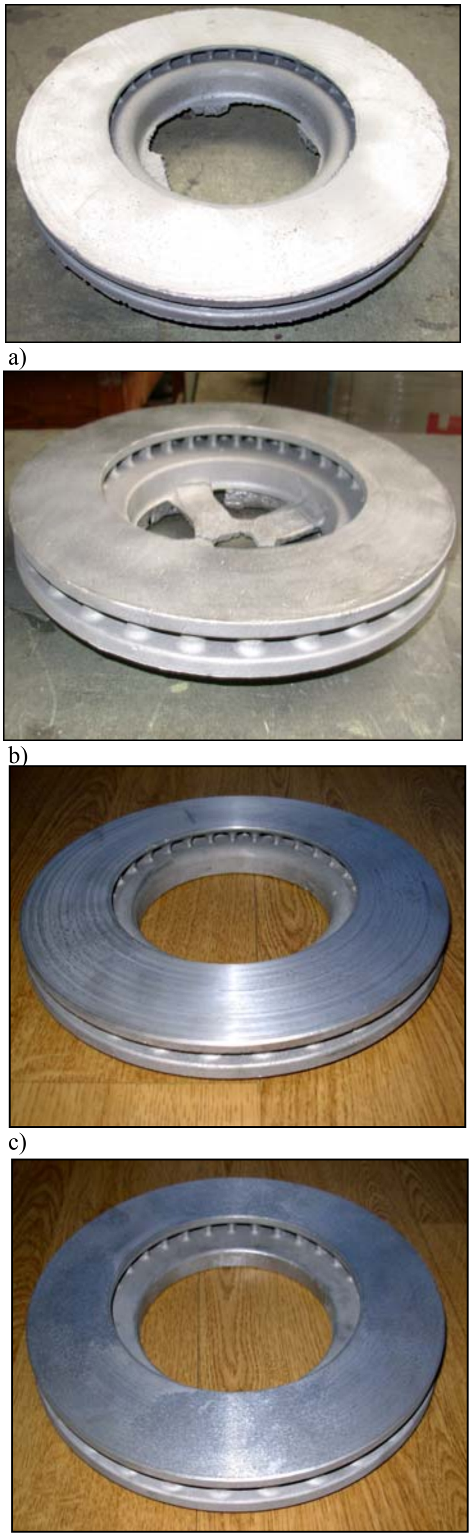
Test castings manufacturing was conducted according to rules applied for permanent mould casting of aluminum alloys, except of higher temperature of the mould, in range 380÷420^{o}C. The gating system was prepared with thermo-insulating aluminosilate material with thermal conductivity of 0,17 W/mK. For protective coating a zirkonite-based dispersion was used. Assumed parameters and their ranges are proper only for studied composites because of their specific rheological properties.



a) b) c)

Fig. 5. Permanent mould for ventilated brake disc casting:a) Virtual model, b) real mould, c) mould with the gating system and the sand core

Unlike the aluminum composite with ceramic reinforcement, in discussed dispersions after the wetting of the particles chemical and physical 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. Test castings were prepared with use of two composites: AlSi12Cu2Fe-$(CrC14)_p$ and AlSi11-$(CrFe25C10)_p$. Activated particles were introduced in quantity range 18÷22%, with granularity 71÷750 µm. Fig. 6 a) and b) show rough castings, fig. c) and d) castings after machining. In fig. a) and c), b) and d) concern AlSi12Cu2Fe-$(CrC14)_p$ and AlSi11-$(CrFe25C10)_p$, respectively. Illustrated examples of brake discs have diameter of: 263 and 285 mm with weight of 2,0 and 2,3 kg. In both cases additions lowering the surface tension were applied and oxidation and resulting in improved castability and modification of the structure.



a) b) c) d)

Fig. 6.Brake disc test castings; a) and b) rough castings, c) and d) after machining. a) and c) composite AlSi12Cu2Fe-$(CrC14)_p$, b) and d) AlSi11-$(CrFe25C10)_p$

3. Summary

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. Moreover, they give possibilities of heat treatment [24]. The consequence of particles reactions is the deterioration of rheological properties of the dispersion. Manufacturing of proper casting requires immediate wetting of the particles and satisfying filling of the mould. Maximal available structure refinement requires combination of modification treatment and high cooling rate. Experimental results confirmed technical possibilities of such process realization, through modification of thermal properties of the mould elements. Comparison of obtained results showed significant influence of iron on possibility of liquid dispersion preparation. AlSi11-$(CrFe25C10)_p$ composite in compare to AlSi12Cu2Fe-$(CrC14)_p$ in spite of comparable iron content showed better final results in form of wider range of technological conditions of dispersion preparation. 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-$(CrFe25C10)_p$ composite advantage. Nevertheless, in both cases satisfying filling of the mould was observed. 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 [22, 23]. Dispersion flow resistance was predicted in studied case just like for investment casting technique described in [18, 19]. For improvement of this property special electromagnetic equipment was prepared. Obtained satisfactory results did not show a need for use of such equipment. It shows potential possibilities of permanent mould casting for composite elements with developed shape.

4. Conclusions

1. Designed permanent mould and assumed conditions of the casting process for composite dispersion enabled complete mould filling in case of elements with complicated geometry – especially in cases of ventilated brake discs. Better, technological properties was observed for AlSi11-$(CrFe25C10)_p$ composite.
2. Following technological parameters of brake discs casting were verified:
   - temperature of liquid dispersion preparation and pouring: 690ºC,
   - mould temperature: 420ºC,
   - application of gating system elements with thermal conductivity of: 0,17 W/mK, metal mould with conductivity of 23 W/mK and core with conductivity of:0,5 W/mK.

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