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Aluminium composite casting dispersion reinforced with iron-aluminium and silicon carbide phases

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Abstract

Aluminium matrix composite with dispersion-reinforced, made by similar to stircasting process was characterised. The mixture of powders was produced by the process of mechanical agglomeration of powdered Fe_xAl_y and SiC with aluminium. The chemical composition of agglomerates was selected in a way such as to obtain 25 wt.% reinforcement of the AlSi9Cu4 silumin matrix. Applying thermal analysis ATD, the alloy solidification process was determined, reading out the typical solidification parameters. The methods of light and scanning microscopy were used to reveal the structure of composite casting. Changes in chemical composition and phase composition of particles of the FeAl intermetallic phase in aluminium matrix were confirmed. The structure of silumin casting with matrix containing microregions of ceramic and intermetallic phases, typical of hybrid reinforcements, was obtained.

Keywords: Aluminium composite casting, Hybrid reinforcement, Modification, Hypoeutectic silumins

1. Introduction

Aluminium alloys are widely used for castings in a variety of industries, mainly in the transport sector for high-loaded parts of pistons and heads in I.C. engines. The operating environment of these castings demands from them good mechanical, plastic and technological properties, which allow making items of very intricate shapes and thin walls. These requirements can satisfy hypoeutectic silumins with high copper content, additionally reinforced by dispersed Fe_xAl_y phases and SiC with aluminium. Ceramic intermetallic FeAl phases in aluminium solution are forming hybrid reinforcements, which additionally improve the tribological properties of alloys, greatly increasing the area of their applications, mainly in automotive industry.

The problem of modification of the base Al-Si system alloys is widely described in literature [1-5] and in monographs [6].

The most popular modifiers of hypoeutectic alloys are single elements like Na, Sr, Sb and complex compounds from Al-Ti-C and Al-Ti-B systems. In hypereutectic silumins, effective modification is observed after introduction of phosphorus and complex carbide-forming elements, like Cr, Mo, W, Co, V [6].

The recently developed concept of studies has allowed for a several percent content of hybrid modifier in the structure of silumin casting. It was also assumed that the composite material would be fabricated by a combined ex-situ and in-situ process of structure formation [7-10].

2. Purpose and scope of studies

The main purpose of the studies was fabrication of an aluminium composite with hybrid reinforcement in the form of intermetallic Fe-Al phases and ceramic phases. Another purpose of the studies was to determine the effect of composite powders on structure modification of an AlSi9Cu4 silumin casting.

The scope of the studies included:

- development of material- and technology-related concept of the manufacture of cast aluminium composites modified with Fe-Al, Al-Fe_xAl_y and Al-Fe_xAl_y-SiC powders,
- determination of a method for fabrication of powders modifying the aluminium matrix,
- development of technological process for fabrication of composites of different structures,
- determination of structure and chemical/phase composition of the AlSi9Cu4 silumin.

In the selection of the chemical composition of composite powders to modify the structure of cast hypoeutectic AlSi9 silumin with elevated copper content, information given in reference literature, the results obtained by the authors in previous research work and the new concept of composite fabrication were taken into consideration. It has been assumed that the introduction of an intermetallic FeAl phase should have a specific effect on the structure of AlSi9Cu4 silumin.

For melting of hypoeutectic silumins modified with hybrid components in the form of Fe-Al, Al-Fe_xAl_y and Al-Fe_xAl_y-SiC powders, the method of composite fabrication covered by patent application was used [11].

3. Research methods and materials

The research methodology was adapted to the previously established concept of the formation of silumin composite material. Composite powders were prepared by the methods of mechanical alloying and self-propagating high temperature synthesis (ASHS). The Fe-Al powder was mixed in a Pulverisette 5 mill for a time of 0,5 h, using base powders in a ratio of 50 wt.%. Iron powder in granulation of up to 60 μm and surface oxidised aluminium powder of up to 40 μm granulation were used. Powder designated as Fe_xAl_y was fabricated by the ASHS technique. It was also mixed with 50 wt.% aluminium powder. The mixture of Fe_xAl_y-SiC powders was next mixed with aluminium powders in a ratio of 50/50 and 70/30.

The structure and morphology of powders were determined by the methods of optical and scanning microscopy. Thus formed composite powders were introduced to liquid silumin in an amount such as to obtain in alloy the composite powder content of 30 and 50 wt.%.

An AlSi9Cu4 (A.380) alloy, characterised by high strength at 200÷300°C, low coefficient of thermal expansion and good abrasion wear resistance, was selected for investigations.

Typical parameters of the silumin solidification were examined by ATD thermal analysis on a Crystaldigraph PC apparatus. The test stand included a PT-600-PvG furnace, a Crystaldigraph recorder and a computer.

Complementary to the examinations of alloy solidification process, the optical and scanning microscopy was carried out. Some specimens were remelted to determine their structure. The structure of the investigated alloys was examined on metallographic specimens taken from samples cut across and along the central axis.

Metallographic sections were prepared according to standard procedure on Struers polishing machine. The structure on the specimen surface was examined and recorded under an Olympus GX-71 microscope.

The morphology of powders and local chemical composition of alloys were determined on a Hitachi microscope with EDX attachment made by Norah using a Voyager software.

Figure 1 shows the test stand for melting of specimens and plotting of the silumin solidification curves.

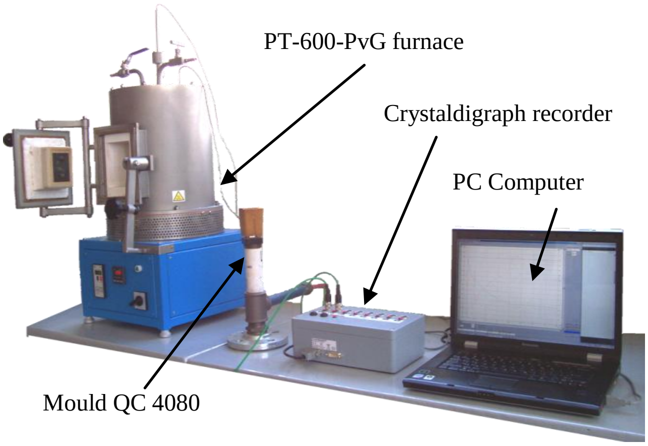

Fig. 1. Test stand for melting and casting of silumins

4. Test results and discussion

Maintaining similar parameters of melting and casting, the tested silumin was poured into a standard QC4080 probe and temperature curves were plotted in function of time (T=f(t)), plotting also the temperature derivative after time (dT/dt=f`(t)). The example of a thermal analysis done for the AlSi9Cu4 silumin before powder addition (a) and after remelting and adding powder is shown in Figures 2 and 3, respectively.

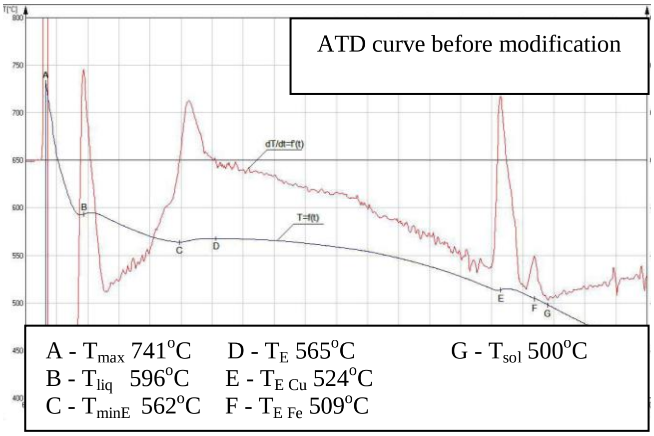

Fig. 2. ATD thermal analysis curve with characteristic points plotted for AlSi9Cu4 silumin before modification

Powders were introduced to molten silumin observing appropriate melting and pouring conditions and maintaining them at a constant level. The results of chemical analysis after the introduction of powders are given in Table 1.

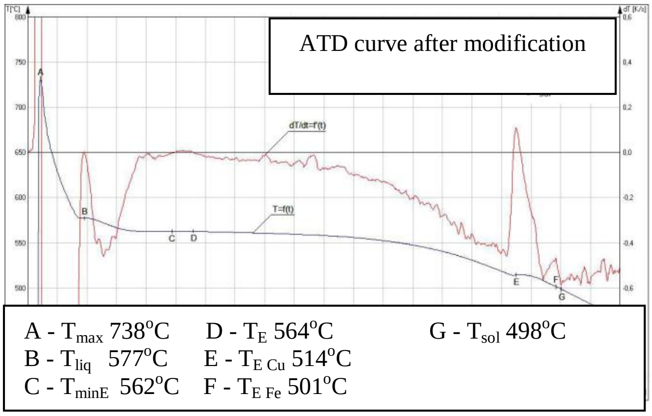

Fig. 3. ATD thermal analysis curve with characteristic points plotted for AlSi9Cu4 silumin after modification with powdered component

Table 1.
Chemical analysis of AlSi9Cu4 silumin (wt. %)

	Si	Cu	Fe	Mn	Mg	Ni	Al
alloy	9,21	3,87	0,44	0,03	0,04	0,13	rest
Mod. 1	9,18	3,99	0,66	0,027	0,032	0,14	rest
Mod. 2	9,39	3,82	1,32	0,003	0,002	0,22	rest

Preliminary analysis of the specimens was basis for corrections introduced to the method of making composite aluminium alloy. Examples of AlSi9Cu4 silumin microstructures before powder introduction are shown in Figure 4, and after adding the powder in Figures 5 and 6.

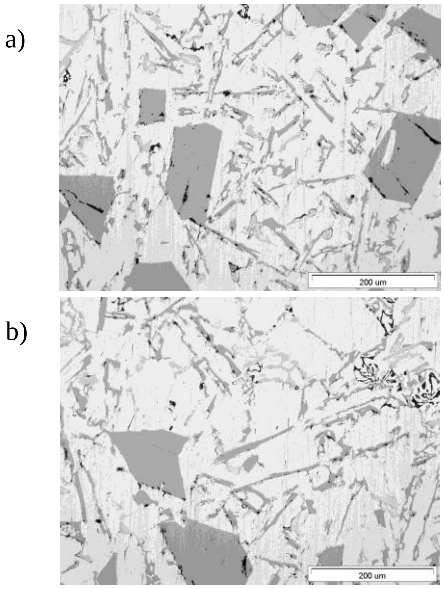

Fig. 4. Microstructure of AlSi9Cu4 silumin before modification

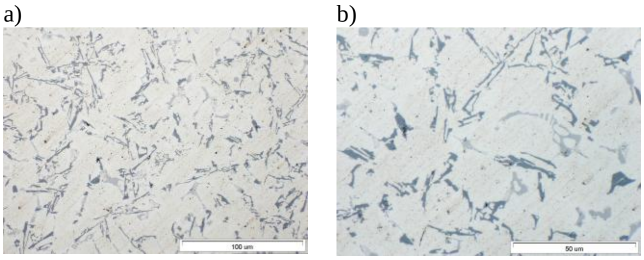

Fig. 5. Microstructure of AlSi9Cu4 silumin after addition of hybrid modifying component (unetched)

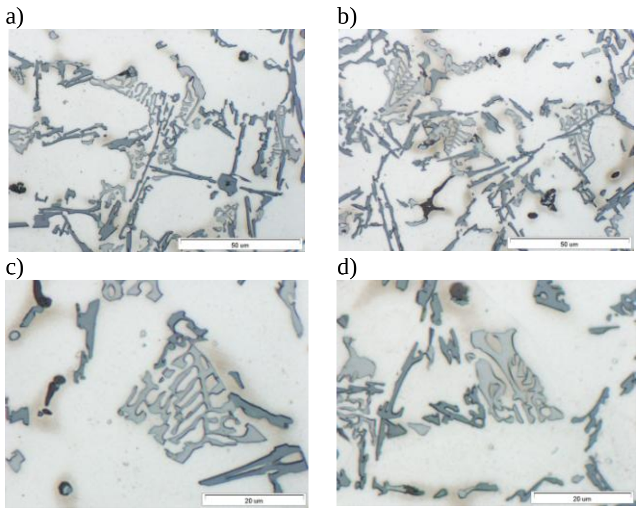

Fig. 6. Microstructure of AlSi9Cu4 silumin after addition of hybrid modifying component (etched)

4. Summary and conclusions

As follows from the characteristic values of the solidification temperature of AlSi9Cu4 silumin modified with Fe_xAl_y and Fe_xAl_y-SiC aluminium powders, the temperature T_{max} was similar in all experiments, proving that similar conditions of melting and casting of the examined alloy were maintained.

The crystallisation temperature of the dendrites of α phase (T_{liq}) assumed the highest value of 596°C for the AlSi9Cu4 alloy in base condition. This fact is well proved by data given in literature [1-4] and is consistent with the phase equilibrium diagram of Al-Si system [6]. The addition of Fe_xAl_y and Fe_xAl_y-SiC aluminium powders resulted in a considerable drop (by 19°C even) of this temperature (577°C).

The crystallisation temperature of a binary α(Al)-β(Si) eutectic assumed similar value and amounted to 564°C, preceded by a two-step temperature drop (T_{minE} 562°C). When the α(Al)-β(Si) eutectic crystallisation ended, an exothermic effect was observed on the ATD solidification curve; most probably it originated from crystallisation of a ternary eutectic containing the intermetallic Al_2Cu phase. This eutectic solidifies at a temperature of 524°C, and after modification with powdered compound a considerable drop of this temperature to a value of about 514 °C takes place. Similar relationships are observed in the solidification of a quaternary Al-Si-Cu-Fe eutectic. For AlSi9Cu4 silumin in base condition, this eutectic crystallises at a temperature of about 509°C, to drop after modification to a value of about 501°C. The end of crystallisation is observed to take place within the temperature range of 498 to 500°C, which is characteristic of the temperature T_{sol}.

The selected results of the investigations of AlSi9Cu4 silumin, dispersion reinforced with intermetallic phases from an iron-aluminium system modified with silicon, document the structure of a new alloy type. Owing to a typical morphology of the iron-rich phases and a homogeneous alloy structure, the aluminium composite should present good mechanical properties and friction wear resistance.

The method of fabrication of the composite silumin with 9% silicon content, adopted also in the manufacture of hypoeutectic silumin of different chemical and phase composition, is subject of patent application [11].

The results of the investigations indicate that the concept adopted in the manufacture of composite is correct and no other similar concepts have been mentioned in the available literature database. In the chosen field of technological research on composite fabrication, the effect of the introduced hybrid component on a mechanism of the hypoeutectic silumins structure modification has not been taken into consideration.

It is expected that structural effects and mechanism of the modification of hypoeutectic silumins will be linked to the morphology, structure, phase composition and percent share of constituents introduced into liquid silumin. In continuation of the research, a higher content of phases modifying the composite structure will be introduced.

Based on the results of own investigations, the following conclusions can be formulated:

1. Practical application of the adopted technological procedure to produce the designed dispersion-reinforced composite structure revealed a significant drop of the crystallisation temperature of aluminium solution dendrites (T_{liq}), amounting to 19°C.
2. The introduction of Fe_xAl_y and Fe_xAl_y-SiC aluminium powders obtained by ASHS also reduced the crystallisation temperature of complex eutectics containing the intermetallic phases of Cu and Fe.
3. The proposed technological procedure for the fabrication of composite material based on hypoeutectic AlSi9Cu4 silumin has resulted in refining of the dendrites of α phase and in transformation of the lamellar α(Al)-β(Si) eutectic into a eutectic containing short acicular precipitates of a phase rich in iron and silicon. This statement is proved by the obtained microstructures.
4. The modifying role of the applied powders was confirmed by the ATD thermal analysis, which revealed distinct drop of the temperature arrest amounting to ~19°C for the α(Al)-β(Si) eutectic (corresponding to its crystallisation point) and to ~10°C for complex eutectics.

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