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The solidification and structure of Al-17wt.%Si alloy modified with intermetallic phases containing Ti and Fe

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Abstract

The article describes the process of casting and solidification of Al-17wt.%Si alloy that have been modified with composite powder containing the intermetallic phases of Ti and Fe. The chemical and phase composition of the applied modifier was described with the following formula: $FeAl_x$–$TiAl_x$–Al_2O_3. Applying the method of thermal analysis ATD, the characteristic parameters of the solidification process were determined, and exo-and endothermic effects of the modifying powder on the run of the silumin solidification curves were observed. By the methods of light, scanning, and X-ray microscopy, the structure of alloy and the chemical composition of the dispersion hardening precipitates were examined. A change in the morphology of Al-Si eutectic from the lamellar to fibrous type was reported together with changes in the form of complex eutectics of an Al-Si-Ti and Al-Si-Fe type and size reduction of primary silicon crystals.

Keywords: Aluminium composite casting, Intermetallic phases, Modification, Hypereutectic 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 $TiAl_x$ 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].

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 [7-9].

Application of procedure and new type of modifier structure of Al-Si alloys with small content of intermetallic phases with iron and titanium is new and not in the literature presented and not used for modification and strengthened of hypereutectic alloys eg. [10-14].

2. Aim and scope of study

The aim of the study was to determine the effect of composite modifier containing intermetallic phases of FeAl and TiAl on the solidification process and structure of Al-17wt.%Si alloy. The scope of the work included:

- development of material and technological concept for the manufacture of AlSi17 alloy modified with an iron and titanium containing modifier,
- selection of technological and research methods tailored to the individual research stages and research plan,
- determination of the structure and phase composition of the synthetic modifier,
- development of basic technological parameters of the aluminium-based composite castings,
- thermal analysis ATD of the investigated silumin and characteristic parameters of their solidification.

In the selection of the chemical composition of composite powders to modify the structure of cast AlSi17 alloy 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 and TiAl phases should have a specific effect on the structure of cast AlSi17 alloy.

For melting of hypereutectic silumin modified with components in the form of Fe-Al, Al-Fe_xAl_y and Al-Fe_xAl_y-$TiAl_x$ powders, the method of composite fabrication covered by patent application was used [15].

3. Material - and technology - related concept of the modification of composite silumin structure

The concept of making composite casting from AlSi17 alloy includes a number of assumptions, allowing for the type and amount of modifier and for the way the technological process is run. To this end, the following assumptions have been adopted:

- the casting manufacturing process will be based on a metallurgical process and powder metallurgy,
- the process modifier will be a composite powder of the predetermined chemical and phase composition,
- the introduced modifier will be a "new" product, not specified by the reference literature,
- depending on the content of individual elements, the complex modifier should act as a modifier of the grain boundaries and cause dispersion hardening of alloys,
- the content of the added modifier should differ: it should be lower for the process which involves modification of the grains and composite structure, and higher for the hybrid hardening, depending on the required level of hardening in aluminium-based $AlMC_s$ composites,
- the technological process should determine the preferred temperature of melt overheating and solidification,
- adding the composite modifying powder in the form of intermetallic FeAl and TiAl phases should result in refining of the standard silumin structure, generating the dispersion of intermetallic phases of the complex Al-Si-Ti and Al-Si-Fe eutectics.

4. Test materials and methods

The research concept of making composite materials based on AlSi17 alloy required the use of a composite powder, whose phase composition was determined with the following formula: $FeAl_x$–$TiAl_x$–Al_2O_3. The granulation of powders was 40 and 60 μm for the surface-oxidised aluminium and iron powder, respectively. The selected alloy of AlSi17 (A 390.0 acc. to EN-AC-46200) were characterised by increased strength in the temperature range of 200-300^{0}C, good abrasion wear resistance and low coefficient of thermal expansion. The synthetic powder was introduced to liquid alloys at a temperature of 740^{0}C. The time of holding the metal bath with the added modifier ranged from 45 to 60 minutes. The selected samples were remelted in a PT-600PvG induction furnace at 780^{0}C and cast into a standard QC4080 Heraeus Electro-Nite sampler with NiCr-NiAl TP202 thermocouple. 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 shown in Figure 1.

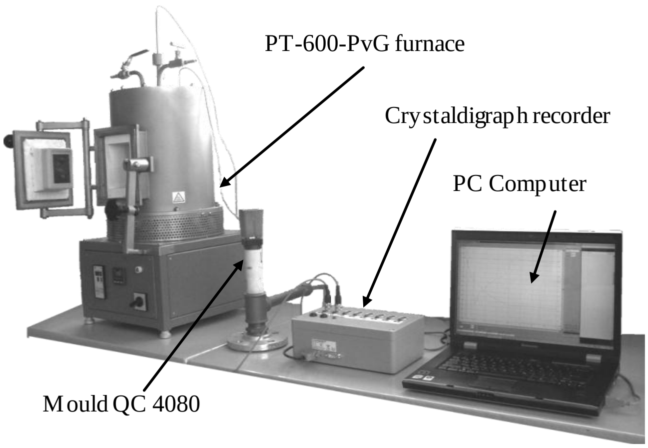


Fig. 1. Test stand for melting and casting of AlSi17 alloy

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.

5. 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 cast AlSi17 alloy before powder addition and after remelting and adding powder is shown in Figures 2 and 3, respectively.

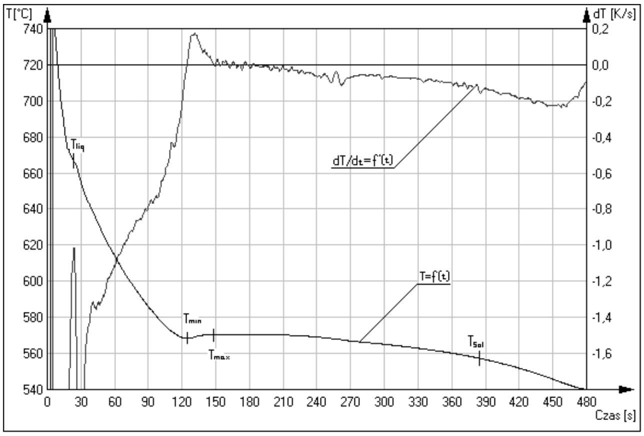


Fig. 2. ATD thermal analysis curve with characteristic points plotted for AlSi17 alloy before modification proces

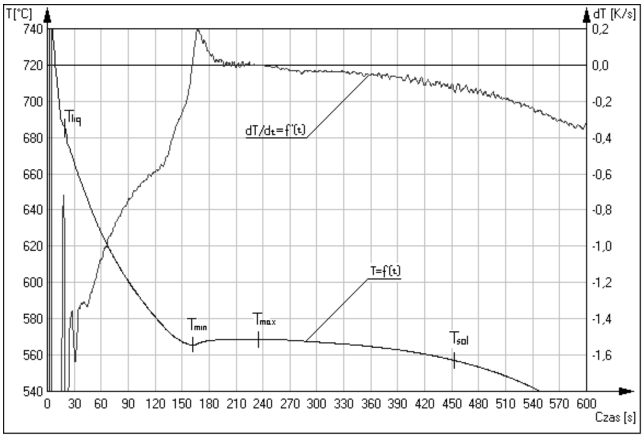


Fig. 3. ATD thermal analysis curve with characteristic points plotted for AlSi17 alloy after modification with powdered component

The results of chemical analysis after the introduction of powders are given in Table 1.

Table 1.
Chemical analysis of cast AlSi17 alloy, wt. %

	Si	Cu	Fe	Mn	Mg	Ni	Al
Alloy	16,81	0,17	0,54	0,03	0,04	0,13	rest

Summary of characteristic parameters of solidification proces of cast AlSi17 alloy before and after the introduction of a composite powder of intermetallic phases of Ti and Fe are shown in Table 2.

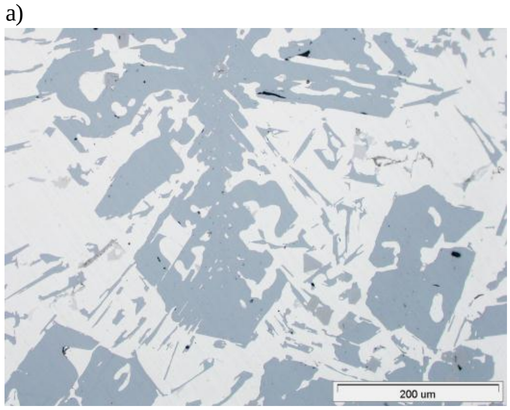
Table 2.
The selected temperatures of solidification process of cast AlSi17 alloy

Alloy	The parameters of crystallization, ^0C				
	$T_{cast.}$	$T_{liq.}$	$T_{Emin.}$	$T_{Emax.}$	$T_{sol.}$
AlSi17	748	670	572	575	556
AlSi17 modif.	744	688	571	575	558

Preliminary analysis of the specimens was basis for corrections introduced to the method of making composite aluminium alloy.

Examples of AlSi17 alloy microstructures before powder introduction are shown in Figure 4, and after adding the powder in Figure 5.

a)



b)

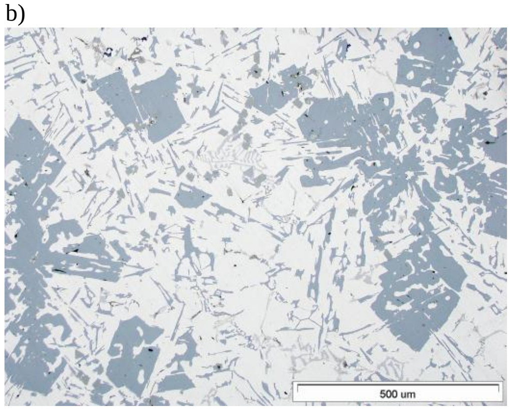


Fig. 4. Microstructure of cast AlSi17 alloy before modification the intermetallic phases of Ti and Fe:
a) magnification $\times$ 200, b) magnification $\times$ 100

Intermetallic phases Al_3Ti and Al_3Fe type in a coniferous precipitates observed in the structure of the cast alloy after modification proces - shown in Figure 5.

These phases are also modified silicon, with the stoichiometric composition of the precipitates varies greatly. It is connected with a high content of silicon in the alloy, as well as the conditions of crystallization of castings [12-18].

Examples of AlSi17 alloy microstructures after adding the composite powder containing the intermetallic phases of Ti and Fe shown in Figure 5.

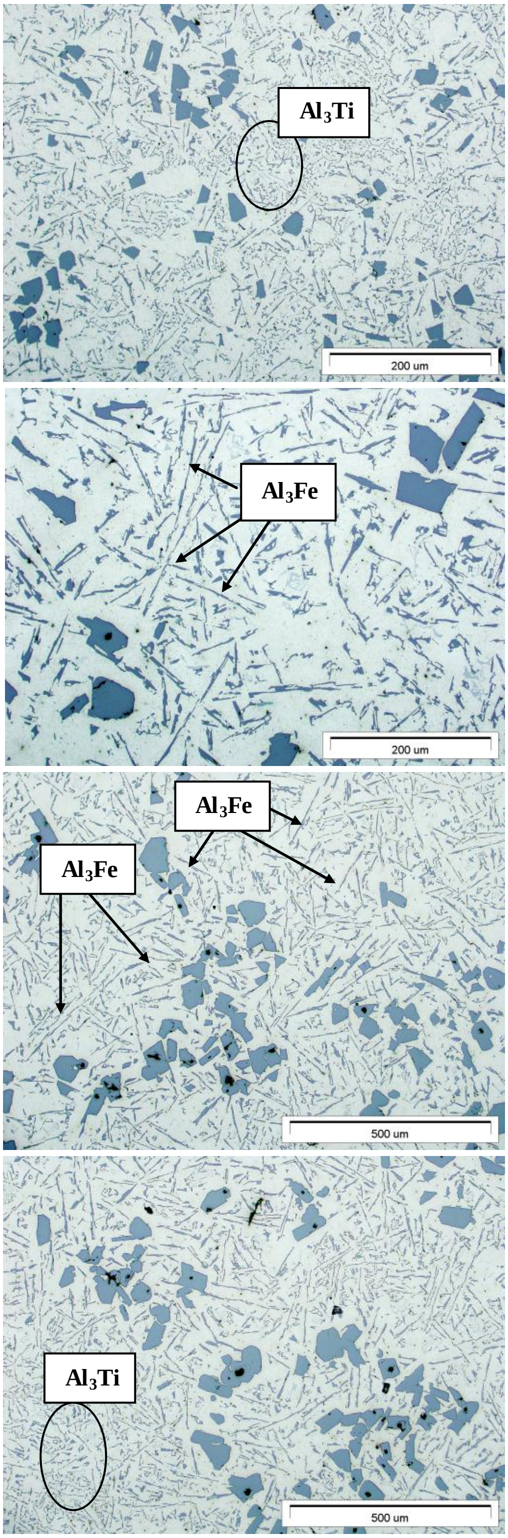


Fig. 5. Microstructure of cast AlSi17 alloy after addition of modifying component (unetched)
a, b) magnification $\times$ 200, c, d) magnification $\times$ 100

6. Summary

As follows from the characteristic values of the solidification temperature of AlSi17 silumin modified with composite powder containing the intermetallic phases of Ti and Fe, the temperature T_{cast} was similar in all experiments (about 740^0C), proving that similar conditions of melting and casting of the examined alloy were maintained.

The crystallisation temperature of the primary silicon crystals (T_{liq}) assumed the highest value of 670^0C for the AlSi17 alloy in base condition. The addition of composite powder containing the intermetallic phases of Ti and Fe resulted in a increase value (by 18^0C even) of this temperature (688^0C).

The crystallisation temperature of a binary α(Al)-β(Si) eutectic assumed similar value and amounted to 575^0C, preceded by a two-step temperature drop ($T_{Emin.}$ $571 \div 572^0$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_3Ti phase. Similar relationships are observed in the solidification of a quaternary Al-Si-Fe eutectic. For AlSi17 alloy in base condition, this eutectic crystallises at a temperature of about 509^0C, to drop after modification to a value of about 501^0C. The end of crystallisation is observed to take place within the temperature range of 556 do 558^0C, which is characteristic of the temperature $T_{sol.}$

The selected results of the investigations of AlSi17 silumin, dispersion reinforced with the following formula: $FeAl_x$–$TiAl_x$–Al_2O_3, document the structure of a new aluminium 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 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 component on a mechanism of the hypereutectic silumins structure modification has not been taken into consideration.

It is expected that structural effects and mechanism of the modification of hypereutectic Al-Si alloys 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.

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7. Conclusions

Based on the results of own investigations on the solidification and structure of Al-17wt.%Si alloy modified with intermetallic phases containing Ti and Fe, the following conclusions can be formulated:

1. Practical application of the adopted technological procedure to produce the designed dispersion-reinforced composite structure revealed a increase value of the crystallisation temperature of primary silicon crystals (T_{liq}), amounting to 18^0C.
2. The introduction of phases of the Ti and Fe aluminium powders also reduced the crystallisation temperature of complex eutectics containing the intermetallic phases of Ti and Fe.
3. The proposed technological procedure for the fabrication of composite material based on hypereutectic AlSi17 silumin has resulted in refining of the primary silicon crystals (β) 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 increase of the temperature arrest amounting to 18^0C for the primary silicon crystals and complex eutectics α-β-Al_3Fe and α-β-Al_3Ti.

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