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Structure of AlSi20 Alloy in Heat Treated Die Casting

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Abstract

The work is a continuation of research on the use of water mist cooling in order to increase efficiency of die-casting aluminum alloys using multipoint water mist cooling system. The paper presents results of investigation on crystallization process and microstructure of synthetic hypereutectic AlSi20 alloy. Casts were made in permanent mold cooled a with water mist stream. The study was conducted for unmodified AlSi20 alloy and a modified one with phosphorus, titanium and boron on the research station allowing sequential multipoint cooling using a dedicated program of computer control. The study demonstrated that the use of mold cooled with water mist stream and solution heat treatment allows in wide range for the formation of the microstructure of hypereutectic silumins. It leads to the growth of microstructure refinement and spheroidizing of phases in the casting.

Keywords: Innovative foundry technologies and materials, Die casting, Water mist cooling, Hypereutectic silumin, Microstructure

1. Introduction

The ongoing work is a part of the studies on the application of a water mist system for multipoint sequential cooling of casting die to produce silumin castings [1-5].

The essence of the research is the efficient cooling with water mist through evaporation of water droplets on a hot surface of the casting die. Analysis of the earlier studies indicates that the cooling of mold with the water mist stream enables shaping of microstructure and achieving high quality casts made of neareutectic silumins with improved properties. Efficiency of heat transfer process is largely determined by the characteristics of the generated stream, optimization amount of air and water in the mist stream and adequate spraying of water.

The aim of the study was to investigate the effect of water mist cooling and heat treatment on microstructure of hypereutectic silumin unmodified and modified simultaneously with phosphorus, titanium and boron. Castings made of these Al-Si alloys are used for heavy-duty pistons for combustion engines. They have good casting properties, corrosion resistance, good mechanical properties at elevated temperatures, abrasion resistance, low coefficient of abrasion and thermal expansion [6,7].

2. Experimental

The study was conducted on a working station (Fig. 1) with use the mold presented in Figure 2. The water mist was produced in the device (1, 2) that dosed the appropriate amount of water and its dispersion in the air by centrifugal spraying of water in a stream of compressed air (3). The mold was cooled with cylindrical nozzles placed perpendicular to the mold surface.

Research mold (Fig. 2) was made of X38CrMoV51 (10) steel.

In the body of mold were installed 3 symmetrical sections of cooling nozzles. Nozzles arranged so that each nozzle section of the mold cools one zone of the casting.
The control of cooling nozzles was carried out using a computerized control system cooling, developed by Z-Tech. The software system includes a set of functions and procedures to monitor and control the course of water mist generation for the multicircuited cooling system using pre-drafted program.

In the mold the test pieces of diameter 10 mm were casted with a use of the synthetic hypereutectic silumin AlSi20 which chemical composition was shown in Table 1.

Researched castings were heat-treated by supersaturating, consisting of annealing conditions: 520°C/4h and cooling in water. Cooling effect on the resulting microstructure was evaluated by using a Nikon MA200 microscope.

Table 1.
Chemical composition of researched Al-Si alloy

Name	Elements, weight %									
	Si	Mg	Cu	Mn	Fe	Ti	P	B	Sr	Al
AlSi20	21,48	0,008	0,004	0,001	0,22	0,0036	0,0018	0,0062	0,0001	Rest
AlSi20	21,37	0,008	0,012	0,001	0,31	0,184	0,0161	0,0420	0,0001	Rest

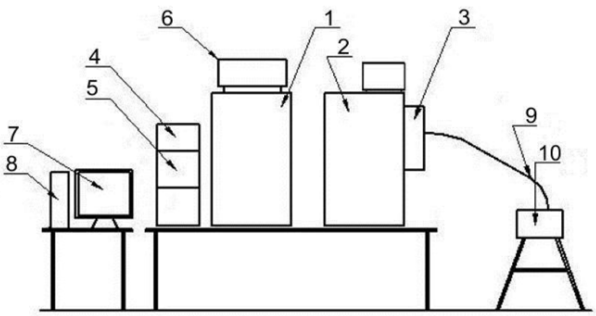


Fig. 1. The scheme of the research station: Modules: 1, 2 – air and water dosing, 3 – mixing of components, 4, 5 – supplying of air and water solenoid valves, 6 – computer cooling control, 7, 8 – PC, 9 – cooling circuit, 10 – research chill

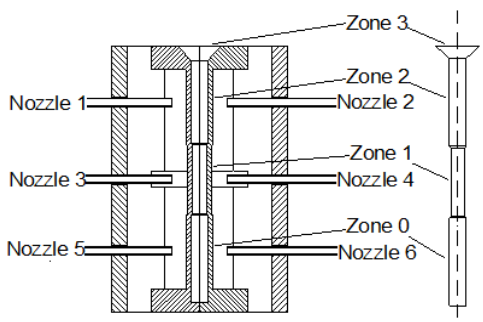


Fig. 2. Section of the research mold and casting, zones and nozzles

3. Results

The paper presents the effect of heat treatment on microstructure of hypereutectic silumin cast in gravity casting die that was cooled with water mist during the solidification process of casting. The research began from analyzing of crystallization process the basic unmodified AlSi20 alloy. It was made with thermal and derivative method (TDA). Cooling conditions of casting die (Fig. 1) were determined based on specific temperatures of crystallizing phases obtained by TDA method.

Supersaturating of castings was conducted simultaneously in the same conditions in a resistance furnace for the both sample types: unmodified and modified with P, Ti, B additives.

3.1. Crystallization of hypereutectic Al-Si alloy

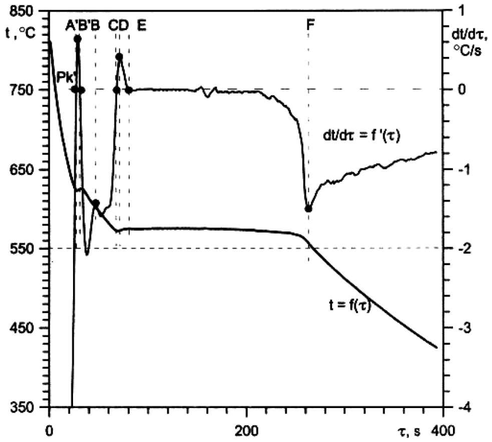
The crystallization of hypereutectic silumins starts from the initial crystallization of silicon crystals. Figures 3 and 4 show respectively representative curves ATD (Fig. 3a) and a flow diagram of crystallization (Fig. 3b) of unmodified hypereutectic silumin and microstructure of researched silumin (Fig. 4) obtained in the casting ATD sample.

There are two thermal effects of A' and B' in the preeutectic crystallization. A thermal effect is caused by the crystallization of large longwall crystal Si (Fig. 3a).

Emitted heat of crystallization of β phase cause the heating up of the alloy from $t_{Lmin} = t_{Pk}$ do $t_{Lmax} = t_{B'}$.

The concentration of silicon in the liquid around the large β crystals decreases creating favorable conditions for nucleation of the α phase on the existing silicon crystals. On the crystallization curve it manifests probably the result of heat at point B - from the crystallization of the α phase dendrites. Further lowering the temperature causes the silumin to enter into a zone of eutectic coupled growth and in terms of irregular eutectic CDEF crystallized lamellar α + β (Al + Si).

a)



b)

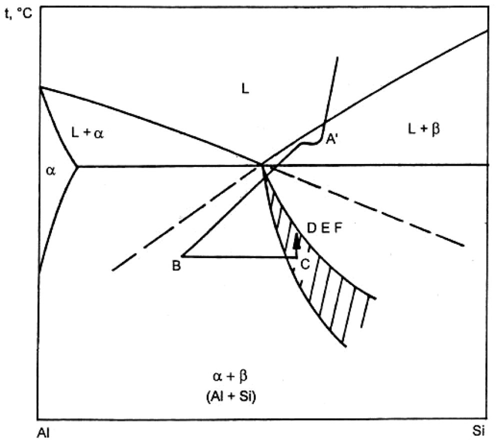


Fig. 3. TDA curves (a) and schematic crystallization process (b) of researched unmodified silumin [6]

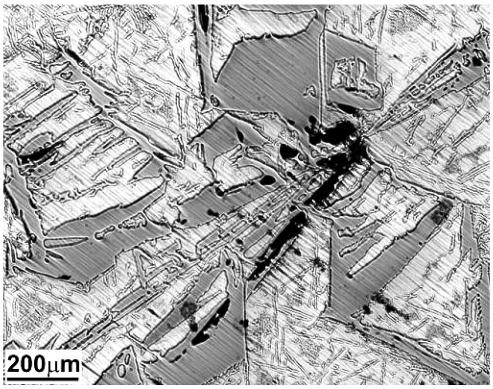


Fig. 4. Microstructure of researched silumin unmodified casted in ATD probe, Phase β (Si), eutectic α+β (Al+Si)

3.2. Structure of castings

Figures 5 and 6 illustrate a representative microstructure of researched silumin wall obtained in casting test mold (Fig. 2) adequately: in the die which was naturally cooling down from an elevated temperature (Fig. 5a,c) and the water spray cooled mold (Fig. 6) after heat treatment.

Figures 7 and 8 show the effect of water mist cooling on microstructure of the silumin modified with P, Ti and B elements after heat treated by supersaturating.

Comparison of the ATD sampler casting with the casting the from casting die, show that the refinement of the microstructure is much smaller for the ATD sampler. Both the preeutectic silicon grains and the eutectic ones are many times smaller. This is probably due to an increase in crystallization rate due to the increased cooling rate in the melt solidification temperature range of 0.3 K/s for the ATD sample to about 3.2 K/s for casting die.

The use of mold cooling water spray resulted in a further increase in the average silumin cooling rate to about 6.0 K/s. The cooling rate was estimated based on from results of the thermal analysis as an average in the solidification temperature range of the cast. Moreover as shown in Figure 6, the microstructure of the cast depicts the additional increase in refinement of the crystallizing phases and a change in crystal morphology of particle preeutectic silicon and eutectic grains.

Longwall silicon crystals are observed: large (100 ÷ 1200 μm) for the ATD sample and small (20 ÷ 200 μm) in the uncooled mold, in this cast almost non-existent. The microstructure of the cast is characterized by preeutectic, probably crystallized silicon dendrites [8]. They are built with thick first order branches, which grow from the nucleus in almost perpendicular directions, and have much thinner edge parallel branches of the second row. The microstructure is also present at the lamellar eutectic dendritic [7] (Fig. 5a).

Change in the morphology of crystallizing phases is probably the result of concentrated supercooling. It is caused by a high cooling rate of the silumin which prevents during the crystallization the flow and equalizing the concentration of the chemical composition of the melt. Under such conditions, a rapid enrichment of liquid crystallization happens among the front dendrites Si (β) of aluminum (α) which is located in the spaces between the branches of dendrite Si.

The modification of silumin in casting poured in the uncooled casting die (Fig. 5b, c) caused a change in morphology, reduction of primary Si crystals and a decrease in the eutectic lamellar interphase distance α + β (Al + Si) in comparison to the casting of the sample and in relation of the ATD and the uncooled cast. Silicon crystals are much smaller (20 ÷ 40 um) and have a compact longwall.

The use of mold cooling water mist caused preeutectic crystals double refinement and reduction of the size of β phase in the microstructure of silumin. From a comparison of cast microstructure (Fig. 5) follows that the mold cooling water mist reduces size of silicon primary crystals and lamellar eutectic grains of hypereutectic silumin modified with P, Ti and B.

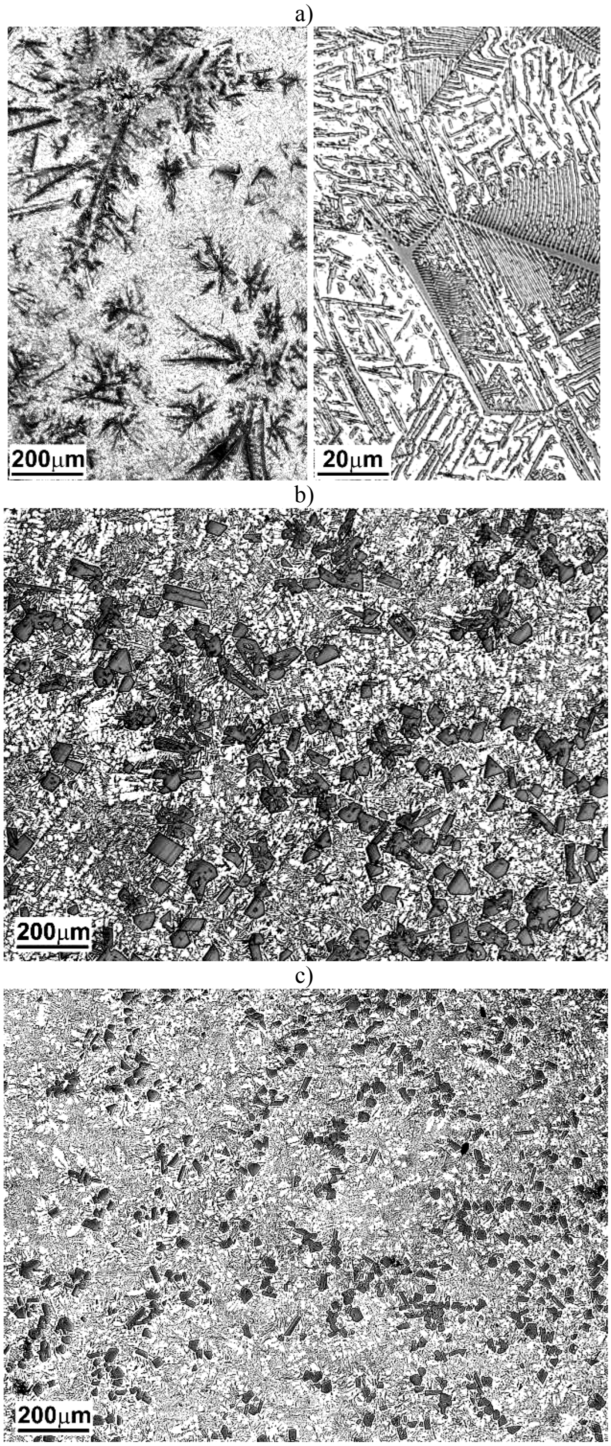


Fig. 5. Microstructure of AlSi20 alloy unmodified (a), modified with P, Ti i B (b, c) poured without cooling (b) and with water mist cooling of casting die (a, c). Phase β (Si), lamellar eutectic α+β (Al+Si)

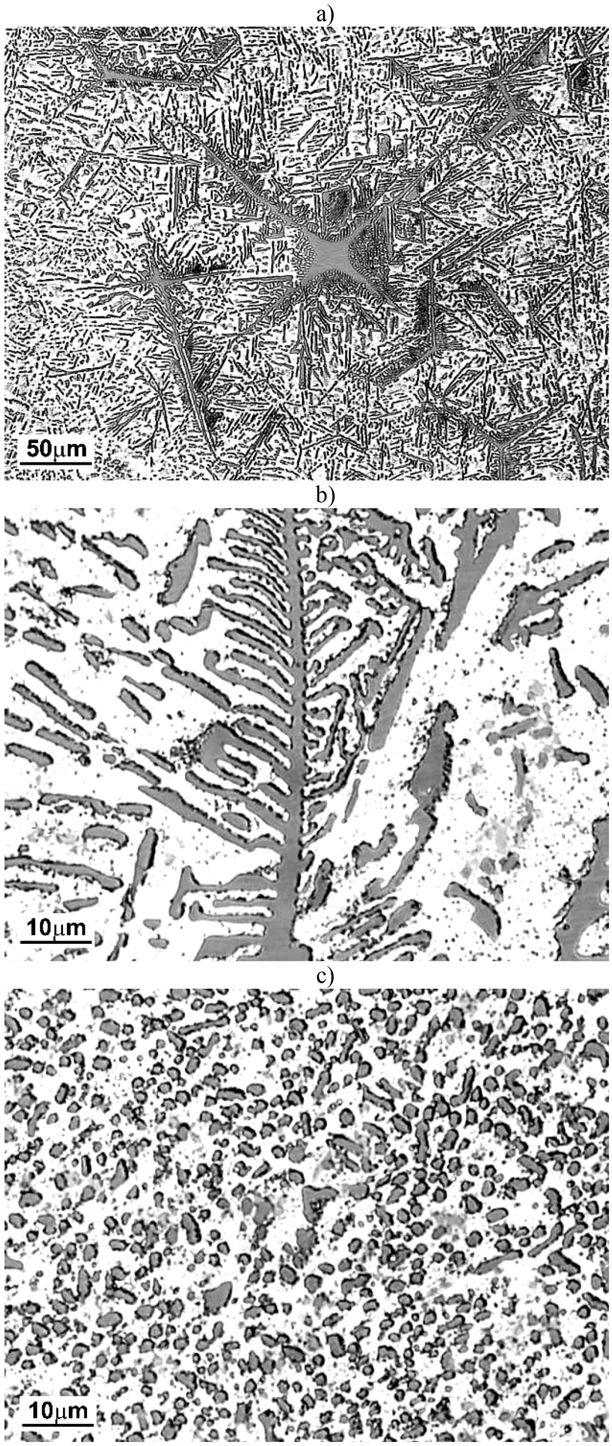


Fig. 6. Microstructure of AlSi20 alloy unmodified of casting made with water mist cooling of casting die, after heat treatment. Phase β (Si), lamellar eutectic α+β (Al+Si)

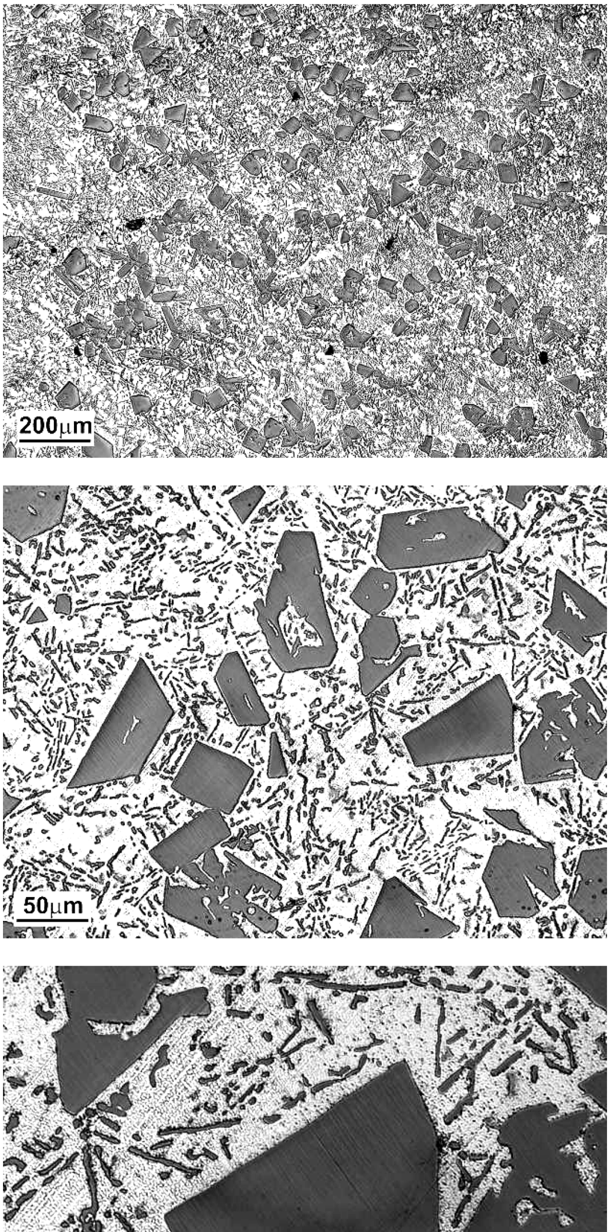


Fig. 7. Microstructure of researched silumin modified with P, Ti and B elements poured by ATD probe (a), in uncooled mold, after heat treatment. Phase β (Si), lamellar eutectic α+β (Al+Si)

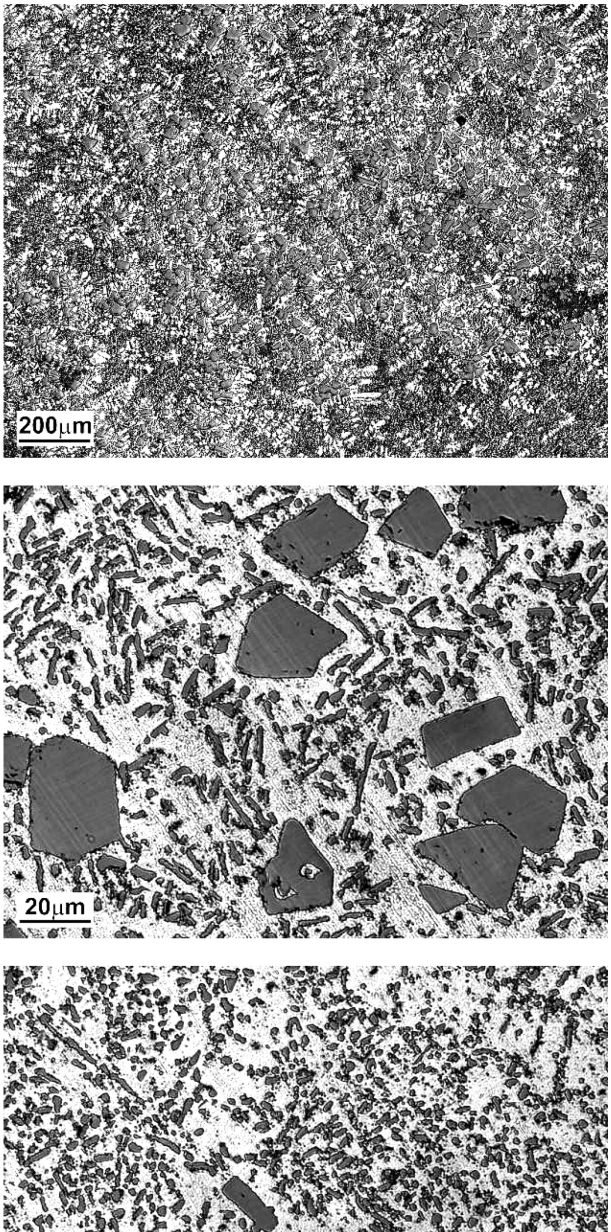


Fig. 8. Microstructure of researched silumin modified with P, Ti and B elements poured by water mist cooling of casting die, after heat treatment. Phase β (Si), eutectic α+β (Al+Si)

The solutioning of studied castings resulted in a change of morphology of the unmodified silumin, preeutectic silicon crystals and the change in the morphology of eutectic Si lamellas (Fig. 6).
The special characteristic changes relate to the dendrites of silicon in the boundary layer that shortly after pouring had thin and long branches of the second order and were shortened and thickened (Fig. 6a). Similar changes occurred in the eutectic dendrites (Fig. 6b). Changes in lamellar eutectic such as reducing and thickening of the silicon plates are noticeable particularly strong in the middle layer of the sample, where the majority of the plates depict spheroidization (Fig. 6c). Change in the microstructure morphology is a result of the saturation in the annealing process.

Comparison of Figures 7 and 8 shows the effect of mold cooling water spray on the microstructure of the hypereutectic silumin modified with P, Ti and B after heat treatment. The research shows that higher cooling rate as a result of mold cooling with water mist increases refinement of preeutectic longwall silicon crystals of the silumin. Heat treatment of these castings also causes rounding of the edges and a platelet shortening and a reduction in spheroidization of eutectic silicon plates. These changes are much larger in castings obtained in the cooled mold than in the one with natural cooling, in which the primary silicon crystals are larger and do not exhibit the edge rounding due to the heat treatment.

In summary, the studies show that the use both the mold cooling with water mist and heat treatment allows for the formation of various types of microstructure in hypereutectic silumins. A wide range of solidification temperature of hypereutectic silumins increases the potential impact of the change of cooling rate on the size, number and morphology of the crystallizing phases.

4. Conclusions

The study shows that the use of water mist cooling of mold together with a heat treatment:

- allows in a wide range for the formation of the microstructure of hypereutectic silumins,
- causes a several time refinement of microstructure compared to the casting from permanent uncooled mold and the TDA sample casting as well,
- reduces size of preeutectic silicon crystals and lamellar eutectic grains in hypereutectic silumin modified with P, Ti and B elements
- causes a shortening and thickening of the second order dendrite arms of preeutectic and eutectic silicon dendrites and coagulation eutectic lamellas in the microstructure of hypereutectic unmodified silumin,
- causes rounding of edges of the primary crystal and the spheroidization of eutectic plates in the microstructure of modified silumin.

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