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Effect of Water Mist Cooling on Microstructure of Hypereutectic Al-Si Alloy

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Abstract

The work is a continuation of research on the use 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 of crystallization process and microstructure of synthetic hypereutectic AlSi20 alloy. Casts were made in permanent mold cooled with water mist stream. The study was conducted for unmodified AlSi20 alloy and modified 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 allows the formation of the microstructure of hypereutectic silumins. A wide range of solidification temperature of hypereutectic silumins increases the potential impact of changes in the cooling rate on a size, a number and a morphology of preeutectic silicon and eutectic $\alpha+\beta$ (Al+Si).

Keywords: Innovative foundry technologies and materials, Casting die cooling, Water mist, Hypereutectic silumin, Microstructure

1. Introduction

The ongoing work is a part of studies on the application of 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 mist of water through evaporation of water droplets on a hot surface of the casting die. An analysis of earlier studies indicate that the cooling of mold with the water mist stream enables the 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 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 (shown in Figure 1) using 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 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 X38CrMoV5-1 (10) steel.

In the body of mold were installed symmetrically 3 sections of cooling nozzles. Nozzles arranged so that each nozzle section of the mold cools and one zone of the casting.

The control of cooling nozzles 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 generating water mist cooling system multicircuited using pre-drafted program.

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

Table 1.
Chemical composition of reserched Al-Si alloy

Name	Elements, weight %								
	Si	Mg	Cu	Mn	Fe	Ti	P	B	Sr
AlSi20	21.48	0.008	0.004	0.001	0.22	0.0036	0.0018	0.0062	0.0001
AlSi20 mod	21.37	0.008	0.012	0.001	0.31	0.184	0.0161	0.0420	0.0001

Cooling effect on the resulting microstructure was evaluated by using a Nikon microscope MA200.

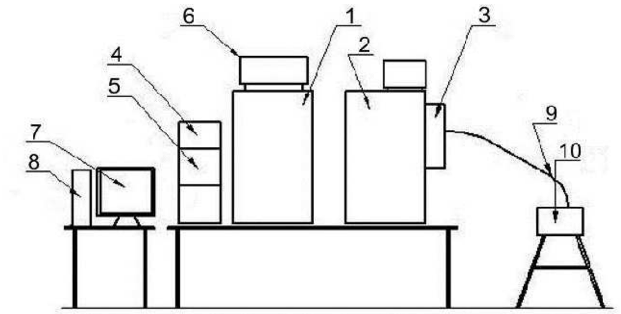


Fig. 1. The scheme of the research station: Modules: 1, 2 – air and water dosing, 3 – mixing of components, 4, 5 – supplying of air and water solenoid valves, 6 – computer cooling control, 7, 8 – PC, 9 – cooling circuit, 10 – research chill

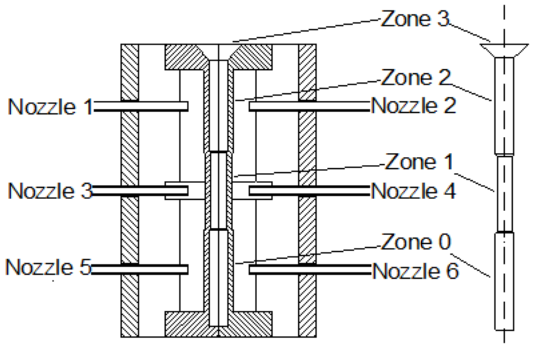


Fig. 2. Section of research mold and casting, zones and nozzles

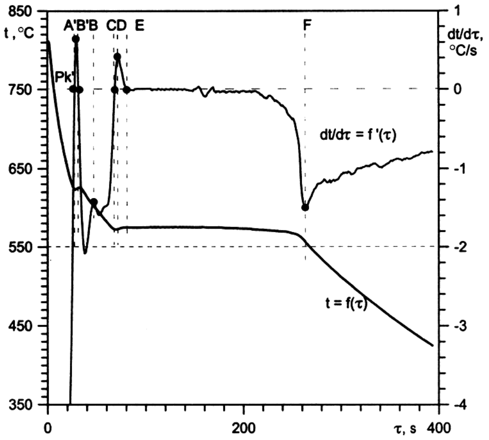
3. Results

In the paper presented the effect of cooling and solidification rate on the crystallization process and the microstructure of hypereutectic silumin. Castings were poured in the shell probe ATD10, in the steel mold cooling down naturally and in the steel mold cooled with water mist stream. Research was also conducted for the modified hypereutectic silumin by additives of phosphorus, titanium and boron.

3.1. Crystallization and microstructure of hypereutectic Al-Si alloy

The crystallization of hypereutectic silumins containing more than 14% of silicon starts from the initial crystallization of silicon crystals. In Figures 3 and 4 have shown, respectively, representative curves TDA (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 TDA sample.

a)



b)

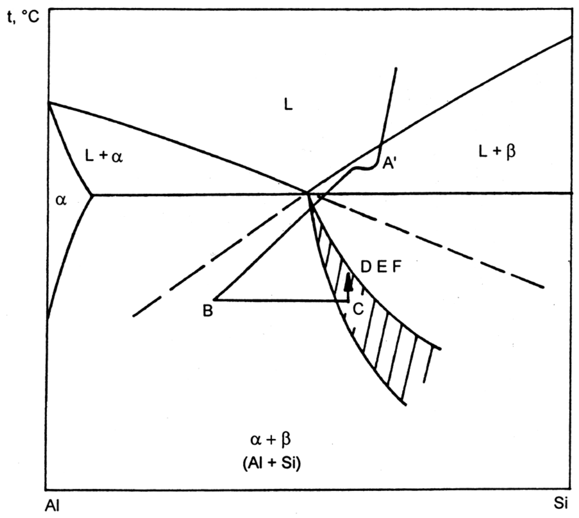


Fig. 3. TDA curves (a) and schematic crystallization process (b) of researched silumin [6]

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 crystals of β decreases creating favorable conditions for nucleation of 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 α phase dendrites. Farther lowering the temperature causes the silumin enter into a zone of eutectic coupled growth and in terms of irregular eutectic CDEF crystallized lamellar α + β (Al + Si).

3.2. Microstructure of permanent mold castings

In Figures 5 and 6 illustrates a representative microstructure of the unmodified researched silumin wall in the middle layer obtained casting mold test respectively (Fig. 2) of cooling naturally at elevated temperature (Fig. 5) and water spray cooled mold (Fig. 6). Research shows that the microstructure of die-cast walls, there are two distinctive zones, boundary and middle one.

Boundary layer is formed mainly by the pillar crystals with a thin layer of frozen crystals deposited on the surface of the casting. The middle layer consists mainly of equiaxed crystals.

Compared with the ATD sampler casting to the casting from casting die, the refinement of microstructure is much less for the ATD sampler. Both the preeutectic silicon grains and eutectic 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 die casting.

The use of mold cooling water spray resulted in a further increase in the average cooling rate silumin to about 6.0 K/s. As shown in Figure 6, the microstructure of the cast, in addition to the increase in refinement of the crystallizing phases of a change in crystal morphology of particle preeutectic silicon and eutectic grains.

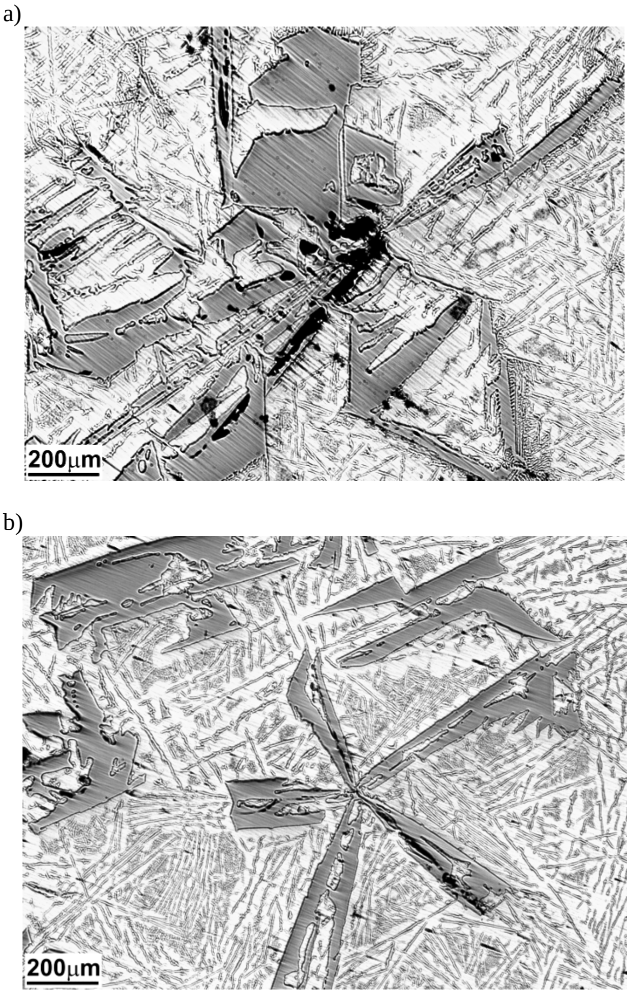


Fig. 4. Microstructure of researched silumin unmodified casted in ATD probe. Phase β (Si), eutectic α+β (Al+Si)

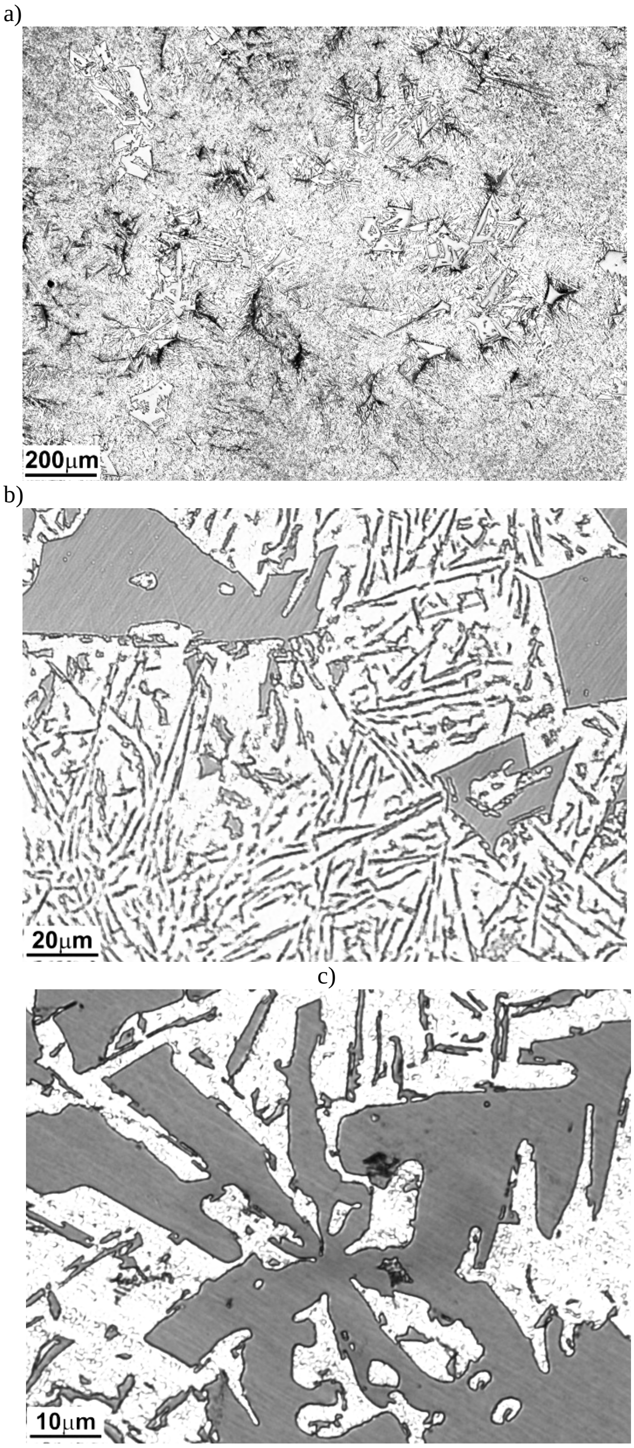


Fig. 5. Microstructure of researched silumin unmodified casted in mold (Fig. 2) uncooled.
Phase β (Si), eutectic α+β (Al+Si)

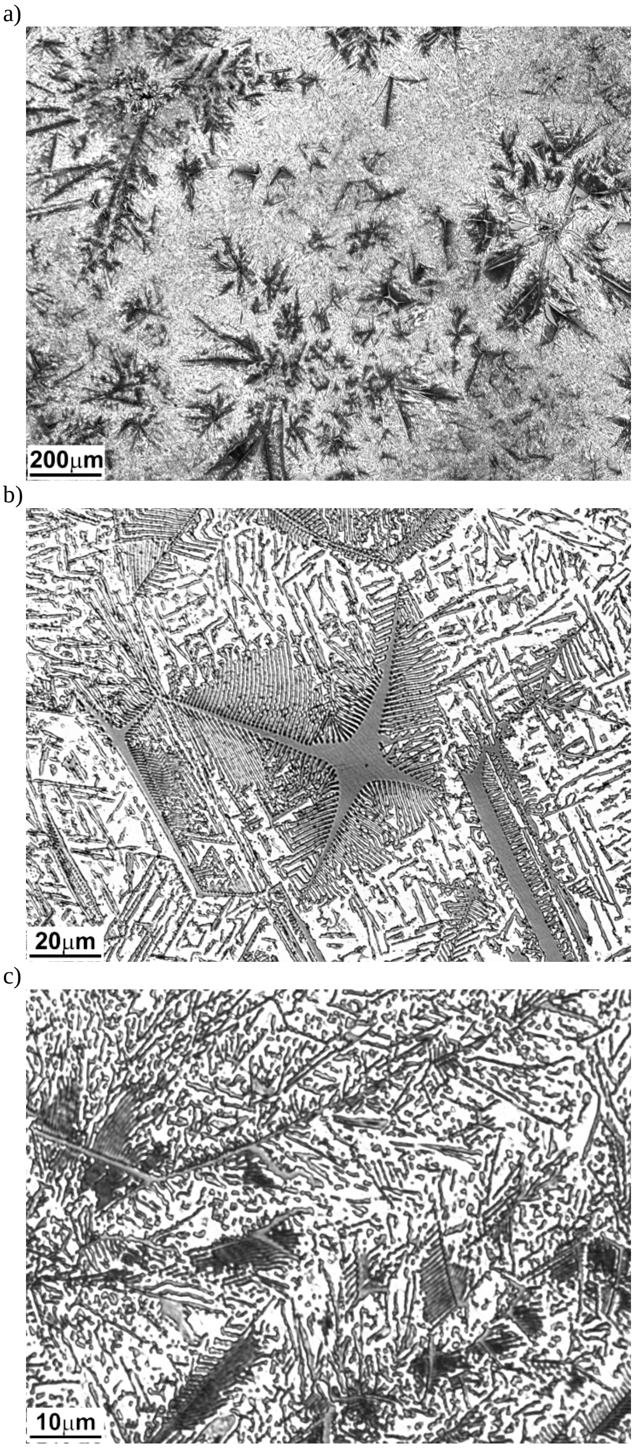


Fig. 6. Microstructure of researched silumin unmodified casted in mold (Fig. 2) cooled with water mist.
Phase β (Si), eutectic α+β (Al+Si)

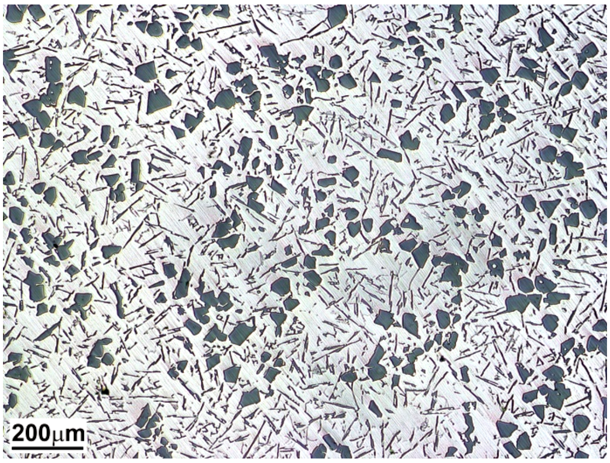
Longwall silicon crystals are observed in the sample ATD as a large (100 ÷ 1200 µm) and in uncooled mold – as a small one (20 ÷ 200 µm) in this cast almost non-existent. The microstructure of the cast is characterized preeutectic probably crystallized silicon dendrites [8]. They are built with thick branches of the first order, 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 and the lamellar eutectic dendritic [7] (Fig. 6c). Dendritic eutectic grains are the dominant component of the microstructure column in the boundary layer of the casting.

Changing the morphology of crystallizing phases is probably the result of concentration supercooling. It is caused by a high cooling rate of silumin, which prevents crystallization of the case where, to equalize the concentration of the chemical composition of the melt. Under such conditions, a rapid enrichment of liquid crystallization front dendrites Si (β) of aluminum (α) which locates in the spaces between the branches of dendrite Si.

Figure 7 shows the microstructure of the hypereutectic silumin modified simultaneously with phosphorus, titanium and boron obtained in the cast: of sample ATD (Fig. 7a), from uncooled mold (Fig. 7b) and from water mist cooled mold (Fig. 7c). The modification caused a change in the morphology and several-times reduction in primary crystal Si and has not changed eutectic lamellar α + β (Al + Si) in the cast sample ATD.

Silicon crystals are much smaller (20 ÷ 40 µm) and have a compact longwall. In the casting made in uncooled mold the preeutectic crystals have similar size as the sample ATD. The use of mold cooling water mist caused their double fragmentation and reduction of the share of this phase in the microstructure of silumin. From a comparison of cast microstructure (Fig. 7) 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.

a)



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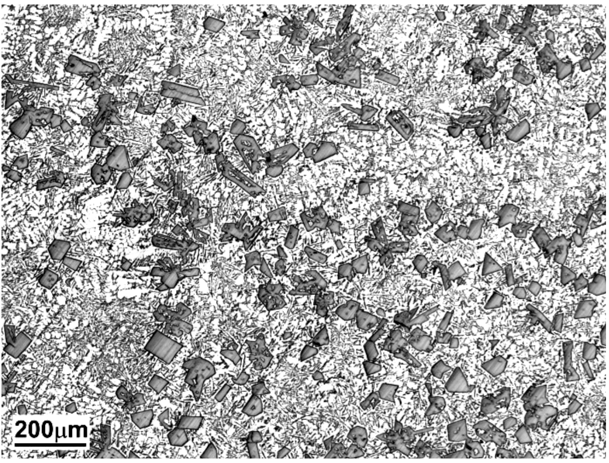

c)

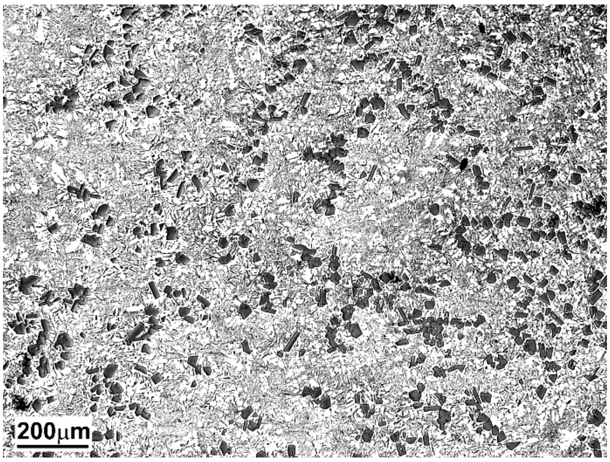

Fig. 7. Microstructure of researched silumin modified with P, Ti and B elements casted in ATD probe (a), in uncooled mold (Fig. 2) and in mold cooled with water mist (c). Phases: β (Si) α (Al), eutectic α+β (Al+Si)

In summary, the studies show that the use of mold cooling with water mist allows the formation of the microstructure of 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 (Si, Al) and eutectic α + β (Al + Si).

4. Conclusions

The study shows that the use of water mist cooling of mold:

- allows the formation of the microstructure of hypereutectic silumins,
- causes a several times refinement of microstructure compared to the casting from permanent uncooled mold and the TDA sample casting as well,

- results in a microstructure of hypereutectic unmodified silumin preeutectic silicon dendrites and dendritic eutectic,
- in hypereutectic silumin modified with P Ti and B elements reduces size of preeutectic silicon crystals and lamellar eutectic grains.

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