Water mist effect on cooling process of casting die and microstructure of AlSi9 alloy

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Abstract

The paper presents the results of crystallization and cooling process of silumin AlSi9 and temperature distribution in the wall of research casting dies made of cast iron and steel in the temperature range 650÷100°C during casting of silumin using water mist cooling consisting with air compressed (0,3÷0,4 MPa) and water (0,35÷0,45 MPa). It's shown the nature and rate of change of casting die temperature and the formation of the temperature gradient at the wall thickness in the axis of the nozzle cooling the outer surface of the wall of casting die. Using derivative curves and regression models were compared to the temporary and average speed of crystallization and cooling of the casting in the 75÷200°C temperature range. The differences of microstructure resulting from a change in the type of casting die, wall thickness of casting and the use of cooling water mist. It has been shown that the use of water mist and the changing wall thickness of die and the casting cooled pointwise lets you control the crystallization process, microstructure and quality of the silumin casting.

Keywords: Innovative Materials and Casting Technologies, Cooling, Water Mist, Die Casting, Silumin

1. Introduction

The results of the paper represent a continuation of studies on quality improving of the casts making by die casting process to shorten the cycle of the process and improving the silumin casts' properties, that were casted in metal [1÷3].

The objective of the study was to analyze the process of heat exchange during cooling of both the casting die and the cast in a specific area of crystallization temperature and cooling in a solid cast, and to research the possibility of crystallization controlling and cast microstructure obtained by means of cooling water mist. Based on previous research in the production of silumin casts by low pressure technology to research selected silumin AlSi9 and casting die made of cast iron EN-GJL-200 [4].

In objective to examine the impact of cooling water mist on the course of crystallization and microstructure of cast silumin tests were also applied to a shaped permanent molds made of steel EN-X37CrMoV5-1 commonly used to build of casting dies. Designed die’s cavity consists of three interconnected areas with a wall thickness of 5÷15 mm and characterized by a great diversity of solidification modulus. At present commonly used the cooling method of casting die rely on taking away the heat with compressed air stream aim towards the special prepared place of external surface of casting die. The air has small effectiveness of heat transfer and it causes that cooling process with air is power-consuming.

The essence of achieving of high effectiveness of cooling with use of the water mist is taking the heat away as a result of droplets water evaporation on the cooled surface. This way is increases the heat transfer repeatedly.
Achievement of the goal consists in researching of self-cooling process of casting die on the laboratory test stand and describing what is the influence on the heat transfer process, silumin’s microstructure the following factors: cooling with water mist, metal of casting die, wall thickness and initial heating temperature of casting die.

2. Experimental

The test stand shown schematically in Figure 1 and its actual status in Figures 2–4. The essence of this study was to silumin AlSi9 casting temperature of 750°C samples (1) measuring φ150 x 20 mm and 0,8 cm solidification modulus in pre-heated to the temperature ranging from 50 to 620°C research die (2). Casting die "1" is made of gray cast iron grade EN-GJL-200 were placed on a base (4) in thermal insulation of the cover (3) the possibility of directional heat exchange with the surroundings only by the lower surface of an unshielded, which were cooled by surface water mist delivered by nozzle (7).

Research casting die "2" made of steel EN-X37CrMoV5-1 was shown in Figures 2, 3 and 4. Castings which were made in the mould consisting of three power section with a wall thickness in the range of 5-15 mm and solidification modulus in the range of 0,16÷0,3 cm. The casting die was cooled poinwise using three nozzles placed in cylindrical sockets near each above mentioned section of the casting. The temperature of casting die "1" was measured simultaneously K-type thermocouples (5) deployed in the axis of the nozzle cooling the casting die the section of 15 mm and wall thickness in the casting, while the die "2" thermocouples positioned within 2 mm from the surface of each of the three sections of the casting and in the casting. Recording of the temperature was conducted with 0,1°C accuracy and 2 Hz frequency using registrars: KD7 (6) and the company LUMEL Crystallograph PC-2T company Z-Tech (9).

Fig. 1. Test stand scheme: 1 – cast, 2 – research casting die, 3 – heat-insulating shield, 4 – base, 5 – thermocouples, 6 – temperature recorder, 7 – nozzle of cooling system, 8 – multichannel cooling device, 9 – PC

Fig. 2. Research stand

Fig. 3. Research casting dies

Fig. 4. Research casting dies with thermal insulation cover (Fig. 1 point 3)
The water mist was being generated in multichannel cooling device (8). It lets to simultaneous dosing and spraying water in channel of the cooling system. Controlling cooling circumferences consisted in the change of the pressure of compressed air in the 0.20 to 0.45 MPa range and of water from 0.25 to 0.50 MPa. Demonstration stream of sprayed water and the starting cooling mist were shown in Figure 5. The investigations of influence of cooling on the microstructure and hardness were made adequately with use MA200 the optical microscope In this work the AlSi9 hypoeutectic silumin was used.

![Fig. 5. Stream of sprayed water (a) and water mist (b) obtained with use of designed rotary sprayer](image)

### 3. Results

The paper examined the distribution of temperature in the cast and at the selected points of the researched casting die wall during the cooling process of the silumin cast with the use of cooling water mist at the air pressure from 0.30 to 0.40 MPa and the water from 0.35 to 0.45 MPa and in other case - without cooling. Figure 6 and 7 shows the change in temperature and cooling rate of casting silumin AlSi9 and temperature in the wall of cast iron research die "1" (Fig. 1) chilled surface water mist at a pressure of air and water, respectively 0.30 / 0.35 MPa. From the data shows that the cooling casting proceeded in several key stages: 1 – silumin liquid cooling, 2 – eutectic crystallization phase α (thermal effect A on the derivative curve), 3 – crystallization of eutectic α + β (DF thermal effect) and 4 – casting cooling in the solid state. Casting temperature reached 350°C after 230 s cooling down in this regard with an average speed of 1,29°C/s.

In addition, studies show that pre-heated permanent molds have considered cross-section of its thick wall temperature of 620÷626°C. After pouring of the silumin the temperature of mould increased to 657°C and the temperature gradient appeared on its thickness. Then the temperature stabilized at the cross walls reaching 632°C. Starting water mist cooling of casting die (Fig. 6, point Ms) resulted in a sharp reduction in temperature of the die and the emergence of the temperature gradient at the wall thickness. Characteristic temperature recorded at a distance of 7, 12 and 17 mm from the chilled surface of the shape of the curve reflects its thermal and crystallization of the casting stages of crystallization effects.

From illustrated in Figure 7 the temperature distribution in the thickness of the research casting die "1" results that filling of its with liquid metal was caused slight increase of the temperature and temperature gradient resulted in thickness of wall of the die. Begin cooling water mist increased the temperature gradient as a result of intensive lowering the temperature at points of cooled casting die located closer to the surface than near the casting. The average value of the temperature gradient in the thickness wall of the die during cooling varied in the range (1,32÷20,8) * 10\(^3\) K/m. The maximum value recorded in the gradient near the surface cooled in time 71 s of the cooling process.

From the Figure 8 studies casting microstructure obtained in research casting die "2", which describes the cooling process in Figure 1 and 7. The microstructure consists of silumin eutectic phase α dendrites and the eutectic lamellar α + β. There was wide variation of quantity and size of crystallizing phases between casting a layer near the surface cooled casting die (Fig. 8c) and a further part of the casting section (Fig. 8a, b), in which the size of dendrites and the distance between lamellas of eutectic α + β is several times greater.

In Figures 9 and 10 was shown the effect of time on the temperature and cooling rate of the pouring gate and the research casting die "2" initial heated to a temperature of 50°C uncooled. The data showed that cooling the casting took place in an average speed of 1,6°C/s reaching the 143 s temperature of 200°C. In the first stage after pouring with the silumin of the mould follows the cooling down to liquidus temperature of the alloy. The process reaches a speed of about 72 K/s. Crystallization of the silumin was recorded on the cooling curve \( t = f(\tau) \) and derivational \( \frac{dt}{d\tau} = f(\tau) \) starts in 4 s at 582°C preeutectic nucleation phase α. From 14 s also crystallizes eutektika α+β. Crystallization process ends after 32 sec while the casting cooling rate increased more than 9 K/s. During this period the temperature in the test points of the die increases to values in the range from 74°C in a thin section of casting and to 88°C in thick and medium wall section of casting ("thin", "thick" and "medium" in Figure 11). Cooling of casting die characterized by low average speed throughout the range of values from -0,047÷0,017 K/s.

Figure 11 presents the effect of time on the temperature and cooling rate of pouring gate and the research casting die "2" pre-heated to a temperature of 520°C and chilled water mist with the air pressure 0.30 MPa and 0.35 MPa water. Uses two stages of cooling water mist using three separate cooling circuits, which nozzles were placed in cylindrical sockets of the die. In the first launched in the 8 s stage (Ms,2), cooled simultaneously by two channels areas of casting die: thick and medium-wall casting, while starting point Ms, cooled permanent molds well in the third part - close to the thin wall casting.

From the tests results that cooling the casting took place in an average speed of 1,08°C/s reaching in 160 s the temperature 400°C in the pouring gate. Cooling of die’s areas as a result of the applied cooling characterized by high dynamics of change. Registered casting die cooling rate reached the maximum temporary value of the test points, respectively from 15 to 26 K/s.
The comparison presented in Figures 6-10 cooling processes of casting and castin dies that use of multichannel cooling system combined with the impact point refrigerant in the slots, you can control the cooling process of the die and casting in a large extent of the contemporary speed of cooling.

Figure 12 presents the view of the casting obtained of research casting die "2" pre-heated to 50°C cooling without cooling. The study shows that the resulting casts in such conditions are characterized by a large number of defects. They occur primarily shrinkage defects in the surface of the wall collapsing part of a thick cast iron weight with the largest and most coagulation module Mk = 0,3 cm. In addition, changes in cross-sectional areas between the parts of casting revealed shrinkage depression of wall and the incomplete representation of the shape of the end of the thinnest part of the casting. The observed defects in the external and internal porosity disqualified of the cast.

In Figure 13 was shown fragments of casting, together with cross sections from which samples were taken for testing the microstructure obtained in the casting process described in Figure 11. Research shows that the resulting cast very well reproduced casting die cavity shape, the walls of the flat have clearly outlined the shape of the sharp edges intersecting walls. Casting surfaces do not show concavity and misruns so significant for the shrinkage defects. A comparison of castings illustrated 12 and 13 shows that the use of a pointwise multichannel water mist cooling system helps prevent the formation of defects in the difficult casting which has form-variable cross-section and of which the solidification modulus of wall is contained in wide range.

In Figure 14 (a-f) was shown the microstructure of unmodified silumin AlSi9 pouring in casting die "2" at its characteristic sections: thin (Fig. 14a, b), the average thickness (Fig. 14c, d) and thick (Fig. 14e, f). The research shows that the microstructure consists of isolated preeutectic α phase dendrites and the eutectic lamellar α + β.

Shown in Figure 14a, b the thinnest part of the casting wall thickness of 5 mm and 0,16 cm solidification modulus is characterized by extremely high dispersion of the microstructure. The size of α phase dendrites present in the test section is less than 0,2 mm. β eutectic phase (Fig. 14b) are compact in the shape of short plates or beads, similar to its appearance silumin precipitates obtained by heat treatment.

The increase in wall thickness of casting up to 10 mm and a solidification module of 0,25 cm (Fig. 14c, d) causes that occur in the microstructure silumin α phase dendrites larger sizes of up to 0,4 mm. An important feature of this part of the casting is eutectics α+β, where the plates as a thin wall (Fig. 14b) are small in length as you did in modified silumin, causing a clear outline the boundaries α preeutectic dendrites.

A further increase in wall thickness of casting (15 mm Mk = 0,3 cm) causes a further increase in the size of α dendrites (>0,5 mm), extending the plates α + β eutectic and the crystallization of additional phases AlSiFeMn, Al2Cu, Mg2Si.

The study shows that the microstructure of silumin has a large homogeneity and low porosity. A comparison of the microstructure of cast in metal molds research received "1" and "2" indicates that intensive cooling water mist with the reduction of wall thickness of casting (5-20 mm) allows you to crush the microstructure of the cast and change the morphology of the crystallizing phases. Yields results suggest an alternative to modification and heat treatment capacity to increase the quality of the microstructure silumin.
Fig. 6. The influence of time on the temperature and cooling rate of casting and casting die wall “1” in distance: 2, 7, 12 i 17 mm from external surface cooled with water mist under pressure 0,30 / 0,35 MPa
Fig. 7. The influence of distance from cooled surface and of cooling time on the change of temperature of die initial heated to 620°C and cooled with used of 0.30 / 0.35 MPa water mist.

t = 1.32 * l + 606

t = -0.3 * l^2 + 26.6 * l + 62.2

t = 5.15 * l + 73

Fig. 8. Microstructure of middle part of casting wall – a), b) and close to edge – c) of AlSi9 silumin achieved in casting die initial heated to 620°C, cooled with used of 0.30 / 0.35 MPa water mist. Dendrites of preeutectic α fase, eutectic α+β.
Fig. 9. The influence of time on the temperature and cooling rate of casting and casting die “2” initial heated to 50°C

Fig. 10. Effect of time on temperature and cooling rate of sections research casting die "2" initial heated to 50°C
Fig. 11. Effect of time on the temperature and cooling rate of casting and research casting die “2” initial heated to 520°C and cooled with water mist under pressure 0.30 / 0.35 MPa.

Fig. 12. Casting received in research casting die „2“ initial heated to 50°C uncooled.
Fig. 13. Casting received in research casting die „2” initial heated to 520°C cooled with water mist under pressure 0,30 / 0,35 MPa

Fig. 14. Microstructure of casting made of AlSi9 silumin in research casting die “2” initial heated to 520°C cooled with water mist. Dendrites of preeutectic α fase, eutectic α+β
4. Conclusions

The following conclusions result from described examinations:
- the change of material, wall thickness and temperature of initial heating of casting die chilled water mist allows to control the intensity of incoming heat casting die in the desired area of the casting and casting die,
- the average of temperature gradient in the wall thickness of cast iron casting die during cooling process varies in the range of $1.32 \pm 20.8 \times 10^3$ K/m,
- casting of silumin AlSi9 in a steel shaped casting die chilled with water mist under pressure $0.30 \div 0.35$ MPa increases the quality of the casting and prevents shrinkage defects,
- water mist cooling of the casting increases the rate of crystallization and cooling of the silumin casting and consequently causing size-reduction and homogeneity of the microstructure of casting.

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