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COMPUTER CONTROL THE COOLING PROCESS IN PERMANENT MOLD CASTING OF Al-Si ALLOY

STEROWANIE KOMPUTEROWE PROCESEM CHŁODZENIA FORMY W ODLEWANIU KOKILOWYM SILUMINÓW

The paper presents the test results of a computerized control system the sequential cooling process of permanent mold with use of water mist in the gravity die casting process.

It describes the process for preparing high-quality casts made of AlSi7Mg alloy that achieves enhanced mechanical properties. A scheme of developed device and drivers for selected methods of sequence cooling for manufacturing of castings made in permanent steel mold was presented here. Also the microstructure and mechanical properties of received aluminium casts were described. It was shown that the use of a computer system to control the water mist cooling point of the mold not only accelerates the cooling of the cast and the gravity die casting cycle shortens, but also it has a positive effect on the microstructure and mechanical properties of castings made of unmodified AlSi7Mg alloy in a raw state.

Keywords: Innovative materials & casting technologies, cooling, water mist, Al-Si alloy

W pracy przedstawiono wyniki badań komputerowego systemu sterowania sekwencyjnym chłodzeniem kokili mgłą wodną w odlewaniu grawitacyjnym. Opisano proces otrzymywania wysokojakościowych odlewów z siluminu AlSi7Mg o podwyższonych właściwościach mechanicznych. Przedstawiono opracowane urządzenie, programy sterujące dla zadanych metod wytwarzania odlewów kokilowych i sekwencji chłodzenia. Przedstawiono mikrostrukturę i własności mechaniczne otrzymanych odlewów siluminowych. W pracy wykazano, że zastosowanie systemu komputerowego do sterowania chłodzeniem punktowego mgłą wodną nie tylko przyśpiesza stygnięcie odlewu i skraca cykl odlewania kokilowego, ale również korzystnie wpływa na mikrostrukturę i własności mechaniczne odlewów z niemodyfikowanego siluminu AlSi7Mg w stanie surowym.

1. Introduction

In the process of casting, solidification of the casting is an essential step of the heat exchange that occurs between the cast, the permanent mold and environment. It determines the type of the resulting microstructure and the properties of cast [1-3]. The most commonly used solidification factor that increases the intensity of the conventional casting in metal molds is to change the wall thickness and the outer surface of the mold wall [3,4]. Further increase in the intensity of heat exchange can be achieved by the use of a forced air or water flow, spraying the outer surfaces or dipping the mold walls in water. The pressure die casting use mainly forms with a closed cooling system which task is to stabilize the temperature field within the pressured mold [5,6]. From the studies on cooling the solid surface with a mixture of free flowing stream of water and air it is apparent that this type of cooling provides a particularly high heat flux (Bi >>1) and favorable economic and regulatory aspects [2,7,8]. In turn the increase of the cooling rate results in a higher aluminium alloy cast dendritic grain fineness and reduces eutectic interlamellar distance [9-13]. The aim of this study was to analyze the impact of the sequential cooling of the selected zones in the mold on the microstructure and properties of the cast. The study analyzed the heat transfer during cooling of the mold at the temperature of crystallization and cooling of the casting in the solid state and to examine possibilities to control the crystallization front and the cast microstructure with a computer program. The aim of this study was to analyze the impact of the cooling sequence selected zones of mold on the microstructure and properties of aluminium alloy casts. Study involved an analysis of the heat transfer process during cooling the mold at a temperature of crystallization and cooling of the casting in the solid state and to explore the possibilities to control the crystallization front and cast microstructure obtained by computer I control the cooling of water mist in selected points of the mold.

2. Experimental

The study was conducted on a research station with using of the research mold from Fig. 1. Water mist illustrated in Fig. 2 were produced in the device by dispensing 0.1 l/min of water, and 150 l/min of air. Water droplets were produced by using of spinning nozzle in the compressed air line, which transported them to the cooled zone of mold.

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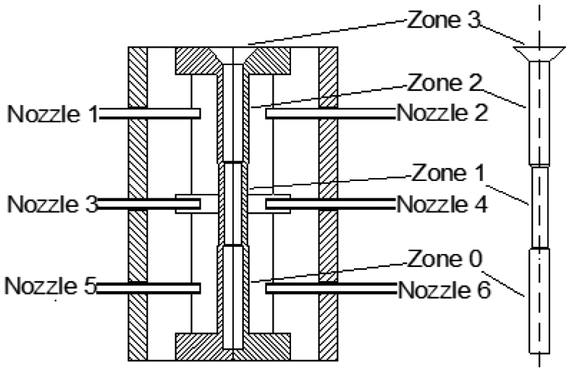

Fig. 1. Section of mold and casting, zones and nozzles

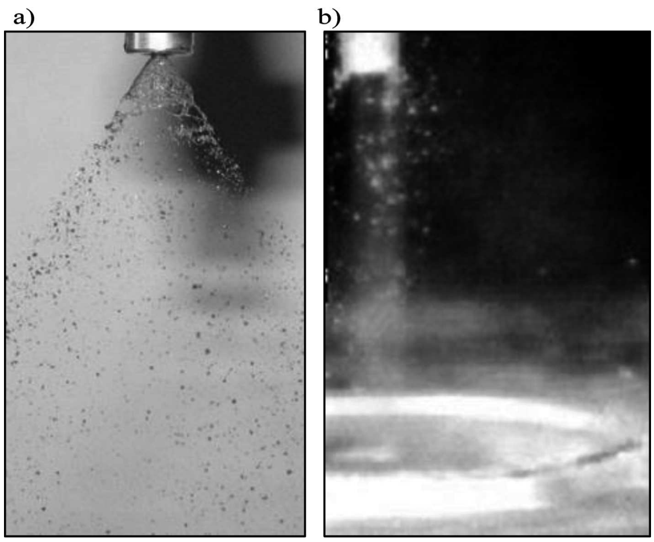

Fig. 2. Generate mist: a – sprayed water with spinning nozzle, b – a stream of water mist cooled directed to the mold surface, magn. x2, registrations camera and fast camera

The metal mold was cooled by placing the cylindrical nozzles perpendicularly to the surface of the mold. The temperature of the mold and the casting was studied using K – thermocouple placed in the casting and mold. For the analysis of temperature zones with heat exchanges a thermal imaging camera from company Optris PI was used.

Research mold was made of steel X38CrMoV5-1. In the body of the mold there were installed symmetrically three sections of cooling nozzles. Nozzles provided in such manner that each section of the nozzle cooled one zone of the mold and casting.

The nozzles were controlled using a computer system developed by a company Z-Tech. System software includes a set of functions and procedures for monitoring and control of the course of the water mist generating in a multi-circuit cooling system.

Investigation of the effect of sequential cooling on the mechanical properties of Al-Si alloy castings were made with performing static tensile test on the machine INSTRON 4485.The sample of "R_m" was casted from technically alloy AlSi7Mg unmodified. The mold was cooled by the methods (M1-M5) presented in Table 1. M2-M4 methods differ used chilled priority zone, adequately: M2 – 1, M3 – 0 and M4 – 2.

3. Results

The first stage of the control program development was to investigate the casting natural, non-cooled cooling process of aluminium alloy in the mold and monitoring the cooling process of the mold and the casting and also to examine the relationship between the values of the temperature in different parts of the mold. Tests were carried out using an infrared camera and thermocouples. Fig. 3 shows the thermal images recorded with temperature changes during pouring and cooling of the mold. The analysis of recorded images shows that filling of the mold starts heating up the top of the mold, middle and bottom. After 1.5 seconds the temperature in the mold flattens out and there is a heat flux received by the base of the mold. The chill heats up, reaching the highest temperature in the 4 second. The research shows that the mold heats up to a temperature in the range from 332 to 403°C.

On the basis of the derivative analysis $dT/d\tau$ of casting temperature there was specified temperature range of the casting solidification and corresponding temperatures of studied chill zones.

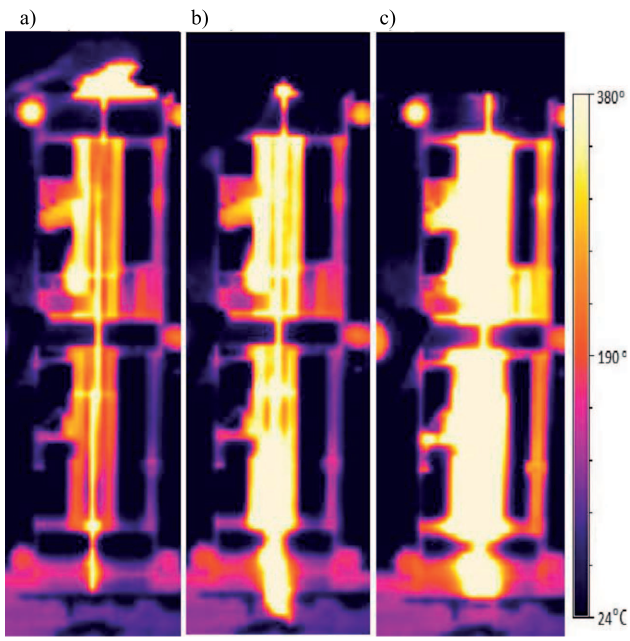

Fig. 3. Changing the temperature of mold preheated to 200°C during pouring the aluminium alloy: a) 1 s, b) 2, 5 s, c) 4 s

The mold reached the highest temperature in zone 2 (Table 1), which is due to its location in the upper part of the mold – the runner. The chill zone 1 has heated to the temperature of about 332°C (Table 1), The temperature of this zone is the lowest among all of the investigated points as the cross sectional in this area is the smallest of whole casting. The temperatures of the chill were logged and used in the development of control program, so that cooling would begin as late as possible in the temperature range of the crystallization process. The average time of the casting mold without the use of cooling is approximately 550 seconds. At the temperature of 200°C the chill reached after 200 seconds after the alloy pouring.

In order to give the solidification priority to the most important part of the cast the control program (M2) should start cooling zone no 1 as soon as possible after completion of molten metal in the mold cavity and at the latest at the beginning of aluminium alloy crystallization. In accordance with the data presented in Table 1, the corresponding mold temperature is 332°C. Then, after the aluminium alloy crystallization, the program can start cooling the remaining zones that no longer will supply the first area and accelerate the cooling of the casting. The cooling process ends below 60°C of the casting temperature.

TABLE 1

Temperature zones of the mold during casting crystallization

	Zone 0	Zone 1	Zone 2	Zone 3
	Temperature, °C			
Start of crystallization	380	332	397	585,68
End of crystallization	364	325	403	511

The first condition turns water valves and air cooling in charge of Zone 2 when the temperature reaches 332°C. The second condition consists of two parts connected by a conjunction "*". It means that all the valves will be turned on when the temperature decreases to the value of 332°C and six seconds of the program operation time elapsed. Saved extra time condition is necessary because of the pre-heating the mold to a temperature 200 C. The time: 6 seconds is based on the registration of the cooling system that allowed the mold to reach a temperature of the crystallization start. During the cooling process there was observed an intense temperature decrease in the initial seconds, combined with the evaporation of water. Later in the process the drops did not evaporate as hard as before. It caused a formation of a thick layer of water, which is a undesirable effect. To prevent this situation, there was used pulse dosing of water in water mist generating system. Reducing the amount of water in the final stage of cooling process requires an additional condition to turn on pulsations after reaching the temperature of 200°C and another one under 100°C. The optimal value pulsation in this case, the mold was 60% and 40% in the last period of cooling process. Endpoint of current version of the program was shown in Table 2. The program cools down the mold by drying it with an air flow. Consequently, it further reduces the casting defects and improves the safety of the work on casting stations. The program reduced the casting time to 61 seconds.

Fig. 4 shows the algorithm of developed cooling program of the mold. The algorithm starts with pouring the molten metal in the mold. The program will first check the temperature condition of 332°C for thermocouple K1. If it has been reached program activates the cooling in the zone 1 and goes to the second condition. If the condition is not met, the program also goes to the second condition. Analogically fulfilling the conditions 3 and 4 turns on the pulsation of water with a certain intensity.

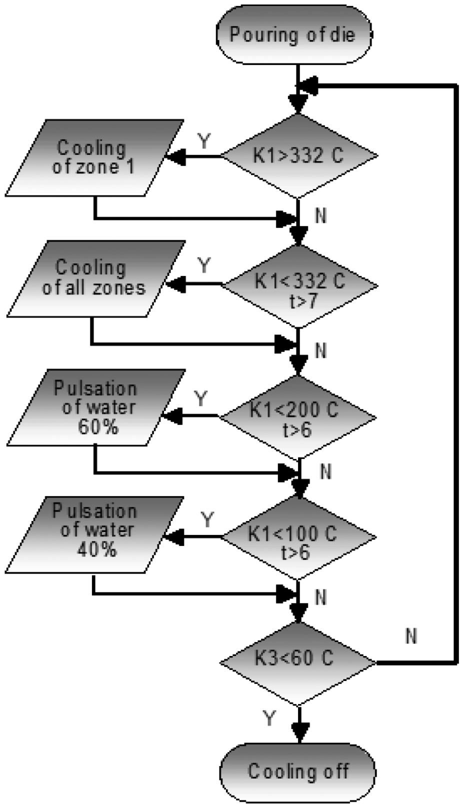

Fig. 4. The algorithm of developed conditional mold cooling control program

The last condition turns off the cooling after reaching the point K3 temperature below 60°C. The computer program checks repeatedly for the occurrence of the control conditions and if any of them is not met, it starts a new iteration of the control program.

TABLE 2

Conditional program

No.	Condition	Action
1.	(K1>332)	Z3=10;Z4=10;Z11=10;Z12=10
2.	(K1<332)*(TIME>6)	Z1=10;Z2=10;Z3=10;Z4=10;Z5=10;Z6=10; Z9=10;Z10=10;Z11=10;Z12=10;Z13=10;Z14=10
3.	(K1<200)*(TIME >6)	Z1=6;Z2=6;Z3=6;Z4=6;Z5=6;Z6=6; Z9=10;Z10=10;Z11=10;Z12=10;Z13=10;Z14=10
4.	(K1<100)*(TIME >6)	Z1=4;Z2=4;Z3=4;Z4=4;Z5=4;Z6=4; Z9=10;Z10=10;Z11=10;Z12=10;Z13=10;Z14=10
5.	(K3<60)	Z1=0;Z2=0;Z3=0;Z4=0;Z5=0;Z6=0; Z9=0;Z10=0;Z11=0;Z12=0;Z13=0;Z14=0

Fig. 5 shows a microstructure of the casting obtained with use of cooling sequence described in the method 3 and one obtained with the water mist cooling multipoint conditioned program.

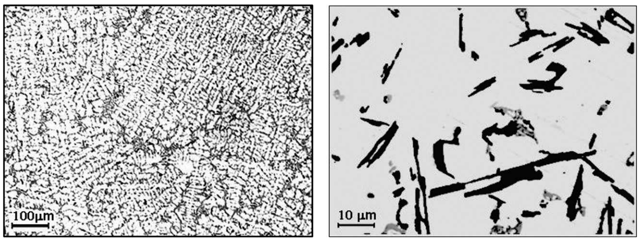

Fig. 5. Microstructure of AlSi7Mg cast obtained in the mold preheated to 200°C chilled with water mist containing 0.1 l/min of water and 150 l/min of air; phase α, eutectic $\alpha + \beta$

The microstructure of tested cast consists preeutectically crystallized α phase dendrites and eutectic lamellar $\alpha + \beta$. There is a high homogeneity and fineness of the microstructure obtained which characterized by a small branching dendrites (I-II level) preeutectic phase of α and short circuit in the eutectic precipitates.

The studies of mechanical properties are presented in Fig. 6. Results show that the use of water mist cooling system on the mold significantly increases the tensile strength R_m, compared to non-cooled castings. The highest average value of R_m = 210 MPa was achieved for castings chilled by M3 method, i.e. with the priority put on the lower part of the mold and the casting. Moreover, the value of other properties that were tested had the following values: $R_{p0,2}$ = 115 MPa, A_5 = 2.7% and HB = 78. It's probably caused by a decrease of shrinkage and porosity defects in the casting and the fine-grained microstructure results from a larger overcooling of the liquid alloy during solidification of the casting.

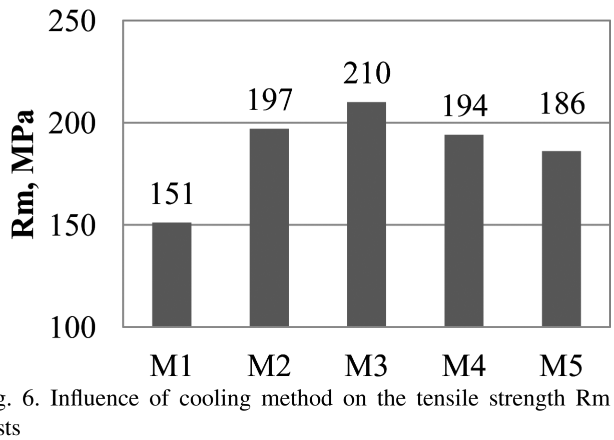

Fig. 6. Influence of cooling method on the tensile strength Rm of casts

The research shows that sequential mold cooling water mist implemented by computer program control system conditional coupled with continuous measurement temperature can effectively influence the structure of the cast, reduce the amounts of defects and increase the mechanical properties of the casting.

4. Conclusions

The research presented in the paper leads to the following conclusions:

- condition-based program coupled with the measurement of mold temperature allows effective control of mold cooling process using an open multipoint water mist cooling system,
- sequential mold cooling water spray increases the homogeneity of the microstructure and increases by about 20-25% the mechanical properties of castings made of silumin AlSi7Mg,
- computer-controlled water mist cooling system ensures to limit the amount of water present in the cooling process to the current evaporation capacity of the mold.

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