Evaluation and Application of Heat-Transfer Coefficients at the Die/Spot Spray in Die Casting

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ABSTRACT

The interfacial heat-transfer coefficient between a die and spot spray was studied for the purpose of numerical simulation. In order to evaluate the simulation efficiency, a cyclic simulation was conducted using calibrated heat-transfer coefficients in actual die casting. The predicted die surface temperatures were in agreement with the experimental results.

Keywords: *die casting, spot spray, heat-transfer coefficient*

1. INTRODUCTION

Die casting is a highly efficient net shape manufacturing process. Lubricant is used to prevent the soldering of aluminum alloys on the surface of the die. Formation of lubricant film on a die strongly depends on the die surface temperature. It is particularly important to design a cooling system to prevent the soldering of aluminum alloys in a die casting process. In case that the displacement of the internal cooling system is difficult, spot spray as an external cooling aid is often used to lower the temperatures of the hot spot areas.

On the other hand, numerical simulations are often made in order to estimate the temperature distribution pattern in a die. However, the die casting cycle consists of several different complex stages, it is extremely difficult to model these stages precisely. Therefore, the spray process which contains complex phenomena is usually ignored in numerical simulations.

The heat-transfer coefficients between materials were studied for the purpose of calculating the temperature distribution pattern[1),2)]. However, the interfacial heat-transfer coefficients between a die and spot spray have not been evaluated in regard to die lubricant and spot spray process.

In this paper, therefore, the interfacial heat-transfer coefficient between a die and spot spray was evaluated and used for cyclic simulation of actual die casting[3),4),5)]. The predicted die surface temperatures were in good agreement with the experimental results.

2. EXPERIMENTAL PROCEDURES

Fig. 1 shows a schematic diagram of the experiment with which the heat-transfer coefficient between a die and spot spray was calculated. The spray time was controlled by the solenoid controlled valve. A spray time was used due to the fact that a constant spray time is used in the manufacturing process in the factories of Ahresty. The size of the test block was 200 x 200 x

100mm. The test block was heated in the electric furnace until an uniform temperature was obtained. Four sheathed chromel/alumel thermocouples were positioned in the test block. Using a high speed camera, the behavior of the water on the surface of the test block was observed at a speed of 1000 frames per second. The experiments were conducted at the Iwate Industrial Research Institute under the conditions shown in **Table 1. Fig. 2(a)-(c)** show the images observed by a high speed camera at temperatures of 473K, 623K, 773K, respectively. The efficient area of the spot spray on the surface of the test block which were determined by the above images, are changed according to its temperature.

Fig. 3 shows the experimental results indicating the relation between the temperature of the test block and the efficient area. The root mean square method gives the following relation for the results in **Fig. 3**.

$$\ln(A)=23.5764-3.021\ln(T) \qquad (1)$$

A: Efficient area(cm), T: Surface temperature (K)

Fig. 4 shows the measured temperature-time curves by the thermocouple. It is found that the temperature at the outside area of the efficient area did not change. The nozzle pressure and distance between the test block and the spray nozzle were varied in order to evaluate its effects on the temperature-time curves. However, the curves were not affected by the nozzle pressure and the distance. The heat-transfer coefficient at the die/air as well as at die/spot spray was evaluated. The test block was held without using any spot spray in order to evaluate its coefficient.

3. CALCULATION METHOD AND RESULTS

Modified STEFAN(Solidification Technology for Foundry Aided by Numerical Simulation) software was used for calculations. The original STEFAN was developed at Tohoku University[6]. STEFAN is a casting simulator for the analysis of transient thermal and fluid flow phenomena. The thermal and physical properties of the materials that were used in the calculation are shown in **Table 2**. The rectangular mesh used for this analysis was 123 x 123 x 63. The measured coefficient at die/air was used for calculations in order to calibrate the heat-transfer coefficient at die/spot spray.

Fig. 5 shows a comparison between the calibrated cooling and measured cooling curves. Two heat-transfer coefficients were needed to obtain agreement with the cooling curves. The heat-transfer coefficients used for the calculations are shown in **Table 3.** The calibrated temperature curves are generally in good agreement with the experimental results, while there is a slight difference between the calibrated cooling and measured cooling curves at a late stage. However, because the time which is used in the simulation of the actual die casting is limited (0-11sec.), there is not a serious problem. The change of the heat-transfer coefficient as the effect of the spot spray was required during 11 seconds. From the observation by a high speed camera, it is found that the vaporization of water on the surface of the test block seemed to continue for only the first 5-6 seconds. Therefore, the actual phenomena on the surface of the test block may be more complex. The complex thermal phenomena on the die surface can be expressed easily using the two constant heat-transfer coefficients and the efficient areas of the spot spray which were determined by Equation (1). Moreover, the same heat-transfer coefficient can be used at temperatures 473K, 538K, 623K, 708K, and 773K.

The following sub-module for STEFAN was developed in order to take into account the efficient areas which are changed by the surface temperature. Once an element is chosen as the location of the spot spray, the program will set the heat-transfer coefficient, the properties and areas for the spray elements according to equation (1). The efficient area will be calculated once for every cycle of the simulation. Therefore, according to the changes in surface temperature with cyclic simulations, the boundary condition will be changed .(i.e., the efficient area will be changed).

4. APPLICATION

Fig. 6 shows an aluminum die casting for a transfer center case. Spot sprays were used to prevent soldering at hot spot areas. A thermograph was used to analyze the temperature distribution pattern on the surface of the die. **Fig. 7** shows the measured die surface temperature patterns after spot spraying (before lubricant spraying). The circles show the location of the spot spray. **Fig. 8(a)** shows the calculated temperature distributions without the consideration of spot spraying. The calculations were repeated for 15 cycles until a cyclic steady state was established. The mesh used for this analysis was 136 x 109 x 56. The calculated temperatures at the spot spray area were higher than the measured temperatures at the spot spray area. **Fig. 8(b)** shows the calculated temperature distribution pattern with the consideration of spot spraying. The calculated die surface temperature pattern when spot spray was used agreed with those obtained experimentally. Based on the results of the application, it has become clear that the consideration of spot spraying is important in the precise calculation of temperature distribution patterns.

5. CONCLUSION

The results are summarized as follows: the predicted temperature distribution patterns based on the calibrated heat-transfer coefficient between a die and spot spray with cyclic simulation were in agreement with those obtained experimentally. In regards to an analysis of a method that can prevent soldering, the consideration of spot spraying is important. The effect of the spot spray can be taken into account by the following simple equation:

$$\ln(A)=23.5764-3.021\ln(T)$$

In future research, practical heat-transfer coefficients at the casting/die and die lubricant/die interface need to be evaluated in order to precisely calculate die temperature.

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Table 1 Experimental Conditions

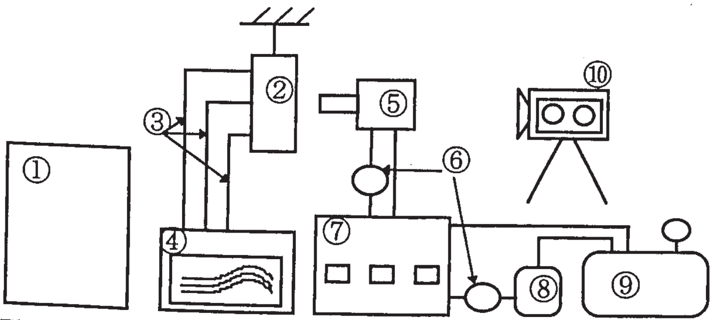
Temperatures (Test Block)	473K, 538K, 623K, 708K, 773K
Spray Pressure	4.9e+5 GPa
Diameter of Spray Nozzle	5mm
Spray Time	1.5 Sec.
Distance	350mm
Temperature (Water)	286K
Die Material	SKD61

Table 2 Thermal properties for casting and die materials (Unit: SI)

Thermal properties	Casting	Die
Density	2700	7300
Specific heat	0.964	0.668
Heat conductivity	100.5	33.5
Latent heat	490	/
Liquid temperature	853	/
Solid temperature	803	/
Initial temperature	873	293

Table 3 The heat-transfer coefficients used for calculations

Time (Sec.)	Heat-transfer coefficient (W/m^2K)
0 - 5	1100
5 - 11	380



① : Electric furnace ② : Test block ③ : Thermocouple ④ : Recorder ⑤ : Spray gun ⑥ : Pressure Gauge ⑦ : Solenoid controlled valve ⑧ : Water tank ⑨ : Compressor ⑩ : High speed camera

Fig. 1 Schematic diagram of the water model experiment

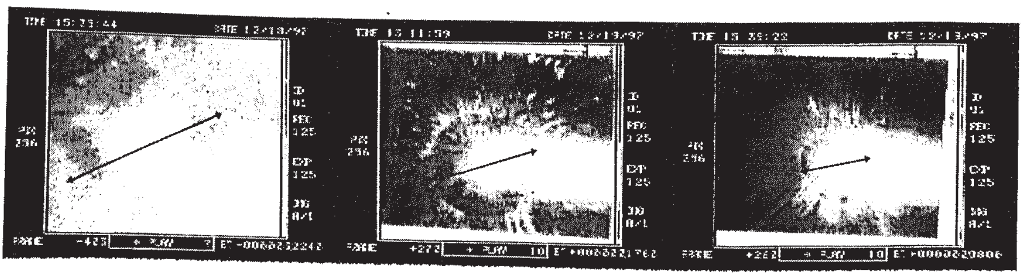


Fig. 2 (a)-(c) Observed images by a high speed camera

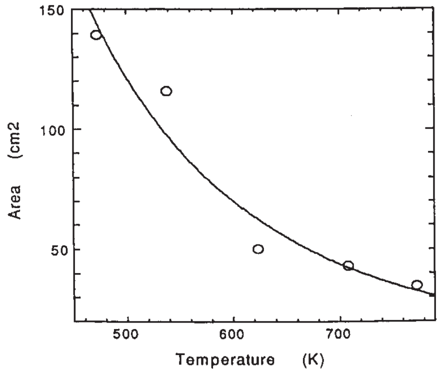


Fig. 3 Relation between the temperature and the efficient area

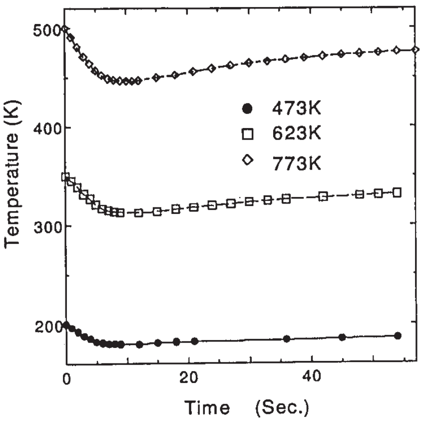


Fig. 4 Measured temperature-time curves

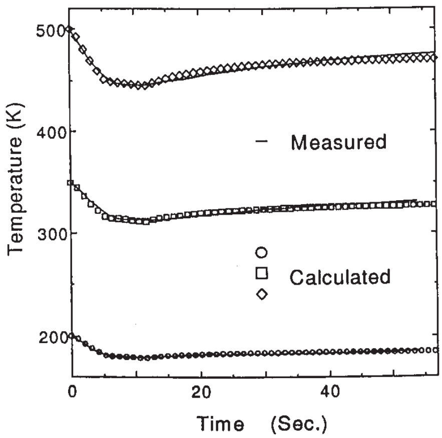


Fig. 5 Comparison of experimental and calculated cooling curves

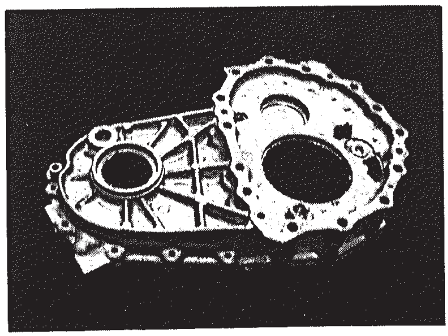


Fig. 6 A casting for a transfer center case

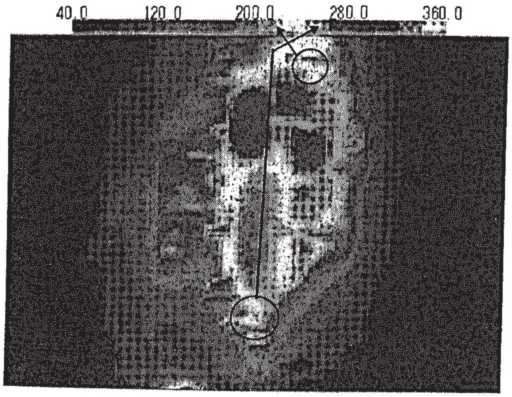
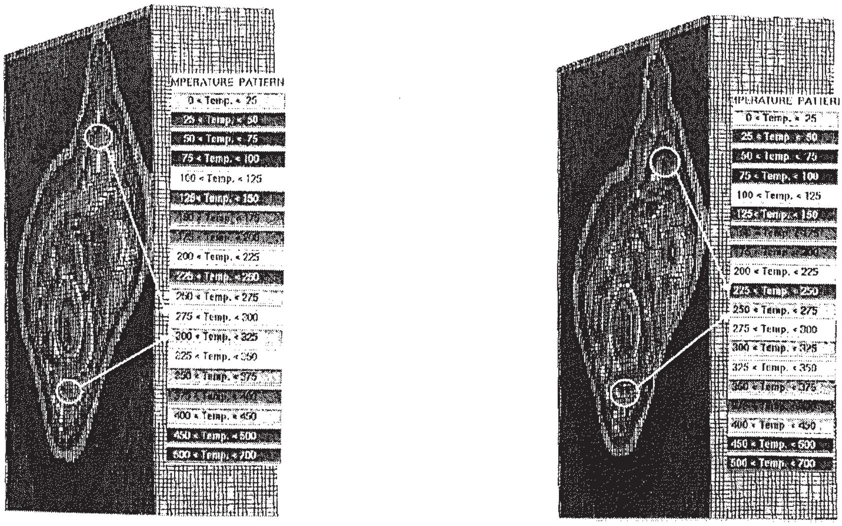


Fig. 7 Measured temperature distributions after spot spraying



(a) Without a spot spray consideration **(b) With a spot spray consideration**

Fig. 8 Calculated temperature distributions