EXPERIMENTAL STUDY OF THE HEAT TRANSFER AND AIR GAP EVOLUTION DURING CASTING OF AN AC4CH ALUMINUM ALLOY

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Abstract. In the context of rapid changes of the technologies, casting becomes a manufacturing process of an increasing use. Therefore, the numerical methods and algorithms for solving heat conduction problems were extensively developed during the last 10 years. Based on finite element techniques, these algorithms provide an accurate analysis of heat transfer. This paper presents the numerical and experimental results of heat transfer coefficients determination, at the cast/core and cast/mold interfaces, during solidification and cooling of a hollow cylinder cast part made of Al-7%Si-Mg alloy (AC4CH).

Key words: aluminum casting, heat transfer and air gap, numerical prediction.

1. INTRODUCTION

In the automotive industry, hundreds of thousands of cast engine blocks and transmission cases are produced every year. Casting processes bring some advantages with respect to other manufacturing processes, such as: minimizing or even eliminating the machining processes necessary to obtain the final products, manufacturing parts of complex geometries that would otherwise require assembly of several pieces, and easily adapting to the requirements of mass production. For assuring the productivity of the casting process, various factors must be controlled as the shape dimension of the mold, the die-coating, the chemical composition, the pouring temperature and so on. Within the recent numerical simulation developments, the prediction of the shape dimensions in casting is one of the encountered problems to be solved, and hence the control of the factors that influence the shape accuracy is of a great importance [1]. The present paper addresses one important factor that has to be taken into account in this context, namely the modification of the heat transfer coefficients at the interfaces between the cast part and the mold, both by air gap formation and the evolution of the effective pressure in the areas of contact.

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2. EXPERIMENTAL SET-UP

2.1. DESIGNING OF THE EXPERIMENT AND CASTING

Casting experiments were conducted in a top poured cylindrical mold manufactured from mild steel with an outer diameter of 231 mm. The shape of the cast part is a tubular cylinder with the following dimensions: top outer diameter 127.9 mm, bottom outer diameter 133.1 mm, inner top diameter 38.6 mm, bottom inner diameter of 44.1 mm, and height of 84.8 mm. The mold is bottom insulated by a ceramic part. The gradient of the temperature in the melt material and the mold is assured by a mild steel core, bottom centered in the insulator. The water flows from downwards in the circular channel of the core. Seven thermocouples are mounted at a depth of 20 mm from the top surface of the mold, as presented in Fig. 1. Thermocouples T1, T2 and T3 are fixed in the mold wall, T4, T5 and T6 are immersed in the cast material, and T7 is fixed in the core wall. During the casting experiments the temperature distributions in the mold, cast and core are recorded. The air gap formation is monitored by recording the displacement of the melt material throughout the experiment through the 3 LVDT transducers. The schematic design of the experiment is presented in Fig. 1a, and the employed equipment is shown in Fig. 1b.

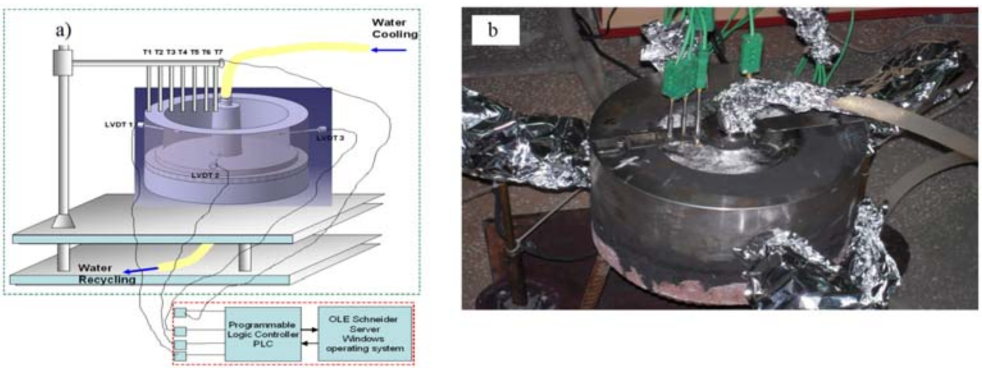

Fig. 1 – Experimental set-up for aluminum casting: a) the set-up of the casting device, with the T1-T7 thermocouples and the 3 transducers, mounted like in the experiment described in Hernandez *et al.* [1];
b) the top poured cylindrical mold, filled with AC4CH aluminum alloy.

Cast material is an aluminum alloy named AC4CH provided by Central Motor Wheel Co., Ltd. Japan and the mold is manufactured from mild steel. This aluminum grade is similar to the ISO aluminum alloy Al-7SiMg with the following chemical composition (Table 1). In order to have the reproducibility of the recorded results, the casting experiment was done three times keeping the same conditions. The results presented as follows are the average values of the three experiments.

Table 1

Chemical composition of AC4CH (%)

Cu	Si	Mg	Zn	Fe	Mn	Ni	Ti	Pb	Sn	Cr	Al
less than 0.10	6.5 – 7.5	0.25 – 0.45	*less than* 0.10	*less than* 0.20	*less than* 0.10	*less than* 0.05	*less than* 0.20	*less than* 0.05	*less than* 0.05	*less than* 0.05	*rest*

2.2. HEAT TRANSFER COEFFICIENT CALCULATION BASED ON EXPERIMENTAL TEMPERATURE PROFILE

The formation of the air gap starts when the solid metal shell becomes strong enough to withstand the pressure from the melt and thereby departs from the mold, due to the contraction. Before the formation of the air gap, heat transfer is due to conduction [2, 4]. When the air gap forms, the heat transfer starts to decrease and can be described by superposition of the radiation and conduction terms. To investigate more deeply the nature of the heat transfer behavior, the experimental temperature profile was plot using the recorded values from the thermocouples T1-T7 (acc. Figs. 2 and 3).

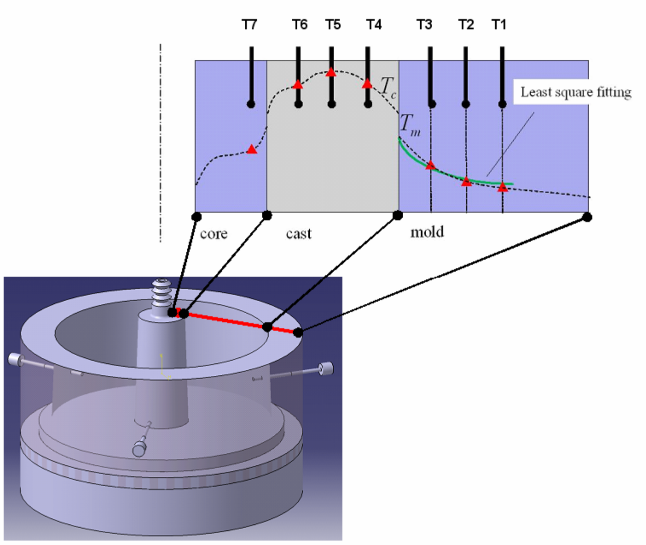

Fig. 2 – Representation of the experimental temperature profiles in the core, the cast material and the mold, which have been used for calculating the surface temperatures T_c and T_m at the interface.

The temperature of the melting aluminum in the furnace was 650°C and the pouring temperature of 600°C has been measured through a calibrated thermocouple. The pouring time was 15 s, so that the analysis of the results has been considered by removing this initial lapse of time. The mold was preheated at

50°C. During the first 100 s, the temperature at the core shows a peak of 180°C, and after this the water flowing through it determines the decreasing of the temperature. The melt aluminum alloy, which is initially at the liquidus temperature, reaches the eutectic temperature within 100 s. At about 150 s the solid skeleton reaches sufficient consistency and the contraction begins to have a significant value.

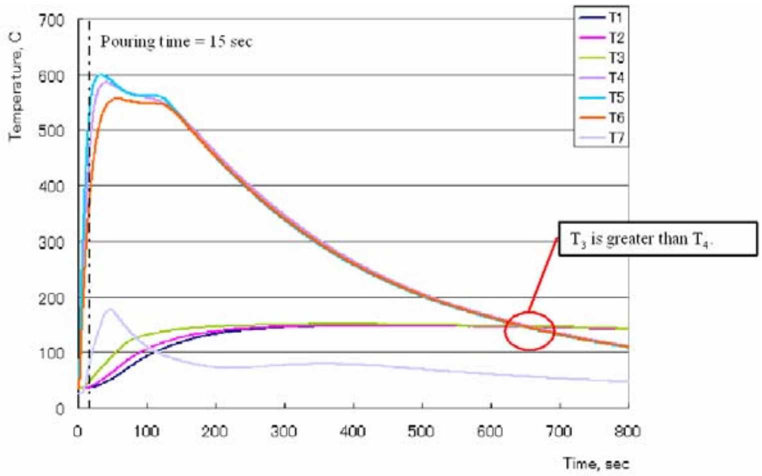

Fig. 3 – Experimental temperature profiles measured during the experiment.

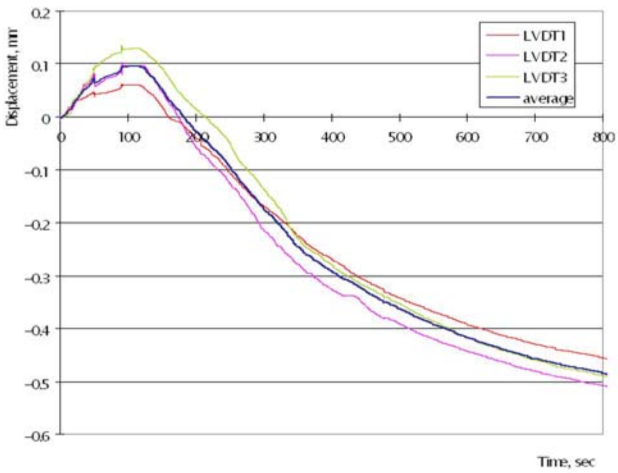

Fig. 4 – Experimental displacement of the transducers LVDT1, LVDT2 and LVDT3 and the average values.

For aluminum, the radiation is insignificant as compared with the conduction. The experimental temperature profile indicates that the heat flux is directed from the cast material to the mold ($T_c > T_m$), until about 550 s after the end of the mold filling. At this moment, the air gap is 0.45 mm. Thereafter, the temperature of the mold becomes greater than the temperature of the cast part ($T_c < T_m$). The heat transfer coefficient (1), can be derived as

$$h = \frac{k\left(\partial T/\partial r\right)_{\text{int}}}{T_{\text{m}} - T_{\text{c}}}, \tag{1}$$

where h is heat transfer coefficient between cast and mold, T_c and T_m are, respectively, the temperatures of the cast and the mold at their interface between the cast part and mold, $\left(\partial T/\partial r\right)_{\text{int}}$ is the temperature gradient at the interface and k is the heat conductivity [3, 5]. This calculation is valid only during the first 550 s after completion of the pouring. As shown in Fig. 5, the heat transfer coefficient evolution estimated by (1), it is proved that decreases, as expected, with the increasing of the air gap (Fig. 6).

The mold temperature increases and become itself a source of heating through the air gap. It could be supposed that a convection phenomenon occurs in this moment and cause a delay in cooling of the cast part until the room temperature.

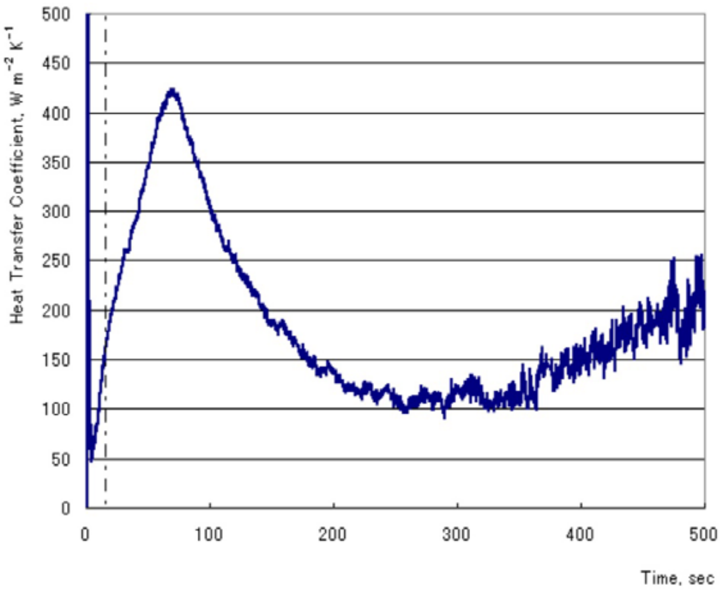

Fig. 5 – Variation of the heat transfer coefficient at the interface.

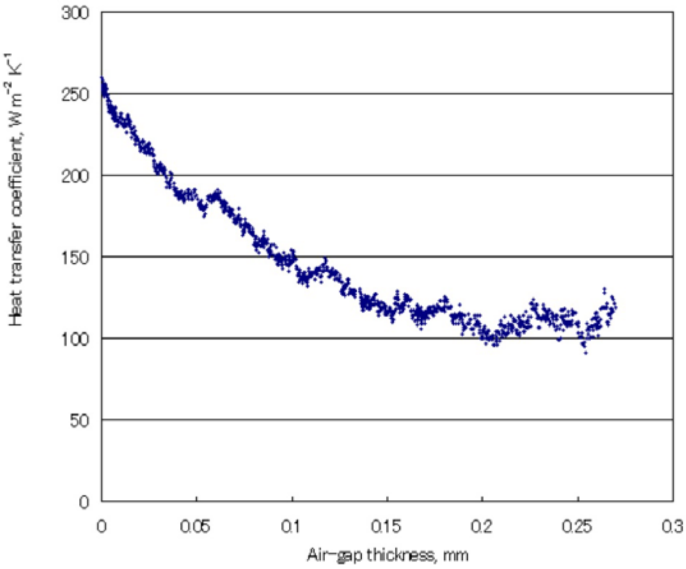

Fig.6 – Air-gap dependency of the heat transfer between the cast part and the mold.

3. CONCLUSIONS

An AC4CH aluminum alloy casting experiment was carried out in order to calculate the heat transfer coefficient and to measure the air gap formed during shrinkage phase between the mold and the cast part. The correlation between the air gap evolution and the heat transfer coefficient shows that between 15 s to 200 s the mold is rapidly heated during the filling of the mold and an expansion occurs that corresponds to the highest value of the heat transfer coefficient. The decreasing of the intensity of the heat exchange noticed after 200 s means that air gap formation starts to play a role between the cast part and the mold. The mold temperature increases and becomes itself a source of heating through the air gap. It could be supposed that a convection phenomenon occurs in this moment and cause a delay in cooling of the cast part until the room temperature. The identified relation between the heat transfer coefficient and the air gap is important for the accuracy simulation of the shrinkage phase of the aluminum alloy cast parts using V-Shrink. The comparison between experimental and simulation results shows a very good agreement. This work will be presented in a further paper of the authors.

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