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Experimental study on the heat transfer behavior and contact pressure at the casting-mold interface in squeeze casting of aluminum alloy

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ABSTRACT

The present paper focuses on the heat transfer and contact pressure at the casting-die interface in squeeze casting process. Experiments were conducted and a "plate shape" was used to cast aluminum alloy A356 in H13 steel die. Based on the temperature measurements inside the die, the interfacial heat transfer coefficient (IHTC) at the metal-die interface was determined by applying an inverse approach. The pressure at the metal-die interface was measured by using Kistler pressure transducer. The acquired data were processed by a low pass filtering method based on Fast Fourier Transform (FFT). Besides, a set of methods was set up to verify the computer program for the inverse model. The results show that the pressure at the casting-die interface and the IHTC rose to the peak value almost simultaneously as soon as the pressure was applied by the press. The higher the applied pressure, the higher the peak value of the IHTC and the pressure at the casting-die interface. It was a pressure maintaining stage immediately after the pressure was applied. During this stage, the pressure at the casting-die interface decreased immediately after it reached the peak value. The IHTC sharply dropped at the beginning. Then, the decrease rate of the IHTC became lower and lower. Besides, the IHTC of the cases with pressure applied was much higher than those without pressure applied. It indicates that the applied pressure greatly improved the contact status of casting and die surfaces and reduced the thermal resistance between the two surfaces. The IHTC profiles of the cases with the pressures 23 MPa and 46 MPa applied did not make much difference, however, when the applied pressure reached 70 MPa, the influence of the pressure at the casting-die interface on the IHTC became very remarkable.

1. Introduction

The use of light-weight components in various applications has increased during the last decade, partly as a result of the increased amount of light-weight metals being used for transportation purposes. The light-weight metal components lead to an overall reduced weight and thus, to reduced energy consumption [1]. The materials of these components are mainly aluminum and magnesium alloys. These alloys are commonly cast using high pressure die casting (HPDC) process which is one of the most efficient methods for the production of complex shape castings in today's manufacturing industry. But defects such as shrinkage and gas pores are often observed in the cast parts. These defects deteriorate the mechanical properties of the casting components, which limits the application of light-weight alloys. Thus, the development of high integrity casting technology such as squeeze casting and vacuum die casting has received widespread concerns [2–4].

Compared to other casting processes, the most attractive features of squeeze casting (SC) are gentle cavity filling and pressurized solidification. Before the solid fraction of the casting becomes high enough, the applied pressure squeezes liquid metal to feed the volume shrinkage effectively. Therefore, squeeze casting can make castings virtually free of porosity, heat treatable and with excellent as-cast quality [5]. Besides, the applied pressure also greatly affected the microstructure and mechanical properties of the casting [6–8]. Two different types of squeeze casting technology have evolved, based upon different approaches to metal metering and metal movement during die filling: these have been given the names 'direct' and 'indirect'. Direct squeeze casting (DSC) is the name given to that process in which molten metal is solidified under the direct action of a pressure that is sufficient to prevent the appearance of either gas porosity or shrinkage porosity.

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The pressure is applied to the entire surface of the liquid metal during freezing, producing castings of full density. In indirect squeeze casting (ISC) process, metal is injected into the die cavity by a small diameter piston, by which mechanism the pressure is also applied during freezing [9].

The heat transfer at the casting-mold interface has very important effect on the casting quality and microstructure. In all the casting process using metallic dies, such as permanent mold casting, high pressure die casting, and squeeze casting, the solidification behavior and the microstructure features of castings strongly depend on the heat transfer at the casting-die interface. Reliable experimental values of the interfacial heat transfer coefficient (IHTC) are of great significance for the control of casting process.

For sand mold casting, permanent mold casting and other casting processes, extensive work [10–17] has been conducted for the determination of the IHTC and many factors were found to have influence on the value of the IHTC. Ho and Pehlke [10,16] suggested that a casting-mold interface may generally exist in the states of (1) a conforming contact, (2) a nonconforming contact, and (3) a clearance gap, with a corresponding trend toward decreasing the IHTC.

In order to accurately determine the heat transfer coefficient during the high pressure die casting process, Dour et al. [18] recommended that some requirements including fast sensor response, proper location of the sensor, and proper way of applying the inverse method must be met. Dour et al. [19] developed a non-intrusive heat transfer gauge and investigated the IHTC of a thin wall aluminum casting. The results showed that a higher fast-shot speed and a lower initial die temperature led to a higher IHTC peak value. Hamasaiid et al. [20] also found that the fast-shot speed and the initial temperature of the die have a great influence on the IHTC peak values.

Guo et al. [2,21,22] reported their work on using a special temperature sensor unit (TSU) to overcome the uncertainty in the installation of the thermocouples and its application in the HPDC to evaluate IHTC of a step-shape casting of magnesium alloy AM50 and aluminum alloy ADC12. The results indicated that the IHTC value increased during initial stage, followed by fluctuation period of the peak values, then dropped abruptly until a much lower level. The higher the initial die temperatures, the lower the IHTC peak values for the thick sections. In thinner steps, a faster shot velocity led to a higher IHTC peak value.

From the above introduction, we know that there have been many researches on the IHTC in different casting process, however, the studies on the IHTC in squeeze casting process are still limited. One of the reasons is that the squeeze casting experiment is hard to perform and the operation procedure is complicated. Some researchers investigated the influence of the applied pressure on the IHTC by conducting squeeze casting experiments [23–27]. Sun et al. [28,29] determined the IHTC of "five-step-shaped" castings of magnesium alloy AM60 and aluminum alloy ADC443 and measured the pressure at the casting-die interface using Kistler pressure transducer. They also established an empirical equation about the peak IHTC value, which is a function of local pressures and solidification temperatures, and discussed the influence of casting thickness and pressure value on the IHTC. Sun and his colleagues paid more attention on how the peak value of the local pressure affected the IHTC. However, the effect of the variation trend and duration of the local pressure on the IHTC was not considered.

A very important character of squeeze casting is that the heat transfer is enhanced due to the tightly contact of the casting and die surfaces caused by the applied pressure. As the solidification of the casting proceeds, due to the deformation resistance and pressure transfer path, the pressure at the casting-die interface depending on the contact status of the casting-die interface varies with time and location. This makes the pressure at the casting-mold interface become a more directly related parameter than the applied pressure to characterize the contact status of the casting-die interface. As a result, the establishment of the relationship of the pressure at the casting-die interface and the IHTC is of great significance for understanding the heat transfer behavior at the casting-die interface. Besides, in order to improve the accuracy of the solidification simulation of squeeze casting [30–33], theoretical model used as boundary condition on the IHTC which is a function of the pressure at the casting-die interface also requires to be established.

In order to establish the relationship of the pressure at the casting-die interface and the IHTC, extensive works need to be done. In this paper, by adopting DSC in the experiment for a plate shape casting, the main target was (1) to design a series of experiments to obtain accurate temperature and pressure data; (2) to set up a set of method to process the data and calculate the IHTC; (3) to investigate the heat transfer behavior at the casting-mold interface in squeeze casting of aluminum alloy A356.

2. Experiment

2.1. Casting

In these experiments, direct squeeze casting (DSC) process was adopted. According to the feature of DSC, the molten metal was poured into the die and then the pressure was applied to the entire surface of the casting. The time interval of the pouring and the pressure applying was about 4–5 s. It means that the effect of the pouring and the applied pressure on the IHTC can be investigated independently. In the practical production process of squeeze casting, due to the complicated structures of the components and different process parameters, the pressure at the casting-die interface varies with time and location. In order to have a clear knowledge of the pressure at the casting-die interface, plate shape casting was designed for these experiments. Because of the simplest shape and pressure transfer path, the pressure at the casting-die interface under various conditions can be obtained by changing the applied pressure and the process parameters. Besides, there were two other reasons for the design of the plate shape casting. First, heat transfer of the plate shape casting can be approximately assumed as one dimension heat transfer. Second, different casting thicknesses can be obtained through regulating the amount of pouring. Fig. 2 shows the plate shape casting with dimension of 140 mm × 90 mm × 30 mm.

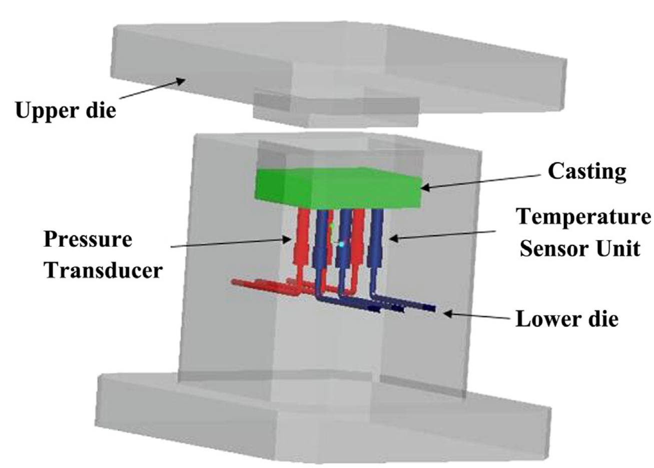

Fig. 1. Configuration of die and installation of the measure unit.