MEASURING FEEDING IN ALUMINIUM ALLOYS

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ABSTRACT

A method to measure feeding in a casting during solidification has been developed. The casting is a plate with a feeder in one end and a chill at the other. Characterization of the apparatus shows that the isotherms are nearly planar, moving from the chill to the feeder. The weight of the plate is measured with high resolution during solidification. By this method one can register the mass flow of molten metal from the feeder into the solidifying plate. The apparatus is well suited to study feeding in different alloys. The simple geometry is easy to model. Results from feeding experiments with various binary Al-Si alloys are presented and compared to a model that assumes 100% feeding of solidification shrinkage.
Keywords: *Aluminium castings, Al-Si, Porosity, Feeding.*

1 INTRODUCTION

Aluminium castings are getting increased attention, mainly because of their application in the automotive industry. Forged structural steel parts are being replaced by aluminium castings to save weight and production costs. Many of these structural applications, such as wheels and suspension parts are very demanding and require mass production of castings without significant casting defects.

The most common and serious defect in aluminium castings is porosity, which is a result of two phenomena, insufficient feeding and/or hydrogen precipitation during solidification. Normally porosity is caused by these phenomena occurring simultaneously; difficulties in feeding solidification shrinkage results in areas in the casting where the pressure is low enough for hydrogen pores to nucleate and grow.

Heat- and fluid flow computer models are often used in the design of castings in order to predict porosity, but due to the complexity of the feeding process, existing codes often fail to predict the location and amount of porosity. New models are, however, being developed as the understanding of the feeding and pore nucleation processes is improved [1, 2]. These must be verified experimentally and therefore accurate experimental data are needed. Data are often obtained by sectioning castings and measuring density and porosity by metallographic and radiographic techniques but this is difficult to compare quantitatively to model predictions.

This paper presents a simple experiment where the feeding during directional solidification in a plate is measured by weighing the casting during solidification. Due to the simplicity of the experiment, it is relatively simple to model and well suited to test modelling results.

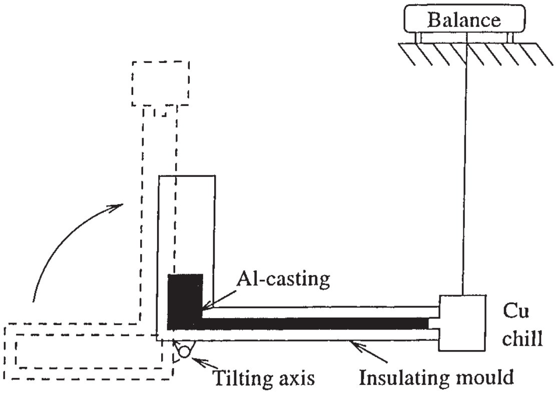

Figure 1: Experimental setup. The mould consists of insulating material and a copper chill. A plate is cast with a feeder placed at one end and a copper chill at the other.

Experiments where feeding has been measured by means of a balance have earlier been reported in the literature[3, 4], but no attempts have previously been made to relate the results to feeding models. The paper describes the experiment, and presents some results for Al-Si alloys.

2 DESCRIPTION OF APPARATUS

The experimental setup is shown on Fig. 1. The mould is made of aluminium plates insulated on the inside with 10 mm thick Fiberfrax Duraboard^{TM} 1200 plates. For pouring, the mould is tilted to an upright position as shown with dashed lines on the Figure. Melt is then poured into the feeder. After pouring, the mould is slowly tilted to a horizontal position. A balance is used to measure the torque around the axis of tilting. As the plate solidifies, melt flows from the feeder and into the plate to compensate for solidification shrinkage. This leads to a weight increase of the plate while the weight of the feeder is reduced. The weight increase of the plate results in an increase in torque around the axis of tilting but the weight reduction of the feeder does not influence the torque as the feeder is placed symmetrically above the tilting axis.

The dimensions of the plate, feeder and the chill are shown in Fig. 2. The copper chill has a large fishtail on the surface that faces to the melt to prevent the formation of an air gap. Steel-mantled, 1 mm diameter thermocouples of type K are used to measure the temperature in the casting during solidification. Temperatures from up to six thermocouples and weight are registered simultaneously with a computer.

2.1 Apparatus Characteristics

Some preliminary measurements with pure aluminium were made to characterize the apparatus and to measure temperature gradients and solidification time. The cooling rate and the solidus velocity in the mold were measured with five thermocouples placed along the centreline of the plate. The rate of cooling, $\dot{T}$, was estimated by finding dT/dt immediately before solidification. The distances between the thermocouples and the chill are given in Table 1 along with the cooling rates.

The cooling rate is high close to the chill but decreases to less than 0.5 °C/s 50 mm from the chill and becomes stable at around 0.3°C/s further away. Fig. 3 shows the cooling rate along

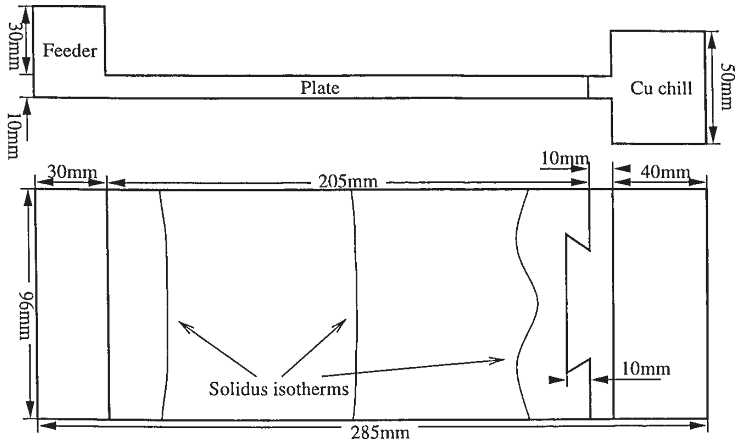

Figure 2: Dimensions of casting and Cu chill.

Table 1: Positioning of Thermocouples.

Thermo-couple no.	Dist. from chill (mm)	Cooling rate (°C/s)
#1	3.5	6.4
#2	14	1.4
#3	55	0.39
#4	95	0.25
#5	174	0.30

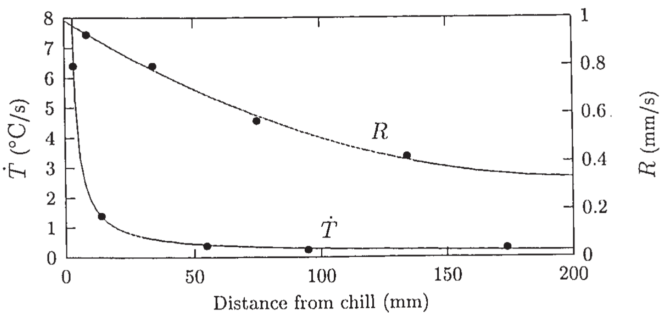

Figure 3: Cooling rates, $\dot{T}$, and solidus velocity, R, in casting.

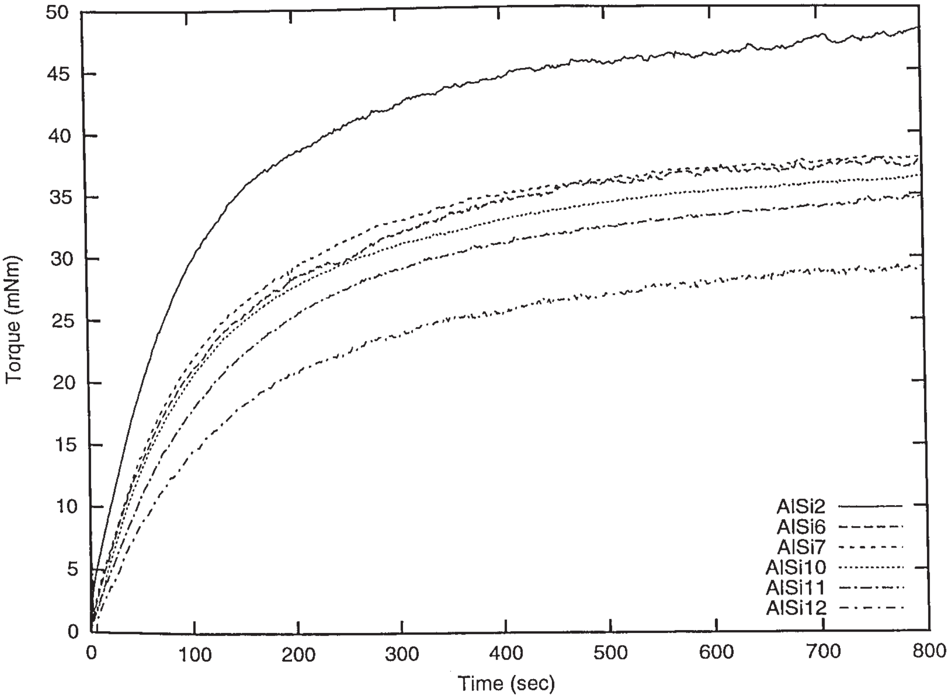

Figure 4: Feeding in AlSi alloys presented as an increase in torque about the tilting axis.

the plate. The shape of the solidification front was determined by placing six thermocouples in a line from the centreline of the mould towards the side edge. It is easy to determine from the temperature curves, the time instant at which the solidus passes the thermocouples. This time, together with the velocity of the solidus isotherm as presented in Fig. 3, were used to construct the shape of the solidus as it passed the thermocouples. It was assumed that the casting is symmetric about the centreline and the thermocouples were only placed on one side.

3 BINARY Al-Si CASTINGS

The apparatus has been tested by casting binary Al-Si alloys with Si contents in the range 2–12wt%. Fig. 4 shows the increase in torque measured during solidification. The torque rises quickly in early stages of solidification as the part of the plate far away from the axis of tilting solidifies. The rate of change in torque decreases for two reasons. Firstly, the solidification front moves towards the feeder and thus the same weight increase gives less increase in torque. Secondly, the rate of solidification slows down as shown in Fig. 3. After solidification ends, the torque curve continues to grow at a constant rate. This is due to the fact that the plate contracts upon cooling and is pulled towards the chill.

The torque increase during solidification is about 25–45 m Nm compared to the total torque of the casting without the mould, which is about 470 m Nm. The largest torque increase occurs in the Al2wt%Si but decreases with increasing Si content in the alloy and the Al12wt%Si alloy shows the least feeding. This agrees with the fact that solidification shrinkage reduces

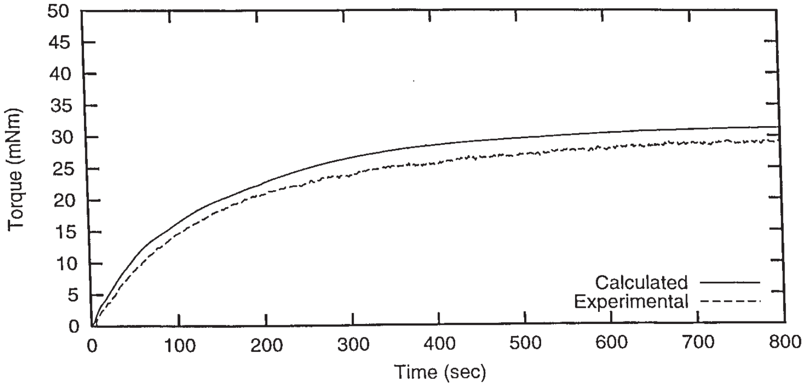

Figure 5: Comparison of measured and calculated torque for Al12wt%Si alloy.

with increasing Si content.

3.1 Comparison with theoretical feeding

It is interesting to compare the measured torque curves to calculated ones. A simple model to calculate the torque increase has been made. The model uses density data for liquid and solid AlSi alloys to calculate the torque increase when it is assumed that the solidification shrinkage is 100% fed. In each time step the total torque, τ, of the casting is calculated from the following formula:

$$\tau = A(T)g \int_0^L x \{g_L(T,C)\rho_L(T,C) + g_S(T,C)\rho_S(T) + g_{eut}(T,C)\rho_{eut}(T)\}\, dx \qquad (1)$$

A is the cross sectional area of the casting and is temperature dependent through thermal expansion. g is the acceleration due to gravity. g_L, g_S and g_{eut} are the volume fractions of liquid, solid Al and eutectic respectively, calculated with the Scheil equation. ρ_L, ρ_S and ρ_{eut} are the densities of the liquid, solid Al and eutectic phases respectively. C is the concentration of Si in the alloy. The temperature T at each position is found by interpolating measured values. The integral is taken from $x = 0$ at the tilting axis and to $x = L$ at the chill.

Data on the density of liquid binary Al-Si alloys are not available. The density used is therefore the average of density for liquid aluminium and silicon given by [5] and results in the following formula:

$$\rho_L(T,C) = 2569.8 - 0.28\,T + 391.4\,C - 0.04\,T\,C \qquad (2)$$

The densities of the solid Al phase and the eutectic phase are calculated using data from [5, 6].

The model has been used to calculate the torque increase for the Al12wt%Si and Al7wt%Si alloys Figures 5 and 6 show that the calculated feeding is slightly larger than the measured one for both the castings. This is expected since the calculations assume 100% feeding while the feeding is somewhat less in reality.

As stated earlier feeding of liquid is necessary to compensate for the solidification shrinkage. Solidification shrinkage is in turn the result of different density in liquid and solid. Feeding models are therefore extremely sensitive for variations in the density. The density in solid for AlSi alloys is relatively well known but data for the density in liquid alloys are lacking. It is

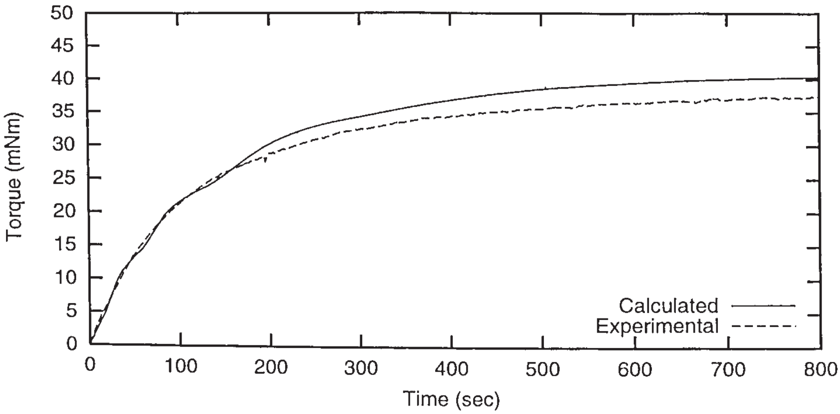

Figure 6: Comparison of measured and calculated torque for Al7wt%Si alloy.

hoped that accurate measurements on the density in liquid AlSi alloys will be made in near future.

ACKNOWLEDGMENTS

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