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Simulation of Casting Technologies for Al-Si-Cu Plate Casting

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Abstract

During the casting of aluminium alloys, the susceptibility to form oxide films is high, due to the turbulent flow of the melt and constant exposure of new surface area. This have impact on the properties of the material and the service life of the casting components. Also, hydrogen solubility in the solid state are very low, which ends up being rejected and causing porosity. After pouring, when solidification occurs, another phenomenon arise called shrinkage. This require excess molten metal to be fed during this phase change to eliminate or reduce the effect of volumetric changes. Filling and feeding during aluminium casting is therefore of paramount importance, and careful steps needs to be undertaken to reduce possible defects in the castings. The objective is to apply studied literature guides and rules and simulate the casting process of aluminium alloys, and understand the how certain defects are occurring during this process. This is a preliminary study towards the understanding of the "macro evolution" of Al-Si-Cu alloy during solidification, which will be the bases for the study of microsegregation of the specified alloy.

Keywords: Solidification Process, Application of Information Technology to the Foundry Industry, Aluminium alloys, Oxide films, Simulation,

1. Introduction

Aluminium alloys has seen increase application in the transport sector in recent times. This is due to need to use parts that is light in mass which have the advantage of reduction in consumption of fuel, performance improvements and the need to adhere to environmental regulations. Reduction in mass can be attained by using aluminium instead of steel or cast iron. [1, 2] The aluminium-silicon alloys which also contains copper (and/ or magnesium) are commercially known as A319.0 (ISO: AlSi6Cu4). It is a popular alloy for various applications from automotive cylinder heads, internal combustion engine crankcases, applications where good casting characteristics and pressure tightness, and moderate strength are required. This is due to their excellent combination of properties such as fluidity, low coefficient of thermal expansion, high wear resistance, high strength to weight ratio, good corrosion resistance etc. [1, 3]

Dross formation is common in all aluminium alloys. It is when an oxide film forms on the surface of the metal instantaneously to the exposure of air (see Table 1). During the pouring from the ladle, this phenomena occurs enters with the metal stream the mould cavity. Turbulence of the metal as it flows inside the mould, not only exposes more metal surface to oxidation, but also entraps oxide films within the casting (oxide folds) leading to a reduction in mechanical properties.

Another property of molten aluminium is that it readily picks up hydrogen from the atmosphere or from moisture-containing refractories, the solubility of hydrogen in solid aluminium is very low, so that as the alloy freezes hydrogen gas is expelled, causing micro- or macro porosity in the casting. [4]

There is no common agreement about the method of gating aluminium castings, although certain principles are acknowledged. Although this is one of the most important steps in producing a good quality casting, it is often the one which is the least understood and, as a result, it is often overlooked.

Table 1: Forms of oxide in liquid aluminium alloy
(Adapted from [4])

Growth time	Thickness	Type	Description	Possible source
0.01 – 1 sec.	1 µm	New	Confetti –like fragments	Pour and mould fill
10 sec. – 1 min.	10 µm	Old 1	Flexible, extensive films	Transfer ladles
10 min – 1 hr.	100 µm	Old 2	Thicker films, less flexible	Melting furnace
10 hrs. – 10 days	1000 µm	Old 3	Rigid lumps and plates	Holding furnace

Another aspect of casting is adequate feeding during solidification. When most metal solidifies, three stages of shrinkage occurs. Firstly, liquid shrinkage due to metal losing volume as it gives up superheat and cools to its solidification temperature. This is followed by solidification shrinkage, which is the transformation from a liquid to a higher-density solid. For pure metals, this contraction will occur at a single temperature, but for alloys it will take place over some temperature range or freezing interval. The last stage is solid shrinkage, when the solid casting cools from its solidification temperature to room temperature. [5] Of these, the second stage is the most critical, as it can account for defect such as internal voids. Typical values for slow cooling aluminium as in sand casting are between 5 - 7%. [6] This implies that an adequate amount of liquid metal need to fed to the solidifying casting to compensate for the shrinkage.

This study serves to produce results using a commercial casting software package to simulate and compare different possible filling and feeding concepts.

2. Experimental procedure

2.1. CAD models

Three gating system designs were produced from a CAD software, with a plate for casting of 130 x 130 x 13 mm. The first was reproduced from what was used by a researcher at the Faculty of Foundry at AGH University of Technology. It has a conical pouring cup with a runner that feed molten metal, at an angle from the top, into the mould. The feeding was based on venting and was open to atmospherically. The size of the feeders was in relations whit the diameter of the runner.

The second concept was constructed from a lecture paper prepared by Campbell and Harding [7] with regards to filling the mould cavity with molten metal. The design includes a small pouring basin, a conical downsprue, a sprue base, a horizontal runner bar, which lead the molten metal towards the bottom of the casting, and an ingate, which introduce the metal into the mould cavity. The objective is to reduce the turbulent, which is an evitable during pouring. Feeding was also based on another lecture paper by the same authors. [8] Rules were applied that leads to effective feeding that will be discussed in the following section.

2.2. Gating system design and feeding rules

The pouring basin had a step introduce to give an offset, which acts to stop the rapid motion of the metal over the top of the sprue and helps to ensure that the latter is completely filled.

A tapered sprue is ideal as it allows the stream of metal to accelerate from the top of the sprue to the base of the sprue and the conservation of matter requires that the cross-sectional area will decrease.

The next stage is to transfer the metal from the sprue into the runner bar via a sprue well (also called a sprue base). This has three important functions, causing deceleration of the metal, constraining the first metal as it exits from the sprue and prevents splashing, and assist to ensure that the runner bar is filled. The well should be the lowest point of the casting and filling system and the metal should always progress uphill thereafter. In doing so, it firstly passes through the runner bar which distributes it through gates to the lowest point or points on the casting. Careful thought has to be given to how the metal will flow through the runner and casting, bearing in mind the need to keep the speed low in order to avoid surface turbulence.

The use of nomograms to design the gating systems is in practice easier. The requirement is to predict or estimate the initial filling rate, which then thereafter can follow the chart to get the dimensions of the sections in the gating system, as depicted on the chart.

The design of the feeders had to adhere to rules. The first rule is a heat transfer requirement known as Chvorinov's Rule, which simply states that the feeder must solidify at the same time as, or later than, the casting. i.e.

Modulus of feeder (M_f) ≥ Modulus of casting (M_c)

Modulus (M) = Volume of casting / Cooling surface area

Therefore as M increases, solidification time increases.

The second feeding rule is normally known as the volume requirement, which states that the feeder must contain sufficient liquid to satisfy the volume contraction of the casting. The volume required can be calculated from the volumetric contraction, α, and the volumes of the casting (V_c) and feeder (V_f), so that

$$\text{Volume required} = \alpha\,(V_c + V_f)$$

This has to be supplied by the feeder, which only works with a certain efficiency, ε, so that sound castings will be produced if:

$$\varepsilon \cdot V_f \geq \alpha\,(V_c + V_f)$$

The third rule is known as the junction requirement, which states that the junction between the casting and the feeder must not create a hot spot. A 2:1 ratio for height to distance is usually an ideal estimation for a feeder dimensions.

Note that according to the lecture paper there is seven rules, but rules four to six applies to more complex shapes, and the seventh is a statement implying that only use feeding if necessary.

2.3. Casting simulation

The CAD file was imported as a STL file into the casting simulation software program MAGMA5.

Sand moulding and Aluminium alloys were chosen from the list options. In this software each component were assigned a material identification, i.e. Casting ID for the plate, runner ID for the gating system and mould ID for the sand mould. The next step were to select the number of nodes and generate the mesh.

Before the casting simulation could be started, the selection of the alloy and type of sand for the mould were required. AlSi6Cu4 and Green sand were chosen respectively, from the available database. Pouring time was assumed for 10 seconds.

3. Results and Discussion

The total porosity is a combination of micro - and macro porosity. It is evident from a comparison of the simulation results (figures 1 and 2) that total porosity was reduced from the first concept. It is visible that porosity and mainly micro porosity is accumulating in the bottom half of the casting and in the gating system.

Figures 3 indicates how the air is entrapped inside the mould cavity. It is evident that for the first simulation, the entrapment is in relation with the macro porosity, but not for the second. Porosity in the second simulation does however follow the filling path of the molten metal into the mould cavity. This may be an indication that hydrogen accompanies the flow and are initially rejected along that path.

The solidification path for the second simulation can justify the micro porosity. This is due to hydrogen not being very soluble in the solid phase of aluminium. Figure 4 shows that at about 94%, the section which is still liquid is in relation with the micro porosity from figure 2.

It should be noted that to deduce the formation of an oxide film, the aging of the fill tracers needs to be studied. For the first simulation it is obvious that oxide layers will constantly form due to the turbulent nature of the downwards flow, thereby possible influences on the mechanical properties. From figure 5 the fill tracers aging, as pouring continues, indicates that the older material is situated in the vortex at the left hand side. This is no indication that an oxide layer is underneath the newer material, as a time lapse animation of the fill tracers indicates that the oxide layer that was formed actually raise to the top surface as predicted.

4. Conclusions

It is clear that porosity is a concern with both simulations. Proper planning and approach towards the design of the gating system and feeding needs to done. Practical experience is required to give insight and best practices of industries needs to be studied.

It can be concluded that filling from the bottom has the advantage of less turbulent, therefore lower possibility for the oxide film to be trapped inside the material.

The reduction in porosity from the main casting cavity was achieved, and can therefore be reason that the guides and rules is valid.

Further adjustment and simulations will be conducted, with regards to the pouring time and dimensions of the gating system and feeders. The objective will be towards the reduction of porosity in the casting.

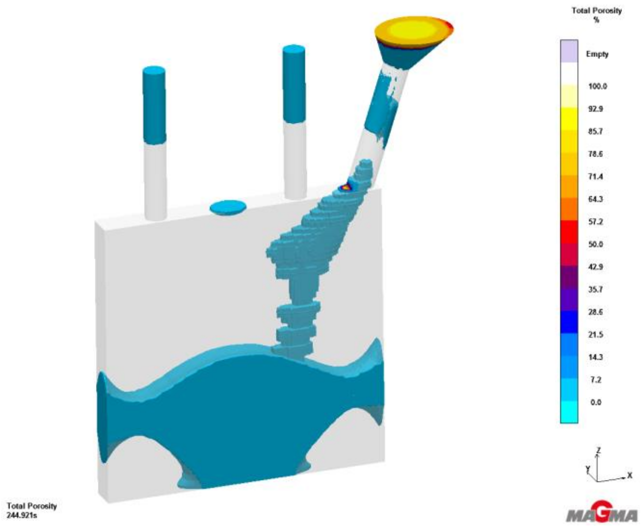

Fig. 1. Total porosity simulation results for first concept

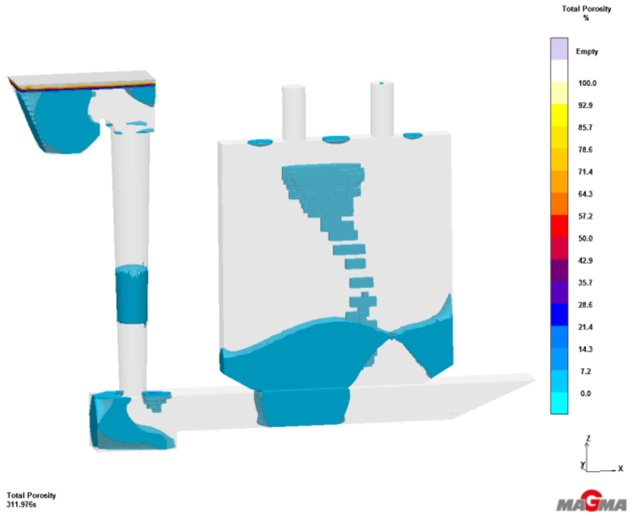

Fig. 2. Total porosity simulation results for second concept

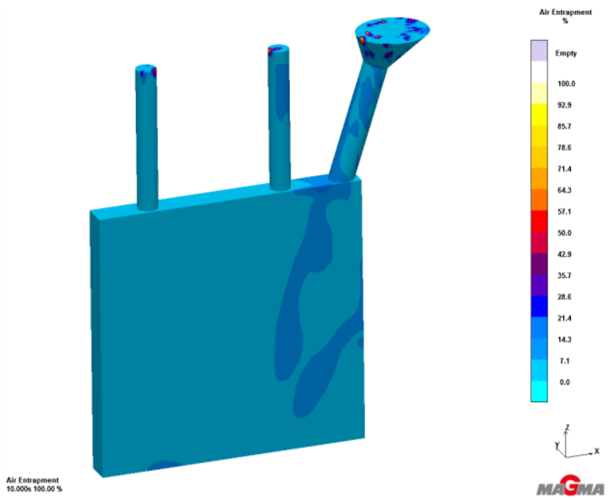

Fig. 3. Air entrapment in first simulation

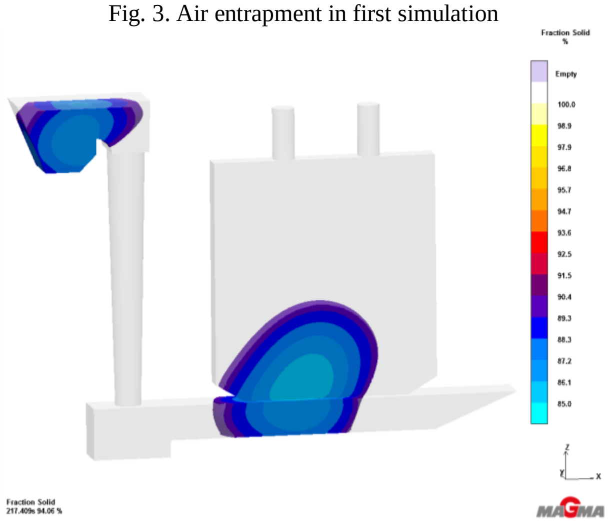

Fig. 4. Fraction solid at about 94% in second simulation

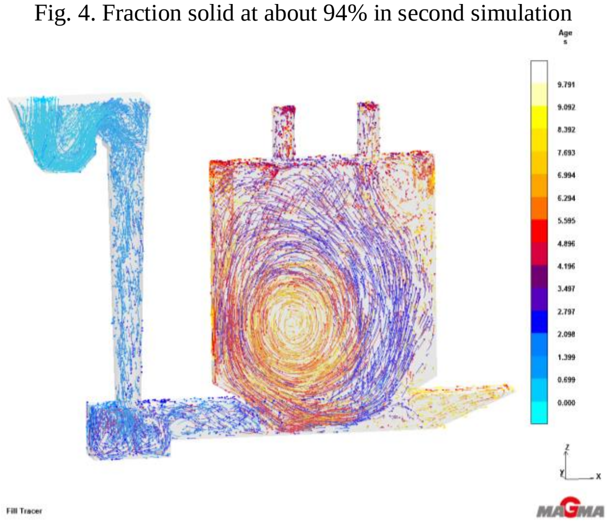

Fig. 5. Fill Tracer simulation for the second simulation with respect to aging time (in seconds)

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