ISSN 2303-4521

PERIODICALS OF ENGINEERING AND NATURAL SCIENCES
Vol. 1 No. 2 (2013)
Available online at: http://pen.ius.edu.ba

Hot Tear-Melt Quality Relationship in 3xxx Aluminium Alloys

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Abstract:

Corrosion resistance, formability and high strength is few of the major properties that makes aluminium alloys preferred choice of material for extrusion or deep drawing processes. Particularly, buildings, windows, doors are main application areas and it is growing. Twin roll casting method is used to produce such materials. One of the common problems faced in this method is called hot tearing. The effect of alloying elements is the reason for this defect. As a result, segregation causes tear and decrease process efficiency. The economic impact is immanent. Thus, it is aimed to study the hot tear tendency of 3xxx series aluminium alloys and the effect of alloying elements will be investigated in this work.

Keywords: Hot-tear, 3xxx series, Aluminium alloys, melt quality, casting simulation.

1.Introduction

It is quite common to have defects in any sort of production methods. Hot tearing is one of the defects that occur during casting processes. The size and distribution of hot tears may be up to 30 vol % of the cast part. During solidification, certain locations on a cast part may freeze later than the surroundings. Thus, these areas will be under negative pressure due to the shrinkage. Depending on the tension generated, this remaining liquid may "tear" to form the casting defect called hot tear. Hot tears may even lead up to the distortion of the cast part. The variables that affect hot tearing can be mainly listed as follows: composition, mould design, filling conditions, process parameters etc.

Campbell [1] pointed out that these defects were associated with hydrostatic tensions in the dendritic network. Therefore many research have been carried out by using Darcy's Law to predict the formation of hot tear in castings [2-20]. However, hot tearing still remains a complex phenomenon. Morever, there is no single type of a test that can measure or standardize these defects. Campbell's model for hot tearing is given in Fig. 2.

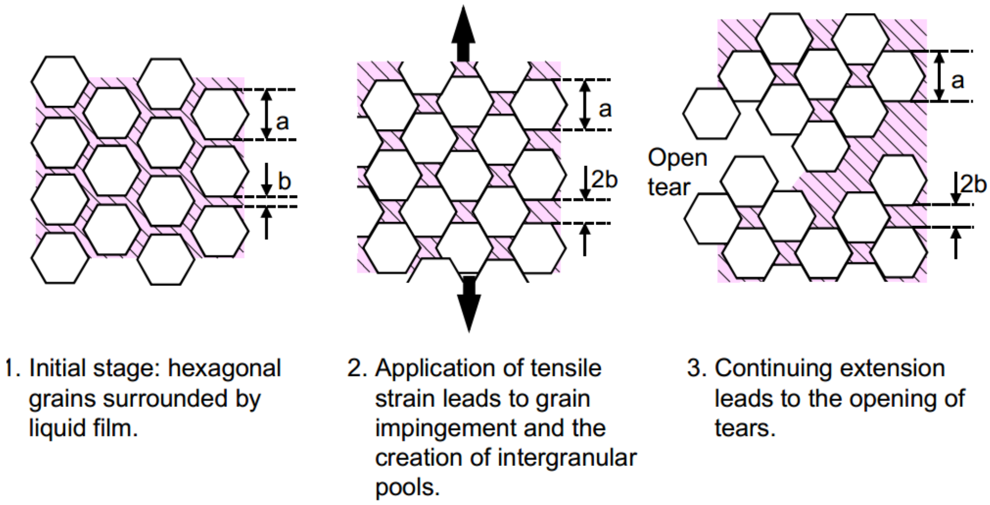


Fig. 1: A simple model of hexagonal grains of diameter "a" separated by a liquid film which initially has a thickness of "b" [1]

DOI: 10.21533/pen.v1i2.26

Therefore, in this study, two different mould designs were used to investigate the hot tearing susceptibility of 3xxx series aluminum alloys by using SolidCast simulation. The contribution of melt quality issue was also introduced into the hot tearing phenomena.

2. Experimental Work

Commercially available 3105 alloy was used to model the hot tearing susceptibility. The composition of the alloy is given in Table 1.

Table 1. Chemical Analysis of A3105 alloy

Al	Cu	Fe	Si	Zn	Mg	Mn	Ti	Cr
Balance	0,30	0,70	0,60	0,40	0,60	0,50	0,10	0,10

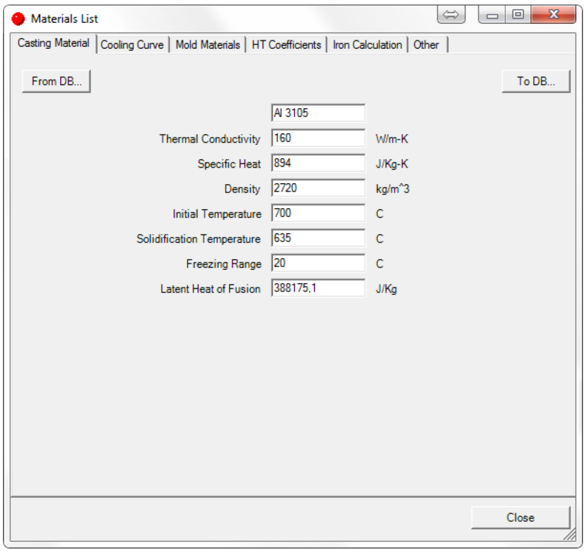


Figure 2. Parameters used in the modelling work.

For the modelling studies, two different melt temperature was selected: 700ºC and 750ºC; and three different mould temperatures were investigated: 20ºC, 120ºC and 250ºC. The parameters used in the simulations are given in Fig. 2.

SolidCast software was used to simulate the casting trials. The dimension of the mould used in the simulation is given in Fig. 3. The moulds were selected to be a sand mould and a permanent mould.

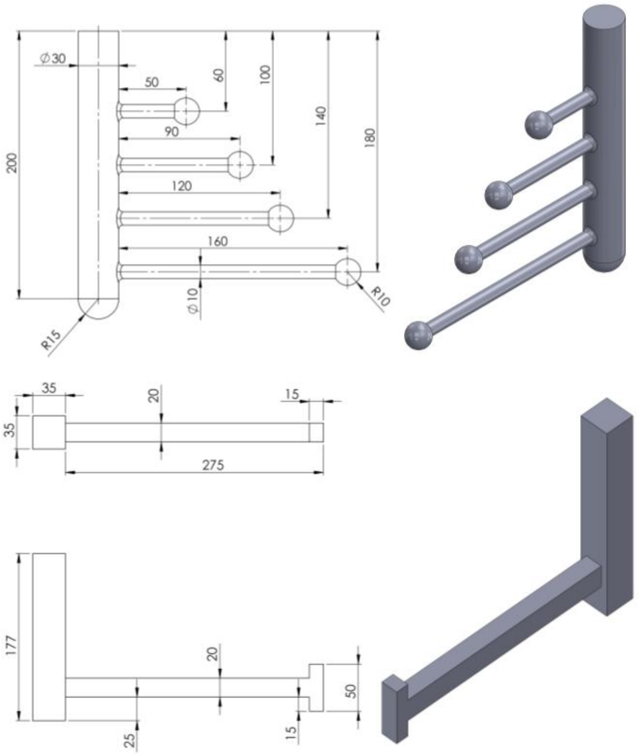


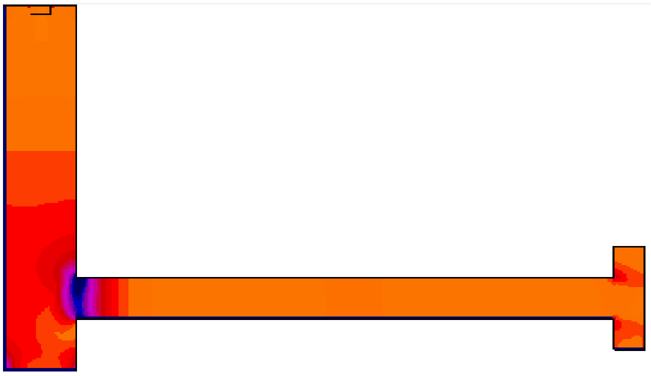
Figure 3. Dimension of the cast parts used in the modelling work.

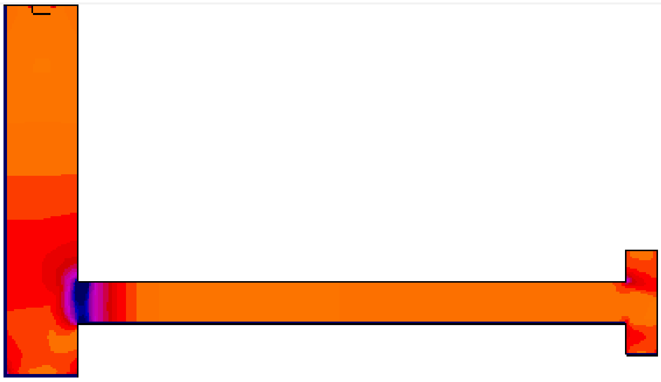
3. Results

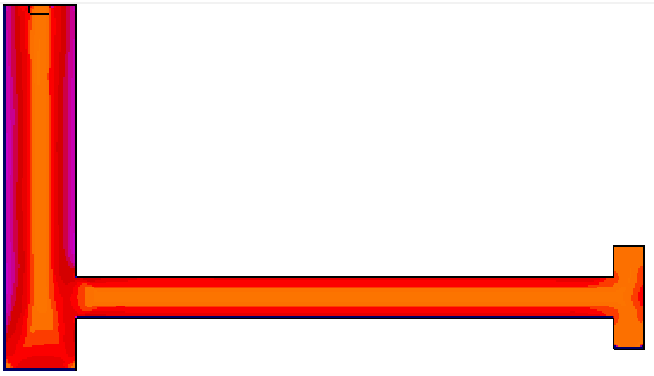
The simulation results that show the olidification time in the moulds are given in Table 2. The simulation results that show the hot spots in the moulds are given in Fig. 4-6.

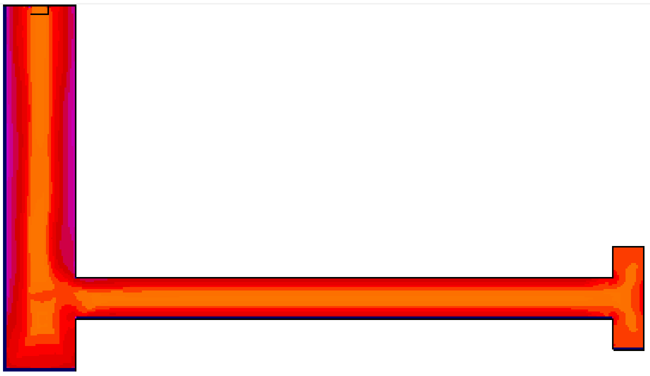
Table 2. Solidification time results

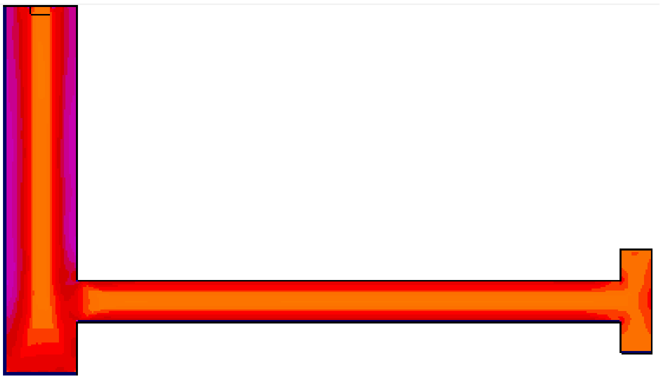
T bone design	**Solidification time(min.)**	**Hot tear susceptibility mould**	**Solidification time(min.)**
Sand mould 700 °C	3.062	Sand mould 700 °C	1.895
Sand mould 750 °C	3.592	Sand mould 750 °C	2.242
Permanent mould (20ºC), cast at 700ºC	0.383	Permanent mould (20ºC), cast at 700ºC	0.287
Permanent mould (120ºC), cast at 700ºC	0.431	Permanent mould (120ºC), cast at 700ºC	0.324
Permanent mould (250ºC), cast at 700ºC	0.539	Permanent mould (250ºC), cast at 700ºC	0.405
Permanent mould (20ºC), cast at 750ºC	0.379	Permanent mould (20ºC), cast at 750ºC	0.292
Permanent mould (120ºC), cast at 750ºC	0.431	Permanent mould (120ºC), cast at 750ºC	0.337
Permanent mould (250ºC), cast at 750ºC	0.591	Permanent mould (250ºC), cast at 750ºC	0.443


(a) Sand mould, cast at 700ºC

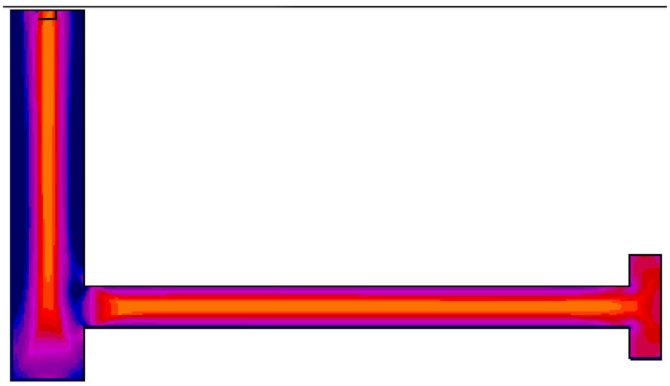

(b) Sand mould, cast at 750ºC


(c) Permanent mould (20ºC), cast at 700ºC


(d) Permanent mould (20ºC), cast at 750ºC

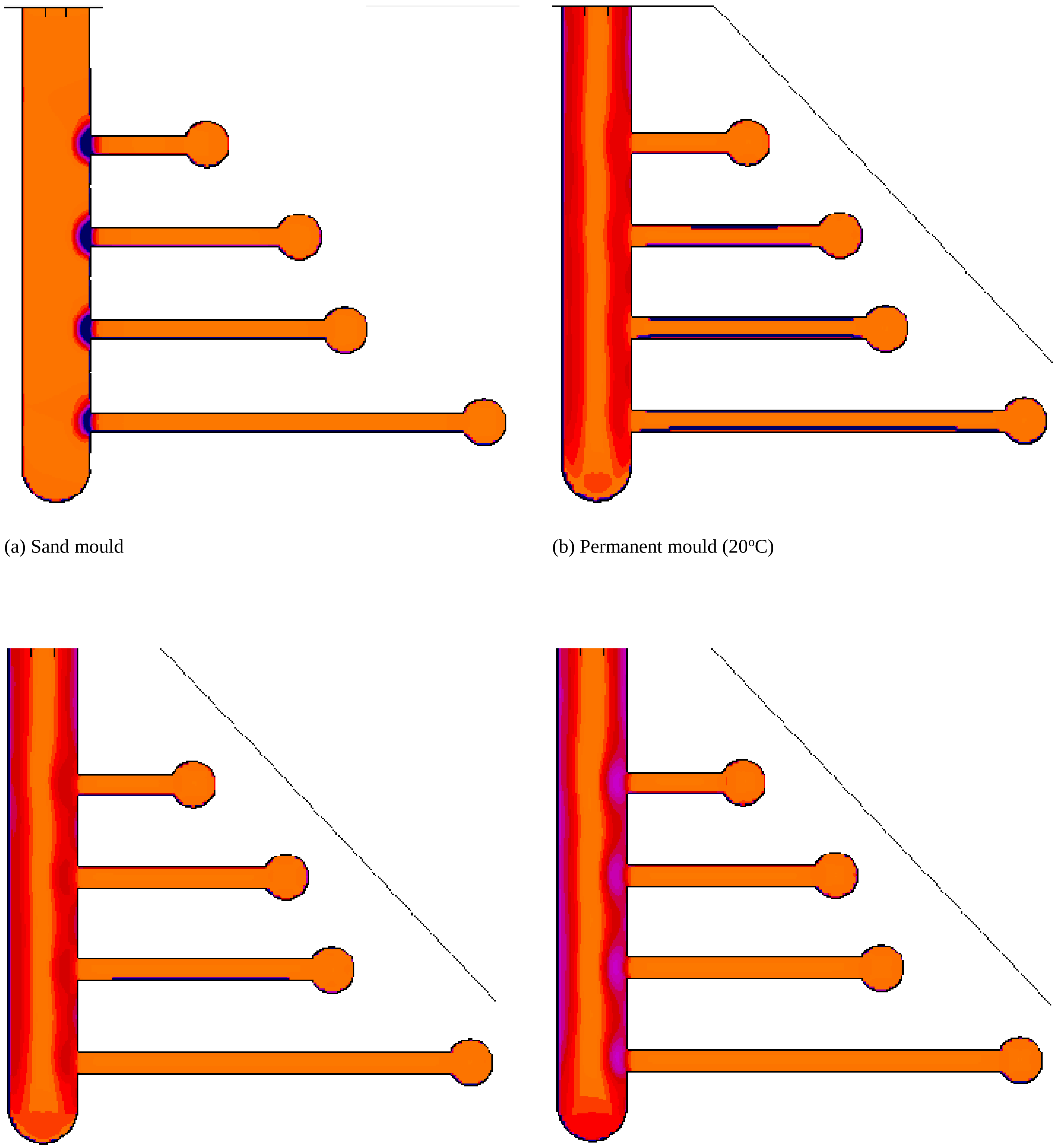

(e) Permanent mould (120ºC), cast at 700ºC


(f) Permanent mould (120ºC), cast at 750ºC


(g) Permanent mould (250ºC), cast at 700ºC


(h) Permanent mould (250ºC), cast at 750ºC

Figure 4: T-bone design simulation results



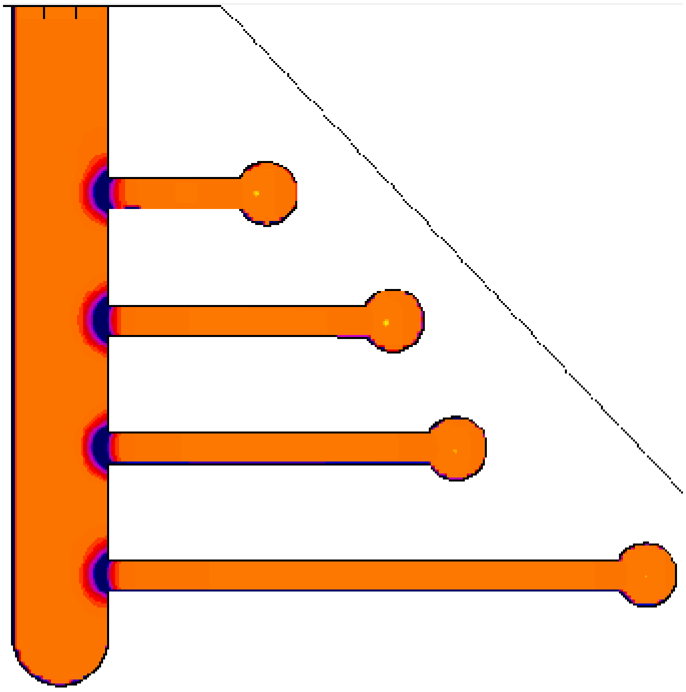
(a) Sand mould

(b) Permanent mould (20ºC)

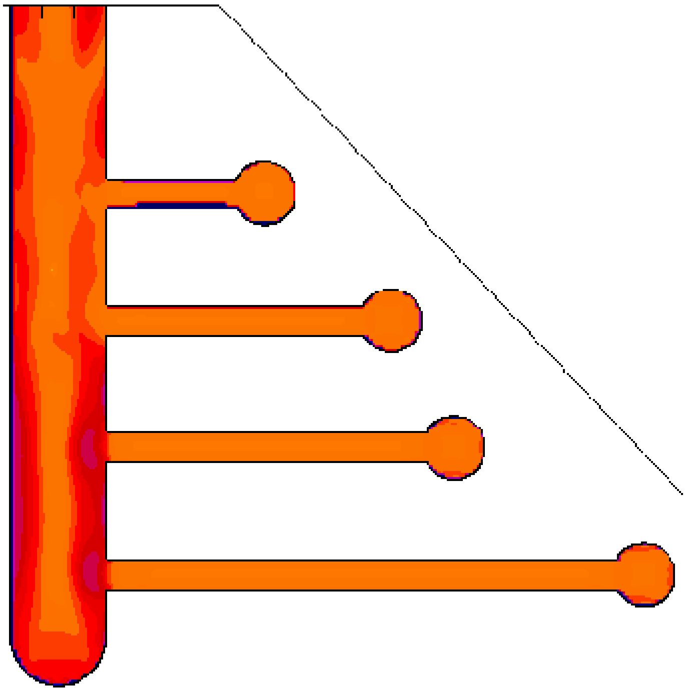
© Permanent mould (120ºC)

(d) Permanent mould (250ºC)

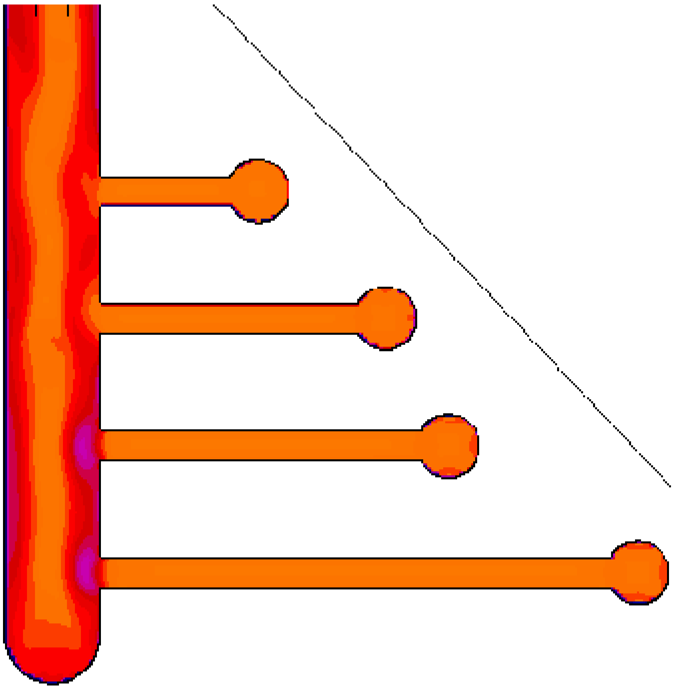
Figure 5: Hot tear susceptibility mould simulation results, cast at 700ºC



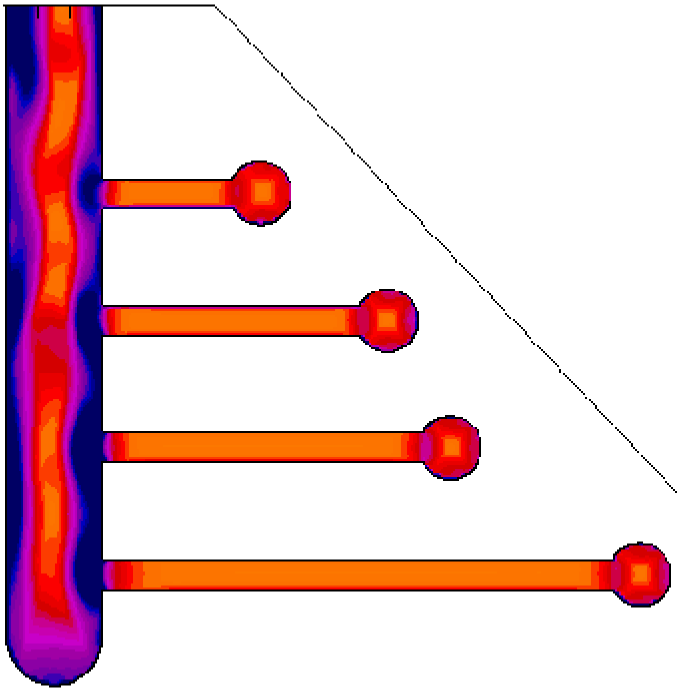
(a) Sand mould



(b) Permanent mould (20°C)



© Permanent mould (120°C)



(d) Permanent mould (250°C)

Figure 6: Hot tear susceptibility mould simulation results, cast at 750°C

4. Discussion

Two of the moulds were designed such that the long and thin cross-sectioned bars would solidify earlier than the thick pouring basin. In this way, there would be a hot spot at the junction points of the bars with the runner. These predictions were verified by the simulation results shown in Figs 4-6.

Different moulds (namely: sand and permanent) were used with different casting temperatures and various mould temperature in order to investigate the hot tearing susceptibility of 3105 alloy.

Thermal strain caused by the contraction during solidification was highest in the sand mould and at the permanent mould heated to 250 ^{o}C. It has been reported that 3105 type alloys exhibit a ductile fracture depending on the dendritic network (equiaxed or columnar).

The difference between the bar mould (Fig. 2a) and T-bone (Fig. 2b) is that with the bar mould, various effects of contraction rates can be examined. However, there are more studies with the T-junction type moulds in the literature.

The simulation results show the areas of hot spots. And the proportion and the distribution of these areas gives an indication

The existing hot tearing criteria have limited applicability. It has always been assumed that for a gap between grains to open into a tear, one of two conditions is required. Either a pressure drop within the mushy zone, or grains are pulled apart and the liquid film thickness increases. In either case, the pressure difference between the local liquid and the atmosphere exceeds the capillary pressure. However, one important aspect of hot tearing is that it needs to be nucleated. Aluminium alloys are known for their protective oxides that forms on the surface of the melt. When this oxide is disturbed during filling (i.e. uncontrolled pouring), a detrimental defect known as bifilms may form and these may be carried into the cast part. Bifilms are in the form of folded oxide skins. Therefore there exists an unbonded gap between these defect which may be readily opened to aid hot tearing.

Hot Tearing Susceptibility (HTC) in the mould given in Fig. 2a is calculated as follows:

$$HTS = \sum [L_i \times C_i] \quad (1)$$

Li is the length of the rod where the hot tear occurs and Ci is the severity of each tear. Severity ranges between 0-4 where 0 means no tear, 4 is the maximum tear where complete separation occur between the rod and the runner. An experimental work will be carried out to correlate melt quality with the HTS and simulation results.

4. Conclusions

Sand mould castings require chilling to eliminate hot tearing.

When permanent mould is used, the temperature of the mould play a significant role for hot tearing susceptibility. At room temperature, the feeding becomes difficult; at 250^{o}C, sharp edges increased hot tearing susceptibility; however, 120^{o}C appears to be an optimum temperature to eliminate hot tearing in 3105 alloy.

Simulation results are useful tool to identify the hot spots in a mould.

Further work is required to investigate the effect of melt quality and hot tearing susceptibility of aluminum castings.

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