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FIXING BOUNDARY CONDITIONDS FOR SOLIDIFICATION SIMULATION OF ALUMINIUM ALLOY PLATE CASTING

A. Pani Kishore and T. S Prasanna Kumar
Process Modeling and Materials Casting Laboratory, Department of Metallurgical and Materials Engineering, Indian Institute of Technology Madras, Chennai 600 036

ABSTRACT

This article reports the simulations carried out for solidification of Al-11.8Si alloy plate casting cast in a gray iron mold, using commercial software FLUENT. Selection of boundary condition is very important in simulating the thermal field in the casting. A variable heat flux boundary condition, which took into account the thickness of the die wall, was applied at the interface. Five thermocouple locations were chosen for validating simulated temperatures with measured temperatures. The simulated cooling curves were in fairly good agreement during the period of latent heat release.

1. INTRODUCTION

Considering the time and the financial constraints involved in setting up and conducting an extensive measurement program, computational fluid dynamics techniques appears as a logical alternative to obtain a more complete view of solidification of castings. The CFD software, FLUENT, is widely used for simulation of fluid flow problems. In the past few decades FLUENT has grown in its capability for addressing a wide variety of flow problems including mold filling and alloy solidification which are of particular interest for metallurgical engineers. However a literature survey and the practical application of FLUENT for solidification problems, indicates that specifying the proper boundary condition during permanent mold casting is still not straight forward. This work is directed towards developing suitable algorithm and lay down a suitable procedure for fixing the proper boundary conditions for simulation of aluminum alloy plate casting using FLUENT, Version 6.1.

2. SOLIDIFICATION MODELING

A rectangular plate casting of 125x150x15 mm^3 along with the feeder of height 40mm,angle of 30^0 and mold wall thickness of 15 mm was considered as shown Figure 1. The location of thermocouples are also shown in Figure 1.A time varying heat flux boundary condition was specified at metal/mold interface, thus neglecting the mold geometry for simulation. The following heat equation was solved for aforementioned casting domain.

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+S=\rho\, c\frac{\partial T}{\partial t} \quad (1)$$

For computations, selection of proper boundary condition is very important in simulating the thermal field in the casting and in turn predicting the porosity, microstructure, mechanical properties etc.,

Kumar and prabhu[1] proposed a 1-D heat flux model at metal/mold interface, which is a function of time, mold thickness and thermophysical properties of mold material for a cast-iron chill without coating. This model gives a method of estimating the heat flux at the metal/mold interface, with the knowledge of chill thickness and thermophysical properties. The heat flux equation given by them are in two parts as described below.

$$q_{\max} = A(d/\alpha)^{B} \tag{2a}$$

$$\frac{q}{q_{\max}}(\alpha)^{0.05} = C(t)^{D} \quad \text{for} \quad t \geq 10 \text{ sec} \tag{2b}$$

In the present analyses, the equation (2b) has been modified by multiplying a fuzzy factor *"f"* to account for the 3-D nature of heat conduction. The modified equation was written as follows.

$$q_{\max} = A(d/\alpha)^{B} \tag{3a}$$

$$\frac{q}{q_{\max}}(\alpha)^{0.05} = fC(t)^{D} \quad \text{for} \quad t \geq 10 \text{ sec} \tag{3b}$$

In this case the equation (3b) was applied as boundary condition on all sides, including the bottom surface. The top surface was insulated as shown in figure1. Symbolically,

$\frac{\partial T}{\partial n} = 0$ (adiabatic boundary condition) on top surface.

$-K\frac{\partial T}{\partial n} = q$ (Neumann boundary condition) on all sides and bottom surface as given in equation (3b).

Initially, it is assumed that mold is completely filled with molten metal and the initial temperature of molten metal is uniform. And also the radiation and buoyancy effects were neglected.
The initial condition was specified as T (x, y, z)=T.

3. METHODOLOGY

The 3D model of the domain (Figure1) is meshed with structured grid with fine and uniform mesh. The thermophysical properties of aluminum alloy were assumed to be constant as the alloy solidifies, as given in table.1. The time step size (0.1sec) for unsteady simulation is chosen such that smooth convergence is achieved. In each time step 100 iteration sweeps were used to solve the discretized equations. No under relaxation parameters were employed. Segregated solution method that sequentially solves each governing equation is used. Convergence is achieved for each time step when energy residuals fall below 10^{-8}. Define-profile macro (User Defined Function) was used for applying variable heat flux boundary condition.

4. RESULTS AND DISCUSSIONS

Figure 2 shows the comparison of simulated cooling curves with the experimental set at different thermocouple locations for a casting thickness of 15 mm. Experimental results for comparison are obtained from Pathak[2]. The error in the computed temperature and experimental temperature at different thermal couple locations along the mid plane of the castings indicated the following.

i) The start and end time of solidification of casting (eutectic arrest) was more accurately simulated than the initial cooling during loss of super heat and the cooling of solidified casting.

ii) Further, the errors during initial and later cooling were attributed to very complex nature of the heat flux distribution at metal/mold interface in cast iron molds as shown in Figure 3.

5. CONCLUSIONS

i) The solidification simulations for Al-11.8 pct Si alloy plates cast in gray iron mold were carried out using FLUENT 6.1.

ii) A variable heat flux model available in the literature was modified and applied as a boundary condition at metal/mold interface.

iii) The simulated cooling curves were fairly in good agreement with the experimental cooling curves during the period of latent heat release.

NOMENCLATURE

S -Phase change source term.
ρ -Density in (Kg/m^3)
k -Thermal Conductivity (w/mK)
C -Specific heat (J/Kg K)
α -Thermal Difussivity (m^2/sec)
d -Mold wall thickness (m)
t -Time (sec)
A, B, C & D are constants.

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REFERENCES

1. Prasanna Kumar, T.S. and Narayan Prabhu, K(1991) Heat flux transients at the casting/chill interface during solidification of aluminum base alloys, Metallurgical and material transactions B, 22B, 717-727.
2. Pathak, S.D. (1984) Feeding efficiency parameters and feeding range for aluminum base alloys cast in metallic moulds. Ph.D. thesis, IIT Madras.

TABLES

Table 1. Material Properties of Al –11.8 pct Si alloy

Material Properties	Liquid metal (Al-11.8 pct Si alloy)	Die material (cast iron)
Density (kg/m^3)	2750	7850
Thermal conductivity(W/mK)	180	57.739
Specific Heat (J/kg K)	1047	552
Latent Heat (J/kg)	460000	
Solidus Temperature(K)	850	
Liquidus Temperature(K)	860	
Initial Temperature(K)	1053	

FIGURES

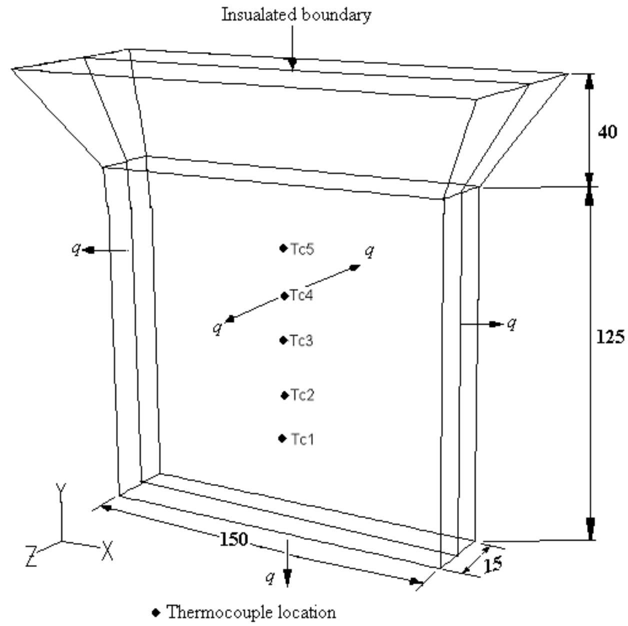
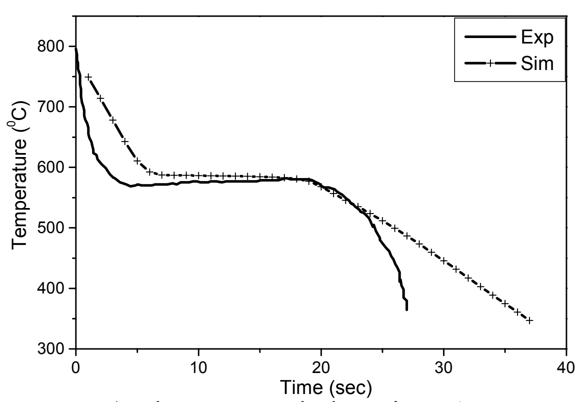
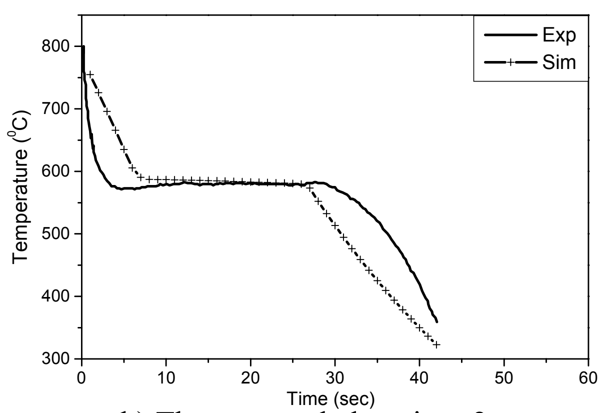


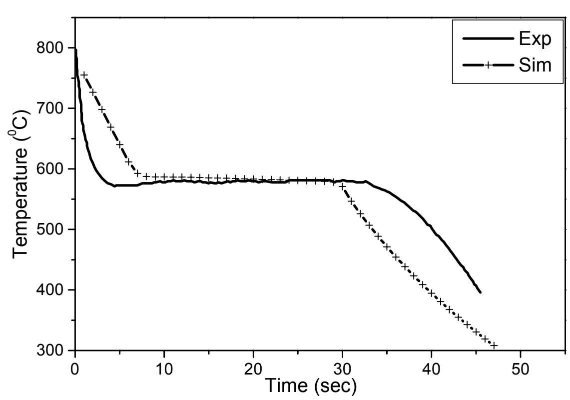
Figure 1 Solution domain of the plate casting with boundary conditions



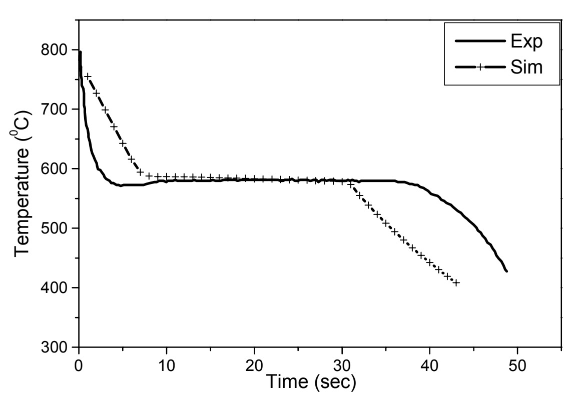
a) Thermocouple location -1



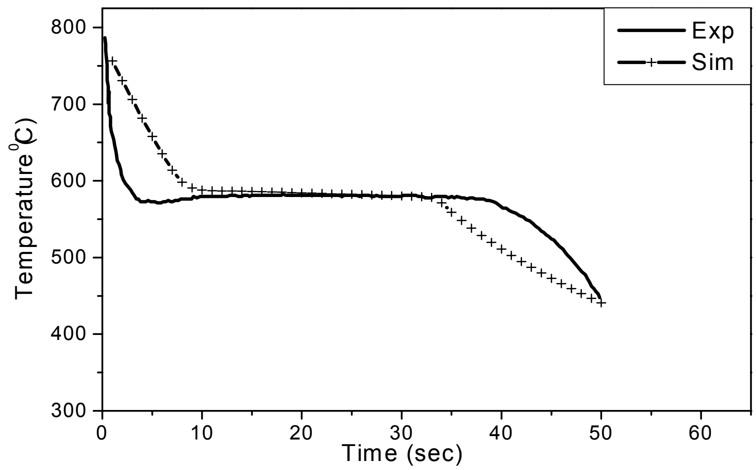
b) Thermocouple location -2



c) Thermocouple location -3



d) Thermocouple location -4



e) Thermocouple location -5

Figure 2. Simulated and experimental cooling curves for the plate casting

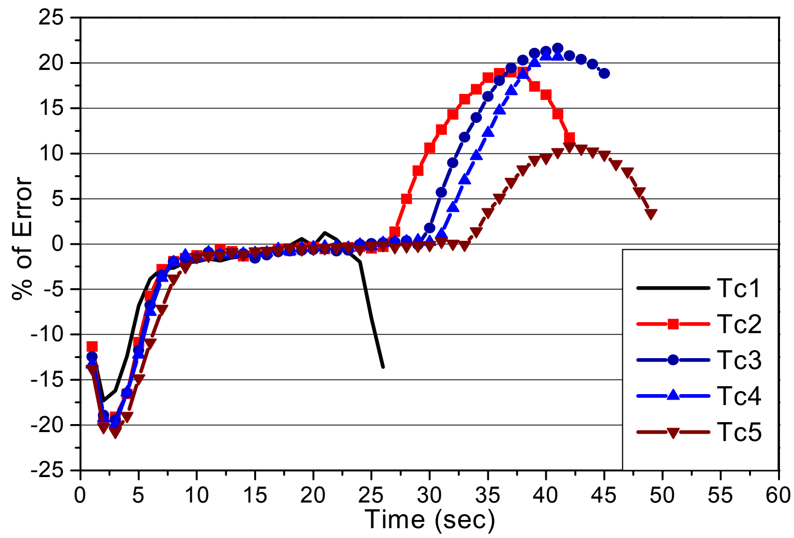


Figure 3. Error Analysis for the plate casting at different thermocouple locations