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NUMERICAL SIMULATION OF SAND CASTING OF AN ALUMINIUM PART

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Abstract: *Sand casting of an aluminium part is studied in the present paper. Simulation is used to diagnose defect formation. Realistic simulation demands proper model setup. Temperature measurements obtained by three thermocouples embedded in the mould were the experimental data used for the validation of casting simulation. Comparison of the experimental with the numerical cooling curves reveals the weakness of the use of one single heat transfer coefficient to effectively reproduce the solidification rate throughout the casting.*
Key words: *sand casting, thermocouples, solidification, simulation*

1. INTRODUCTION

Sand casting is a widely used casting process, where molten metal is poured under gravity into an expandable mould made of sand (Woodbury et al., 1998). This process is extensively used for the production of large parts of complex shapes with low equipment cost. It is characterized by relatively poor surface finish and high porosity (Campbell, 1993). For improvement of the process, casting conditions should be properly selected (Pagratis et al., 2007).

Casting simulation has become a valuable tool in the hands of engineers, in order to design and control the casting process (Cellini & Tomesani, 2008). It is important that initial conditions and conditions, material properties and numerical analysis parameters are correctly defined. The objective is to obtain knowledge concerning the evolution of solidification of the part, since it affects the quality of the casting (micro-structural properties, formation of defects).

In the present work, experimentally measured temperatures are used for the validation of simulation results. Furthermore, using the experimental cooling curves, the different heat flow rates across the cast metal and mould surfaces are depicted.

Fig. 1. (left) The produced casting part, with its gating system (riser, sprue, runners) (right) The wooden pattern assembly.

2. EXPERIMENTAL

The experiments were based upon the sand casting method. Silica sand was used for mould making, with the following chemical composition: 90-95% SiO_2, 5-8% Al_2O_3, 0.01mg/l organic additives (phenol). Moulds were prepared with regular hand moulding technique. The alloy used was commercially pure aluminium Al99.5 (series 1000).

Melting was conducted in a graphite crucible of max capacity of 1kg, using a resistance furnace. The melt was superheated to the temperature of 740°C (80°C above liquidus). It was then ladled and poured into the mould, which was formed by the pattern. The geometry of the casting, see Fig. 1, was rather simple, consisting of a cylinder (with diameter / height: 50/50 mm) and two truncated cones, fitted one on each side of the cylinder, in a symmetrical manner; total length of the part reaching 92.5mm.

Since the objective of the experiments was to measure the variation of the temperature of the melt with time close to the mould – metal interface, calibrated K-type thermocouples were embedded in the mould. The three thermocouples used were located as shown in Fig.2, inside the mould material, on the parting surface of the mould, which constitutes the geometric center of the casting part. All thermocouples were connected to a D/A converter. Data were recorded for 90 minutes to a PC, using LABVIEW platform for data acquisition.

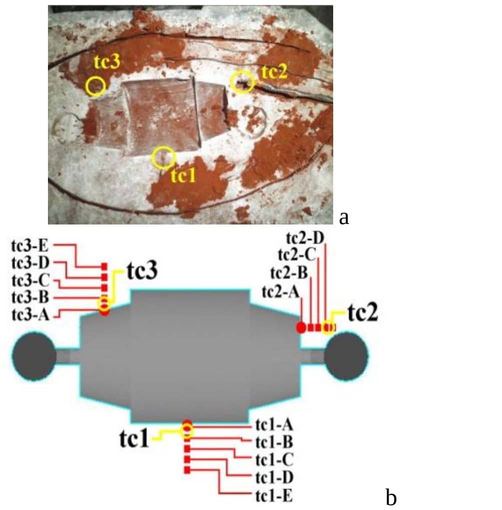

Fig. 2. (a) Mould drag section and (b) thermocouple locations.

3. NUMERICAL MODELLING

3.1 Finite element model setup

ProCAST 2004.1 by ESI Group was used as the simulation tool performing coupled thermal - flow analysis. Average mesh element was 2 mm for the casting part and the gating system, and up to 8 mm for the mould. The input parameters for the simulation were the experimental conditions. The initial mould temperature was 20^{o}C, the initial melt temperature was 740^{o}C.

The mass flow rate of the melt was calculated according to Bernoulli equation to be 0.4kg/s at the entrance of the pouring basin. The material properties of the silica sand and Al, with respect to temperature, were taken from handbooks.

3.2 Heat transfer coefficient

Heat Transfer Coefficient (HTC) between metal and mould is a parameter used in casting simulation, representing the heat flow at the metal/mould interface. It depends on thermo physical properties of the contacting materials, casting and mould shape and size, processing techniques, mould roughness, coatings, contact pressure, melt superheat, initial mould temperature (Campbell, 1993; Pagratis et al., 2007). For the present sand casting simulation, the HTC used is taken from literature (Trovant, & Argyropoulos, 2000), see Fig. 3.

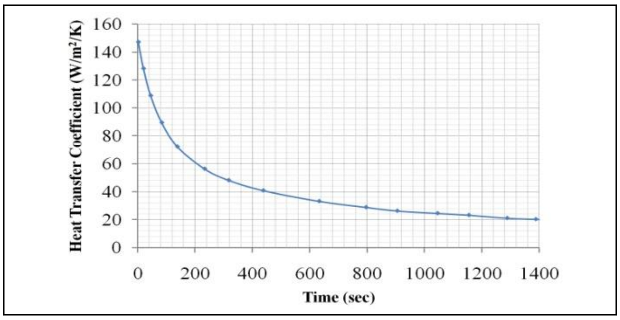

Fig. 3. Heat transfer coefficient adopted.

4. RESULTS

The experimental measurements are plotted together in Fig. 4(a). The maximum temperature measured by thermocouple ‘tc1’ is 535^{o}C, t=264s, whereas the peak temperature values for thermocouples ‘tc2’ and ‘tc3’ are 318^{o}C, t=277s and 232^{o}C, t=373s respectively.

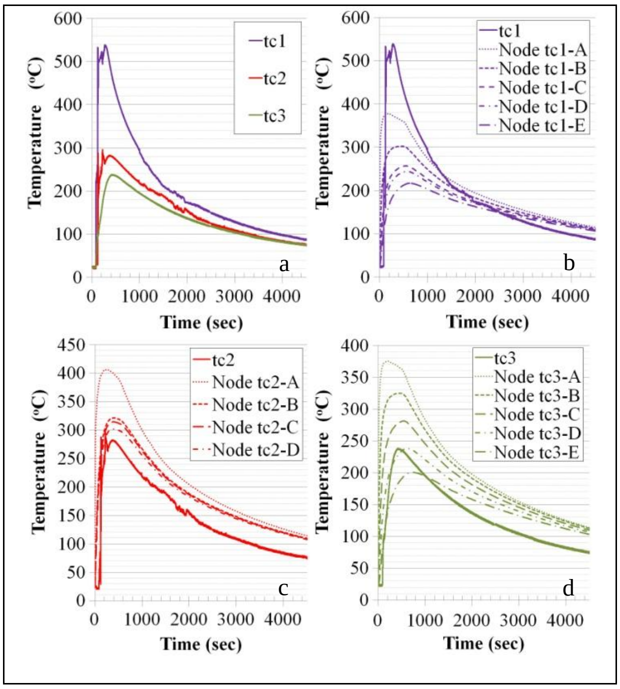

Fig. 4. (a) Experimental cooling curves, acquired from the three thermocouples, (b) Experimental and Numerical cooling curves for location 1, (c) for location 2 and (d) for location 3.

Fig. 4(b) shows the experimental cooling curve that corresponds to ‘tc1’ plotted together with five numerical cooling curves. These five curves are the calculated temperature histories for nodes near points A-E, see Fig. 2(b). Point A is the node closest to the metal/mould interface, point E is rather far. The cooling curves plots of points A-E present the large drop of temperature, a few mm from the interface, leading to the conclusion that the good knowledge of the exact measurement location is crucial. Fig. 4(c) & 4(d) are similar diagrams, referring to ‘tc2’ and ‘tc3’.

It is observed that the experimental measurements acquired by ‘tc2’ are in good agreement with the numerical results of the node ‘tc2-C’. In the case of thermocouple ‘tc3’, the numerical curve from node ‘tc3-D’ is the one that approaches the most the experimental one. As for ‘tc1’, none of the numerical cooling curves were able to predict the peak temperature measured.

Solidification time varies significantly, see Fig. 5(a), within the casting, as anticipated because of the large moduli differences; the casting is thick in the middle cross section, whereas the runners have a rather small cross section. This non-uniform solidification, results in porosity formation, as shown in Fig. 5(b) & 5(c).

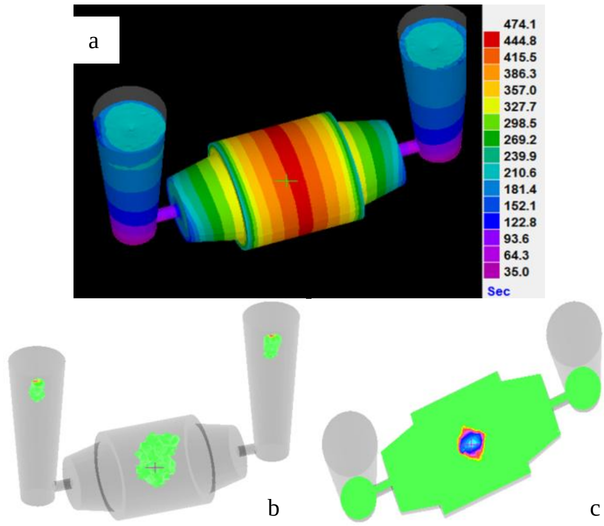

Fig. 5. Contour plots of the simulation results: (a) solidification time (b) porosity (c) porosity in the cross section of the part.

5. CONCLUSION

The experimental cooling curves acquired from three thermocouples embedded in three different locations of the mould presented significant differences in their peak values. The highest value corresponded to the thermocouple that was placed close to the thicker cross section of the part. Simulation of the sand casting process was conducted, using the experimental conditions as inputs, and a HTC from literature, which lead to good results. The numerical cooling curves for the two out of three locations of interest were successfully compared to the anticipated ones. The one case that failed was near the thicker cross section of the casting. Using one HTC for the whole casting signifies similar heat flux through the mass of the casting, which is certainly not true, taking into account the experimental results. This leads to the necessity of combined investigation of the HTC value at different parts of the casting.

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