ESTIMATION OF HEAT TRANSFER COEFFICIENT IN PERMANENT MOLD CASTING USING ARTIFICIAL NEURAL NETWORKS

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Abstract: *Dimensional accuracy of the cast parts strongly depends on cooling history which is mainly related with casting parameters. Cooling history refers also to heat transfer coefficient through cast/mold interface. This is a very difficult task for researchers to deal with, considering the difficulty in estimating and controlling the heat quantity which crosses the interface and mold wall going to ambient. The paper presents the estimation of heat transfer coefficient evolution during solidification of a hollow cylinder cast part. Artificial neural networks are very useful and reliable tools in prediction and estimation of casting parameters. Even if there are many previous relevant studies concerning the heat transfer coefficient determination at the cast/mold interface, researchers still deal with many uncertainties related to application of numerical developed models to a variety of dimensions and geometry.*

Keywords: *heat transfer coefficient, artificial neural network, casting*

1. Introduction

Determination of heat transfer coefficient at the cast/mold interface is of a great importance. This is of a real use because indicates the heat quantity which transfers from cast to mold, determining the cast part in terms of microstructure quality. This dictates the level of final mechanical properties, a very important desiderate for designers and engineers.

The interfacial heat transfer coefficient determination, independently from the casting process used for manufacturing parts, represents a very important step in process generation of a numerical reliable tool which should allow the prediction of common defects.

This is very important because the occurrence of such defects may serious affect the casting process leading to manufacturing of parts which do not correspond to their functioning purpose.

The modeling of cooling/solidification phase can bring important advantages in improving the casting processes by indicating some phenomena which may lead to formation of defects. These defects may seriously affect the quality and mechanical properties of the cast parts.

This paper aims to explain the importance of studying the interfacial heat transfer coefficient and presents a technique based on artificial neural networks method for determining this coefficient.

Artificial neural networks are powerful tools of a very easy use with very reliable results. Recently, numerous studies concerning the artificial neural networks used for prediction of some parameters of very complex manufacturing processes, as casting, have been carried out.

2. Previous research survey

Studies concerning the determination of heat transfer coefficient at the cast/mold interface have been carried out by Palumbo et al. [Palumbo,2015]. They studied the heat transfer coefficient in sand mold casting using an optimized inverse analysis. They proposed a numerical/experimental methodology which makes possible to determine the most of the parameters depending on temperature history. This means that, by using the methodology proposed by Palumbo et al. [Palumbo,2015], the difference between the numerical and experimental values directly measured with thermocouples can be minimized.

Sun et al. [Suna,2011] analyzed squeeze casting process due to obvious advantage of this type of casting related to slow cavity filling. They presented an analysis of the casting process through the determination of the heat transfer coefficient at the cast/mold interface by two methods: extrapolation method and numerical inverse method. Their results show that the values of the heat transfer coefficient obtained by inverse method are more precise than the values obtained by extrapolation method.

Assar [Assar,1992] studied the heat transfer coefficient at vertical and horizontal interfaces between the mold and cast during cooling and solidification of the melt material.

Rajaraman et al. [Rajaraman,2008] studied the interfacial heat transfer coefficient by two methods: control volume technique and Beck’s algorithm. They compared the results obtained by the two methods and concluded that volume technique produces precise results and this does not requires step-by-step iterations and calculations in time domain until the specific time is reached.

Research conducted by Zhang et al. [Zhang,2013] focused on the determination of the heat transfer coefficient at the cast/mold interface during cast material solidification. The method used is based on the least-squares technique and sequential function specification method. They compared the numerical and experimental results concluding that inverse procedure and algorithm presented by them are feasible and lead to an effective determination of heat transfer coefficient.

Kovacevic et al. [Kovacevic,2014] estimated the heat transfer coefficient at the cast/mold interface by an iterative algorithm based on function specification method. The experimental values of the thermal history were used for solving an inverse thermal conduction problem.

Guo et al. [Guo,2008] analyzed the factors that influence casting process and determine the evolution of the heat transfer coefficient in time. They concluded that the process parameters have a great influence on interfacial heat transfer coefficient evolution, a closer contact between the cast and mold leads to higher values of this coefficient.

Prasad et al. [Prasad,2013] also studied the effect of casting parameters on the evolution of heat transfer coefficient. They founded that the air gap dimension at the cast/mold interface, the gas type at the interface and the mold material have the great effect on the heat transfer coefficient value.

Hallam et al. [Hallam,2004] studied the resistance factors at the heat transfer which mainly act at the interface between the cast and mold in aluminum gravity die casting. The thermal resistance of these parameters has been analyzed by determining the coating layer thickness. At the same time, the influence of air gap thickness at the cast/mold interface was studied.

The use of artificial neural networks is a very precise way to predict some variable process parameters. Their determination usually needs very powerful and expensive tools which most of the time need a long computing duration [Susac,2016].

3. Experimental and numerical procedure

In order to determine the heat transfer coefficient at the cast/mold interface a very simple geometrical model consisting in a hollow cylinder made of Al-Si alloy cast inside a steel mold was used, Fig. 1.

The experimental device for measuring the temperature in cast and mold was more detail presented in previous work [Susac,2013, Susac,2008].

During solidification and cooling of cast alloy, the temperature evolution of cast material and mold was monitored by a data acquisition system.

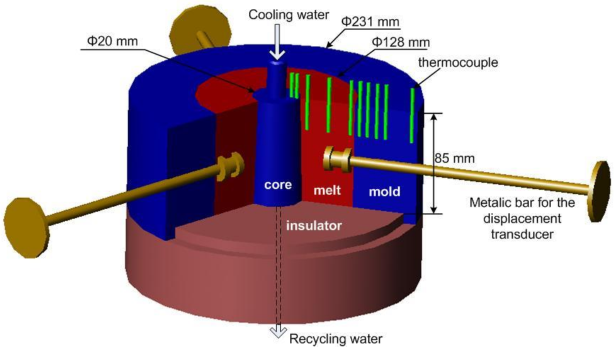

Figure 1: *Schematic view of casting experimental set-up used for thermal field dynamics monitoring during alloy solidification [Susac,2013].*

These values were used for calculating the heat transfer coefficient at the cast/mold interface by a gradient extrapolation method.

The heat transfer coefficient was calculated using Eq. (1) [Susac,2008]:

$$h = \frac{k\left(\frac{\partial T}{\partial r}\right)_{\text{int}}}{T_m - T_p} \tag{1}$$

where h is heat transfer coefficient between cast and mold, T_c and T_m are, respectively, the temperatures of the cast and the mold at their interface between the cast part and mold, $\left(\partial T / \partial r\right)_{\text{int}}$ is the temperature gradient at the interface and k is the air heat conductivity.

The analysis of heat transfer coefficient was carried out for the first 250 seconds of the solidification-cooling phase considering the fact that the largest heat quantity transfers from cast to mold in the first moments after mold filling.

4. Artificial neural networks

The prediction of time dependent heat transfer coefficient was carried out using artificial neural networks method. The main advantage of this method consists in much reduced computing time and the error between measured and predicted values is very low. This leads to very accurate results.

The neural model used for prediction of interfacial heat transfer coefficient has 3 layers: input layer with 3 neurons, hidden layer with 6 neurons and output layer with 1 neuron. The scheme of the proposed neural model is presented in Fig. 2.

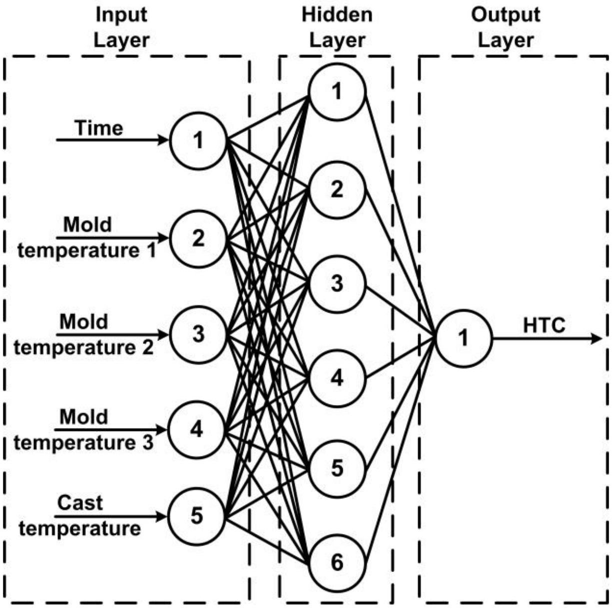

Figure 2: *Artificial neural model used for heat transfer coefficient prediction.*

The input parameters are: mold temperature measured in 3 points on radial directions (one point located at 2-3 mm measured from the interface with melt – *Mold temperature 1*, one point located at the half distance of the mold thickness – *Mold temperature 2* and one point located at 2-3 mm measured from the mold/ surrounding air interface – *Mold temperature 3*), melt temperature measured at 2-3 mm from the mold/melt interface – *Cast temperature*.

The output parameter is heat transfer coefficient (*HTC*) at the cast/mold interface, which, at the beginning, was calculated by a gradient extrapolation method.

Fig. 3 presents the comparison between the values of heat transfer coefficient determined from experimental values by a gradient extrapolation method and the values determined by training the artificial neural networks.

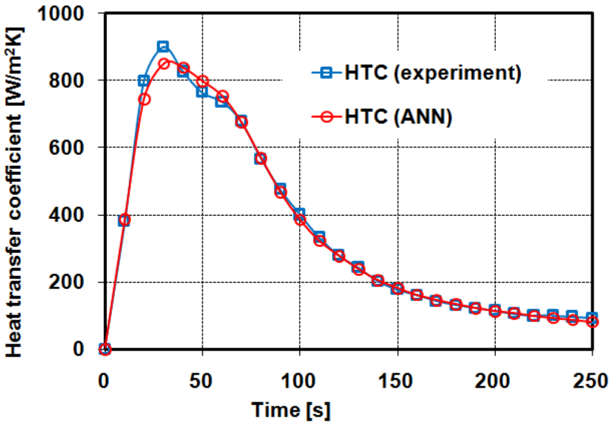

Figure 3: *Comparison between the values of HTC determined by a gradient extrapolation method and artificial neural networks prediction.*

It can be easily seen that there is a very good agreement between the results obtained by both methods; the average error of predicted data is 2.72 %.

At the end of mold filling phase, there is a very good contact between melt and mold which leads to a very fast heat transfer through mold wall to surrounding air.

5. Results and discussion

Once the melt solidifies, primary forms of dendrite skeleton occur.

Therefore, the melt is in semi-solid state and continuously shrinks.

Finally, when dendrite formations are strong enough to withstand the metallostatic pressure, an air gap will occur at the cast mold interface. This air gap plays a thermal barrier role.

For this reason, the heat quantity dramatically diminishes.

The goal of artificial neural networks use in estimating the heat transfer coefficient is to optimize the casting process, especially for reducing the duration of designing-manufacturing-testing cycle.

6. Conclusions

This paper presents the estimation of heat transfer coefficient at the cast/mold interface in permanent mold casting of a hollow cylinder part made of Al-Si alloy.

First, the heat transfer coefficient at the cast/mold interface was determined by a gradient extrapolation method. For this, the temperature history of the cast and mold was used. The temperature was measured in different locations in the cast and mold at the same depth.

Second, the interfacial heat transfer coefficient was determined by artificial neural networks method.

There is a very good agreement between the results calculated by the two methods; the calculated average error is 2.72 %.

Therefore, heat transfer coefficient can be easily determined based on a neural model, depending on the thermal filed dynamics in time of the cast and mold.

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