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CONTROL MODEL OF COOLING-SOLIDIFICATION PROCESS AIMING AT INTEGRATING THE DESIGN AND MANUFACTURE OF THE CAST PART

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ABSTRACT

The casting process control continues to be a very important deziderate for actual industry. During the last decades, researchers sought to identify new solutions for designing and manufacturing of products which had to fit their purposes. Many times, their work failed. This paper presents a theorethical algorithm for controlling the casting process, based on experimental results and artificial nural network prediction. The final goal is to manufacture parts with improved mechanical properties. There is the posibility to control the solidification phase of the casting process, even in permanent mould casting, the result consisting in advanced parts which correspond to industry criteria.

KEYWORDS: casting, prediction, artificial neural network, manufacturing.

1. INTRODUCTION

During the design and manufacturing stages for a new cast part, there is necessary to exactly determine what form the final product should take to fulfill its purpose.

This can mean to repeatedly design and manufacture the part which leads to an expensive and time-wasting process. To overcome this problem, numerical simulation can be applied to determine the exact design to satisfy the requirements of a new product development [1].

Additionally, structure analysis using a CAD system to evaluate product strength with quantitative results for such factors as material strain and stress can be used instead of conventional experiments. However, the model data used to make a numerical simulation cannot define the material property of a product but only its shape or surface.

The material property is assumed to be uniform and without any defects, though a real product actually has many minute hollows and uneven material distribution. This is why there are always discrepancies between experimental and numerical analysis.

Many authors [2-5] have shown that a proper geometry can effectively reduce the defects arising in the casting designs. On the other hand, a proper geometry leads to an adequate temperature pattern during solidification phase [6]. Identifying the best possible geometry is an important task and requires high technical design. Cast part geometry must consider both processing and functional requirements.

During cooling-solidification phase of the cast, the cooling rate and solidification time are global parameters that determine the microstructure formation.

Controlled variation of these parameters can influence the mechanical properties of the cast material. The aim of the paper is to develop a neural control model of the part thermal field dynamics and a control scheme of cooling-solidification phase.

This control scheme represents a tool for a robust control of solidification phase in casting, in order to meet customer requirements concerning dimensional quality and mechanical properties.

2. EXPERIMENTAL SET-UP

The experiment consisted in a hollow cylinder part cast inside a mold with external wall and inner core both made of steel. A detailed description of the experimental set-up design was presented in previous work [7,8]. During alloy solidification and cooling, the temperature was measured inside the core, cast and mould, on radial direction. The experimental data was monitored and recorded by a computerized system consisting in a programmable logic controller (PLC) connected to a Windows Operation System. The experimental device is presented in Figure 1.

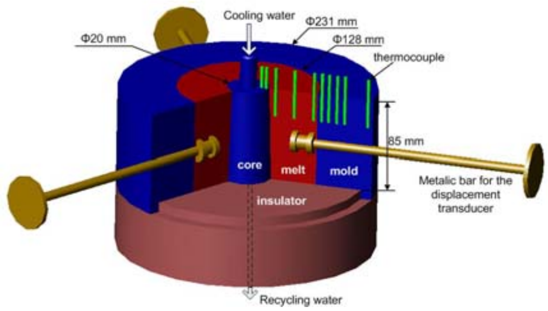

Fig. 1. Experimental set-up [8]

3. ON-LINE CONTROL SCHEME

In permanent mold casting, the designing and manufacturing stages can be integrated to obtain: i) a better correlation between mechanical properties and tension state during the functioning of the part and ii) a very high precission of the cast part, which is mainly affected by the solidification shrinkage.

To reach these desiderates, a new scheme for controlling the solidification/cooling process is proposed. In any location of the part, the solidification and cooling can be controlled by linking the cooling rate of the cast part with the modulation of the cooling water rate.

The proposed control scheme is based on: i) the monitoring of the thermal field dynamics of the casting system components (for example, the mold thermal field); ii) the prediction of the thermal field dynamics of the cast part and iii) modulation of the cooling water rate in any location depending on the evolution in time of the solidification/cooling process and its relation with the microstructure of the cast material and mechanical properties.

4. NEURAL NETWORK MODEL

The thermal adjustment of the melt cooling rate will be verified in an economical manner, which presupposes the use of experiment and finite element software results of the cast part solidification process.

Thus, the numerical simulation results such as thermal field dynamics, thermal stresses or solidification shrinkage, calculated in any point of the cast part, become input data for training the neural network.

The neural network is trained for limited intervals of the parameters. Within these intervals, it is not necessary to carry out any other numerical simulations because the trained network has the function of a reduced order model.

By neural network interrogation, the prediction of the real values of the cast temperature are deduced. Then, these values are compared with the initially imposed values of the temperature.

To validate the functionality of the designed control scheme, previously presented experiment was considered.

Thus, the following steps were completed:

- the generation of a data base by experiment and finite element numerical simulation of the solidification/cooling process of the cast part, by varying the control parameters of the process;
- training the artificial neural network NNMODEL using the data base obtained by numerical simulation;
- prediction of the thermal field dynamics in selected locations, using the neural model and
- numerical validation of the thermal field dynamics prediction by real monitoring solidification/ cooling of Al7SiMg alloy.

The goals of using the neural network method for studying the solidification/cooling process are: i) significantly reduces the calculation time and obtains an optimal solution for designing the casting system and ii) the tendency to develop a rapid and accurate tool to obtain data about the relations which exist between the process variables.

Moreover, the neural network training allows the calculation of a virtual set of process variables, avoiding the experiment repetition and even the numerical simulation.

Experimental testing of on-line control system was carried out for the same casting system used for numerical simulations. The casting system consisted in a permanent metallic mould isolated at the bottom side and the core was cooled by water to creat a thermal gradient mainly on radial direction. The cast was a hollow cylinder made up of Al7SiMg.

The thermal field dynamics in the core, cast and mold was measured with three thermocouples located at a depth of 25 mm.

The first thermocouple was located in the mold at a distance of 3-4 mm from the cast/mold interface (T_B), the second one was located at the core at a distance of 3-4 mm from the cast/core interface (T_C) and the third one was immersed into the melt (T_A).

The measured thermal field dynamics was used to calculate the temperature evolution on the same points, by the semi-inverse method.

Then, by varying the input parameters, a set of numerical simulations were run in order to generate a data base, which was necessary for training the neural network.

The neural control scheme shown in Figure 2 is applied to adjust the temperature of a location in the cast (point A). The correction applied to the temperature of this point is programmed so that the obtained curve of the temperature should superimpose on the plotted curve requested by the customer, after the structural analysis of the part is completed. This temperature dynamics leads to the desired microstructure around point A.

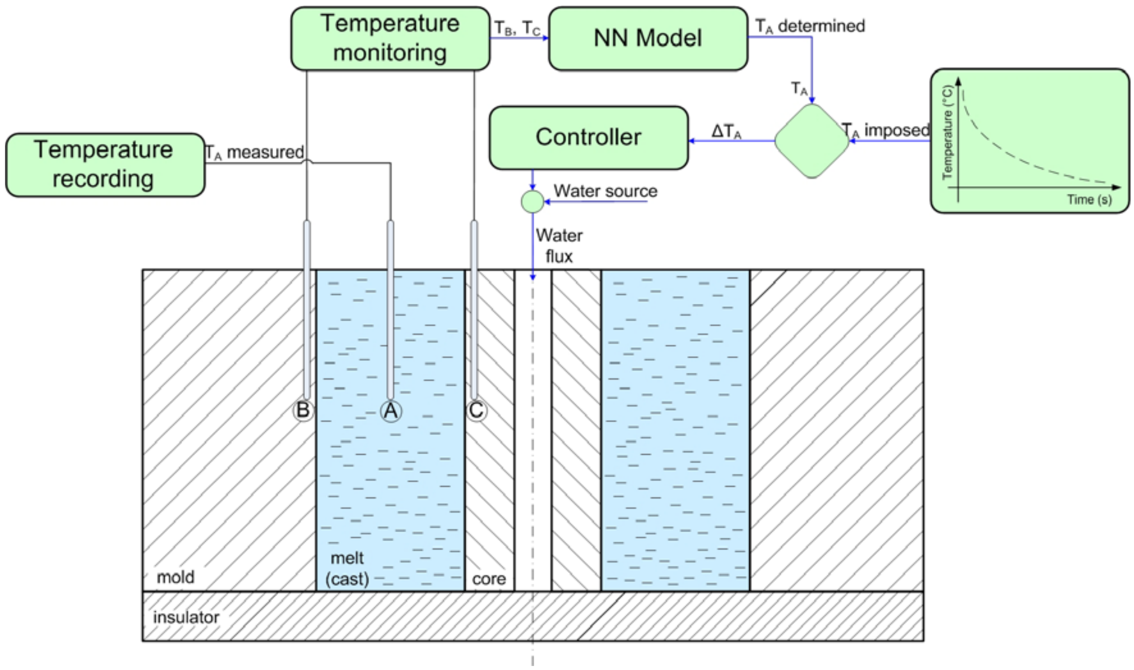

Fig. 2. Neural control scheme of the casting process of an industrial part

Therefore, this area will have some improved mechanical properties so that the part will comply with the maximum principal stresses during its functioning.

The part geometry design considers the anisotropy of the mechanical properties and avoids the microstructure defects. Based on the thermal field dynamics of the cast, the reference temperatures of the casting system are calculated.

At the same time, the casting system monitoring consists in monitoring the temperatures in points B and C, located near the cast/mold and cast/core interfaces. The temperature error in point A will be calculated by a control program which consists in a programmable logic controller. This controller will send the correction value to a rate control valve of the cooling water. Therefore, a new concept is proposed – the programmed path of the thermal field.

5. RESULTS AND DISCUSSION

The experimental thermal field dynamics in point A was compared to the thermal field dynamics initially requested by the customer. The control errors are less than 2% for the time interval 0...300 seconds (Figure 3). This is very important knowing that the most important phase of the casting process is solidification.

The thermal field dynamics shown in Figure 3 corresponds to a final shrinkage of 0.45 mm for a part outer diameter of 128 mm. The air gap dimension resulted from calculation was 0.40 mm, this value being compensated by modifying the mold diameter. The difference between the two values is 0.05 mm and it is the real dimensional error caused by cast shrinkage during solidification/cooling process.

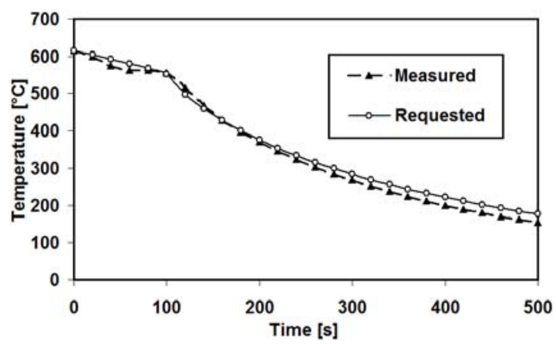

Fig. 3. Comparison between measured and requested thermal field dynamics in point A

The value of the error is very small when compared to the results usually obtained by permanent mold casting. This underlines the performances of the neural control system.

6. CONCLUSIONS

The control model and neural control scheme presented in this paper and validated numerically for a hollow cylinder cast part contribute to the development of the casting design flexibility.

The designers determine the maximum principal stresses of the cast parts by means of a finite element simulation and then, they calculate the values of the mechanical properties, so that they cope with the loading requirements.

Thus, part deformation will be limited and cracks and wear during part operation will be avoided. The designer maps the anisotropy of the mechanical properties and chooses the proper option which correspond to the customer requirements.

Being flexible, this schema can develop new trends in industrial engineering, where the part geometries become more and more complex.

A proper training of the neural network with the results obtained by varying some input parameters may lead to an improved result of the proposed neural control model.

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