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TOWARDS IMPROVED MECHANICAL PROPERTIES OF ALUMINUM ALLOY CAST PARTS

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ABSTRACT

The improvement of the cast part quality, meaning the geometric precission and the mechanical properties, is an important goal for researchers. There is a twofold aim: (i) the reduction of the costs related to the cast part mechanical machining and (ii) a high level of the cast part strength during functioning, by obtaining a proper crystalline structure during melt material solidification/cooling. This domain mainly refers to the relation between the melt material solidification/cooling process and the cast part crystalline microstructure. This approach has two aspects: (i) the modelling of the melt material solidification/cooling process in order to programme the optimal thermal field dynamics and the control of the thermal field evolution depending on its programmed dynamics.

KEYWORDS: thermal field dynamics, mechanical properties, melt solidification, permanent mold casting.

1. Introduction

Numerical simulation is constantly used in casting industry for a better understanding of both the critical aspects related to heat transfer and fluid flow phenomena and the relations between them and the metallographic structures and the formation of microstructure defects in the cast parts.

Some of the thermophysical properties necessary for obtaining very accurate results by using numerical simulation are very often totally missing in case of some alloys which have a very high commercial interest for casting industry.

The casting technologies have many advantages as the flexibility of manufacturing some complex geometry. Furthermore, by controlling the casting process, can be obtained, through a single processing operation, a cast part which corresponds to the imposed mechanical properties and quality level.

This new concept – near-net-shaping – can be applied in casting by controlling the precision parameters of the process.

In casting industry, the casting part defects caused by solidification shrinkage represents a major cause for rejection. Some researchers stated that pore formation is determined by the heat transfer mechanism between the cast and mold, shrinkage solidification or improper feeding of the mold.

This work focuses on the influence of the heat transfer coefficient over the microstructure of a cast part made of Al-7Si-Mg alloy.

2. Experimental work

The experiment consisted in casting a hollow cylinder part (Al7SiMg alloy) inside a permanent metallic mold with the outer wall and core both made of mild steel (OLC45). The filling of the mold was done by free-fall of the melt under the action of gravity force. The outer diameter of the mold was 231 mm and the inner diameter of the mold was 128 mm. The mold was insulated at the bottom and the core was cooled by water in order to create an unidirectional thermal gradient mainly on radial direction. The cooling channel of the core had a diameter of 6 mm. The core was designed conically (half angle of 2°) in order to avoid destruction when extracting the cast.

The experimental set-up used for heat transfer coefficient and air gap determination is shown in figure 3.

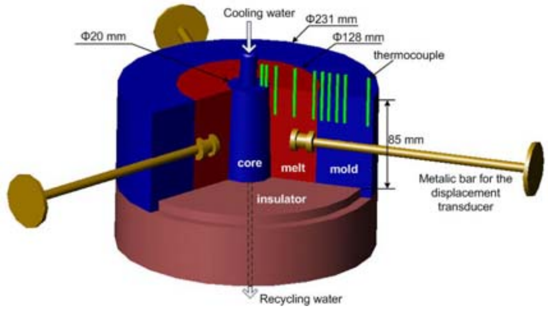


Fig. 1. *Scheme of the experimental set-up used for heat transfer coefficient and air gap determination*

Before filling, the mold was coated with a thin layer of refractory paint in order to avoid the chemical interaction between mold and melt materials. During the solidification and cooling of the cast, the thermal field dynamics was monitored with 10 K-type (chromel-alumel) thermocouples, mounted along the radius of core, cast and mold, at a depth of 25 mm.

3. Numerical work

The cast geometry is based on the model used by Hernandez [Chaper 1], the main improvements consisting in:

- the thermal field dynamics in the core, cast and mold was monitored with 10 chromel-alumel thermocouples, located along radial direction, in order to determine a very accurate temperature gradient. In this direction, a sensitivity study has been carried out, in order to determine the optimal position and the minimum number of thermocouples for an accurate heat transfer coefficient determination at the cast/mold interface;

- the displacement of the outer wall of the part was monitored with 3 linear variation displacement transducers in order to verify the deformation behaviour of the cast during solidification/cooling. The cast displacement was measured with a very high precission (10-3 mm order).

4. Results and discussions

• *Heat transfer coefficient*

Temperature variation on radial direction in the mold, has a great importance for temperature gradient calculation. A very accurate calculation of the thermal field dynamics will lead to a very accurate calculation of temperature gradient at the interface and therefore to a very accurate heat transfer coefficient determination. The evolution of the heat transfer coefficient between the cast and mold is shown in figure 2.

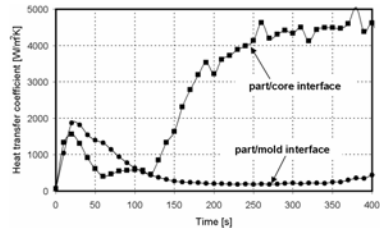


Fig. 2. *Evolution of heat transfer coefficients at the part/mold and part/core interfaces for Al-7Si alloy*

At the cast/core interface, the heat transfer evolution is influenced by the occurance of the contact pressure between the cast and core due to the cast shrinkage. A larger contact surface between the cast and the core will determine a faster heat transfer between them.

The heat transfer coefficient at the cast/mold interface is explained by the formation and growth of the air gap dimension (figure 2). The air has a low conductivity (kaer = 3,08·10-2 W/m·K) and acts like a barrier for the heat transfer. When the air gap forms the value of the heat transfer coefficient significantly decreases until it reaches a value between 100-200 W/m^{2}K.

• *Air gap formation*

The difference between the displacement of the inner wall of the mold (calculated) and the outer wall of the cast (measured) is the air gap dimension (figure 3).

From the very first moment the mold filling is completed, there is a tendency of the melt material to shrink (figure 4) due to the formatin of the first denditric structures. Since the structures are not strong enough (liquid phase >> solid phase) they dissolve.

The air gap dimension was determined considering that the mold has a constant thermal resistance at temperature variations and the core temperature does not influence the cast shrinkage.

In figure 3 is shown the measured radial displacement of the outer wall of the part and the calculated radial displacement of the inner wall of the mold and in figure 4 is shown the air gap evolution with time.

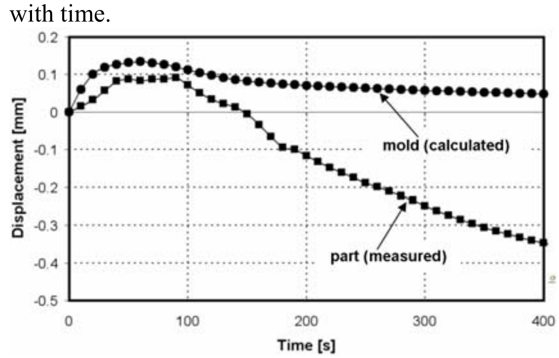


Fig. 3. *Displacement of the mold (calculated) and part (measured)*

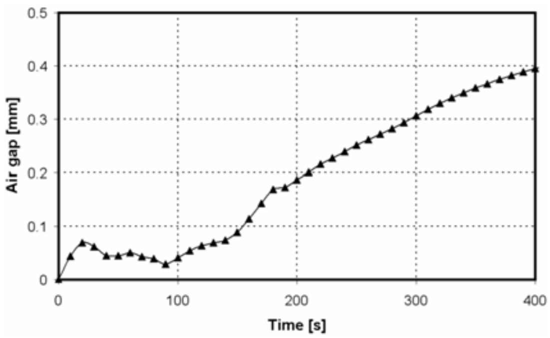


Fig. 4. *The thickness of the air gap which is formed at the cast/mold interface due to part shrinkage*

5. On-line casting control scheme

The on-line control scheme shown in figure 5 was developed for permanent mold casting. The casting process control links the design phase with the manufacturing phase and aims at generating flawless parts.

The casting process design starts with CAD model generation of the part, followed by a structural analysis by means of a finite element simulation. The structural analysis presupposes the imposing of the boundary conditions identical with the real conditions during part operation.

The result of the structural analysis is a set of principal stresses mapped on the part volume. To deal with these stresses, the mechanical properties of the part should be mapped according to the stress distribution, so that the physical integrity of the part will not be affected.

By controling the thermal field dynamics in any area of the part, the desired mechanical properties of the part can be obtained. Additionally, defects such as pore formation due to the solidification shrinkage can be avoided if the proper cooling rate in different areas of the part is determined.

The online control scheme shown in figure 5 was applied to an experimental system consisting in a permanent metallic mold. Inside the mold an aluminum alloy was cast. The cooling rate of the melt was controled in different locations by varying the cooling water rate.

When monitoring the thermal field dynamics of the casting system, the monitored variables were the temperatures in different locations of the system, which were selected based on the preliminary structural analysis of the cast part. The number of monitoring points should offer enough and correct information concerning the thermal field dynamics of the monitored areas in the cast part.

Before applying the control scheme, many data sets were generated by finite element numerical simulation of the solidification/casting process, by using different values of initial temperature of the melt, mold and cooling water. For these cases, the thermal field dynamics of the casting system was evaluated, by calculating the temperature in selected locations of the casting system. So, a number of data sets was generated and then these data sets were used to train an artificial neural network.

The control model of the thermal field dynamics of the casting system was carried out using neural network method, mentioned as „NN techniques” in figure 5.

The neural control model conceived was used to predict the part real temperature in the monitored locations and then, to compare the resulting thermal field dynamics with the imposed dynamics.

To obtain the desired thermal field dynamics, the cooling water rate of the casting system was modified in order to compensate for the part temperature deviation. The compensation value will be the difference between the two temperatures.

During the solidification of the melt, the control was carried out in each time interval when the monitoring system recorded the thermal field dynamics indicated by the casting system sensors.

Thus, the thermal field dynamics of the casting system was monitored and recorded and became an input parameter of the neural network, NNModel, which was trained. The output parameters were the part real temperature, i.e. the values of the temperatures belonging to the selected areas of the part.

Each of these values was compared with the reference values, i.e. with the imposed temperatures of the cast part, given by the thermal field dynamics imposed by the customer.

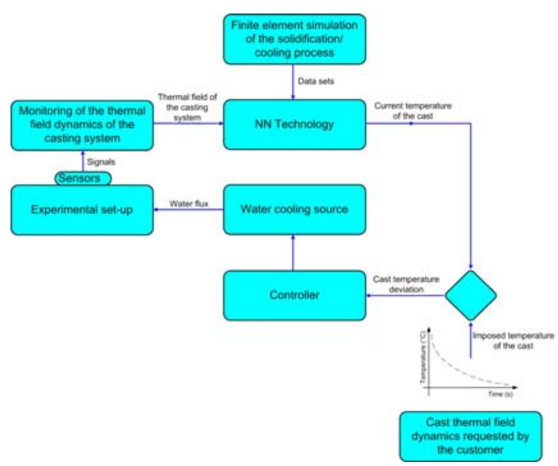
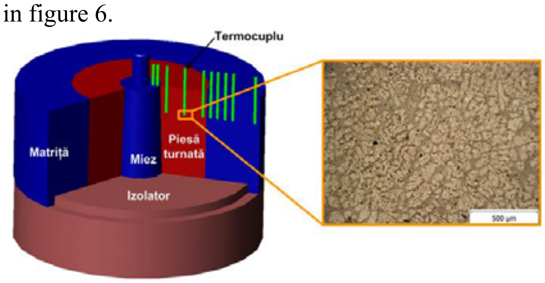


Fig. 5. *The on-line control scheme of the permanent mold casting*

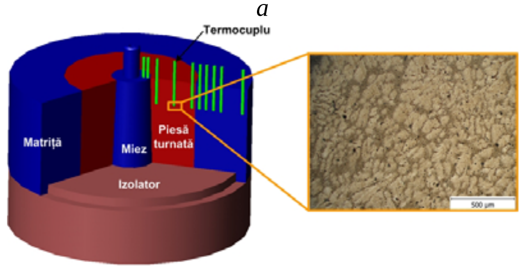
The reference temperature was determined in the designing phase of the part. Then, the structural analysis was carried out, knowing that the structural analysis is related to the mechanical properties of the part.

The difference between the real and the reference temperature dynamics represents the deviation from the programmed evolution of the cast thermal field dynamics. This will be the input data for the water cooling controller.

When the cast temperature reaches ambient temperature, the cast cooling ends, and the cooling water flow will be stopped. After solidification/cooling phase ended, the cast parts were extracted from the mold and the microstructure around the temperature measurement locations was analized. The analized microstructure area are shown in figure 6.



a



b

Fig. 6. *Microstructure analysis of the cast parts: a) higher cooling rate; b) lower cooling rate*

The microstructure consists in solid component α and dendritic grains (meaning about 60%) and the rest of 40% consists in dark crystals of eutectic mixture (α+Si).

By comparing the samples shown in figure 6, it can be seen the fine-grained microstructure of the first sample caused by a higher cooling rate. This determined a limitation of the grain growth.

Therefore, it can be stated that the cooling rate has a significant influence on the cast part strength meaning that a slow cooling rate will lead to the formation of a coarse microstructure which will materialize in a good strength of the cast part.

6. Conclusions

The schema developed in this work can be applied to die casting process, on the condition that a proper cooling system is designed, so that it can be controlled on-line.

Automatization of the casting design is possible due to the integration of the design and manufacturing phases in a virtual environment which allows the completion of all steps starting from CAD generation and ending with the desired cast microstructure.

Acknowledgements

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Îmbunătățirea proprietăților mecanice ale pieselor turnate din aliaje de aluminiu

—Rezumat—

Îmbunătățirea calității pieselor turnate este un deziderat important pentru cercetători prin: reducerea costurilor legate de prelucrarea pieselor turnate şi un nivel ridicat al rezistentei în funcționare a pieselor turnate, prin obținerea unei structuri cristaline adecvate pe timpul solidificării şi răcirii materialului.

Acest domeniu se referă la relațiile între procesul de solidificare/răcire a materialului topit şi microstructura cristalină a piesei turnate. Această abordare prezintă două aspecte: (i) modelarea procesului de solidificare/răcire a materialului topit în scopul programării unei dinamici optime a câmpului termic şi controlul evoluției câmpului termic în funcție de dinamica programată.