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NUMERICAL SIMULATION FOR TECHNOLOGICAL INTERPRETATION OF SOLIDIFICATION PROCESS CASTINGS

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ABSTRACT: This paper is typical for industrial applications of the numerical methods. The technological domain aimed by this paper is the obtaining of castings. In this paper a new method on numerical simulation with reduced resolution and a possibility of technological interpretation of solidification process castings are presented, effective for constructive and technological optimization. Thermal conductivity, release of the latent heat of solidification, and volume contraction inducing the formation and the repartition of internal and open shrinkages in the solidification process are the physical phenomena taken into account. The model is applied to casting-alloy (alloy in liquid phase, intermediate phase and solid phase), mould, feeder, internal chill, surface chill, and chill in mould. The numerical method is based on heat flow rate through the faces of the cells. The temperature variation is determined from the total heat balance, in which the boundary conditions are also included.

KEY WORDS: Solidification, numerical simulation, simulation, casting, optimization

1. INTRODUCTION

The process of solidification is complex and it is characterized by hydraulic phenomena (the flow of alloys in the system of feeding, the flow in the cavity of mould), thermal phenomena (the transport of heat in alloy-casting, in technological elements, at interface of the technological elements), phenomena of the transport of mass (the redistribution of alloying element in the mass of alloy), phenomena of volume contraction with the formation of the shrinkages.

The paper presents an economic numerical model, based on well studied and robust numerical algorithms, for utilization on personal computer. The originality of the paper is connected to the new method of the interpretation of numerical data, which, at a reduced resolution, offers the possibility of technological interpretation of solidification process castings, effective for constructive and technological interpretation.

2. STRUCTURE OF THE NUMERICAL MODEL

The numerical model is characterized by the following elements:
- the model is general, taking into account several technological domains: alloy-casting, mould, feeder, internal chill, and chill in mould;
- the technological complex is defined in tridimensional system (cylindrical or rectangular coordinates in accordance with the configuration of castings);
- the thermophysical characteristics of the technological elements are characterized by average values specific for the intervals of analysis ;
- the model takes into account the release of the latent heat according to the lever rule;
- the process of the transport of heat in technological elements takes place by conductivity, in accordance with Fourier equation;

- the process of the transmission of heat begins when the mould is filled by alloy;
- the numerical method is based on heat flow rate through the faces of the cells;
- the temperature and solid fraction are determined from the total heat balance, in which the boundary conditions are also included (Dirichlet, Cauchy, Neumann conditions).

3. INTERPRETATION OF NUMERICAL DATA

The solidification direction graph (fig.1), is obtained by representing the solidification time for each level of the numerical mesh in terms of the height of the level. The solidification graph presents three zones: positive slope zone, constant zone, negative slope zone.

The positive slope zone is favourable to the directional solidification, because the solidification front advances constantly from the lower to superior part, this zone being usually affected by an open macroshrinkage. The negative zone is inauspicious to the solidification process, because the solidified zone includes under its level unsolidified parts. This zone presents the possibility to form internal shrinkages. The constant zone presents the specific feature to solidify at the same time and this zone is affected by microporosities.

The form of the directional solidification graph allows estimations on the solidification process taking place for the different technological variants. Using this model, numerical simulations for the constructive and technological optimization of casting are made.

4. THE CONSTRUCTIVE AND TECHNOLOGICAL OPTIMIZATIONS

In this paper, the solidification direction graphs are used to project the constructive form and to optimize the technology of body in gray cast iron, with a wall thickness of 30-40 mm and the size of 2455x1240x1400 mm. The numerical analysis is made for the ensemble of body with guides (fig.2), providing information of advance of solidification front.

The solidification direction graph provides information of advance of solidification front. Thus, figure 3 presents the solidification directional graph for the guide with feeder under the conditions of the absence of the vertical and horizontal walls and the isolation of the external surface of the alloy at the level of the feeder. The solidification direction graph presents the following three zones:

- positive slope, zone <1-2> at the inferior part of the cast, propitious to the solidification process;
- constant zone, <2-3>, situated at the middle of the guide, inauspicious for the solidification process;
- positive slope, zone <3-4>, at the top of the guide, propitious for the solidification process.

The ideal graph of the solidification direction presents a positive slope on the whole height of casting. The quality of the casting is disturbed by the part 2-3, where due to simultaneous solidification microporosities are created. To analyse possibilities of the technological action the following situations are considered:

- the external surface of the feeder is isolated;
- the external surface of the feeder is not isolated;
- the internal surface of the casting is in contact with a chill.

The analysis is made using the report at ideal form of the solidification direction graph (fig.3.b). The variant without isolation of the external surface of the alloy at the level of the feeder presents solidification directional graph (constant and decreasing zones at superior part-fig.4-graph a). The utilization of the variant with isolated surface of feeder has good effects on the solidification of the superior part and the slope of the solidification directional graph becomes positive (fig.4-graph b). This variant, as well as the precedent one, presents a common part of constant solidification time. This conclusion proves that the formation of constant zone is not influenced by the coefficient of heat transfer at the level of the free surface of the alloy. The part of the constant zone has bad effects on the compactity of the casting. The utilization of the chill at the bottom of the casting reduces the height of the constant zone of the solidification time (fig.4 - graph c), but it is not eliminated. The presented variants have drawbacks, that are improved by the numerical simulations.

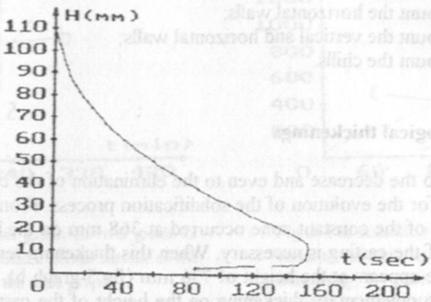

Fig.1. An example of solidification direction graph

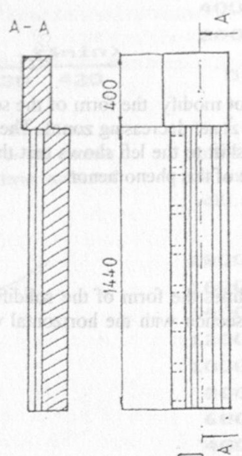

Fig.2 The simplified form of casting for analysis

In the simulation of the solidification direction graph the following possibilities have been considered:

- the isolated guide, without taking into account the other constructive elements of the casting;
- the guide, taking into account the technological thickenings;
- the guide, taking into account the vertical walls;
- the guide, taking into account the horizontal walls;
- the guide, taking into account the vertical and horizontal walls;
- the guide, taking into account the chills.

4.1. The influence of the technological thickenings

The thickenings of the body lead to the decrease and even to the elimination of the constant zone (fig.5-graphs b and c) This solution is favourable for the evolution of the solidification process. From the analysis of the graph a (fig.5) one notices the appearance of the constant zone occurred at 368 mm on the height of casting. This is the height where the first thickening of the casting is necessary. When this thickening remains constant on the height of the casting, a new constant zone appears at the height of 736 mm (fig.5-graph b), shifted to the superior part, but with the same bad effects. A supplementary thickening on the height of the casting at 736 mm leads to the elimination of the constant zone (fig.5-graph c). The thickening in two steps has favourable effects on the transformation of the solidification directional graph in a favourable graph.

4.2. The influence of the chill

The utilization of the variant with chill and thickening has better effects than the simple variants. This conclusion results from the analysis of the direction solidification graphs for the mentioned variants (fig.6). Using thickening and chill, the solidification direction graph tends to its ideal form.

4.3. The influence of vertical walls

The vertical walls, attached to the guide, do not modify the form of the solidification direction graph, preserving the same three zones (growing zone, constant zone, decreasing zone). The modifications occur in the shift of the graphs to the left (fig.7-graphs b and c). The shift to the left shows that the solidification process is quicker. The enlargement of the specific surface is the cause of this phenomenon.

4.4. The influence of the horizontal walls

The introduction of the horizontal walls modifies the form of the solidification direction graph, in accordance with graphs b and c in figure 8. At the intersection with the horizontal walls a worsening of the order of the solidification of the alloy occurs.

5. CONCLUSIONS

From the numerical analysis we have the following conclusions:

- the variant without isolation of the external surface of the alloy at the level of the feeder presents an inappropriate graph of the solidification direction, in the sense that it presents at its superior part a decreasing slope;
- the utilization of the variant of isolation of the external surface at the level of the feeder has favourable effects on the graph of the solidification direction;
- the heat transfer coefficient in the external surface at the level of the feeder has not an important influence on the formation of the constant zone;
- the utilization of the variant with chill has favourable effects on shape of the graph of the solidification direction;
- the vertical walls do not amend essentially the shape of the graph of the solidification direction;
- the horizontal walls amend inauspiciously the shape of the graph of the solidification direction.

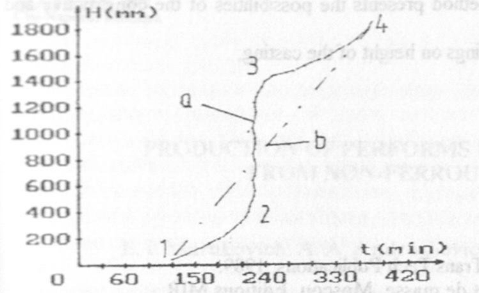

Fig.3. The solidification direction graph for the guide of figure 2: a- the graph for the isolated external surface of the alloy at the level of the feeder; b- the ideal graph.

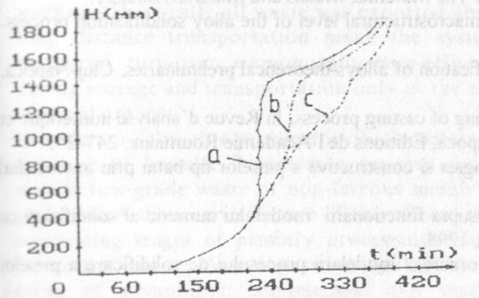

Fig.4. The solidification direction graphs for the variants: a- the exterior surface of feeder is isolated; b- the exterior surface of the feeder is not isolated;c- the exterior surface of casting is under influence of the chill.

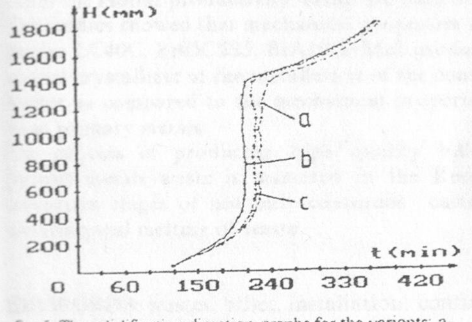

Fig.5. The solidification direction graphs for the variants: a- the variant without thickening; b- the variant with a thickening; c-the variant with two thickenings.

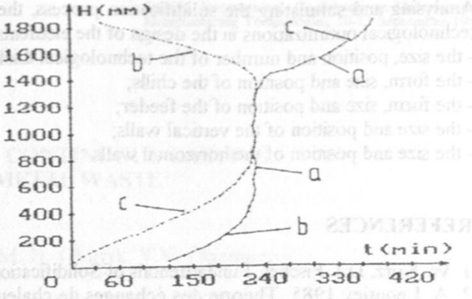

Fig.6. The solidification direction graph for the variants: a- chill at inferior part and without thickening; b- chill at inferior part and with thickening.

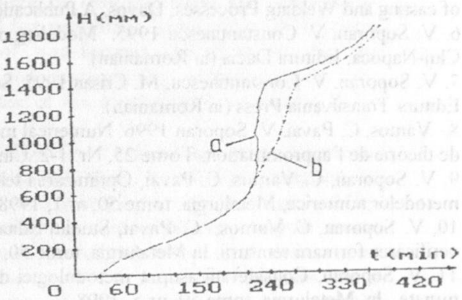

Fig.7. The solidification direction graph for the guide without horizontal walls in the variants: a- without vertical walls; b- with two vertical walls; c- with all the walls.

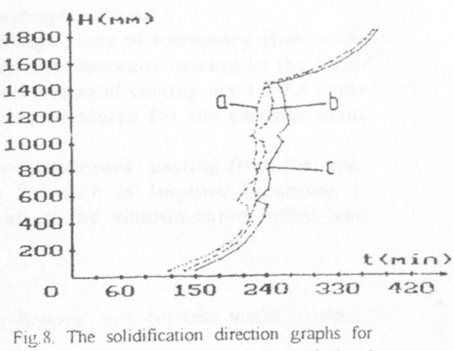

Fig.8. The solidification direction graphs for guide for the variants: a- without the vertical and horizontal walls; b- only with horizontal walls; c- with horizontal and vertical walls (complete casting).

Analysing and simulating the solidification process, the method presents the possibilities of the constructive and technological optimizations in the design of the elements:
- the size, position and number of the technological thickenings on height of the casting;
- the form, size and position of the chills;
- the form, size and position of the feeder;
- the size and position of the vertical walls;
- the size and position of the horizontal walls.

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