OPTIMIZATION OF THE PROCESS OF CASTING FORMATION BY CPC METHOD USING COMPUTER SIMULATION

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Abstract:
A common approach for optimization of casting technologies is presented. The approach is illustrated on an example of the technological solution for the formation of automotive carrier using gas counter pressure casting method (CPC method) or low pressure die casting method (LPDC method) but it could be applied with success in die-casting too. It consists of series of computer simulations of filling and crystallization of the casting, which is accompanied with targeted changes in technology based on the analysis and evaluation of the results. A concept of "natural" simulation is introduced. The influence of main technological factors and parameters are studied and analysed. As a result, a technology forming free of defect casting is obtained.

Key words: optimization, casting formation, computer simulation

1. Introduction
The development of methods and approaches for optimization of foundry technologies is a natural extension and upgrade of mathematical modeling and its algorithmic version - computer simulation [1,2]. Initially, iterative-interactive approaches [3,4] appear where the optimal solution is reached through a sequence of simulations following changes made by the computer operator. The modern software packages for simulation of casting technologies incorporate the latest developments in this field, offering simulations with a high degree of adequacy. One of the leading among them is a software package MAGMAsoft of the company MAGMA GmbH, based in Ahen, Germany. Currently, he is actively used for simulation and optimization of casting technologies [5,6]. In this article the latest version of MAGMAsoft - MAGMA5.3 is used for the presentation of an approach for optimization of casting technologies using CPC or LPDC methods.

2. Results of “natural simulation”
Under "natural" simulation below we will understand simulation of casting formation in the mould with simple geometry. It can be assumed as cube, parallelepiped or straight cylinder. In MAGMA5.3 such kind of moulds are generated with the tool “Automatic mould”. The obtained results from such kind of simulation give an idea about the nature of the filling of the mould cavity with liquid metal and the type of crystallisation, mainly arising from the geometry of the casting. They point on the possible defects due to the geometrical characteristics and the masses distribution in the casting. Based on the analysis of these results, the first changes in technology are realized to reduce the defects.

Taking into account the construction of CPC machine the casting-mould system is positioned on the steel plate of the machine into an air cylindrical volume – Fig.3.

Fig.1. 3D geometry of the carrier
Fig.2. Natural mould
The natural investigation starts with simulation of filling of mould cavity. The distance between plate of the CPC-machine and the level of molten metal in furnace is supposed as 400mm. The differential pressure law is constructed using heuristic opinion. It is presented on Fig.4 in tabular and graphical form.

Some of the vents for gas evacuation are located along the parting line in 20mm with area of cross-section $1\text{mm}^2$. The others are located on the top of the casting as it is pointed on Fig.5. Their cross-sections are calculated on the base of the clearance of the ejectors, which is assumed as 0.1mm. The simulation starts with initial temperatures as follows:

- $T_0$ (molten metal) = 700°C;
- $T_0$ (mould) = 300°C.

Temperature field of the melt during the process of filling is obtained in sequence of moments of time. One of them are pointed in Fig.6. For better visualization, the empty part of the casting is presented as transparent. The filling of mould cavity is finished for 7.68sec. It is well seen that the filling run smooth from down to top without turbulences.

The software calculates gas pressure end gas evacuation during the filling and as a final result give as the gas entrapment in the end of mould filling. This criterion function of MAGMA5.2 is shown on Fig.7. As it is well seen there are not critical zones with air pockets into the volume of the casting.

MAGMA5.2 allows to follow the trajectories of some chosen points during the filling process - Fig.8.

The main result of solidification is presented with criterion “Porosity” on Fig.9. The areas of mass-deficit and high level of porosity are localized clearly. This result describes mainly the influence of geometry of the casting. The next stage of the research includes developing new mould parts and appropriate cooling system.
3. Optimization of the technology

On the base of obtained results above an interactive and iterative procedure starts. Basically, every optimization process works with the following scheme, regardless whether a black box or an analytic procedure is used: the user describes the problem in a mathematical way by determining some parameters:

1. Input variables with their corresponding ranges of variation (these are the parameters of the simulation that will be varied: geometry of mould parts, initial temperatures, places and intensity of cooling etc.)
2. Output variables (they contain the results of the simulation in concentrated form);
3. Constraints;
4. Objectives (maximize or minimize certain combinations of output variables).

If this is done, a set of start designs is defined, the so-called DOE (Design of Experiments) sequence. These are the base points of the numerical optimization. For each of these designs a complete simulation has to be performed. Subsequently, the algorithm can use the output values for generating new designs according to the objectives and the type of optimizer used. Depending on the selected optimization strategy the algorithm will stop after a certain number of iterations. In practical optimization problems, the algorithm sometimes cannot find the final solution in the first attempt, because the user may find some hints how to modify ranges of variation, constraints and objectives for an even better solution during the optimization. The user himself has to decide if he wants to continue with modified parameters. This decision may require much of computation and also casting experience. The flow chart of Fig.10 shows the optimization process:

Following this procedure, a final technology is developed. The geometry of the used mould parts is shown on Fig.11 and Fig.12.

The geometry, and places of chosen cooling are presented on Fig.13.
The configuration of the vents is the same like by the natural simulation. Simulation was performed on a cyclical process involving 20 cycles. Die open time was assumed as 30sec. Some control points are chosen. Their positions are presented on Fig.15.

![Fig.14. Differential pressure law during the filling](image)

![Fig.15. Control points. Places.](image)

The working regime of cooling system is given in the next table – Table 1.

<table>
<thead>
<tr>
<th>No of cycles</th>
<th>Time (IN) sec</th>
<th>Time (OFF) sec</th>
<th>Medium</th>
<th>Debit m³/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>50</td>
<td>1950</td>
<td>Water</td>
<td>1.58k</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>1950</td>
<td>Water</td>
<td>2.05k</td>
</tr>
<tr>
<td>30</td>
<td>650</td>
<td>3300</td>
<td>Water</td>
<td>1.96k</td>
</tr>
<tr>
<td>40</td>
<td>650</td>
<td>3300</td>
<td>Water</td>
<td>0.85k</td>
</tr>
<tr>
<td>50</td>
<td>750</td>
<td>3300</td>
<td>Water</td>
<td>0.85k</td>
</tr>
<tr>
<td>60</td>
<td>750</td>
<td>3300</td>
<td>Water</td>
<td>0.91k</td>
</tr>
<tr>
<td>70</td>
<td>800</td>
<td>2000</td>
<td>Water</td>
<td>0.85k</td>
</tr>
<tr>
<td>80</td>
<td>800</td>
<td>2000</td>
<td>Water</td>
<td>0.85k</td>
</tr>
<tr>
<td>90</td>
<td>800</td>
<td>2000</td>
<td>Water</td>
<td>0.92k</td>
</tr>
<tr>
<td>100</td>
<td>1250</td>
<td>3300</td>
<td>Water</td>
<td>1.05k</td>
</tr>
<tr>
<td>110</td>
<td>0</td>
<td>0</td>
<td>Water</td>
<td>0</td>
</tr>
<tr>
<td>120</td>
<td>2000</td>
<td>3300</td>
<td>Water</td>
<td>0.21k</td>
</tr>
<tr>
<td>130</td>
<td>350</td>
<td>2000</td>
<td>Water</td>
<td>0.85k</td>
</tr>
<tr>
<td>140</td>
<td>350</td>
<td>2000</td>
<td>Water</td>
<td>0.35k</td>
</tr>
</tbody>
</table>

Note: Time starts from the beginning of filling. The time dependant graph of the calculated temperatures in these points is shown on Fig.16.

![Fig.16. Curves in control points](image)

The main of the cycle parameters are listed below:
- Time (Filling) = 7.68sec.
- Time (Pressure OFF) = 270sec.
- Time (Die Open) = 30sec.
- Time (Filling&Solidification) = 324sec.
- Cycle Duration = 354sec.

The temperature field in the casting obtained during solidification process in 20-th cycle is presented in Fig.17 in a moment of time.

![Fig.17. 65% solidified](image)

On the next two figures (Fig.18-19) fraction of liquid metal during solidification in some moments of time is shown.

![Fig.18. 35% Fraction Liquid](image)
MGMA5 offer some criterion functions for estimate the quality of the formed casting. The most important of them the criterion “Porosity” is shown in Fig.20.

4. Some structural predictions for the formed casting
Some structural predictions for the formed casting are obtained on the base of computer simulation. They are given in the next figures (Fig.21-Fig.26).
5. Conclusion
On the base of the obtained results the presented technology can be successfully offer for implementation into foundry practice.
Finally, it should be noted that the presented optimization approach is a powerful tool for significantly increasing the efficiency of the design and development of the casting technologies by enabling the production of high quality products with minimal material and energy costs. Therefore, it is also a powerful tool for enhancing the competitiveness of the foundry companies.

6. References
5. Recent Foundry Simulation Software. MTM’07, 28-29.03.2007, 95-98.

Fig.25. Distribution of Mg$_2$Si phase

Fig.26. Distribution of primary phase