Computer aided casting methoding of railway system

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Abstract

Authors prepared the casting technology for the frog. Casting method has been verified by simulation, using MAGMASOFT technique. In multistep simulation it was found that the positioning of casting in the mould feeding and some details of construction must be changed. Finally authors have presented the optimised solution of the technology which eliminates the porosity of casting. Analyses of the distribution of the stress during solidification and cooling in the mould proves that the deformation of casting is acceptable.

Keywords: Monobloc frog; Simulation; Solidification; Distribution of Stress.

1. Introduction

Modernization of the Polish railways is absolutely necessary to join the transeuropean system. It means the adaptation to high speed trains at least 200 km/h and axle load not less than 230 kN [1]. For this aim the carbon steel rails are successively replaced by modern, produced in Poland low alloy bainitic steel, much more durable, resistant for the friction and dynamic tension. [2,3]. The modern rails are until now joined with traditional, carbon steel frogs produced by mechanical treatment and welding of elements. Several producers of railways use the monobloc cast high manganese frogs imported from other countries of EU. In 2006 authors began the project, sponsored by the Ministry of the Sciences and Higher Education to study the possibility of the production the bainitic steel frogs easy to join with the rails - in Polish foundries. The aims of the project are as follow:

\begin{itemize}
  \item Selection of a chemical composition of bainitic steel fulfilling all demands of buyer: UTS minimum 1350 MPa, elongation 12\%, hardness 330-400 HB and ductile-brittle transition temperature below –30° C. Cast steel has to be easily welded with the rail material.
  \item Elaboration of a casting methoding assuring the II group of overall casting quality and the I group in the region of the edge. (ISO standard 1690). It means that steel must be very clean and the casting very well fed during the solidification process. The foundry sand has to guarantee the clean surface of the casting and be easy to regenerate.
  \item Establishing parameters of heat treatment and procedures of quality control.
\end{itemize}

Numerical modelling as a tool for analyzing such processes like mould cavity filling, casting solidification or thermal stresses in castings is known since years. In initially it was applied rather to simple shaped castings [4, 5], but with growing computer power the limitation no more exists. Computer systems like MAGMASOFT enable analyzing real castings regardless casting technique applied [6 – 9].

In the paper authors present some results of optimization of casting methoding by computer simulation using MAGMASOFT system to analyze mould cavity filling, casting...
solidification as well as thermal stresses. An optimum casting methoding has been prepared to fulfill the condition of the best feeding of casting during solidification and minimal deformation when cooling.

2. Optimization of casting methoding

Initial shape of the frog, designed by producer of frogs is presented on the Figure 1. This five meter long thin-walled casting with varying cross-section is very difficult to feed. As a first approach, horizontal casting position with the rail head laying down has been selected. Such casting position is often used for high manganese cast steel frog since it ensures good quality of working surfaces of the casting. On each cross-section of the bottom ribs one top feeder has been placed as well as two adjacent side risers, see the Figure 2. At this early stage, time consuming filling cavity simulation was skipped and casting solidification simulation was performed only. An example of results of the simulation is presented in the Figure 3. It shows feeding of the casting. White means sound casting, while colours denote shrinkage defects. The reason of such poor quality is explained in the Figure 4.

Distribution of solidification modulus values show that the side risers are not able to feed the hot spot in the middle of casting, since they solidify earlier than the hot spot. A numerous simulation variants with bigger side risers was has been performed but still with the same result. The side risers were not able to feed the hot spot through relative thin ribs. As a next step, the side risers have been removed while the top risers have been enlarged. Additionally, cylindrical material allowances below the risers have been applied to obtain better riser necks. However, still without good results, since the thin rail neck rail breaks feeding process.

Simulation of casting solidification without any riser is shows, in the Figure 5; that hot spot is located in the same place regardless casting position. However, the hot spot can be fed better if rail heads are on the top position. To obtain a better
feeding pattern, the cross-section of the frog has been corrected to ensure directional solidification, see the Figure 6.

![Image](50x604 to 259x677)

Fig. 6. A cross-section of the frog: initial design (left), and final design enabling directional solidification (right)

Next, the ribs on the bottom side of the frog have been removed. To find a right position, number and size of risers, a number of solidification simulation has been performed. After establishing feeding system, a smaller but sufficient number of bottom ribs has been added again. In the last stage of the casting methoding optimization, an appropriate gating system has been designed, see in the Figure 7.

![Image](40x386 to 282x490)

Fig. 7. Final casting methoding: optimized feeding system and gating system. Filling simulation was also performed, although not shown in the paper

Metal enters mould cavity from the bottom side, flowing through extensive system of runners, to ensure uniform temperature of liquid metal before solidification. The Figure 8 shows an example of casting solidification on the same cross-section as already shown on the Figure 3 (this time no rib is present there). It is clear, that directional solidification occurs. As a result, sound casting is obtained both in the analyzed cross-section, as well as in other critical cross-sections. Some additional cooling ribs have been added at casting ends, to improve soundness in the regions. A small porosity occurs between some risers, but generally the proposed casting methoding may be accepted. Feeders removing from the working surfaces of the casting will require more efforts, but such feeders position gives more rigidity to the working surfaces.

To check distortion of the casting, thermal stresses have also been analyzed. The Figure 10 shows distribution of normal stresses along casting length. Distribution of the stress shows, that top risers located between external rails counteract greater distortion of the top surfaces of the casting. The Figure 11 shows displacement of the casting in the vertical direction using multiplication factor equal to 15. It can be seen that distortion of the upper surface of the frog along its length does not exceed 3 mm.

![Image](326x538 to 524x687)

Fig. 8. An example of solidification of a casting cross-section for optimized layout: directional solidification occurs. Solid fraction: a) 10%, b) 20%, c) 70%
3. Conclusions

Optimisation of technology of the frogs proved that for very long and complicated steel casting classical method of the mould technology cannot be adapted. The simulation of the temperature distribution indicates that the porosity free casting cannot be obtained, without change of its positioning in the mould, and some changes of construction. Such modifications will raises the cost of the mechanical treatment but eliminates the defects of casting. After the multi step simulation one can receive the optimisation of the casting methoding. Simulation is the unique way to study the distribution of stress during solidification and cooling of the casting. It is very important for the long casting of bainitic steel. Proposed technology limits the deformation of 5 m long casting to less then 3 mm.

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