COMPUTER MODELING OF CASTING PROCESSES FOR HEAVY STEEL INGOTS

O.A. Broytman*, Ph.D. (OOO Siemens, Volynsky lane, 3A, 191186, Saint Petersburg, Russia);
D.Yu. Saraev, Ph.D. (OOO Siemens, Letnikovskaya str., 11/10, bld. 3, 115114, Moscow, Russia);
A.V. Monastyrsky, Ph.D. (ZAO CSoft, Molodogvardeyskaya str,, 46-2, 121351, Moscow, Russia);
I.A. Ivanov, Ph.D. (OAO CNIITMASH, Sharikopodshipnikovskaya, 4, 109088, Moscow, Russia)

Abstract

Heavy steel ingots are used as raw-parts for manufacturing of turbine rotors for fossil power and nuclear power plants, mill rolls, etc. These parts have to be uniformly structured and perfectly balanced, and therefore - defect-free. The casting technology for such large-scale steel ingots has to be optimized in order to save resources, increase yield, and improve quality of ingots. Computer analysis is a good way to optimize the casting technology virtually, shorten the trial casting stage and minimize the lead time. This research work is devoted to the deep computer analysis of traditional technologies for casting of heavy forging ingots. A number of processes is considered: hydrodynamics, solidification, heat transfer and stress effects in ingot-tooling system, porosity formation, feeding effectiveness and macrosegregation. The modeling is performed using commercial casting simulation software packages as well as with some original models. This research is targeted at development of recommendations for casting technology optimization. Modeling results are compared with experimental data for verification and improvement of computer models.

Key words

Steel forging ingot, computer modeling, casting processes, prediction of quality, technology optimization.

Introduction

Large steel ingots (in the range of 100-300 t) are typically used as blanks for production of turbine rotors, mill rolls, shafts for ship propellers, etc. High quality of casting is required for acceptable performance and high industry standards. Such cast parts, operating as elements of complex machinery, have to provide sufficient level of mechanical properties over the life time. Often, when the mass production is not needed, the number of identical ingots is limited to few pieces only, which implies some individuality of such production procedure. In addition, the complexity of casting process and potential losses, resulted from non-optimized technology, increase significantly the level of responsibility of the caster engineering team and this responsibility grows with increasing size of ingots. Due to very large amounts of metal consumed, it becomes crucial to combine advanced approaches ensuring high quality castings with economic measures, which allow increasing the yield.

Due to the above mentioned reasons, the computer modeling becomes increasingly important for a virtual analysis and optimization of the casting technology. Universal commercial casting simulation software (CSS) is typically used for such analysis, and sometimes, a simulation software, which is developed for specific problems of ingot casting. From the point of view of a modern CSS, the simulation of ingot casting may seem simple due to the simplicity of geometry and conventionality of the casting method. Nevertheless, very large ingot sizes, as well as long lead times of large ingot castings, generate some additional complexity to the problem definition and analysis of modeling results. This work is devoted to the analysis of casting technologies for some large forging ingots. Additionally, in the present paper we outline a number of ingot related problems, which can be solved with the state-of-the-art computer modeling tools and attempt to evaluate the efficiency and quality of obtained solutions. Finite-element CSS ProCAST, CSS PoligonSoft, and finite-difference (2D) software tool "Large Ingot", developed by CNIITMASH specially for ingot casting, were used.

Background and problem statement

The following main tasks for computer diagnostics of production of large ingots are outlined here: analysis of melt circulation and its cooling during the pouring process, study of heat transfer during solidification of ingot, which takes into account both the convection of melt and formation of gap on metal-mould interface, analysis of conditions for formation of porosity and shrinkage, examination of risers effectiveness, prediction of macrosegregation, and reveal susceptibility to mould's damage. Two ingots of 142 t and 80 t were investigated in the present work (Fig. 1). Both ingots are designed using conventional technology for such large cast blanks. Nowadays, due

* Contact data: Oleg A. Broytman, OOO Siemens, Corporate Technology, CT T RU HW, Volynsky lane, 3A, 191186, Saint Petersburg, Russia; phone: +7-812-324-83-59; fax: +7-812-324-83-42; email: oleg.broytman@siemens.com

to wide use of new materials with advanced heat-insulating or exothermal properties, there is a trend to use smaller cylindrical risers and a lower tapper. Nevertheless, ingots in old design are still widely produced; metallurgical plants are simply inert to change to the new technology since it is related to additional investment costs and to uncertainty about the performance of new technology. In such cases, the computer modeling can help evaluate new technologies, as well as analyze and optimize the old production technologies. The motivation to investigate ingots of conventional design was driven by the interest of our partners, who produce such ingots at present and possess large amounts of experimental data.

The ingot of 142 t is cast of 25KhN3MFA steel (chemical composition shown in Table) into a tooling from grey iron, which is preheated to ~100-350℃. Pouring temperature is 1580℃. Pouring is performed in vacuum using intermediate ladle. The vacuum is removed once the pouring is finished. Then, the free surface of melt is covered with a rice husk ash and a heat-insulating cap. The ingot is removed from the mould after 48 hours. From the point of view of solidification process, the ingot has favorable design: the height to characteristic diameter ratio is ***H/D***=1, the taper to one side is 8%. The ingot of 80 t is cast of 35KhNM steel (chemical composition shown in Table) into a tooling from grey iron, which is preheated to ~100℃ using technology similar to the case of 142 t ingot. Ingot geometry: ***H/D***=1.9, the taper to one side is 1.7%.

Element / Steel	C	Si	Mn	Ni	Mo	V	Cr	Cu	S	P
25KhN3MFA	0.23	0.37	0.38	3.46	0.41	0.09	1.58	0.13	0.011	0.010
35KhNM	0.38	0.25	0.42	1.57	0.30	–	1.00	–	0.028	0.021

Table: Ladle composition of utilized steels (%wt.)

In order to compare results obtained by different simulation software, the model parameters have to be carefully tuned. Since the heat transfer is one of most important processes, which determines the quality of ingots, the temperature distribution fields obtained by different software tools were verified with experimentally available data. If the temperature fields fit well to the experimental data, it can be assumed models for calculations of porosity, deformation, macrosegregation etc, which might be implemented differently or not implemented in some software tool, work in similar conditions. In such a way, the results obtained by different simulation software could be correctly compared, or they could complement each other. To achieve such agreements between different models, special attention has to be devoted to the input parameters, like material properties, since their number can be different for different software tools.

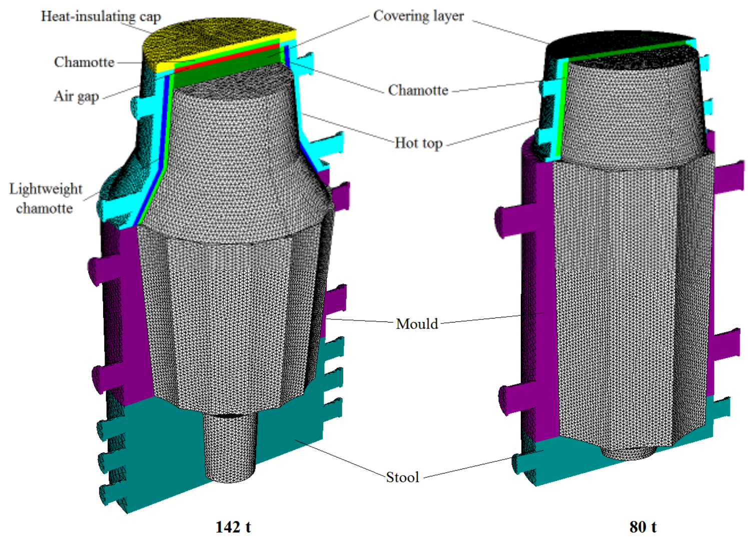


Figure 1: Finite-element models for ingots of 142 t and 80 t plot in PoligonSoft preprocessor

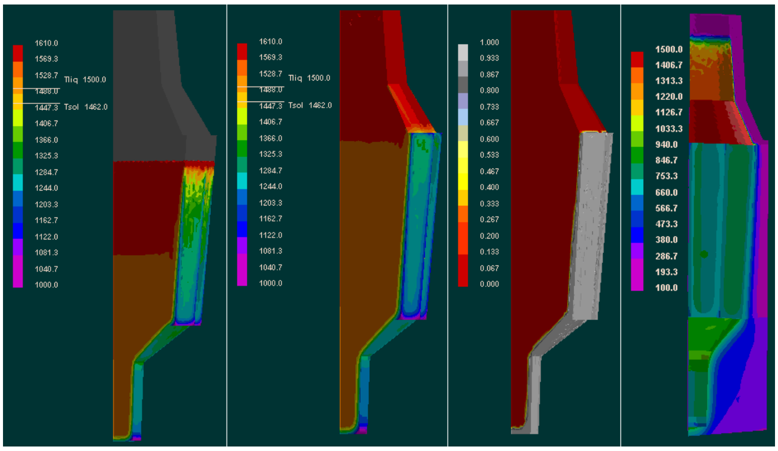
The thermal properties of tooling materials are taken from the internal CSS databases, the thermal and mechanical properties of ingot steels are generated based on their chemical composition using the “Thermodynamic Database Fe” module of ProCAST. We used the following boundary conditions: the heat transfer between the modeling object and ambient air takes into account convection and radiation, the radiation and conductive-convective heat transfer mechanisms are considered for the air gap, which is growing on the ingot-mould interface during surface solidification of ingot.

Modeling of pouring of melt

Liquid metal can be poured into the tooling cavity from the top or from the bottom. Nowadays, the uphill teeming is used more often because it can improve the quality of ingots. The uphill teeming helps prevent excessive oxidization of the melt; therefore, vacuum may be not needed. Also, this method helps improve the quality of ingot surface, which may lead to reduction of cracks generated during subsequent forging. However, the maximal size of ingot, obtained by uphill teeming, is usually limited to ~200 t, which is explained by the growing complexity of tooling with increasing mass of the melt. For this reason, downhill teeming is typically used for large ingots.

Modeling of melt pouring by downhill teeming has been performed using ProCAST. To avoid computational problems with the falling stream of melt, the mass source is initially located at the bottom of tooling cavity and it is moving up in such a way that its position always coincides with the melt free surface. Of course, this simplification reduces the accuracy of modeling but it allows avoiding computational problems related to the complex hydrodynamics of falling stream and free surface, which are typical for finite-element software. On the other hand, the calculation of temperature fields during and after the pouring is sufficiently accurate. The large mass of melt and relatively short pouring time (in comparison to the solidification time) cause a low cooling intensity of the melt. It would have been similar if we took into account the forced convection from the falling melt. Long solidification times of large steel ingots increase the probability of setting the regular thermal regime [1], when the process does not depend on the initial conditions including the temperature distribution after the pouring of melt.

However, the temperature fields during and after pouring are important for the virtual diagnostic of the pouring process. For example, it is important to identify overcooled regions in the melt, enhanced local growth of solid crust near the mould surface, which may lead to a detrimental effect of the quality of ingot surface, overheating of the tooling, which may lead to partial melting of mould surface, or to stool erosion when combined with the impact of the falling stream.



a b c d

Figure 2: Temperature fields in 142 t ingot during its pouring (modeling in ProCAST):
a – ingot temperatures after 16 min from start;
b – ingot temperatures by the end of pouring after 26 min;
c – solid fraction after pouring;
d – tooling temperatures after pouring

The results of pouring calculations for ingot of 142 t are shown in Fig. 2. The average temperature drop in the melt after the pouring (26 min) is 40-50°C. The temperature drop remains stable from intermediate (Fig. 2a) to the final (Fig. 2b) pouring stage due to the poor cooling rate of large mass of melt and continuous heating coming from the newly entered hot melt portions. At the end of pouring, a solidified metal crust approximately 5 cm thick appears on the surface of ingot body. At the same time, the riser surface is still liquid which is explained by a lower heat transfer from the melt to chamotte heat insulation and by the pouring conditions in which the hottest metal remains in the riser at the end of the process. Analysis of temperature fields for the iron tooling during and after the pouring (Fig. 2d) shows that there are no dangerous overheated zones in it. Also, it is good that the chamotte isolation near the lower cone of the riser is significantly heated from the melt.

Modeling of solidification, porosity and shrinkage formation

The key stage in the whole modeling procedure, crucial for accurate forecast of ingot quality, is the calculation of temperature and phase fields during solidification. We have compared the results obtained by different software tools with experimental temperatures, measured during the real casting procedure with using thermocouples installed in the different regions of tooling's surface on the depth of few mm (Fig. 3).† All software used show acceptable agreement of calculated results and experimental data.

The configuration of 142 t ingot is a driving factor of its unidirectional solidification. The liquid phase has a conical shape expanding to the top during the whole solidification process (Fig. 4), while the mushy zone is concentrated on the side surface of the cone. Due to these features, there are no reasons for formation of a centerline weakness (Figs. 5a, 5b).

Configuration and other technological features of the 80 t ingot make it impossible to avoid simultaneous solidification in the centerline zone (Fig. 4), which leads to formation of centerline weakness (Fig. 5c). Initially, the shape of liquid phase zone is close to conical, but its shape changes quickly and after about 10 hours, the unfavorable feeding conditions for the centerline zone become evident. The advanced PoligonSoft porosity model [2], which can predict macro- and microporosity by calculation of displacements of free surfaces in all isolated hot spots and melt filtration in the mushy zone, respectively, showed that a centerline weakness is formed by the mixed mechanism. The calculated porosity along the centerline is 0,5-2,0% in the PoligonSoft scale.

Calculation results of predicted porosity in examined ingots are in good agreement with the data from the manufacturer.

Undoubtedly, the producer's aim is to avoid a centerline weakness in cast blank since these defects may be not fully eliminated during the forging procedure. Ingot casters know that the quality of conventionally produced ingots, in particular, the tendency to centerline weakness (typically located under the level of 1/2-3/4 from the height of ingot body), depends mostly from the ingot's geometry. The influence of tooling preheating on ingot temperature distribution is limited. The heat transfer to the tooling is reduced simultaneously with formation of significant solid crust, which is accompanied by the growth of air gap between the mould and ingot. In this case, the heat transfer from the liquid and mushy zones to the solid crust plays significant role. The effect of riser is limited to a certain depth and the effectiveness of its heat-insulation is usually intended to decrease the metal content in it by decreasing of its height, but this measure is not able to prevent porosity inside the ingot body.

We have dealt with a number of problems, in which we demonstrated that additional heat insulation of the riser does not result in a better ingot quality. A virtual model allows using ideal thermal insulation of the riser, which is even impossible in reality. Such calculations demonstrated that the needed solidification control can be achieved by changing geometry of ingot. To avoid the formation of centerline weakness, the heat transfer can be controlled by special measure, such as: application of non-uniform refractory coating of the surface of mould, design the system for additional heating and cooling of different parts of the tooling, design special pockets inside the tooling filled with air or materials with different thermal properties.

If the free surface of riser of 142 t ingot is covered with insulating material right after the pouring, it is possible to avoid appearance of solid shell at the metal-insulator interface. The depth of pipe-shrinkage in this case is close to 700 mm (Fig. 5a). Computer modeling shows that in the case when the free surface is insulated after some time (typical technological delay is about 30 min), or the heat-insulating cap is either not installed, or the free surface is not covered at all, the solid shell appears on the free surface and shrinkage grows to the depth of up to 1100 mm, i.e. a bit deeper than the upper cone basis of riser, and the shape of shrinkage cavity becomes conical. Thus, there is enough metal in the riser for the case of poor insulating as well. The modeling shows that the area under the shrinkage, which contains highly-impure melt solidifying at the end, is always located in the lower cone of the riser. The ingot was designed for lower insulating effectiveness, using vermiculate as covering material, but for the case of new covering material the size of riser is excessively large. Modeling results suggest that the size of riser may be decreased by 20%.

† Thermocouple No. 3 worked for first 12 hr only.

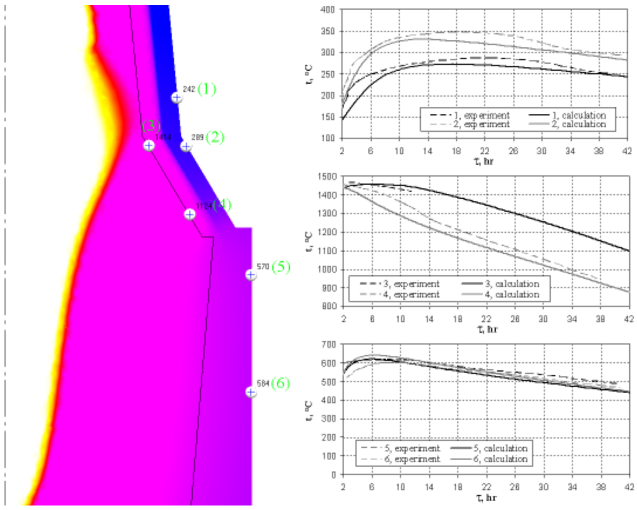


Figure 3: Time dependant temperatures at different points of the tooling surface according to the modeling results of PoligonSoft and experimental data (142 t ingot)

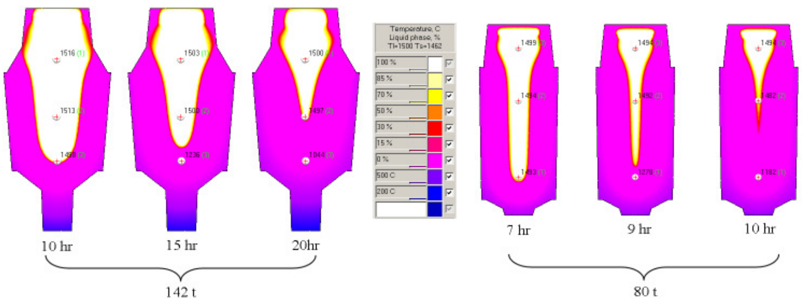
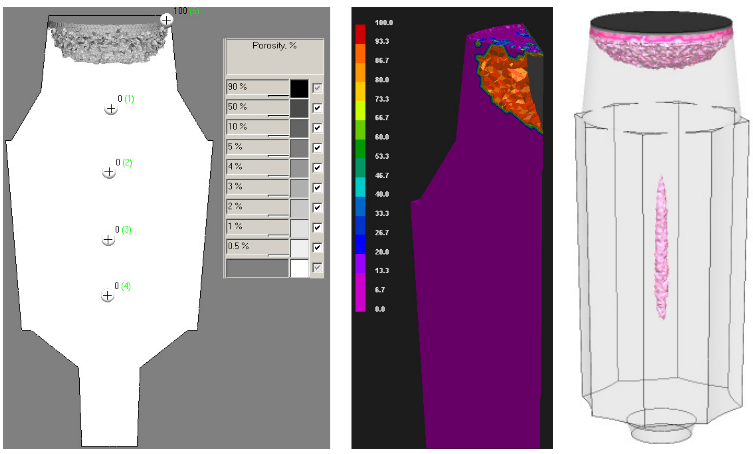


Figure 4: Typical evolution of liquid fraction in 142 t and 80 t ingots (modeling in PoligonSoft)



a b c

Figure 5: Model prediction of porosity and shrinkage defects in different ingots:
a – 142 t ingot, riser's free surface is insulated directly after the pouring (PoligonSoft)
b – 142 t ingot, riser's free surface is insulated after 30 min. after the pouring (ProCast)
c – 80 t ingot, zones with porosity more than 0,5% are shown (PoligonSoft)

The problem of formation solid shell on the surface of riser is not trivial: after pouring the free surface of the melt moves down, but at the same time the heat is transferred from the surface to ambient, which can lead to formation of thin layer of solidified metal. This layer has a dish shape because of some shrinkage realized above. The effect of solidified shell on the top surface is often not given sufficient attention in many CSS, because these software tools are mainly oriented towards shaped casting, for which the detailed calculation of metal-ambient interactions is not critical. PoligonSoft has a quite accurate model for prediction of porosity, which takes into account displacements of free surfaces. However, it is difficult to model there (within one simulation run) the formation of solidified shell on the surface, because to do this, the program has to separate the mechanisms of formation of top shrinkage and macroporosity inside the cast blank. A special top shrinkage model is implemented in ProCast [3], which allows to model solidified shell formation for the case of cooling of significant metal surface at air (Fig. 5b).

Modeling of dynamic of gap formation on the ingot-mould interface

The effect of formation of a gap on metal-tooling interface deserves special attention. Modern CSS, which are mostly oriented on modeling of shaped castings, in most cases do not have fast-working models accurately describing the influence of the on heat transfer during solidification. In the case of shaped casting, it is not typical to have a gap along the whole surface of the metal-mould interface. In reality, for shaped castings one observes regions of good contact between metal and mould mixed with gapped regions. In many cases CSS can calculate solidification problem simultaneously with stress-strain state calculations, which takes into account the mechanical interaction between the casting and the mould and change of their sizes and shapes. This feature helps to predict the value of gap. The down side of such calculations is that the solution of stress-strain state problem slows down the calculation time dramatically. It is possible to develop special software, which would work with ingots of simple shapes, with simplified solution for the problem of gap formation. An example of such specialized software is “Large ingot”, which uses a fast-working model to predict the actual gap value ***l***. In this model, if one ignores the non-uniformity of internal temperatures in the solidifying shell, which would correct the result insignificantly, and changing mould dimensions, one could write for ***l***:

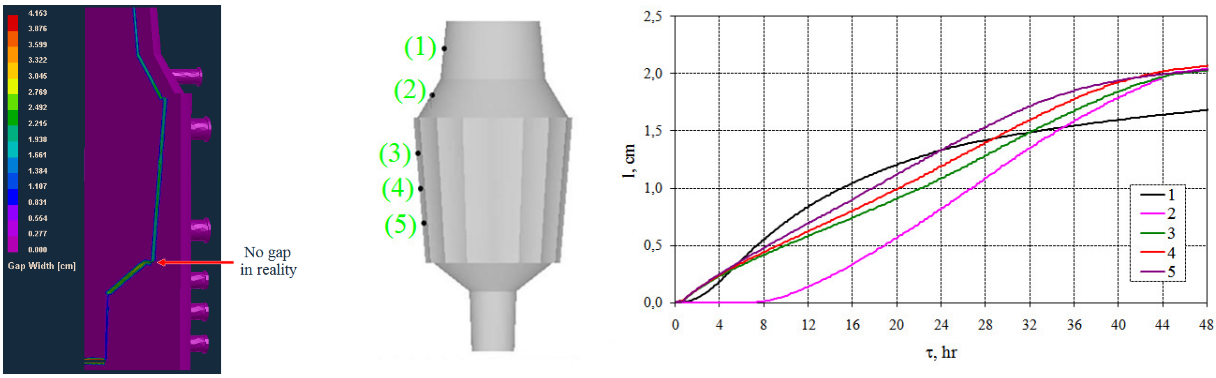
$$l^{(k)} = R_{mld} - R_{ing}\left[1 - \alpha_T\left(T_{ing}^{(k)} - T_{ing}^{(k+1)}\right)\right], \qquad (1)$$

where $\boldsymbol{\alpha_T}$ is the coefficient of linear heat shrinkage of solid metal; $\boldsymbol{R_{ing}}$ is the distance between the centerline and ingot’s surface; $\boldsymbol{R_{mld}}$ is the distance between the centerline and moulds’s surface; $\boldsymbol{T_{ing}^{k}}$ и $\boldsymbol{T_{ing}^{k+1}}$ are temperatures of ingot’s surface at time moments τ_k and τ_{k+1}, respectively (***k*** is the timestep number).

Fig. 6 shows the results of gap formation in time for 142 t ingot obtained with deformation calculation in ProCAST. The mould is assumed to be rigid. The ProCast model does not take into account the gravity of ingot. Obviously, the ingot will move down in reality as the solidified crust in the bottom region will increase. Thus, the 142 t ingot is able to move down continuously by the actually calculated value of imaginary gap between the stool and the horizontal part of the protrusion on the lowest region of the ingot’s body (Fig. 6a). In some conditions this moving may be hindered by direct contact between the side surfaces of mould and ingot.

Solving of a simple geometrical task gives an answer to the question about the side gap correction in assumption of a possibility of down movement of ingot by the value of imaginary gap. An estimative calculation for a different points along the height of 142 t ingot’s side surface shows that the gap value correction does not exceed ~9%, which is not critical apparently. Additionally, this calculation showed that the ingot is able to bear on the mould’s side surface for a first 30 min only, including the pouring time. This bearing may cause tearing of solidified shell and transverse cracks on the ingot’s surface. All statements above refer to 142 t ingot, which has high taper of side surface. A low taper will lead to a lower correction of side gap, as well the time of hindered down movement will be decreased.

Usually, CSS do not include fast-working models for gap calculation like (1), which allow to quickly estimate the gap for certain conditions of casting process; therefore, the correction of solution of heat transfer problem is only possible when heat transfer is modeled simultaneously with stress-strain state problem. ProCAST calculates simultaneously changing heat transfer conditions as the gap changes. If the calculations of stress-strain state of cast blank are not needed, such simultaneous solution seems to be redundant because it significantly enlarges the calculation time. In case of lack of time resources, the CSS should use a predefined heat transfer coefficient for the ingot-mould interface. In the present work the heat transfer coefficient $\boldsymbol{\alpha}$ for the ingot-mould interface has been estimated, which can be considered as typical for the case of large ingots, particularly, for the 142 t ingot.



a b

Figure 6: Prognosis of a gap between mould and ingot according to the modeling results of ProCast: a – gap value before the stripping of the ingot (48 hr); b – time dependant gap values in selected points near the ingot's surface

The heat exchange on the elemental region of metal-mould interface is realized with a parallel transfer through the segments of a close contact (their fraction is S_1, the heat transfer coefficient for these segments is α_{cont}), through the conductive-convective (fraction is S_2, coefficient is α_{air}) and radiative (fraction is S_3, coefficient is α_{rad}) transfer in a gap. Hence the resulting effective heat transfer coefficient may be defined by the following simplified model:

$$\alpha = S_1\alpha_{cont} + S_2\alpha_{air} + S_3\alpha_{rad}\,; \qquad \alpha_{rad} = \frac{\varepsilon\sigma\left(T_{ing}^4 - T_{mld}^4\right)}{T_{ing} - T_{mld}}\,;$$

$$\alpha_{air} = \frac{\lambda_{air}}{l}\,, \qquad (2)$$

where T_{ing} и T_{mld} are actual temperatures on the ingot's and mould's surfaces, respectively; ε is the adduced emissivity factor, which takes into account emissivity of mould's and ingot's surfaces; σ is the Stefan-Boltzmann constant; λ_{air} is the conductivity of a gas in the gap. The model (2) corresponds to the PoligonSoft method of calculation of α, as well as to a classical method, which is implemented in other CSS with a different level of details. Obviously, the following statement is correct for complete gap near the considered elemental region: S_1=0, S_2=S_3=1. The above described calculation data for a gap value and surface temperatures allowed to estimate α according to presented formulas (2). The calculated value of α is typical for the case of large ingots. The effective heat transfer coefficient quickly stabilizes on the level of 130-80 W/m^{2}K. Determined values are well agreed with a known data for a heat transfer conditions in the gap on the ingot-mould interface [4, 5]. The efficient and accurate solution of a large ingot thermal task may be provided by applying the heat transfer coefficient estimated above for a relatively fast occurring conditions of a significant gap formation (in particularly, ~2 hrs for the 142 t ingot, when the surface temperature of solid crust is ~1100°C). It can be assumed that the coefficient has only slight changes in case of large ingot size variation or dimensional instability of the mould.

Modeling of natural convection in the melt

The investigation of the melt natural convection influence to the temperature fields may be considered as an actual problem. To solve it, a number of ProCast calculation were performed. In these calculations the hydrodynamic solver wasn't stopped after the solving of a pouring problem. Fig. 7 shows a characteristic distribution of convective streams in the melt for the moment of the 142 t ingot solidification period. Circulating melt velocities are not high; they drop ~ten times for a first 3 hr, and not exceed $2{\cdot}10^{-3}$-$1{\cdot}10^{-3}$ m/s for a next crucial period during the ingot solidification from 3 to 15 hr. The discovered velocities are in good agreement with published data [6]. However, the convection significantly influences the temperature field of the ingot (Fig. 8). The rate of convection influence was estimated through a direct comparison with calculation results, obtained at the same initial conditions, but with hydrodynamic solver not activated for the solidification period.

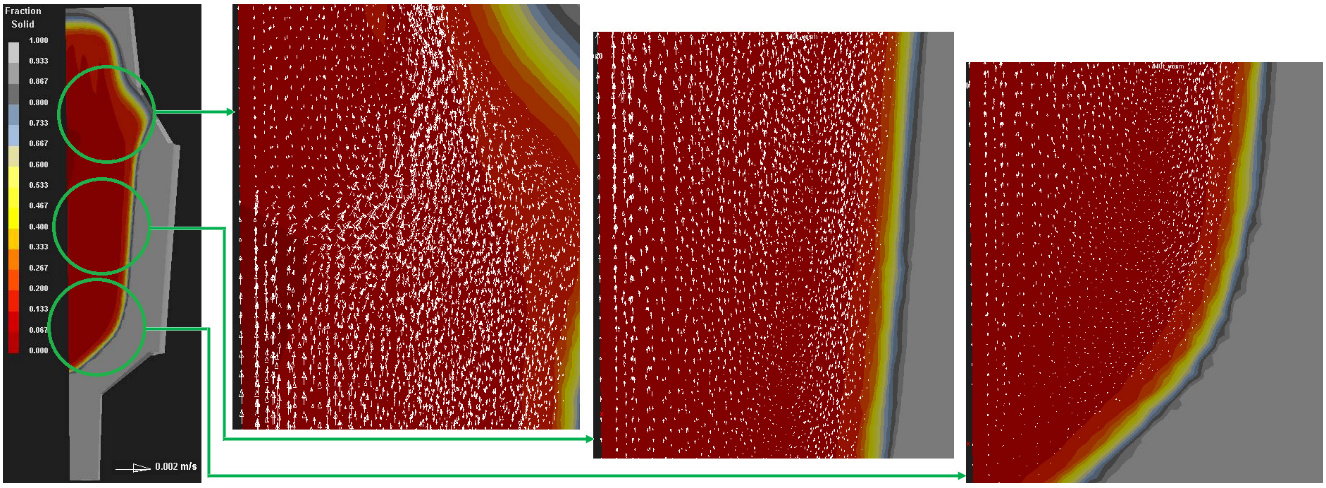


Figure 7: The distribution of convective streams in the melt after 5 hr from a start of solidification of the 142 t ingot according to the modeling results of ProCast

Simultaneous modeling of thermal and hydrodynamic problem in CSS for a solidification period is a rare case due to need of significant time and computational resources. Our modeling experience shows that cast blank quality prognosis could be improved by taking convection into account. Nevertheless, based on porosity and shrinkage prognosis for 142 t and 80 t ingots, it may be judged that there are no significant corrections on quality prediction results. Circulation of convective streams leads to a relatively equal decrease of solidification times in different regions of the ingot's body. Temperatures of liquid, mushy and solid zones of the ingot's body are predicted to be lower, while riser temperatures to be higher. However, the mentioned circumstances do not indicate the possible economy of a metal in the riser or decreasing of a possible tendency to centerline weakness. In fact, temperature differences among neighboring regions of the melt inside the ingot's body, as well, as differences between their local solidification times are almost the same as for the case of calculated results performed without natural convection taken into account.

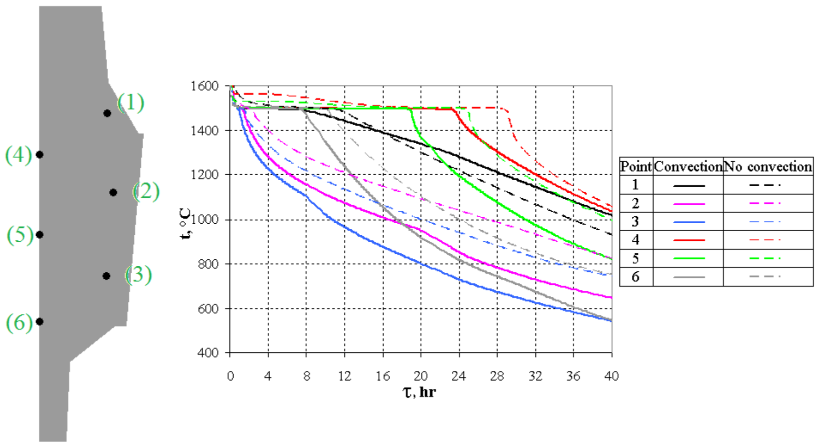


Figure 8: The influence of natural convection to the temperature fields during solidification of 142 t ingot: comparison of temperatures in selected points according to ProCast modeling for conditions of a presence of convection (solid lines) and its absence (dashed lines)

Modeling of macrosegregation along the centerline

The software "Large ingot" was utilized for prognosis of macrosegregation. The software includes a model which corresponds with the classical theoretical principles [7] of macrosegregation modeling for the solidification conditions when the diffusion in solid phase is depressed while the diffusion in liquid phase is fully realized. The key feature of the software is related to different elements effective partition coefficients incorporated in table form. These tables were obtained with generalization of big amount of experimental data collected during the practical investigations of macrosegregation of elements vs. the cooling intensity (equivalent size of the ingot).

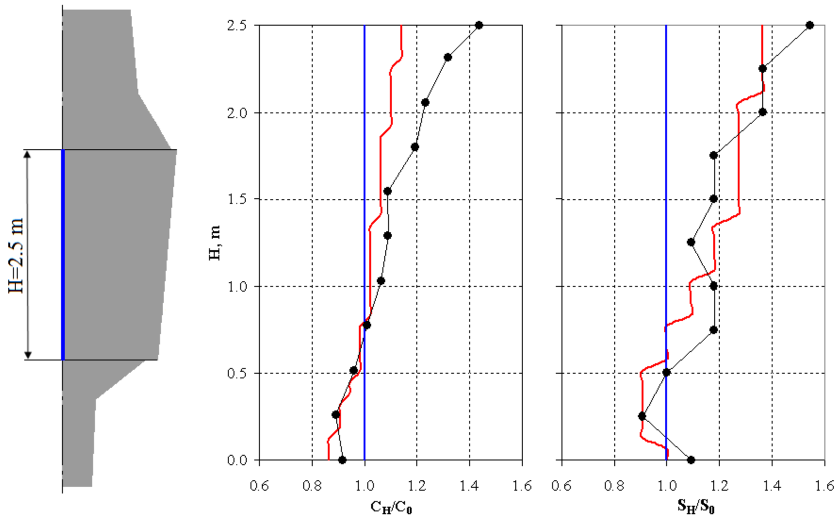


Figure 9: Macrosegregation of carbon and sulfur along the 142 t ingot's body centerline according to the modeling results of "Large ingot" software (red lines) and experimental data (points)

Significant macrosegregation leads to the dangerous non-uniformity of mechanical properties distribution in final product after the quenching procedure. Computational prognosis for macrosegregation of carbon (C_H) and sulfur (S_H) along the centerline of 142 t ingot are presented at the Fig. 9 as deviations from initial ladle composition (C_0 and S_0 for carbon and sulfur, respectively). The macrosegregation along the centerline of 142 t ingot's body was considered as acceptable. Modeling results are in good agreement with the experimental data for a major part of ingot. The noticeable deviation from the carbon experimental data is observed in the topmost region of the ingot's body. This deviation may be explained by underrated values of partition coefficient for significantly high concentrations.

Modeling of stress-strain state of the mould

The mould experiences high thermal stresses during the ingot solidification as well as during air cooling after the ingot is stripped. These stresses may lead to the mould cracking. The mould should be stable for as many cycles as possible; therefore the computational investigation of mould stability and measures on decreasing of thermal stresses is an actual task.

Stress-strain state analysis of the 142 t ingot's mould was performed in PoligonSoft. The mould material is brittle at normal conditions; however, it becomes more plastic after the heating to higher temperatures. The following air cooling of the mould increases the probability of a brittle cracking. The analysis of calculation results by the criterion of tendency to brittle cracking allowed discovering of the dangerous zones (Fig. 11). These crack germs introduce the local weakness of the mould material, and may progress to the main crack during the next cycles.

It may be recommended to decrease the cooling intensity of the moulds after ingots stripping to avoid moulds cracking. This may be achieved by simple measures such as installing of a cap, which will decrease a heat transfer from the internal side surface.

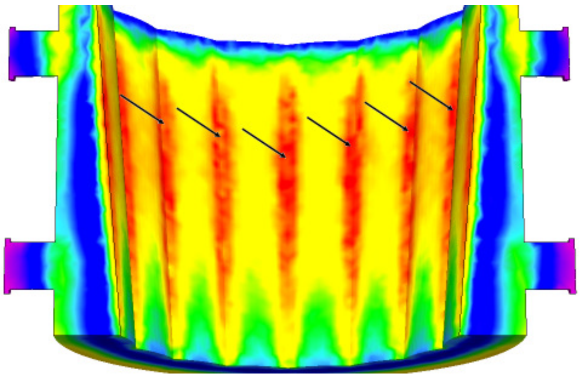


Figure 10: 142 t ingot's mould crack tendency according to the modeling results of PoligonSoft (dangerous zones are marked with a red color)

The analysis of mould-melt interaction should consider the possibility of partial melting of mould's surface [8]. Damaging of mould's surface in such a way leads to stress concentrations in the damage zones followed by cracks. The overheated regions of the mould's surface should be covered with an extra layer of a refractory coating.

Conclusion

The main difficulties in the modeling of large ingot casting are related to long duration times of all processes influencing cast blank quality. Most casting simulation software is oriented on simulation of shaped castings. For this reason they may not include special tools to model process features specific for large ingots (such as formation of non-uniform gap or closed shrinkage in the riser, etc.) or these tools work with insufficient level of rapidity, accuracy or safety.

The present work attempted to examine features of specialized software packages, educe their strengths and weaknesses from the point of view of needs of modeling of large ingots, and specify nuances of how to define the problem to improve the adequacy of modeling results and shorten the calculation time. Computer analysis of processes of ingot casting performed in this work helped generate recommendations for improvement of technology.

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