ANALYSIS OF THE INFLUENCE OF ALLOYS FEEDING PARAMETERS DURING SOLIDIFICATION ON SOUNDNESS SIMULATION FORECAST IN DUCTILE IRON CASTINGS

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SUMMARY

Efficiency of Virtual Prototyping methods depends on many factors in pre- and post-processing stage. For the efficacy of casting’s soundness prognosis, critical solid fraction for mass feeding and critical solid fraction for interdendritic (capillary) feeding, are important parameters describing alloy’s feeding abilities. In the paper, it has been presented results of experimental and simulation researches, and the main aim was to specify above parameters for selected ductile iron. Experiments have included castings preparation, thermal analysis of the cast-mould system and shrinkage defects recognition, next the thermal validation and validation for shrinkage location and its intensity. It has been analyzed the influence of pouring temperature, critical solid fraction parameters, alloy’s contraction on casting’s soundness prognosis – “Shrinkage” parameter. Especially it has been analyzed influence of critical solid fraction parameters for conformity of experiments and simulation results.

Key words: casting, simulation, shrinkage prediction, post-processing parameters

1. INTRODUCTION

The most efficient method of designing and optimisation for production processes in the field of material engineering is Virtual Prototyping VP [7]. In casting technology can be observed from many years development of this method, in which are used coupled physical models and their effective solutions applied for complex technology

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cases. Modelling of casting processes is mainly aimed at providing description of motion of the liquid/solid interface in alloy [10,1,11] and forecasting quality of virtually formed castings, indicating especially the locations of discontinuities (porosity) [7]. Such a quality of prognosis is affected directly by parameters of calculation stages, so-called pre- and post-processing factors [5,10]. The work presents the problems of validation for selected applied model of shrinkage defects prognoses in the castings made of the ductile iron. Validation has concerned simulation system PamCast 2001 [9].

Classical designing of casting feeding, based on empirical knowledge and executed from many years, consists of defining feeding zones within the whole casting: according to required functions: riser–neck–hot spot–connected walls–parasitic walls and balancing analysis of solidification. The analysis includes:

- directional orientation of solidification process in the riser direction, with safe increase in wall modulus of directly feeding wall, about 20%,
- division of the feeding zones of casting among particular risers (e.g. with possible use of chills),
- the distance of under–riser feeding and the presence of natural and artificial boundary zones,
- the balance of the whole casting demand to liquid metal compensating shrinkage of the alloy feeding, in comparison with feeding abilities of the riser (the kind of the riser and FEM of the risers insulation).

Such a way does not allow to conduct analysis for dynamic course of feeding at particular stages of the casting solidification process. It is still a basis for the first technological design – a technological conception of the casting process. It should be noticed that in case of designing the feeding of cast iron castings (especially ductile cast iron) an advantageous compensation of matrix shrinkage by graphite should be considered, together with strong thermo-mechanical interaction between graphite expansion and mould (with its stiffness).

In this classical procedure, it is impossible to make use of commonly applied parameters characterizing effectiveness of the feeding, and used in the simulation forecasts with regard to the morphology of the alloy solidification and flow (i.e. critical values of solid phase fractions, density variations due to temperature, basic thermophysical parameters of the metal and the mould materials) are not considered in classical designing process. The fact that these parameters are not taken into consideration in classical designing, opens new possibilities in feeding optimization using VP. In the paper have been analyzed connections and conditions for this optimization.

2. EXPERIMENTAL TESTS

The experimental research comprised execution of two casting groups: a reference plate casting (Fig. 1) and a valve ball casting (Fig. 2) made of a ductile iron EN-GJS-450-10 [3]. In order to assess varying pouring conditions in the industrial casting
process of a valve ball, a set of ten castings have been manufactured under varying pouring temperatures \( T_{ini} \) from 1411 to 1305 [°C]. In reference plate castings (a stepped plate of two thickness 25 and 50mm) the temperature changes in selected locations of the cast-mould system have been recorded in order to carry out dynamic temperature validation [7] and to determine averaged thermal conductivity \( \lambda \) and specific heat \( C_p \) [4,2] (green sand). The castings knocked out from the mould, have been checked visually and, afterwards, controlled by penetration method. It has enabled detecting and locating their shrinkage defects. The effect of pouring temperature on the size and intensity of the defects has been thus confirmed on this stage of tests.

3. NUMERICAL SIMULATION

The aim of simulation calculations was to indicate the conditions of validation for the whole model applied in PamCast 2001 [6], for the sake of compared forecasted and real shrinkage defects. Material data of ductile iron have been adopted in accordance with the PamCast 2001 data base (for ductile iron GGG40). On the other hand, the thermophysical data of the mould material have been assumed on the grounds of dynamic temperature validation [7]: \( \lambda = 1.44 \) [W/mK], \( C_p = 1.61 \times 10^6 \) [J/m^3K]. Boundary conditions were as follows: neglected resistance at the cast-mould interface, at the mould-environment interface – \( \alpha = 20 \) [W/m^2K], \( T_{env} = 20 \) [°C]. In order to perform the computation the spatial discretization elements have been generated (the FVM method) of the size equal about to 2.5mm. In the case of a pattern plate, due to its simple shape and accuracy of forecast, only the solidification process has been calculated, with estimated average temperature after mold pouring on the level \( T_{ini}=1260, 1300 \) i \( 1340 \) [°C] (data from preliminary filling calculation). On the other hand, in case of the valve ball casting, basic computation included simulation of the solidification process as well (\( T_{ini}=1307, 1291, 1271, \) and \( 1257 \) [°C]), however, this time preceded by comparison calculation of the course of mould filling. In case of simulation forecasts of the shrinkage defects the following parameters have been \emph{a priori} defined: alloy shrinkage \( S \), critical solid fraction of mass feeding \( f_1 \), critical solid fraction of interdendritic feeding \( f_2 \), and initial temperature \( T_{ini} \). The simulation has been made for the following shrinkage values \( S: 1, 2 \) and \( 3 \) [%], with values in twos of critical solid fractions \( f_1=0.1 \) and \( f_2=0.3, f_1=0.4 \) and \( f_2=0.6, f_1=0.7 \) and \( f_2=0.9, f_1=0.1 \) and \( f_2=0.5, f_1=0.3 \) and \( f_2=0.7, f_1=0.5 \) and \( f_2=0.9 \). In this way there were expressed different cases of connections between solidification morphology and flow abilities in feeding zone.
4. RESULTS ANALYSIS

Among parameters available in the post-processing stage of calculations in PamCast 2001 particular attention was paid to a classical “Shrinkage” parameter and to temperature gradient $G$, cooling rate $R$ and Niyama criterion $N$ (calculated in selected solidification time points).

In the reference plate the growth of initial temperature $T_{ini}$ results in enlarging the defect area and intensity, according to the expectations, with the defect translating towards the upper surface of the plate (an example for $f_1=0.1$ and $f_2=0.3$ on Fig. 2). Similarly, increase in $f_1$ and $f_2$ (improvement in flow abilities during feeding) manifests in concentrating the contraction cavity defect in the area of the upper casting surface, simultaneously occupying growing part of the surface, with division of the phenomenon into a surface-approaching defect (called shrinkage depression) and internal (secondary) defect. Increasing alloy shrinkage $S$ results in enlarging the defect area, changing its shape, and growing intensity of shrinkage porosity, particularly for $f_1=0.1$ and $f_2=0.3$ (poor flow abilities during feeding). Temperature gradient $G$ (Fig. 3a) calculated at the moment of reaching the solidification temperature $T_s$ indicates location of the defects in the thin and thick walls of the casting (while in an actual casting only in the thick one). Iso-surfaces of cooling rate $R$ (Fig. 3b) indicate that the defect should be located only in the thicker part of the plate. The Niyama criterion $N$ (Fig. 4) indicates a large defect area in the thin and thick plates, when assuming value 1 (one) as an critical value (like for cast steel, according to Niyama).
Fig. 2. Shrinkage defect for $S=2\%$, for $f_1=0.1$, $f_2=0.3$, and for temperatures $T_{ini} = 1260$, 1300 and 1340 [°C].

Rys. 2. Wady skurczu dla $S=2\%$, $f_1=0.1$, $f_2=0.3$, oraz temperatur $T_{ini} = 1260$, 1300 i 1340 [°C].

It was affirmed, that the defects occurring in a real casting are correctly forecasted on the grounds of the Niyama criterion, in range $N = 0.00 – 0.63$ (for $T_{ini} = 1300$ [°C]). The data resulting from the $N$ criterion do not depend on the critical fractions $f_1$ and $f_2$, and material shrinkage $S$ [%], nevertheless, they vary with the temperature field, controlled by the temperature $T_{ini}$.

In case of a cast of valve ball the parameters $G$, $R$, and $N$, enabling comparative forecasting of the cast defects, indicating the defects of the cast and riser. Prolongation of interdendritic feeding period ($f_1=0.1$, changing $f_2=0.3$ to 0.5) resulted in increase of intensity of shrinkage porosity in the area of the riser neck, the direct explanation is difficult. On the other hand, shorter period of mass feeding in the case of alloy with good abilities for interdendritic feeding (with $f_2=0.9$, changing $f_1 = 0.7$ to 0.5) caused only slight growth (intuitively justified) of the shrinkage defect in the proximity of the riser and casting connection (that is logic). Change in the manner of feeding $f_1/f_2$, through lowering the mass feeding abilities and raising interdendritic feeding abilities (a change from $f_1=0.4/f_2=0.6$ to $f_1=0.3/f_2=0.7$) resulted in formation of a very small and concentrated shrinkage defect. Longer feeding period, that is improvement feeding abilities for both mass and interdendritic feeding (the growth in $f_1$ and $f_2$) results in translation of the shrinkage cavity downwards to the riser [8].
Increase in the initial temperature $T_{ini}$ results in the growth of the area and intensity of the forecasted defect. Increase in the alloy shrinkage $S$ results in increase of the shrinkage defect (the growth of its area and intensity) in the riser and in formation of contraction cavity in the casting, after solidification of the neck.

Comparison of the distribution of the location and intensity in real and virtual castings indicated that the values $f_1=0.1$ and $f_2=0.3$ (Fig. 5 and 6) the best describe the properties of considered ductile iron. The values are lower than proposed for this ductile iron in PamCast 2001, and in other simulation systems. Moreover, the investigation showed that the values $S=1$ and $2\%$ are appropriate, and it has confirmed another opinions in this subject. The comparison of simulation results calculated with different and extreme parameters in the test have been shown on the figure 7.

Fig. 3. Simulation results: a) temperature gradient $G$ and b) cooling rate $R$ in reference plate casting ($T_{ini}=1300$, $S=2\%$, $f_1=1.0$, scale 0.0 – 1.0).

Rys. 3. Wyniki symulacji: a) gradient temperatury $G$ i szybkość chłodzenia $R$ w odlewie płyty referencyjnej ($T_{ini}=1300$, $S=2\%$, $f_1=1.0$, skala 0.0 – 1.0).

Fig. 4. Shrinkage defect in real and virtual (Niyama criterion prediction) reference plate casting ($T_{ini}=1300$, $S=2\%$, $f_1=1.0$, scale 0.0 – 1.0).

Rys. 4. Wada skurczowa w odlewie rzeczywistym i wirtualnym odlewu płyty referencyjnej ($T_{ini}=1300$, $S=2\%$, $f_1=1.0$, skala 0.0 – 1.0).
5. CONCLUSIONS

The paper presents the results of experimental – simulation research performed for selected castings made of ductile iron. It was proved that the results of simulation forecasts considerably but also diversely affect the parameters that determine the alloy flow abilities during mass and interdendritic feeding, temperature of the alloy after mold pouring and alloy shrinkage. These factors decide of the location, intensity, and shape of the forecasted shrinkage defect. In order to perform effective computation aimed at
the prognosis of the casting quality (shrinkage defects), previous validation of the parameters affecting the shrinkage defects is necessary. While testing the range of this influence with reference to real castings, it has been affirmed, that border values of critical solid fraction for mass and interdendritic feeding, which gave the best forecasting of shrinkage, are significantly lower than these recommended in materials data bases of simulation systems, also in PanCast 2001. In order to determine these values for another alloys and castings, it is necessary to lead to dynamic temperature validation of thermal model applied in simulation system [7].

It has been pointed next time in our research, that Niyama criterion defined in the past for steel casting, can be also used for ductile cast iron. It is necessary to study and apply right border value of the criterion.

It is well known, that physical grounds of the model for shrinkage defects determination (and coupled with thermal model) are based on temperature distribution during solidification and balance of feeding flow depending on alloy shrinkage. So that, an effective method for the model validation for the sake of critical solid fractions \( f_1 \) and \( f_2 \) is the one described in this paper.

Rationalization of concluding about casting quality (in respect of shrinkage defects – soundness), should take into consideration the execution of the described validation.

Fig. 7. Shrinkage defect for: a) \( T_{\text{ini}}=1257, S=1\% , f_1=0.1, f_2=0.3 \) and b) \( T_{\text{ini}}=1307, S=3\% , f_1=0.7, f_2=0.9 \).

Rys. 7. Wada skurczowa dla: a) \( T_{\text{ini}}=1257, S=1\% , f_1=0.1, f_2=0.3 \) i b) \( T_{\text{ini}}=1307, S=3\% , f_1=0.7, f_2=0.9 \).

REFERENCES

ANALIZA WPŁYWU PARAMETRÓW ZASILANIA STOPU PODCZAS KRZEPNIĘCIA NA PROGNOZY SYMULACYJNE ŚCISŁOŚCI ODLEWÓW Z ŻELIWA SFERoidalnego

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