USE OF SIMULATION TO REDUCTION OF FAULTY PRODUCTS

Jan Strohmandl [1]

Simulation as an analytical and expert system has increasingly more important role in the development process of new products. Producing of healthy castings without foundry errors is the big issue in modern foundries. Foundry simulation software can do a lot to help improve the disposition of castings, gating system and feeder system and it can assure good filling and solidification conditions and also produce healthy casting without the need of the old method "try and error". One can easily change a lot of parameters for filling and solidification and create the best proposal for production. It makes possible to get a wide range of information that allow reducing various adverse effects and processes in the early stages of design. Production by lost wax investment casting process is one of the advanced technologies of castings production. We can use this technology in the case of products with complicated shape or hard machinable materials. Computer simulation gives us the answers to the correctness of the designed construction. The article deals with the issue of application of computer simulation for analysis of quality castings production, as the main predictive tool for reduction of faulty products.

Keywords: simulation, faulty products, quality, casting.

1. Introduction

Producing of quality casting is a process which depends to the use of modern highly specialized computer programs. It is because of increasing market demands. According to the type and complexity of the future product we can use different programs for development, design of the product in the primary phase, and then for design of correspondent foundry moulds. In the final phase of the process we can use computer programs for simulation of foundry processes. Computer programs present an efficient tool for optimization of designed production technologies [1]. This proactive approach to product design produces significant reduction of defective production.

The investment casting or “lost-wax” process is a production method for making parts from molten metal. The process begins with the manufacture of a pattern that is the same shape as the end product. Usually made of wax formed in custom tooling, the individual pattern elements are joined to form a wax-pattern assembly. The assembly is repeatedly dipped into ceramic slurry and coated with sand stucco to build up a shell, which is then dried. When the shell is dry, the

[1] MSc., Tomas Bata University in Zlín, Faculty of Logistics and Crisis Management, nám. T.G. Masaryka 5555, 760 01 Zlín, Czech Republic, e-mail: strohmandl@flkr.utb.cz

assembly is placed in an autoclave and the wax is melted out. When empty, the mould is heated to the proper temperature and molten metal is poured into the mould. As the metal cools, it solidifies into a casting [2].

Its application is in various parts of electric motors, through parts of pumps, parts for optical industry, aviation and medical equipments, military weapons and also for structural parts of sport equipments. At the present the most wide-spread sport is golf, which needs demands of high quality equipments. Sports equipment, namely the head of the golf clubs, which include various types according to their use, are made from casting alloy Ti based or from anti-corrosive steel [2], [3].

2. Application of computer simulation for the process of reducible model formation

The process of design and formation of reducible model creates an area where by the help of computer simulation it is possible to obtain very important information. One of the most important data that we can find out, are information about the course of the cavity form filling and solidification of fluid metal in the foundry mould. This is based on using of solution of the equations of incompressible fluid, depending on the Reynold´s number, the friction losses, direction of the gravity and uses the heat transfer equation.

We can evaluate from the results of the simulation for filling and solidification that the sprue and feeder systems realize directionally solidification and also the production of sound casting. By the help of computer simulation we can very easy make changes for the sprue and feeder system without new sprue and feeder system production. Also the simulation allows us to determine the heat stress which is created in the casting [4], [5], [6]. The use of computer simulation has significance for quick resolution of technological problems already in pre-production preparation of castings, systematic elimination of technological defects, less of the preparation time and reduction of production costs.

3. Process of reducible model formation for the golf head with implementation of simulation

Production process of golf head reducible model is possible to characterize and describe by the block scheme presented by the Fig. 1.

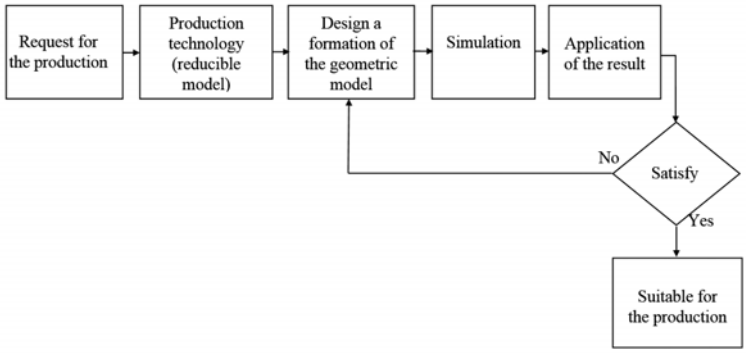

Fig. 1. Process of reducible model formation by application of computer simulation with using NovaFlow&Solid

The initial level of the formation process is a requirement for making a concrete product – the golf head. In this stage, based on factors as a function, design etc. the appropriate production technology is selected – the method of reducible model. For its right application it is necessary to use computer support of the production by the CAD software. This tool will design initial geometric model of the golf head and consequently the design and formation of geometric model of the form.

Within the frame of this design phase it was calculated and designed the sprue system for production of the head by the technology of reducible model based on the graphic design of the golf head (Fig. 2). It was selected so-called tree with six floors and three castings for one floor (Fig. 3). Calculation of the sprue system was based on this equation [1]:

$$V_n = k \,.\, \xi \,.\, Mod^3 \,.\, (1 + \beta)^3 + 3 \,.\, \beta \,.\, V_f \,.\, n \quad (1)$$

where: V_n – volume of the feeder [m^3],

Mod – casting module [m],

k – dimensionless coefficient for the distance of the place of liquid metal mouth to the feeder,

ξ – dimensionless coefficient for the feeder form,

β – coefficient of volume changes during the solidification [%],

V_f – form volume [m^3],

n – number of castings per floor.

Fig. 2 presents the model of golf head with the sprue system created by CAD system CATIA V5 R19 [7].

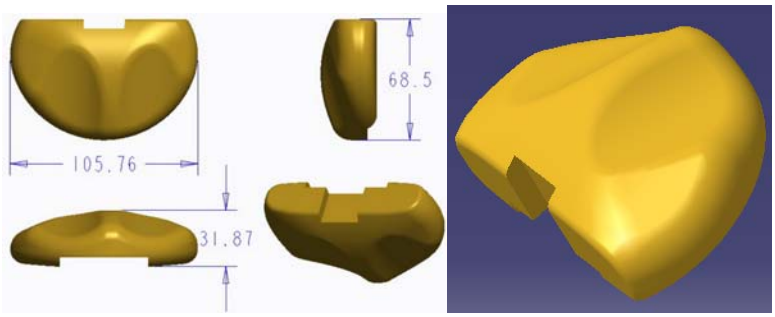

Fig. 2. The golf head

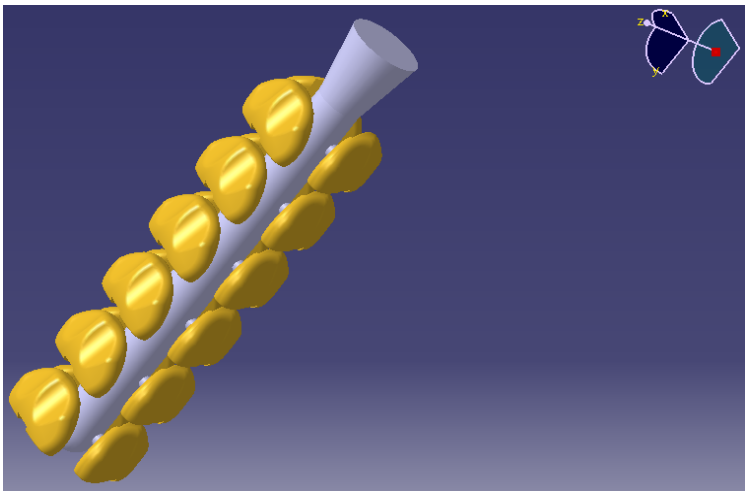

Fig. 3. Visualization of the sprue system and castings

Creation of the simulation calculation model is the next step of the process design. By its help we realize simulation experiments with a view to disclose shortages of the designed model [8].

The process of optimization is realized during the step "Application of the result" with a view to find suitable parameters for realization of casting process by the help of reducible model. According to the continuous evaluation of the results it is realized the backward correction of geometric models and it is again realized the simulation process. This cycle is repeated until the moment when the results of simulation are suitable for production technological requirements and the designed model will be generated as a suitable for requirements of the production process.

4. Application of the computer simulation

The method of computer simulation was used by design of reducible model form for a golf head. This set was tested by computer simulation because

of verification the correctness of the designed sprue system, investigation of possible defects in the pre-production stage, especially in terms of shrinkages creation in the casting.

The shrinkage in the casting is created as a result of physical processes by reducing the metal volume by its solidification. The metallurgical purity of the steel from which is the casting of the golf head is also very important [9], [10]. The shrinkage is a defect in case of its allocation in the casting.

The computer simulation was realized by the program NovaFlow & Solid CV [11] and it verifies the correctness of the designed sprue system. The simulation was realized for the ingate with the diameter 20 mm and 35 mm and it faced to the thickest part of the casting and it filled the function of the feeder neck.

Fig. 4 shows the course of solidification by the different level of the solid phase, by the ingate with the diameter 20 mm.

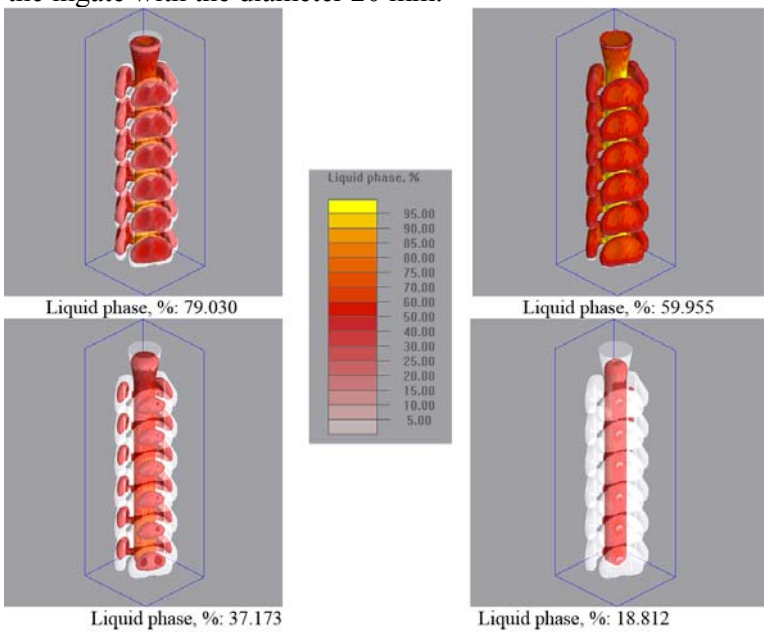

Fig. 4. Simulation of solidification

Fig. 4 presents the fact, that the content 37.173% of the liquid phase effects the conclusion of the melting in the casting, there is no connection from the sprue and thus the casting has a great probability of shrinkage formation. Fig. 5 proves this supposition – prediction of shrinkages formation.

The shrinkages are allocated in the thick places of the casting, where is the melting conclusion – the ingate solidified before the casting solidification.

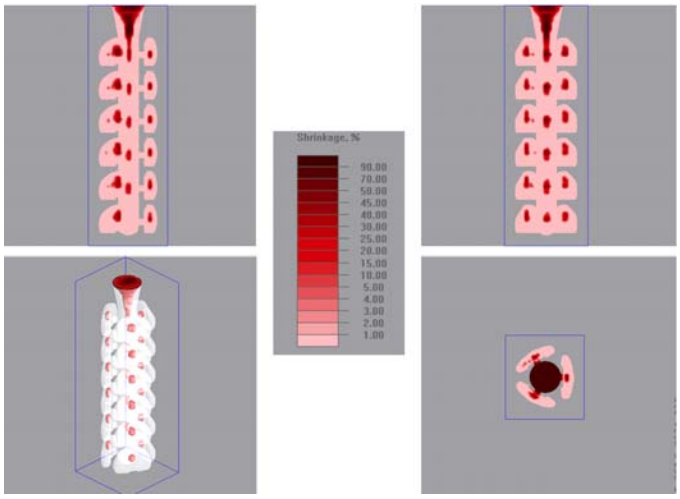

Fig. 5. Shrinkage prediction

Based on these facts the cross-section of the ingate was enlarged to 35 mm and it was realized simulation of solidification again.

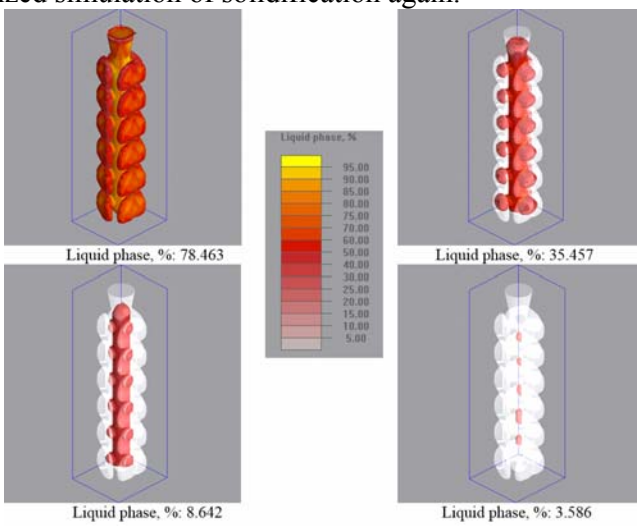

Fig. 6. Simulation of solidification

The simulation of the solidification process for the whole system is presented by the Fig. 6. The next analysed data is the prediction of shrinkages formation, which is presented by the Fig. 7.

From the prediction of shrinkages formation by the Fig. 7 it is evident that the shrinkages are allocated in the sprue canal after the modification of the ingates size what is evident also from the course of solidification (Fig. 6). The melting solidified uniformly and there is not a closed liquid phase in the casting, i.e. the sprue solidified after the casting solidification. The ingate enlarged on the 35 mm

had adequate feeding ability for completing of the metal reduction in the course of solidification.

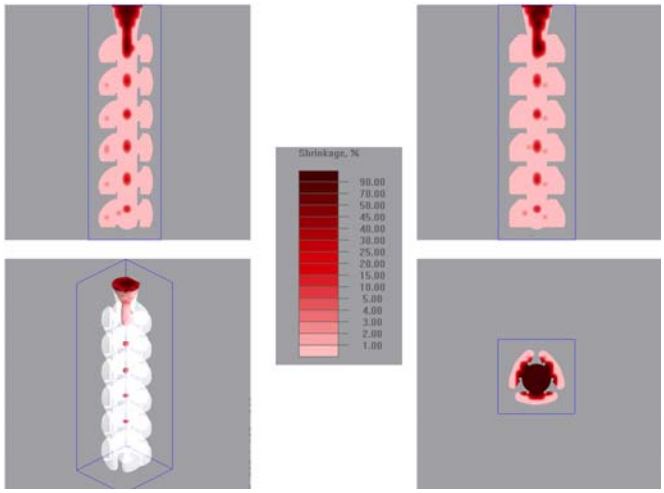

Fig. 7. Shrinkage prediction after enlarged the ingate

5. Conclusion

Computer simulation brings new opportunities for investigation and analysis of technological processes in the field of metallurgy. It makes visible foundry phenomena that are realized in the sprue system and in the casting by the form filling with liquid metal and by its solidification. The main benefit is in the improving of castings production which is presented by the final quality and last but not least by saving of costs in the preproduction stage. Simulation programs used in the metallurgy provide a wide range of information about the flow of molten material and about the process of solidification. It is possible to draw a conclusion from these facts which give rise to the production enhancement [12]. Therefore, enterprises which realize this fact, still increases and they implement computer simulation during the stages of the production process [13], [14]. With this fact is also linked an increased demand for experts in metallurgy which are able to work with different software products.

Computer simulation of golf head produced by lost wax technology has depicted to failure diameter of ingate (20 mm). Fig. 4 shows process of solidification in the liquid phase: 18.812%, 37.173%, 59.955% and 79.030%. Consequently it was made a prediction of shrinkages formation, which is documented by the Fig. 5. This figure shows that there was a conclusion of the melt in the casting and formation of shrinkages in the cast. This was due to the fact, that the ingate was solidified early. On this basis, the ingate was enlarged to ø35 mm. Fig. 6 shows process of solidification of the melt with this ingate diameter and the liquid phase: 3.586%, 8.642%, 35.457% and 78.463%. From the

prediction of shrinkages formation (Fig. 7) we can see that the melt consecutively solidificated from the cast and the last solidified the channel. The shrinkages have been places in the channel and did not interfering the castings.

Computer simulation revealed the causes of shrinkages creation in the cast due to insufficient ingate diameter. On the basis of this fact the ingate diameter was augmented and it was arranged a positively directed solidification and healthy castings without the shrinkages.

Advantages of computer simulation implementation are:

- increase in technical, quality and price parameters for the foundry production with the possibility of substantive reduction of reserves,
- time and costs reduction for development of new products technology.

R E F E R E N C E S

[1] *P. Futáš, D. Fecko, G. Fedorko, I. Vasková,* "Počítačová simulace v hutních procesech", in CAD, **vol. 23**, no. 2, 2013, pp. 26-28.

[2] *M. C. Perry,* Investment casting Institute, 136 Summit Avenue, Montvale, NJ 07645-1720, www.investmentcasting.org

[3] *J. Arulmoli, B. Vu, M.-Je Sung, F. A. Mohamed, J. C. Earthman,* "Spark production by abrasion of titanium alloys in golf club heads. Fire and Materials, 2014, DOI: 10.1002/fam.2235

[4] *P. Futáš, I. Jelč, I. Vasková, G. Fedorko, V. Molnár, P. Kačmáry,* "The Gist of Thermal Stresses of Cast Iron Castings", in Manufacturing Technology, **vol. 13**, no. 2, June 2013, pp. 173- 178.

[5] *E. Anglada, A. Meléndez, L. Maestro, I. Domiguez,* "Adjustment of Numerical Simulation Model to the Investment Casting Process", in Procedia Engineering, **vol. 63**, 2013, pp.75-83.

[6] *D. J. Browne, K. Sayers,* "Experimental measurements of investment shell properties and use of the data in casting simulation software", in Modelling of Casting, Welding and Advanced Solidification Processes, Metals & Materials Society, London 1995, pp. 441-448.

[7] *V. Molnár, G. Fedorko*, Catia – základy projektovania 2, Faculty of Mining, Ecology, Process Control and Geotechnology, Technical university of Košice, 2007.

[8] *M.M.A. Rafique, J. Iqbal,* "Modeling and simulation of heat transfer phenomena during investment casting", in International Journal of Heat and Mass Transfer, **vol. 52,** 2009, pp. 2132-2139.

[9] *A. Pribulová*, "Influence of Blowing of Argon on the Cleanness of Steel", in Archives of foundry engineering, **vol. 12**, no. 3, 2012, pp. 91-94.

[10] *D. Baricová, A. Pribulová, A. Rosová, "*Steelmaking Slag – Waste or Valuable Secondary Raw Material", in SGEM2013 Conference Proceedings, 2013, pp. 437-442.

[11] *http://novacast.se/products/novaflowsolid/*

[12] *N. Husáková, D. Marasová, "*Simulácia - komparácia simulačných programov", in: Logistika v teorii a praxi, november 2010, Uherské Hradiště, November 2010, pp. 76-81.

[13] *G. Fedorko, I. Vasková, D. Fecko, V. Molnár, N. Husáková,* "Change of the flow rate and its effect on simultaneous filling of the mould", in Metalurgia International, **vol. 17**, no. 9, 2012, pp. 226-229.

[14] *A. S. Sabau, "*Numerical Simulation of the Investment Casting Process", in Transactions of the American Foundry Society, no. 05-160(04), 2005.