ANALYSIS OF THE INFLUENCE OF THE GATING SYSTEM SHAPE ON THE FILLING AND SOLIDIFICATION OF DUCTILE IRON CASTINGS

[1]Karel GRYC, [1]Ladislav SOCHA, [1]Jana SVIŽELOVÁ, [2]Tomáš PRÁŠIL, [2]Ivan HOTOVÝ, [2]Pavel ČÍŽEK, [2]Jan ŠTEFÁNEK

[1]Institute of Technology and Business in České Budějovice, České Budějovice, Czech Republic, EU, gryc@mail.vstecb.cz, socha@mail.vstecb.cz, svizelova@mail.vstecb.cz,

[2]MOTOR JIKOV Slévárna a.s. České Budějovice, Czech Republic, EU, tprasil@mjgroup.cz, ihotovy@mjsl.cz, pcizek@mjsl.cz, jstefanek@mjsl.cz

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Abstract

The article deals with numerical simulations of filling and solidification of ductile iron castings produced in the MOTOR JIKOV Slévárna (Foundry). The simulations we performed in the ProCAST simulation software. The research analyses the geometry of the gating system consisting of two Branches, with a total of 12 castings type “YOKE A”. Each of the Branches contained a different gate shape. The operational partner defined operating conditions. Based on it, casting, solidification and stress states were calculated. An analysis of selected parameters was then performed to verify the influence of individual shapes of gates on the filling and solidification. Some differences in filling and solidification between the individual Branches were found. However, these differences are not significant. The findings are discussed in the text of this paper.

Keywords: Foundry, ductile iron, numerical simulation, ProCAST, gating system

1. INTRODUCTION

When analysing foundry defects, it is necessary to realize that one of the causes of their occurrence is an unsuitable gating system. The gate is one of the most important mould parts, since all the metal that fills the mould cavity flows through it. The gating system purpose is to ensure [1, 2]:

- Uniform, even and continuous filling of the mould cavity at optimum speed
- Prevent the mould walls and core damage
- Ensure that all parts of the mould cavity are completely filled with liquid metalRemoval of impurities and slag in the last stage of casting
- Directional solidification

The technologists’ main task is to design the best possible gating system with regard to defects occurrence in the final castings. It is a demanding task since it is necessary to develop a gating system for every specific shape and size of the casting, walls thickness, alloy, etc. [1-4]. Presently, this topic is being dealt with in several works, since optimization of a gating system with regard to the final products quality remains a very topical theme. For example, by the gating system modification, the relevant work authors [5] managed to ensure the castings rejects rate reduction by 20 %. The work [6] analysed the sprue height impact on the resulting structure and mechanical properties of a casting. Study [7] analysed the “sprue base“ influence on the mould filling course.

Presently, simulation software provides a significant advantage; using the software, it is possible to predict filling and castings solidification and, simultaneously, it allows realization of any change of the gating system geometry, as well as of the casting conditions. Numerical simulations are very popular in the foundry industry. For example, study [8] dealt with numerical simulations of an optimized gating system with the aim to suppress air entrapment into metal by surface turbulences minimization. Similarly, study [3] also dealt with the gating system design and optimization using simulation software. Its goal was to ensure even and level filling of a heavy casting. Aim of study [9] was to design a gating system for a turbine casing casting using numerical simulations. The resulting design was verified by an experimental melt. The casting has shown a good compliance with the numerical simulation The study [10] authors verified various approaches of a casting gating system design, with subsequent experiments with hot metal, using numerical simulations. In a similar way we could mention many other studies, e.g. [11-22], focused on casting production optimization.

Presently, the ongoing research at the Environmental research centre of ITB in ČB is focused on optimization of a ductile iron casting production. For the relevant purpose operating melts take place, with the aim to assess influence and efficiency of the designed and modified production technological processes, out-of-furnace processing, casting and thermal processing of ductile irons castings. The research also includes numerical simulations in the ProCAST software, focused on the melt properties, on setting of conditions for casting, solidification and cooling of ductile iron castings, with the aim to identify and prevent problems in the designed production technology, which might result in defects occurrence. This paper presents the numerical simulations results, the aim of which was verification of the gate shape on a mould filling and on the resulting castings quality. Based on numerical simulations, the results will be further verified within trial operating melts.

2. EXPERIMENTAL PROCEDURE

The study proper was focused on the “YOKE A” type casting (see **Figure 1**), which serves as a valves rocker arm in truck motors. The castings are cast gravitationally into bentonite moulds. A non-permanent mould for gravitational casting includes 12 pieces of castings in a layout shown on **Figure 2**. The gating system includes two types of gates. Branch 1 includes the original shape gates. Branch 2 includes gates with shape modification, shown on **Figure 2** on the right. The casting is manufactured from the EN-GJS-700-2 material, the general composition of which is shown in **Table 1**.

Figure 1 Geometry of the “YOKE A” type casting

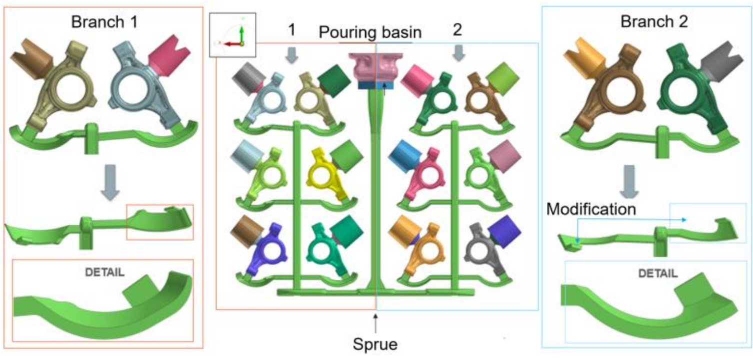

Figure 2 Gating system geometry and castings layout

Table 1 General chemical composition of the EN-GJS-700-2 material

Element	C	Si	Mn	Mg	Cu
Content (wt%)	3.8	2.4	0.4	0.033	0.045

Computational geometry has been created for the numerical simulations purposes; it was represented by a mould cavity, i. e. castings including the gating systems, filter and risers (see **Figure 2**). Subsequently, a virtual mould has been modelled to the geometry of castings with a gating system; its size corresponded to the real mould used in operating conditions. Thus, prepared geometry has been further covered by a 3D computational mesh, featuring 4 183 050 elements. **Figure 3** shows an example of a computational geometry surface and volume mesh to provide an idea concerning the structure.

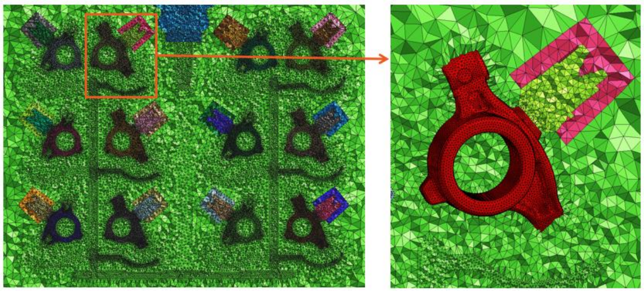

Figure 3 Example of a surface and volumetric computational mesh

Further, a gravitational vector in the direction of the negative Y axis, casting temperature, heat transfer conditions, coefficients of heat transfer among the casting system components and boundary conditions have been defined for the correct course of filling and solidification. **Table 2** specifies materials of the casting system individual components. The mould temperature of 30 °C and the bentonite mixture moisture of 3.6 % have been taken into account for the calculation purposes. The calculation was realized using the Thermal and Flow module.

Table 2 Materials of individual parts of the casting system

Name	**Casting/Riser**	**Gate**	**Pouring basin**	**Mould**	**Filter**
Material group	Alloy	Alloy	Alloy	Mould	Filter
Material	EN-GJS-700-2	EN-GJS-700-2	EN-GJS-700-2	Green Sand	10 PPI

3. RESULTS AND DISCUSSION

This chapter includes the analysis of key results of filling and solidification, with the aim to map the influence of a gate shape change in the process of casting the “YOKE A” casting.

Within the casting course, metal passes through the sprue into a distribution duct where it is distributed into two directions (Branch 1 and Branch 2). From there it rises through two main gates that fill gradually individual levels of the gating system. The system filling is symmetrical; within the system, the thermal field is much alike in the entire volume. Minor deviations, could be seen in the shape gates running directly into the castings; the cause was their different shape. Together with the thermal field, the filling course is in certain stages drafted on **Figure 4**. The castings did not solidify within the casting course. Therefore, no cold shuts occurrence or no metal misrun in the system is expected. In general, the simulation predicts uniform distribution of the thermal field, symmetrical on individual levels. The hottest castings are located on the last floor and the temperature of castings closer to the sprue is higher by 40 °C, which is caused by higher heating through of the relevant area. At the filling end, the cast iron temperature still remained above the liquid temperature.

Through the solid fraction portion, **Figure 5** shows the solidification course. The castings solidification proceeded from end zones to risers. The castings solidified towards the central ring after disconnection from the gates. Simultaneously, the relevant central area solidified towards the riser, where two solidifying Branches were formed, which were being pulled into the riser. Solidification inequality was detected at closer scrutiny between Branch 1 and Branch 2 of the gating system. The difference was most evident at ca 45 % of solid phase, when the volumes of not completely solidified metal in the ring area of the casting were being separated, as shown on **Figure 5**. Solidification proceeded faster in the left part of Branch 1 and in the right part of

Branch 2, probably owing to their location at the mould wall and faster heat removal. Later, porosity formed in this place as well.

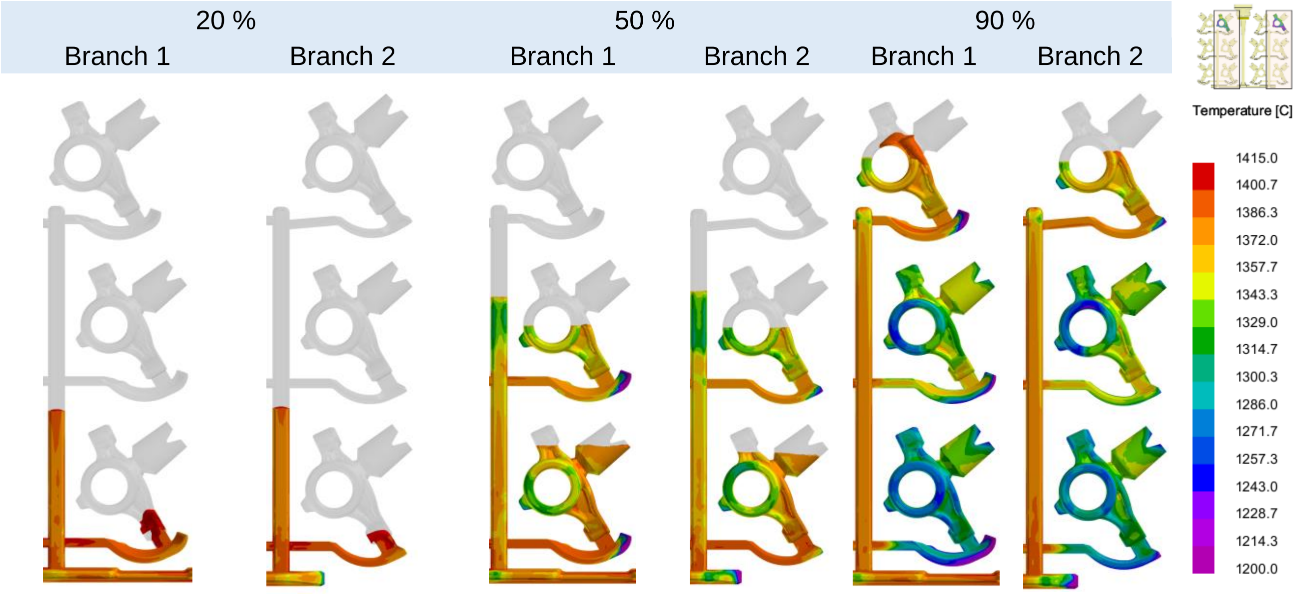

Figure 4 Example of a filling course and of a temperature field

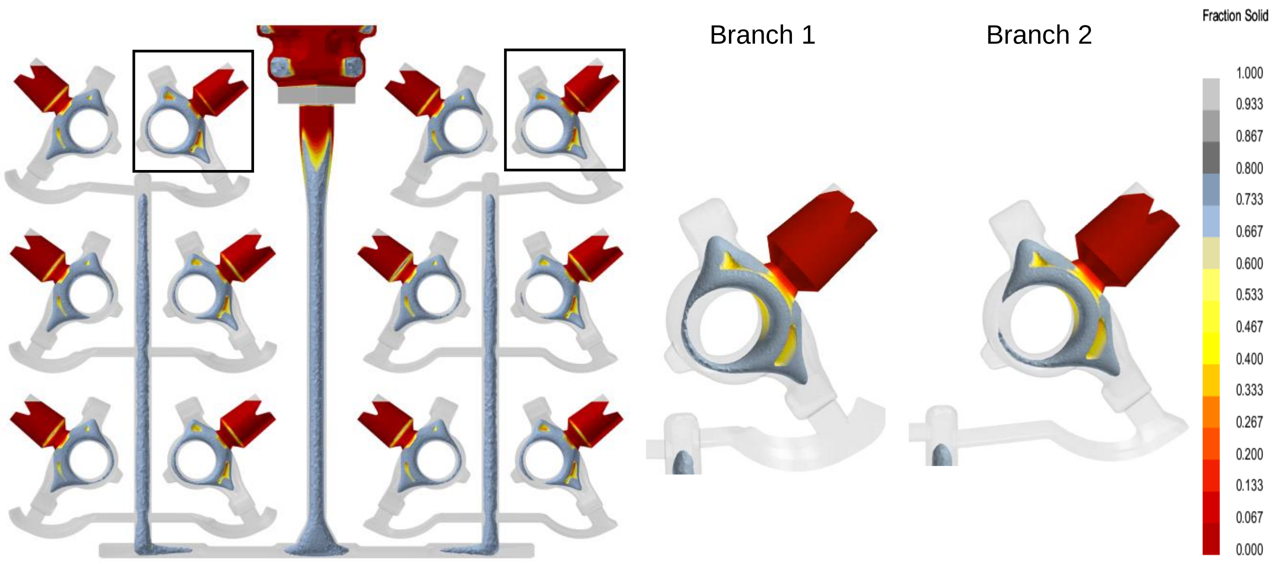

Figure 5 Representation of castings solidification in individual branches

Figure 6 shows general visualization of porosity occurrence in a metal volume. It is evident that simulation predicted a smaller area of porosity in one area at the central ring margin in case of all castings. That means in the area where the liquid phase volumes are separated, as described above. Porosity occurrence in castings was not predicted outside the relevant area.

Figure 7 represents illustrative comparison of porosity volume in castings from Branch 1 and Branch 2. It is evident that the casting for Branch 2 contains lesser porosity volume. This knowledge can be also applied on total porosity volume in castings in each branch. Castings from Branch 1 contained porosity with the total volume of 0.0077 cm^3, while total porosity volume in castings from Branch 2 was 0.0065 cm^3.

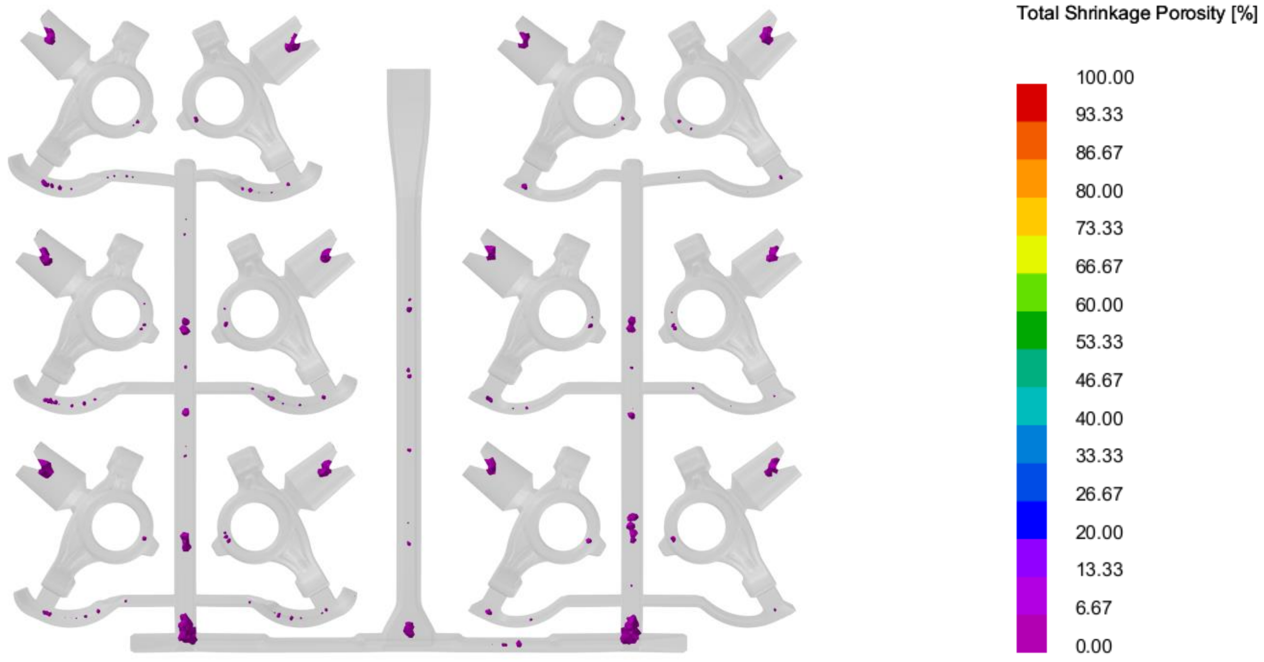

Figure 6 Porosity visualization

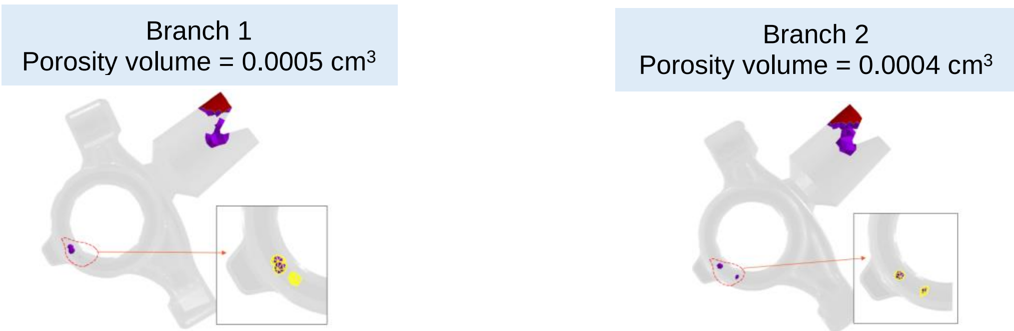

Figure 7 Illustrative comparison of porosity volume in castings from individual branches

4. CONCLUSION

The work deals with numerical simulations of casting a “YOKE A” type casting from ductile cast iron, with focus on verification of the gate shape influence on the casting course. A computational geometry with a 3D network was created and boundary conditions were defined for this purpose in cooperation with the industrial operational partner, MOTOR JIKOV Slévárna (Foundry). The relevant input data were entered into the ProCAST simulation software, in which the castings filling and solidification were computed. Based on the computed results, the following conclusions have been established:

- The mould filling proceeds relatively symmetrically. Minor deviations can be seen when comparing the filling of Branch 1 and Branch 2. Branch 1 with a more massive gate fills faster than Branch 2 with modified a gate shape.
- The castings did not solidify within the casting course. Therefore, cold shuts occurrence and misrun are not expected.

- Castings in individual branches solidified directionally. Faster solidification was noticed in the left part of Branch 1 and in the right part of Branch 2. This concerned castings close to the mould wall, where heat removal is faster.
- Porosity occurrence was predicted in castings on the central ring margin where the liquid phase volumes are being separated. When compare individual branches it was determined that Branch 2 with a modified gate shape included lower porosity volume.

It follows from the above conclusions that the gate shape modification had no significant impact on the course of a “YOKE A” type castings casting. However, the gate shape modification might result in porosity reduction in the relevant castings. Nevertheless, it is necessary to further verify this fact within operating melts and subsequent analysis of defects occurrence in castings.

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