INFLUENCE OF THE CHILL SIZE ON THE POROSITY FORMATION IN DUCTILE IRON CASTING

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https://doi.org/10.37904/metal.2022.4457

Abstract

This paper describes the numerical modelling of solidification of ductile iron castings intended for the shipbuilding industry. Numerical simulations we performed in the computer software MAGMASOFT®. The purpose of numerical simulations was to predict solidification under defined casting conditions to verify whether the proposed production technology is adequate. Attention was focused mainly on the porosity occurrence in the casting, which is determined at a stated location using an ultrasonic test. Variants with different types of chills were simulated to determine their effect on the size of porosity. The results of these variants are presented in this paper. The variant with the best results was then recommended for production under operating conditions.

Keywords: Metallurgy, casting, ductile iron, numerical simulation, MAGMASOFT®

1. INTRODUCTION

In practice, castings can be porous, and they can contain inclusions or other imperfections that contribute to quality deterioration. Such imperfections are considered a real defect when they impact the product function or appearance [1]. The relevant defects have various impacts on the final casting quality. Defects that worsen the structure integrity, and thus worsen the final casting properties, are crucial. In general, such defects cannot be removed and, in consequence, the relevant product has to be liquidated with resulting related financial loss. Regarding forged pieces, workpieces and other metal products, the porosity occurrence can be prevented by using semi-finished products of corresponding quality, by mechanical machining, etc. [2]. However, in case of castings that are not subject to further machining porosity has to be dealt with by production technology modification, best before the casting process [3]. However, the porosity minimization task is complicated and it requires taking into account the material chemical composition, casting temperatures, inoculation method, risers, as well as the mould proper material and design [3-6].

In foundries, solution of the defects causes is considered one of the most important aspects. In an ideal case, the causes are removed prior to the production start. In this regard, software for numerical simulations is a substantial advantage. After successful validation of a model, numerical simulation can be an efficient tool for relatively fast verification of the designed corrections in the production technology. Nowadays, by using numerical simulations, it is possible to predict the complete process, from the technology plan [7,8, 9] through castings casting [10,11], including solidification [12-14], stress states [13-17], defects prediction [13,14,18,19] and resulting metallographic structure of a casting [19-21].

The presented article is a part of a complex research and development, focused on introduction of cast iron products with spheroidal graphite according to CSN EN 1563 standard [22], which is realized in cooperation with the KOVOSVIT MAS Foundry a.s. Company. Castings from such cast iron are meant, in particular, for the shipbuilding industry, gearbox manufacturers, compressor manufacturers, power industry and automobile industry, where above-standard processing of materials is expected. Primarily, the research works deal with production technology modification through optimization of the existing and introduction of new technological procedures and their efficiency evaluation by chemical and metallographic analysis [23] and mechanical tests. Numerical simulations in the MAGMASOFT® [13,14] software are used for verification and modification drafts of the existing technology.

The work describes the optimization course of a mould for production of a SCHAFT 1 casting for the purpose of achieving the required internal structure with regard to porosity occurrence. The mould modifications were verified in the design stage by numerical simulations in the computational software MAGMASOFT®. The primary simulation realized at the gating system design revealed the necessity of a chill presence in the mould. The follow-up simulations which are presented by this article deal also with testing of various sizes of the chills and with their function at minimization of porosity volume in a casting so that it would comply with the customer´s requirements (porosity dimension must be smaller than 25 % of the casting wall thickness).

2. DEFINITION OF NUMERICAL SIMULATIONS

Figure 1 shows the SCHAFT 1 casting type geometry. The casting represents a component for ship manipulators manufacturers for medium-sized ships. The casting is manufactured from the EN-GJS-400-18-LT material; that means cast iron with spheroidal graphite and ferrite matrix with guaranteed value of impact energy at -20 °C [22, 24]. Chemical composition of the EN-GJS-400-18-LT material is specified in **Table 1**. That is to say, in case of the relevant casting type above-standard material quality is required, as well as achievement of the required chemical composition, structure and mechanical properties.

Geometry of the SCHAFT 1 casting type, together with the gating system and other components of the casting system, is shown on **Figure 1**. Next, **Figure 2** depicts the layout of two types of the analyzed chills; their dimensions, together with the variants identification, are specified in **Table 2**.

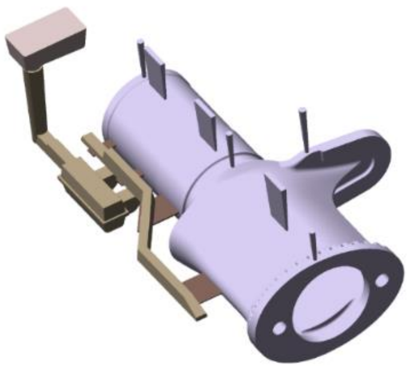

Figure 1 Computational geometry

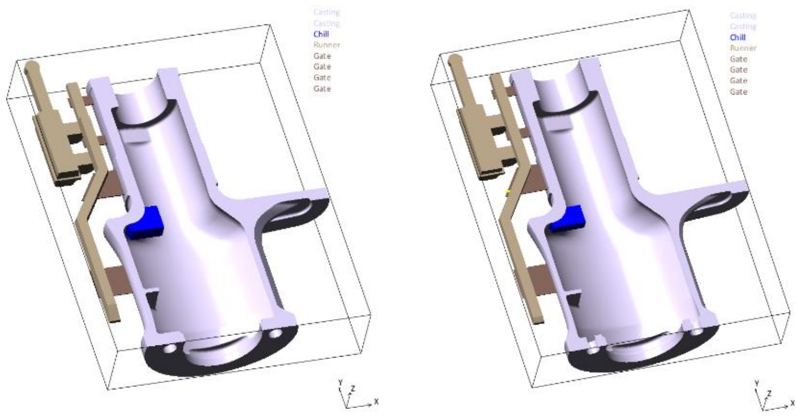

Figure 2 Chill location (left: chill A, right: chill B)

Table 1 Chemical composition of material EN-GJS-400-18-LT

Range	C	Si	Mn	P	S	Cu	Mg	Cr
Min.	3.50	1.90	0.10	×××	×××	×××	0.040	×××
Max.	3.60	2.00	0.15	0.040	0.010	0.05	0.060	0.02

Table 2 Designation of simulated variants and dimensions (mm) of chills

Variant	Chill type	Height	Width	Length
V0	Without chill	-	-	-
V1	A	80	204	150
V2	B	50	204	150

A computational mesh with the element size of 4 - 6 mm for all elements of a casting system (with the exception of a mould) was generated for the casting system geometry. The resulting mesh for a SCHAFT 1 type casting consisted, in total, of 513,357 elements. Input parameters for numerical simulations of a casting were defined on the basis of operating data, supplied by the KOVOSVIT MAS Foundry a.s. Company. The parameters include chemical composition of the material, casting temperature, inoculation method, materials for the mould manufacturing, time of the casting filling, etc. In operating conditions, cast iron with spheroidal graphite used for manufacturing of the relevant casting type is inoculated in two stages: preinoculation in a ladle and inoculation by blocks in a pouring basin. A one-stage inoculation in a basin was used for the calculation.

Filling and solidification calculation was realized in the simulation. The calculation of a single variant lasted ca 48 hours. Considering the character of this article specialization, only the solidification results will be presented below.

3. RESULTS DISCUSSION

Figure 3 shows a casting solidification in various stages of the V0 Variant. It is evident that owing to its shape, the casting solidification does not proceed directionally. At the beginning solidifies its front part with a flange with thinner walls. The first hotspot forms in the flange; however, it was not problematic. In the following stages solidification moves to the second part of the casting, where more hotspots develop. In general, they do not present any complication from the resulting quality viewpoint. However, a problematic hotspot occurrence was identified in the final stage of solidification in case of Variant V0, which represents a primary variant without a chill. On **Figure 3** it is shown in red. Porosity was detected at the relevant area. It is shown on **Figure 4**. The relevant porosity reached the value of 92 % of the unfilled volume and its dimensions exceeded the values specified by the customer (dimension up to 25 % of the wall thickness).

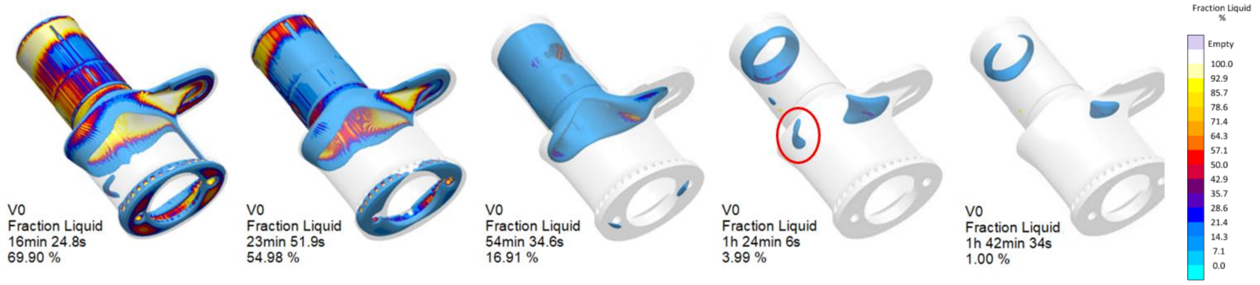

Figure 3 Solidification course in various stages - Variant V0

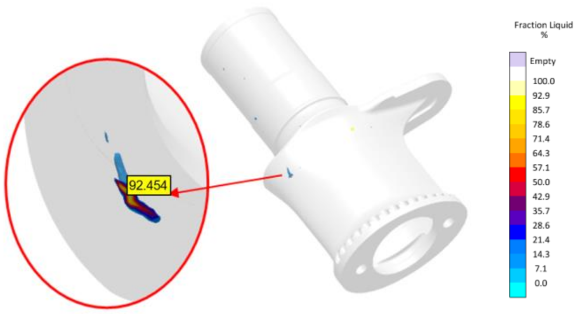

Figure 4 Porosity occurrence in a casting - Variant V0

In order to suppress a hotspot occurrence which appeared in case of Variant V0 and which caused development of a large porosity area, a V1 Variant was defined. A chill was implemented in the problematic part of the casting; its purpose was to eliminate the hotspot and, at best, to prevent porosity occurrence. In case of Variant V1, the casting solidification is shown on **Figure 5**. At the beginning, solidification is rather similar to that in the V0 Variant. In the following stages, the relevant area on the casting is cooled. However, the porosity analysis has shown that the designed modification was not successful. The chill did not eliminate the porosity; it has only shifted to another area, while it has shown basically the same percentage of unfilled volume as in case of Variant V0. Moreover, the porosity areas in other parts of the casting have increased. The relevant porosities have also shown substantial dimension and a not negligible percentage of unfilled volume, as shown on **Figure 6**.

Figure 5 Solidification course in various stages - Variant V1

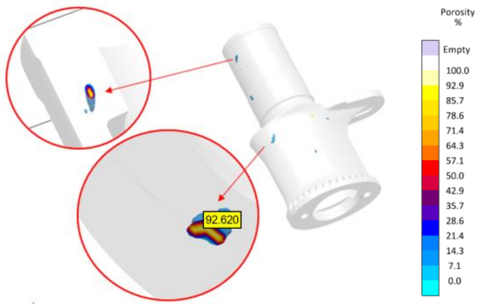

Figure 6 Porosity occurrence in a casting - Variant V1

Variant V2 was designed on the basis of the V1 Variant; it included a smaller dimension chill (compared to the V1 Variant chill, it was smaller by 25 %), located in the same area, as shown on **Figure 7**. At the beginning, solidification had again a similar course as in case of Variant V0. At the final stages of solidification we can see partial cooling of the original hotspot where a large porosity developed.

Figure 7 Solidification course in various stages - Variant V2

The porosity analysis has shown that this modification is successful. As shown on **Figure 8**, all the porosities which occurred in Variant V1 were reduced. Their dimensions were already in compliance with the customer´s requirements. It is probable that the real casting porosities will have a smaller dimension, since their dimensions in the MAGMASOFT® software were measured from an area with 10 % of the material unfilled volume.

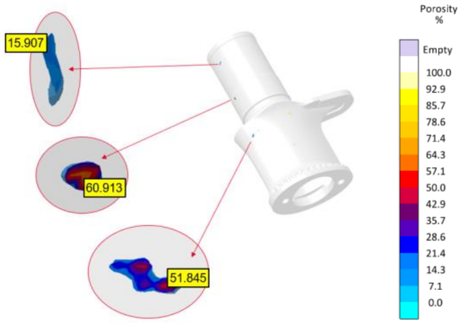

Figure 8 Porosity occurrence in a casting - Variant V2

A mould for casting of a SCHAFT 1 casting was constructed on the basis of the V2 Variant and operation melts were realized. Afterwards, the manufactured casting was tested non-destructively with regard to internal defects occurrence, using the ultrasound test according to the CSN EN 12680-3 standard [25]. To sum up, regarding internal quality, the product complied with the customer´s requirements.

4. CONCLUSIONS

Numerical simulations of the SCHAFT 1 casting solidification were carried out within the scope of the work, with the aim to optimize the production technology in order to be able to satisfy the customer´s qualitative parameters. 3 variants of numerical simulations were defined; each of them used a different chill type. The required calculations of casting solidifications were performed on their basis. The results analysis was focused on the casting solidification course, with regard to porosity occurrence. The established conclusions can be summarized in the following points:

- ✓ In case of the primary Variant V0, which did not include a chill, a large porosity area developed in the problematic part of the casting. The porosity exceeded the dimension requirements specified by the customer and, moreover, its value reached 92 % of unfilled volume.
- ✓ A chill was used in case of Variant V1 to prevent porosity development, which appeared in Variant V0. The chill purpose was to break the hotspot in the relevant area and thus prevent major porosity occurrence. However, this effect was not achieved. The resulting V1 Variant porosity was only shifted to another part of the casting, while it still amounted to 92 % of unfilled volume. Moreover, other large porosity areas were predicted.
- ✓ A chill was also used in case of Variant V2, however, compared to the V1 Variant, it was reduced by 25 %. This modification was successful, since the resulting porosities reached a smaller percentage of unfilled volume and their dimensions were in compliance with the customer´s dimensional inspection.

A mould was constructed on basis of the V2 Variant and an operating melt was carried out, within which a SCHAFT 1 casting was manufactured. The subsequent ultrasound test did not discover any substantial defects; therefore we can say the casting complied with the customer´s requirements with regard to the casting internal quality.

ACKNOWLEDGEMENTS

The paper was prepared under the support of the Czech Ministry of Industry and Trade within the scope of the TRIO programme, as part of projects Reg. No. FV40036 "Research and development of complex technology of castings production from high-quality ductile iron castings".

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