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Influence of Type and Shape of the Chill on Solidification Process of Steel Casting

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Abstract

The article is a case study of the steel milling ring casting of about 6 tonnes net weight. The casting has been cast in the steel foundry the authors have been cooperating with. The aim was to analyse the influence of the shape of the chills and the material which was used to make them on the casting crystallization process. To optimally design the chills the set of the computer simulation has been carried out with 3 chills' shape versions and 3 material's versions and the results have been compared with the technology being in use (no chills). The proposed chills were of different thermal conductivity from low to high. Their shapes were obviously dependant on the adjacent casting surface geometry but were the result of the attempt to optimise their effect with the minimum weight, too. The chills working efficiency was analysed jointly with the previously designed top feeders system. The following parameters have been chosen to compare their effectiveness and the crystallization process: time to complete solidification and so-called fed volume describing the casting feeding efficiency. The computer simulations have been carried out with use of MagmaSoft v. 5.2 software. Finally, the optimisation has led to 15% better steel yield thanks to 60% top feeders weight reduction and 40% shorter solidification time. The steel ring cast with use of such technology fulfil all quality criteria.

Keywords: Solidification process, Crystallization process, Computer simulation, Steel casting, Chill

1. Introduction

The heavy steel casting production process requires detailed analysis of solidification, crystallization and heat flow in the casting. The better view on them the greater quality and profit can be obtained. To prepare best technology we need to focus on solidification process, guiding it in a planned manner [1-3]. Asking yourself how to affect it in such large detail, authors decided to use massive chills, which shape and material are the subjects to the analysis presented in the following article.

This article presents initial analysis of chill examination which is a small part of large project concerning new approach

to chill application in steel casting manufacturing process. This know-how will allow the authors to prepare best technology for analogous heavy steel castings by improving the quality of key areas, decreasing feeders and improving total technological efficiency. Process engineers often underestimate potential of using chills, which this article should convince them to implement in most cases.

2. Materials and methodology

Three materials, three shapes and variants of thickness were used in computer simulations carried out with MagmaSoft v. 5.2 to compare the effectiveness of selected solutions. Assessment criteria were based on solidification process – crystallization starting areas, separation and closure of crystallization areas, total solidification time and metal volume necessary to supply the casting (fed volume). The mesh cube dimensions were 2x2x2 mm.

In basic (initial) technology no chills were used. Shape and main dimensions of the casting ring are shown in figure 1. Basic technology was characterized by the following parameters:

- Casting material: GS-52 acc. to DIN 1681,
- Pouring temperature: 1570°C,
- Molding sand: Alphaset,
- Mold dimension: 1850x1850x1000 mm,
- Total casting weight 8760 kg (excluding gating system),
- Total feeders weight: 2685 kg (6 pieces of AXOV12 - H500, each in exothermic sleeve – FOSECO KALMINEX wall thickness 30 mm).

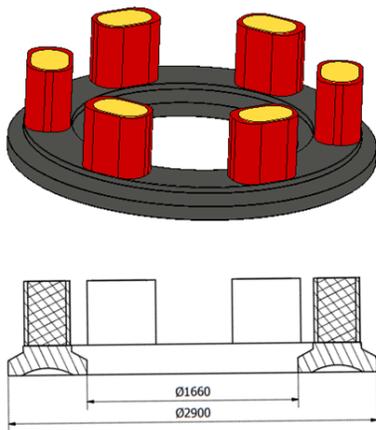


Fig. 1. Milling ring basic (initial) technology

2.1. Chills materials variants

Three material variants of chills were tested, material with high thermal conductivity, material with low thermal conductivity and material with intermediary thermal conductivity in relation to the two previous ones, as this parameter is crucial in this area of studies [4-5]. Table 1 presents selected parameters of the chills materials variants [6].

Table 1.
Parameters of chills materials

Material ID	Initial temperature	Specific heat in 1000°C	Thermal conductivity in 1000°C
I	400°C	617 J/kg*K	28 W/m*K
II	20°C	1925 J/kg*K	58,2 W/m*K
III	20°C	960 J/kg*K	1,15 W/m*K

2.2. Chills shape variants

Following chills shape variants were tested with either two or three variants of their wall thicknesses:

a) Construction variant I – full segmented chills.

Set of 6 chills, placed under the cast, every 30° in places between the feeders. Each chill took 30° of ring's bow length. The cross section corresponded to the bottom contour of the casting, and were increased by a thicknesses of $a_1 = 37.5$ mm and $a_2 = 75$ mm variants, as shown in figure 2. Due to the largest contact surface, the solution, as expected, had the most impact on the solidification process, as except heat transfer coefficient and thermal conductivity it is a key factor allowing solidification control.

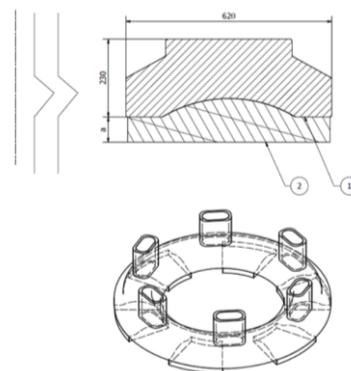


Fig. 2. Technology of the first construction variant

b) Construction variant II – L-shaped inner chilling ring.

Ring with L-shaped cross-section mounted on the entire internal cross-section of the casting. The chill adhered both from the inside and from the bottom to the considered casting, as shown in figure 3. The inner ring caused that during the solidification, an insulating air gap is not formed as shown in studies [7] as a shrinkage effect, which translates into the efficiency of the chill.

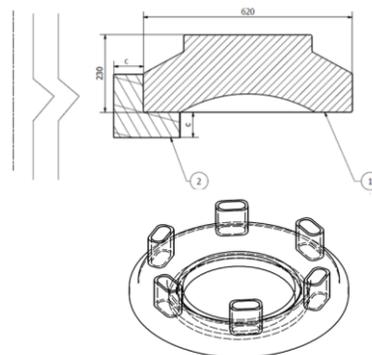


Fig. 3. Technology of the second construction variant

c) Construction variant III - segmented divided chills.

Set of 12 chills, placed under the casting, every 30° in places between the feeders. Each chill took 30° of ring's bow length. The internal chill was L-shaped, external – had rectangular cross-

section, as shown in figure 4. The solution turned out to be the least effective.

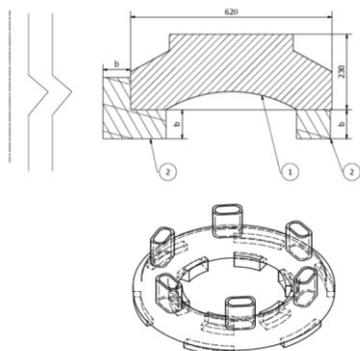


Fig. 4. Technology of the third construction variant

2.3. Methodology

Twenty five numerical simulations have been done with MagmaSoft v. 5.2. Boundary conditions of each simulation were consistent with those quoted above. Due to middling important impact and limited calculation time, the process of filling the mould was omitted, authors focused on analysing only the solidification of the casting. By analysing successive solidification frames, chills can be designed to shape the zones of solidifying metal, move them as close to feeders as possible, which have a positive effect on the reduction of the feeders size. However, like shown in figure 5, this method requires subjective interpretation of the results – bridges between liquid phases should be as small as possible due to the risk of porosity in this areas. Chills made it possible to obtain a large amount of solid phase in the casting before starting noticeable metal crystallization in the feeders. A measurable indicators as total solidification time and fed volume were summarized afterwards in the article.

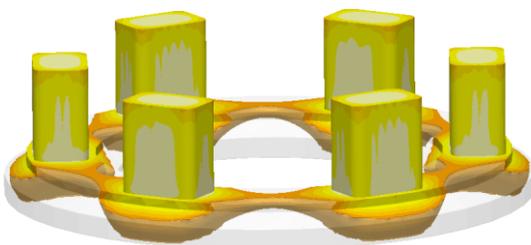


Fig. 5. Moment just before the separation of liquid metal zones in solidifying ring

3. Results and discussion

The casting in basic technology (without chills) solidified, of course, the longest time 19 641 s (5,45 hours). Among

the variants tested, the shortest times were obtained in the first material variant (full segmented chills). The shortest solidification time was obtained for the chills made of material I with a thickness of 75 mm – 14 536 s (4,03 h). Material II with a thickness of 75 mm proved to be more effective than the chill made from material I with a thickness of 37,5 mm. This indicated that both these materials work very well as chills. Material III showed slightly faster solidification times than the casting without chills (time differences were 542 s for thickness of 75 mm and 670 s for thickness of 37,5 mm). Interestingly, the larger layer of chill made of material III did not caused any drop in solidification time. Construction variants I and III resulted in creation of artificial end zones of feeding separating the feeding areas of neighbouring feeders resulting in reduced tendency for porosity.

The first construction variant with chills thickness of 75 mm and the I material type made it possible to reduce the gross weight of the casting by 1595 kg, which translates into a 15% increase in yield and save of almost 1000 kWh of energy [8]. In the optimized technology, it was possible to use 2 size classes smaller feeders, according to FOSECO's database, achieving reduction of the single feeder weight from 447 kg to 179,5 kg! Feeders for both basic and optimized technology have been compared in the figure 6.

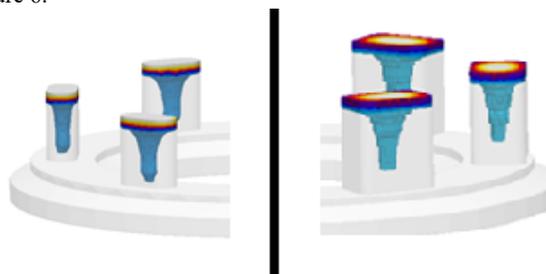


Fig. 6. Comparison of shrinkage in construction variant I, material type I (left side) and basic technology (right side)

Comparative charts for every construction and material variants were presented in the figures 7 and 8. As expected solidification time is dependent on the thickness of the chill as its heat capacity, solidification times for first material type were the shortest, while third material used has shortened just a bit the solidification times. In two cases increased thickness of chill material III decreased solidification time. The highest reduction of total solidification time was always achieved for material I with the highest thickness, interestingly full segmented chills from material I with thickness of 37,5mm resulted in exactly the same solidification time reduction as segmented divided chills from material II with thickness of 150mm. As shown on the figure 8, the fed volume amplitude for each riser was only 9 kg comparing optimal and basic variants, which slightly improved the feeders efficiency. In the following figures 9, 10, 11 the processes of metal solidification by the time were shown. Third material variant thickness had no noticeable effect for the solidification progress, while the second material variant thickness had greater impact on the solidification time than thickness of the first material type. The highest difference in solidification course can be seen from the beginning to 12000s. The highest difference in solidification course can be seen With I construction variant in

which use of I material variant chills allows to obtain up to 30% more solid phase in comparison to initial technology which would definitely affect the mechanical properties of the casting in a positive way. In construction variants II and III difference is still visible and allows to achieve nearly 10% more solid phase in the

same time in comparison to initial technology. Figure 12 presents comparison of the solidification processes for basic and optimized technologies. Due to reduced feeders sizes, optimized technology with no chills (red curve) has been placed on the chart to show the direct effect of the chills to the solidification progress.

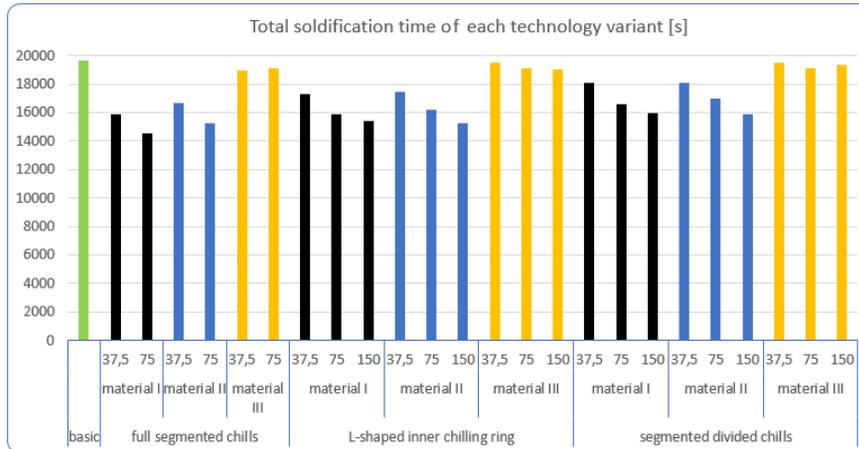


Fig. 7. Solidification times of examined variants

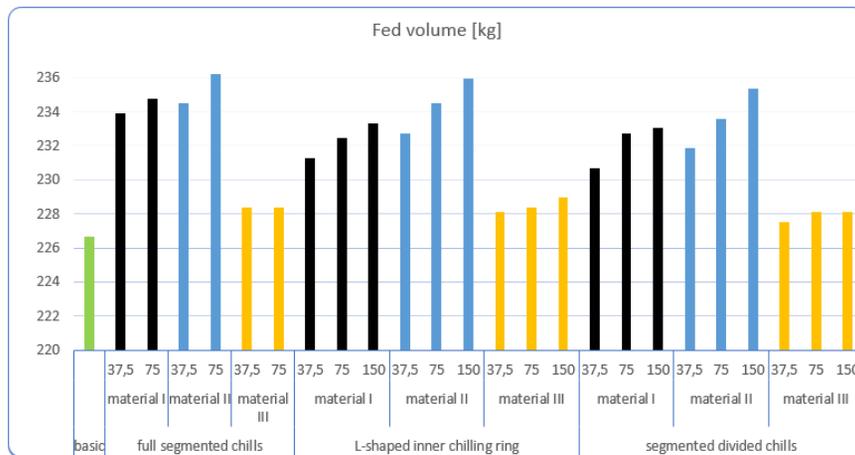


Fig. 8. Volume of metal [kg] necessary to feed the casting properly

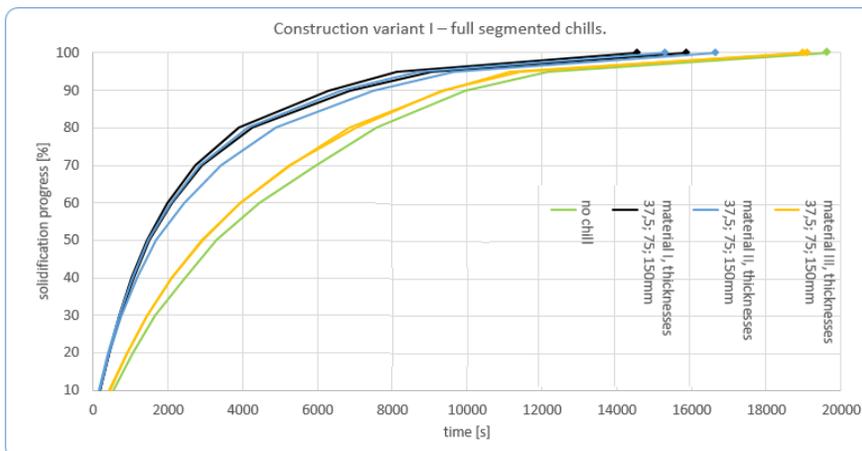


Fig. 9. Amount of solid phase over time for first construction variant

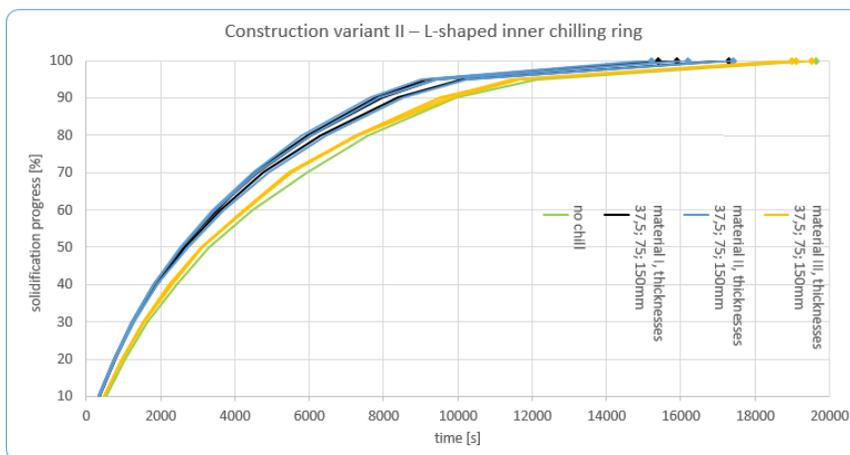


Fig. 10. Amount of solid phase over time for second construction variant

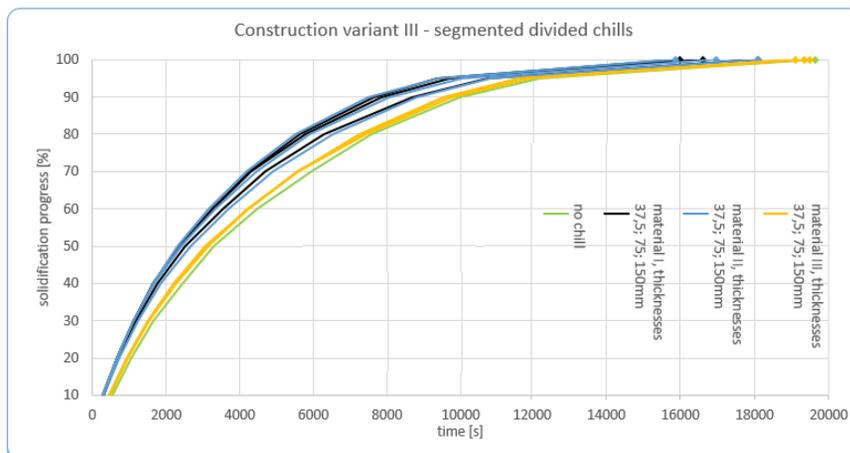


Fig. 11. Amount of solid phase over time for third construction variant

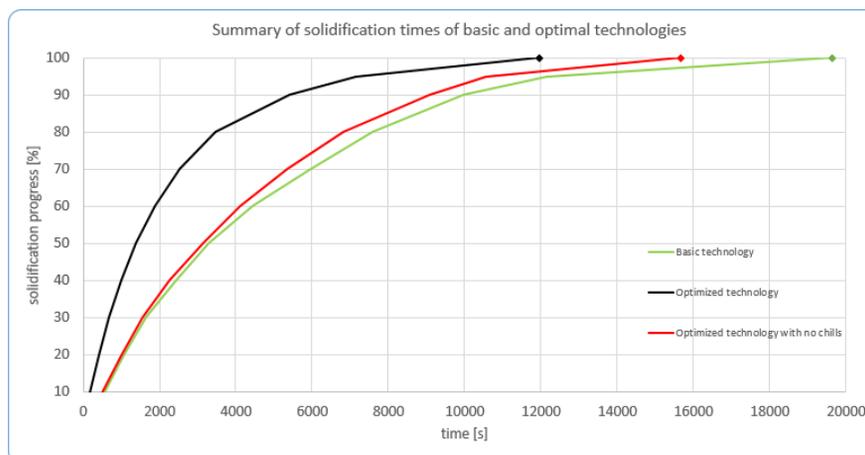


Fig. 12. Comparison of the solidification processes for basic and optimized technologies

4. Conclusions

Problem of designing optimal casting technologies is still present in the industry. Despite many years of experience in the plant, process engineers often downplay usage of chills to optimize yields, which may result from routine, fear of possible defects or ignorance.

Construction variants I and III resulted in creation of artificial end zones of feeding separating the feeding areas of neighbouring feeders resulting in reduced tendency for porosity.

Chills significantly shortened solidification times, which allows to accelerate the production cycle. With reference to the basic technology, the solidification time in the optimal technology was 2h and 6 min shorter, which save a 30% of total crystallization time.

Optimization of the technology resulted in a 15% increase in yield (1595 kg) and a reduction in the weight of the feeders by as much as 60%! This allows to save about 1000 kWh of energy needed to melt the extra metal volume in arc furnace.

Article presents initial analysis of chill calculation which is a small part of large project concerning new approach to chill application in steel casting manufacturing process. Next step of optimization issue will consider the use of covered feeders and increase the number of chills, with different, more uniform shape. Furthermore, it would be highly desirable to perform non-destructive testing (magnetic or radiographic examination) of the zones where bridges between liquid phases disappears and compare these results with numerical data.

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