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Pressurized gating system design and optimization in steel castings

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Abstract

The aim of this study is to establish a correlation between the proven version of the pressurized gating system for steel castings and the cost-effective version of the pressurized gating system in industrial conditions. In the study, a computer-aided design solid modeling program was used in the design of the pressurized gating system for steel castings and the ratio of the pressurized gating system was selected as 1: 3: 1. Flow simulation of the gating-designed casting part was made in computer-aided design metal casting simulation. In the study, calculations used in the design of the pressurized gating system were made based on the weight of the part and effective casting height. The study clearly shows that the well-designed pressurized gating system has revealed that it plays a significant role in preventing non-metallic casting defects in steel castings, such as sand, gas, and slag. In addition, the '' Spin Trap '' that is recommended to be used in gating systems in ferrous based castings in the literature, was used for the first time in the ÇİMSATAŞ foundry in the steel castings at the end of the runner in the pressurized gating system and the appropriate result was obtained. Computer-aided flow and solidification simulation was used in the design of the gating system containing Spin Trap.

1. Introduction

In steel castings, all the cavities created in the sand mold are called the gating system for the liquid metal to fill the mold cavity without any problems. As important as the effective use of feeders in a cast part is, the correct design of the gating system is just as important. The basic components of the gating system in the casting processes; casting chamber (casting countersink), vertical runner, horizontal runner, and ingate consists of four parts. Although the main task of the gating system is to direct the molten metal and fill the mold with molten metal, a well-designed gating system plays an important role in preventing various casting defects (non-metallic inclusions such as sand, gas, and slag) that may occur on and inside the casting part [1-3]. Likewise, a poorly designed runner system can cause errors in the last part that may require repair, or cause the part to be scrapped. Well-designed gating system; should be able to fill the mold at the appropriate time, direct the liquid metal to the desired and/or targeted location, allow air and gases to escape from the mold, prevent non-metallic inclusions from entering the mold, not cause the mold to deteriorate with erosion, not cause gas suction due to turbulence, and should be of minimum weight [3-9].

2. Pressurized Gating System

The tightest cross-sectional area of the pressurized gating systems used in steel casting processes is the ingate. Horizontal runner, vertical runner, and casting chamber are designed according to the ingate cross-sectional area. In the pressurized gating system, the total cross-sectional area decreases towards the mold cavity, and back pressure formation is prevented by the pressure of the liquid metal in the runner. In the pressurized gating system, the gas absorption is significantly reduced because the horizontal runner remains constantly filled throughout the casting period. In addition, the use of a pressurized gating system in steel castings ensures uniform filling in the ingates and minimum runner weight for high runner efficiency. For the pressurized gating system to be designed successfully, the molding system conditions, the total weight of the part (total part weight including the gating and feeders), the position of the part in the mold, it is necessary to determine the cope side and drag side heights of the part. Typical ratios used in pressure gating system design are 1:3:2 and 1:3:1 [3-6].

3. Spin Trap System

It is known that the pressurized gating system in steel castings can significantly prevent the penetration of non-metallic inclusions such as sand, gas, and slag, which are formed during the pouring of the liquid metal into the part. However, in some cases, there are situations where the pressure gating system fails to prevent these inclusions from entering the part. There are many versions of various slag capture systems in the literature for steel castings. In recent years, the use of a Spin Trap chamber at the end of pressurized gating systems for steel castings has been recommended by many authors in the literature. The Spin Trap system is defined in the literature as a version of the slag trap system used for the development of the gating system in the casting processes. The main purpose of the Spin Trap system is; to obtain a cleaner casting part by grabbing non-metallic inclusions such as sand, gas, and slag that the gating system cannot prevent from entering the part, and to optimize the gating system [6-15].

4. Material and Method

In this study, it is aimed to develop a pressurized gating system for steel castings by using a computer-aided solid modeling program. The pressurized gating system design of the fork part is based on the total weight of the part (total weight including gating and feeders). The part was molded in the green sand molding system and cast in the ÇİMSATAŞ foundry. In the study, the material of the part was determined according to the TS EN 10293 standard (material of the casting part is G17CrMo9-10 + QT). Due to the high carbon equivalent of this material and the visuality of the part, it is aimed to minimize non-metallic inclusions such as sand, gas, and slag that may occur on the surface of the part during casting. The total weight of the part is 145 kg and the effective casting height is 33.2 cm. The pressurized gating system design of the part was made in the computer-aided solid modeling program and the flow simulation of the part was made in the computer-aided metal casting and solidification program.

In the study, the cope side height of the casting part was determined as 330 mm and the drag side height of the casting part was determined as 37 mm. The filling time of the part was determined with the help of the equation given in Equation 1. The coefficient of 'k', which varies according to the total weight of the part in this equation, was found by using the graph given in Figure 1.

$$t = k\sqrt{W} \tag{1}$$

Here; t: filling time (sec), k: filling time coefficient, W: represents total weight of the casting part (Ib-Ib: pounds,1 Ib. = 0.452 kg).

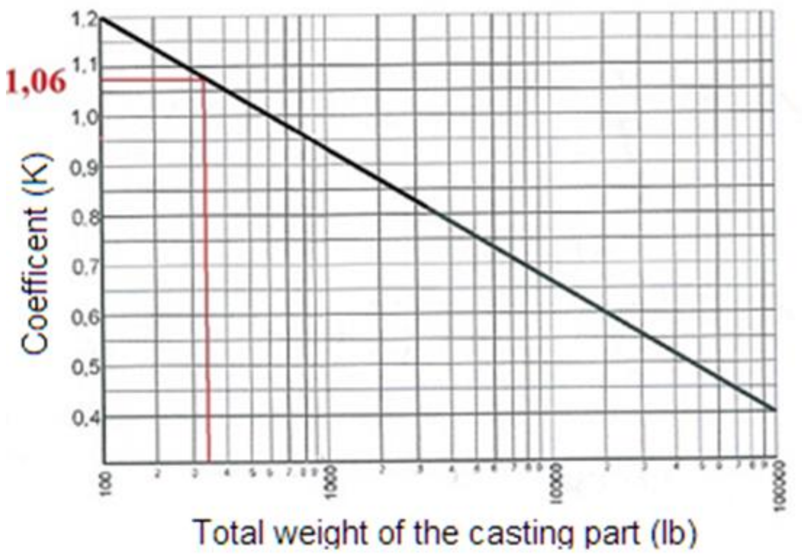

Figure 1. The coefficient 'k' corresponds to the total weight of the part

The weight in kilograms corresponding to 1 lb. is 0.452 kg. According to this;

145 kg / 0.452 kg/lb. = 320.8 lb.

The coefficient 'k' is 1.06, corresponding to 320.8 lb. in Figure 1. Accordingly, the filling time of the part;

$1.06\sqrt{320.8} = 19$ sec.

In the study, after the filling time of the part was calculated, the effective casting height during the casting of the part was determined. In the calculation of the effective pouring height, the schematic representation in Figure 2 was used and the equation given in Equation 2 The effective casting height of the part was found with the help of;

$$h = H - (P^2 / 2c) \quad (2)$$

Here; h: effective pouring height (cm), H: distance between the sprue inlet and the ladle (cm), P: the cope side height of the part (cm), c: the depth in the lower degree region of the part (cm).

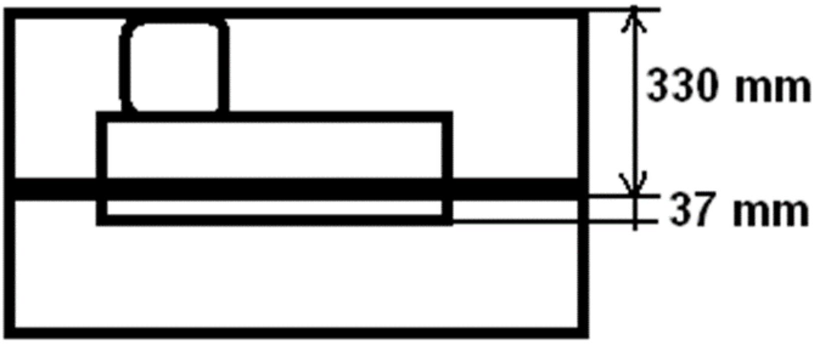

Figure 2. Schematic representation of the top and bottom heights of the part to be molded

The 'H' dimension is the distance between the ladle and the sprue hole. Based on the experiences of the ÇİMSATAŞ foundry, calculations are made by taking the 'H' dimension as a reference in the gating system designs, 25 cm above the cope side height in the resin molding system, and 20 cm above the cope side height in the green sand molding system.

$$H = 33 + 20 = 53 \text{ cm.}$$

Effective casting height of the part;

$$h = 53 - (332 / 2 \times (33 + 3.7)) = 38.2 \text{ cm.}$$

In the study, after the effective casting height of the part is calculated, the metal flow rate is given in the equation given in Equation 3. with the help of and calculated using the graph in Figure 3.

$$v = C\sqrt{2gH} \quad (3)$$

Here; v: metal flow rate (cm/sec), C: flow coefficient, H: effective casting height of the part (cm), g: gravity acceleration (981 cm/s^2).

From the graph in Figure 3, the metal flow coefficient corresponding to the total weight of the casting part was determined as 0.706.

$$0.706\sqrt{2 \times 981 \times 38.2} = 193.3 \text{ cm/sec.}$$

The volume, filling time and metal flow rate of the casting part was calculated to determine the ingate cross-sectional area, which is the most important step in the pressurized gating system design of the casting part. The ingate cross-sectional area of the casting part is given in equation 4 with the help of determination.

$$A = V/t \times v \quad (4)$$

Here; A: ingate cross-sectional area (cm^2), V: part volume (cm^2), v: metal flow rate (cm/sec).

In order to calculate the ingate cross-sectional area of the part, the part volume must be calculated. Part volume;

$$145000 \text{ gr} / 7.2 \text{ gr/cm}^3 = 20138.8 \text{ cm}^3.$$

Ingate cross-sectional area;

$$20138.8 / (19 \times 193.3) = 5.48 \text{ cm}^2.$$

In the study, the gating system ratio was chosen as 1:3:1 in the design of the pressurized gating system. However, since the ingate of the casting part has an angle of 90° concerning the gating system, the ingate cross-sectional area has been multiplied by a factor of 1.8 and calculated according to the casting practice of ÇİMSATAŞ foundry. According to ÇİMSATAŞ casting practice, the ingate cross-sectional area of the casting part;

$$5.48 \times 1.8 = 9.86 \text{ cm}^2.$$

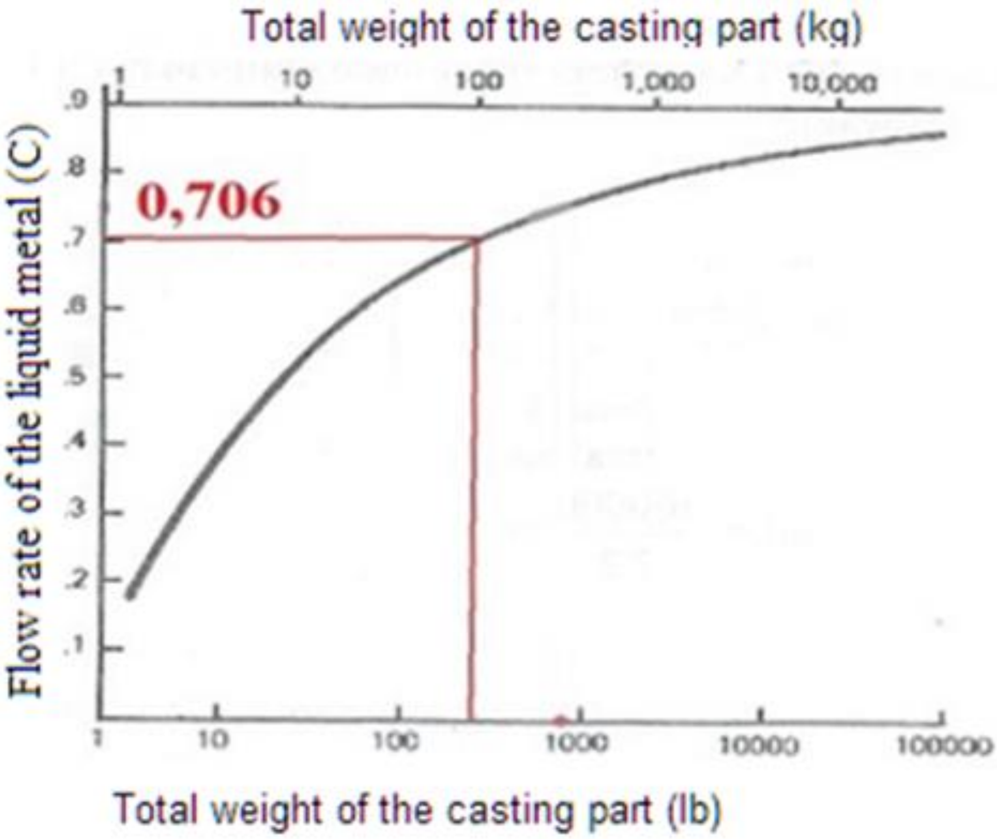

Figure 3. Metal flow coefficient corresponding to the total weight of the casting part

Table 1. Pressurized gating system ratio and dimensions

Gating system ratio	vertical runner	horizontal runner	Ingate
1:3:1	1 9.86 cm²	3 29.58 cm²	1 9.86 cm²

The visual of the pressurized gating system, which was designed in the computer-aided solid modeling program using the data in Table 1, is shown in Figure 4.

Metal flow and filling simulation of the casting part, for which the pressurized gating system is designed; with lip pouring ladle and pouring temperature 1600°C made by choice. The nominal chemical composition of the casting part was selected as shown in Table 2 and the metal flow and filling simulation was performed.

Table 2. Nominal chemical composition of the casting part

Contents	% C	% Mn	% S	%P	% Si	% Ni	%Cr	% Mo
min	0.13	0.5	0	0	0.4	0	2nd	0.9
Max	0.2	0.9	0.02	0.02	0.6	0.3	2,5	1,2

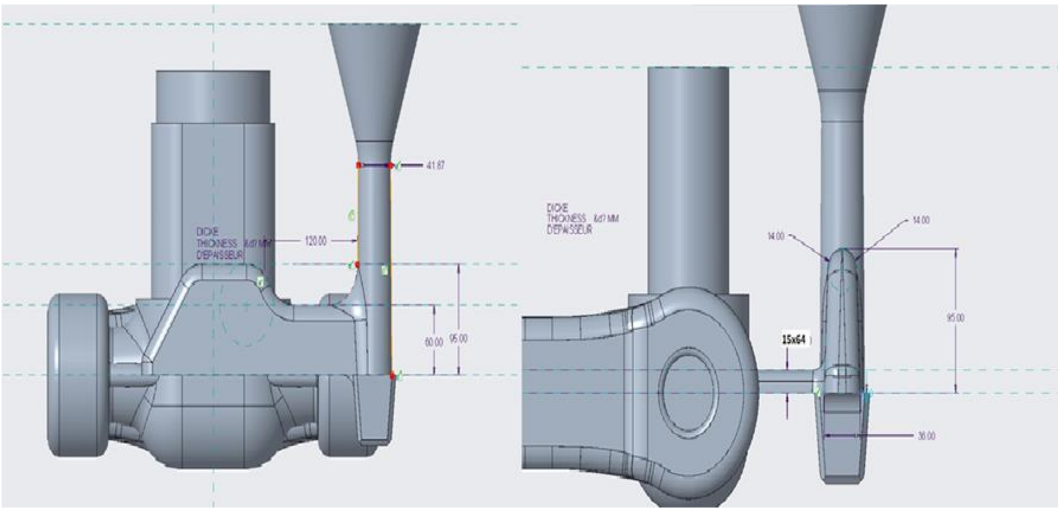

Figure 4. Schematic representation of the designed pressurized gating system

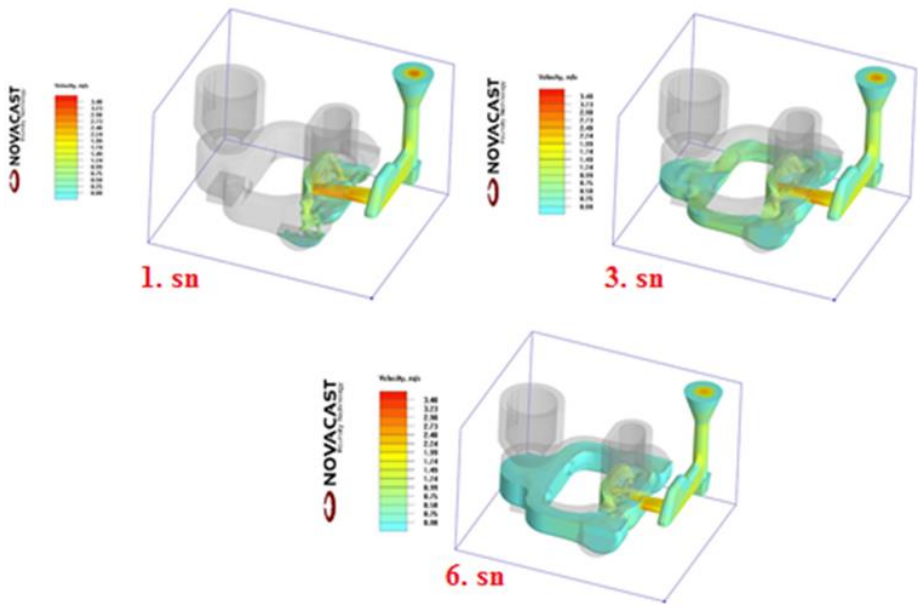

Figure 5. Image of the metal flow and filling simulation of the casting part at 1, 3, and 6 seconds

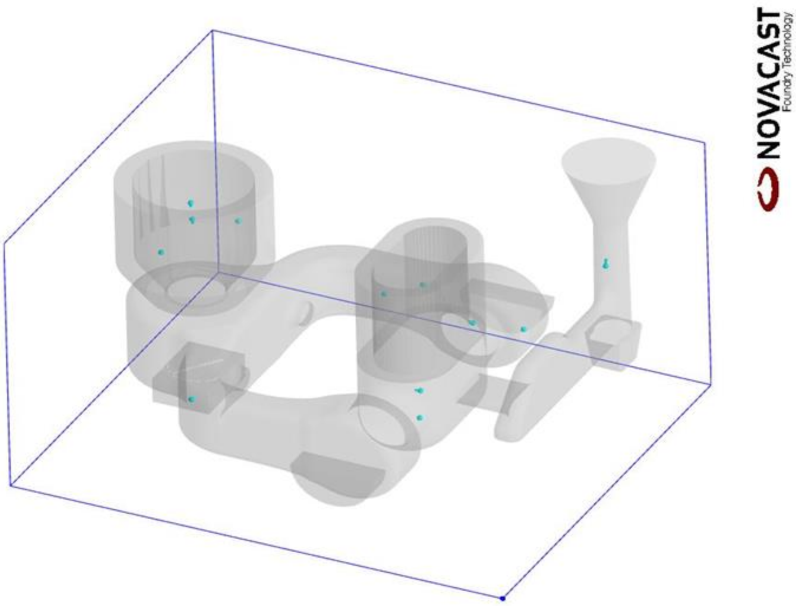

Figure 6. Image of the slag simulation of the casting part

After simulating metal flow and slag on the part, 12 parts were molded in the green sand molding system in the ÇİMSATAŞ foundry and the castings were carried out with a lip pouring ladle at 1586 °C.

Figure 7. Image of casting parts with a pressurized gating system

By using the metal flow and filling simulation data of the part for which the pressurized gating system was designed, the Spin Trap chamber was placed at the end of the gating system without changing the dimensions of the part gating system, and the part was simulated again under the same conditions as shown in Figure 8-9.

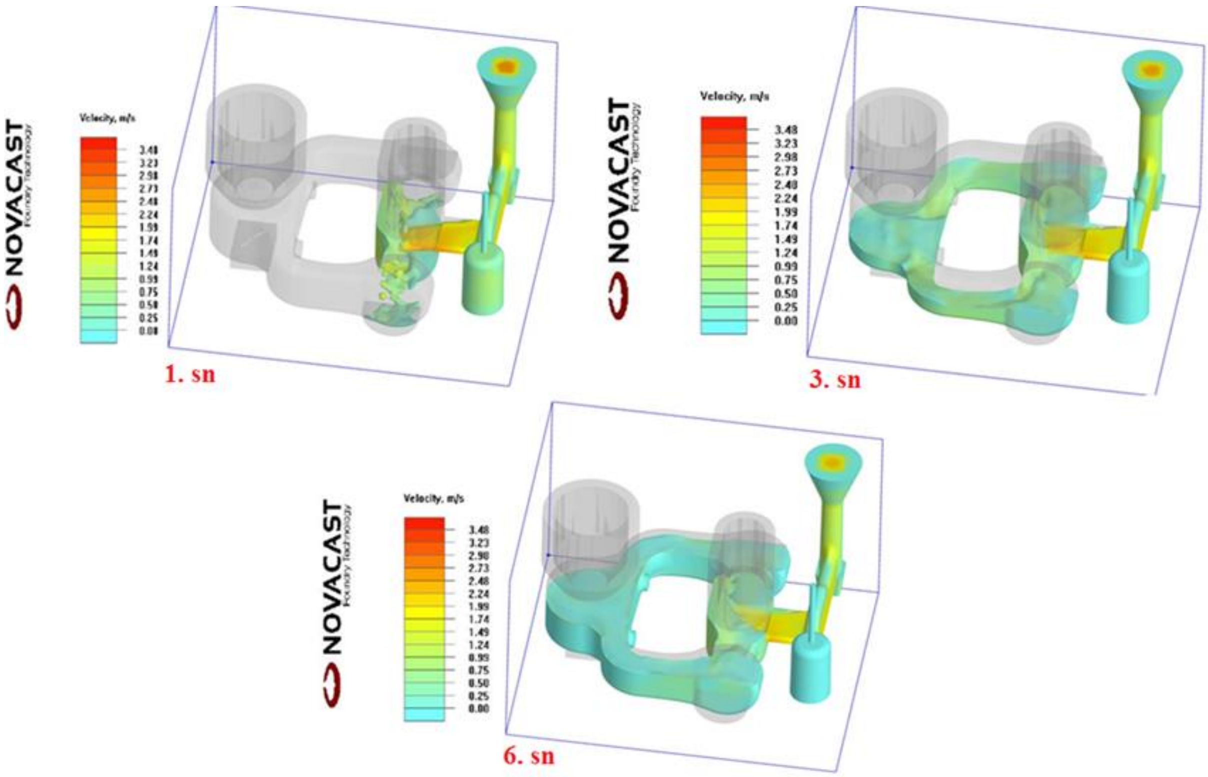

Figure 8. Image of the metal flow and filling simulation of the casting part at 1, 3, and 6 seconds

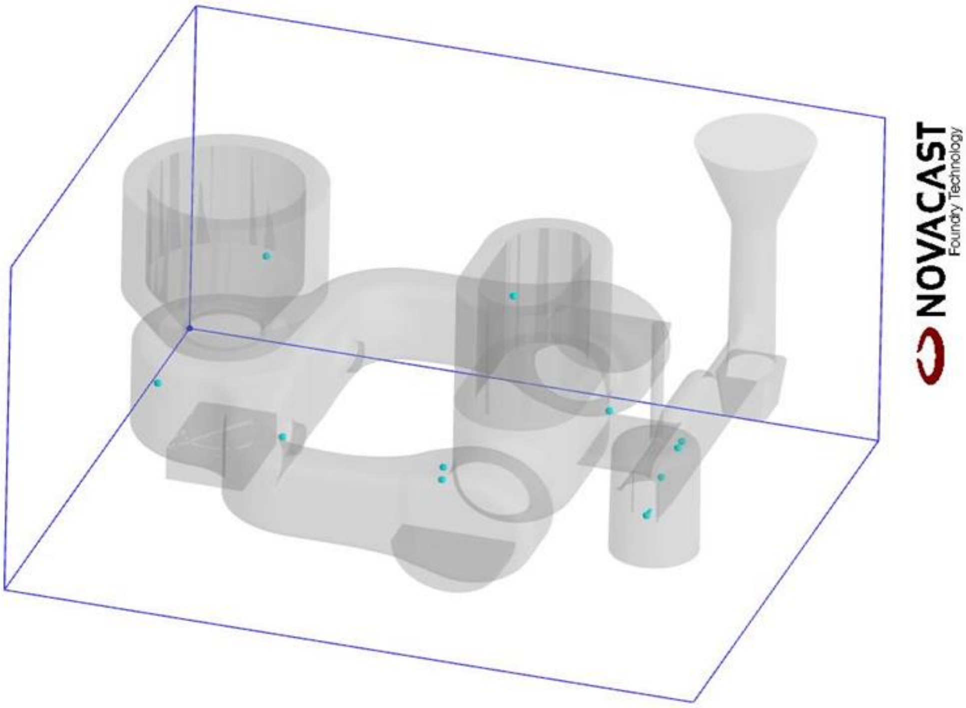

Figure 9. Image of the slag simulation of the casting part

According to the simulation results data, the Spin Trap chamber was assembled at the end of the pressurized gating system on the part model, as shown in Figure 10.

Figure 10. Image of the Spin Trap chamber assembled on the pressurized gating system in the part model

After the Spin Trap chamber was assembled on the part model, 12 parts were molded in the green sand molding system in the ÇİMSATAŞ foundry and the castings were carried out with a lip pouring ladle at 1586°C. The sand molds of the parts with Spin Trap chambers where the castings were made were shake-out and the parts were cleaned. In the next operation, the Spin Trap chamber from the gating systems of the parts was cut with a torch. The Spin Trap chambers that were cut with a torch were firstly examined by eye. The Spin Trap chambers, which were cut with a torch, were first visually inspected. Then, the Spin Trap chambers were examined by performing the destructive inspection.

Figure 11. Image of the casting parts with the Spin Trap chamber

5. Findings

In this article, casting parts were designed according to the simulation results with different pressurized gating system versions. The findings were obtained from the simulation and casting results of the parts.

- It is found that the simulation results highly represent the actual casting results.
- Although the pressurized gating system for steel castings minimizes the penetration of non-metallic inclusions into the part, it has been concluded that in some specific cases there may be situations where these inclusions cannot prevent their penetration into the part.
- The filling times of the casting parts without the Spin Trap chamber were in the range of 17-18 seconds, and the filling times of the parts poured with the Spin Trap chamber were in the range of 19-20 seconds. It has been observed that the spin trap chamber increases the total weight of the part by 4 kg and the filling time of the part by 2 seconds.
- In Figure 5; It has been observed that the velocity of the liquid metal is in the range of 2.24 – 2.48 m/s at the ingate, and in the simulation of the part with the Spin Trap chamber in figure 8, this velocity value remains in the same range.
- In Figure 6; Although the data that the part gating system could not catch slag was obtained, the presence of non-metallic inclusions that can be seen in the gating systems of the cast parts in figure 7 was detected.
- In Figure 9; It has been observed that the Spin Trap chamber significantly captures non-metallic inclusions in the first moments of part filling, and the pressure gating system increases the capturing capacity of these inclusions in the first moments of casting. The results obtained in Figure 12 revealed that the part simulation significantly confirmed the actual situation.
- In Figure 13; Destructive inspection was performed on the Spin Trap chambers and the presence of non-metallic inclusions was detected in the cut pieces.

6. Results

Although the pressurized gating system for steel castings minimizes the penetration of non-metallic inclusions into the part, it is concluded that it cannot prevent the non-metallic inclusions escaping from the ladle during casting to entering the part at the desired level.

With the design of the Spin Trap chamber pressure gating system in the ÇİMSATAŞ foundry, the surface quality of the cast steel parts has improved positively. The improvement in the casting part surfaces which get obtained by using a spin trap was reduced the rework needed (such as cosmetic welding, grinding, etc.).

The results of the study show that the Spin Trap chamber, which has been widely used in non-ferrous castings in recent years, has also given positive results in the steel casting process.

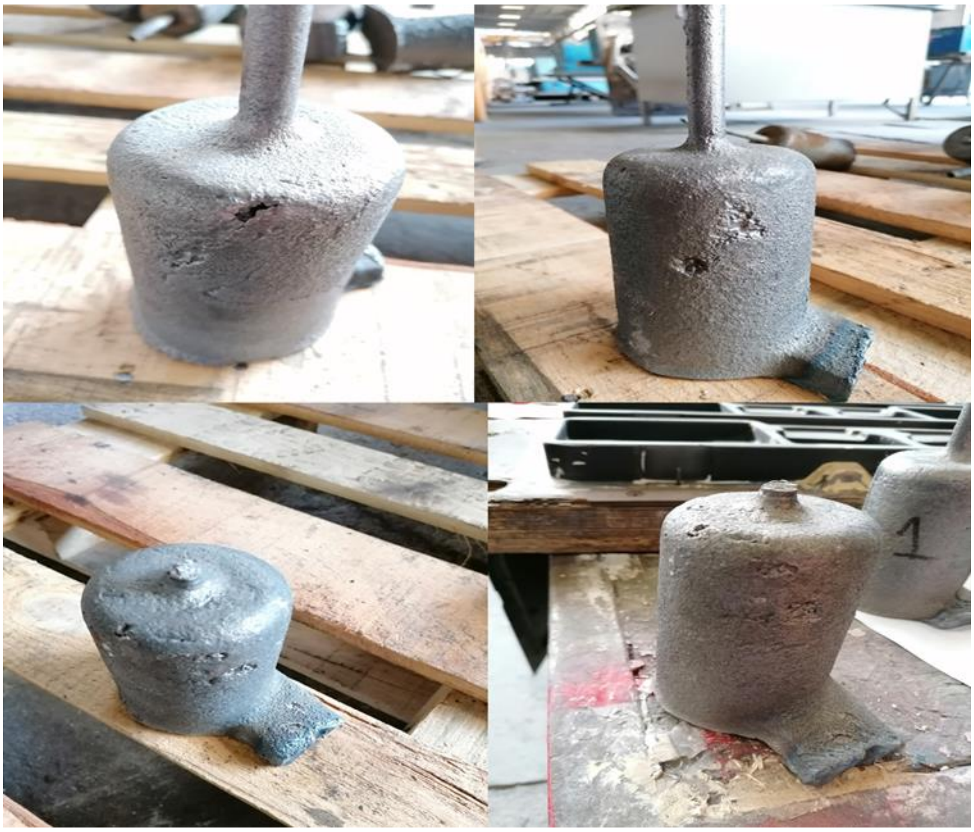

Figure 12. Images of inclusions captured in the Spin Trap chamber

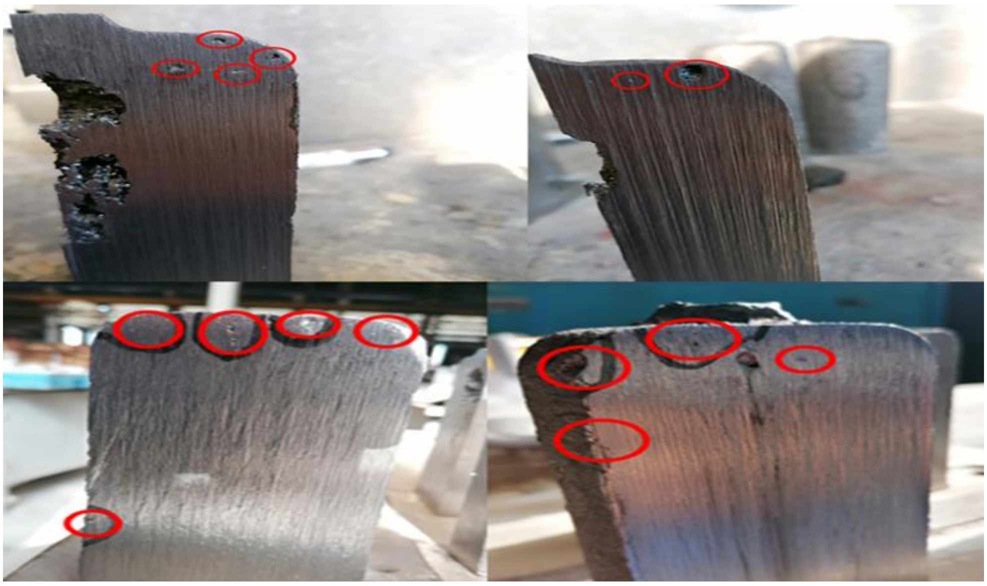

Figure 13. Images of non-metallic inclusions trapped inside Spin Trap chambers

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Author contributions

Mustafa Murat Zor: Conceptualization, Methodology, Software **Alper Yoloğlu:** Data curation, Writing-Original draft preparation, **Serdar Kesim:** Visualization, Investigation, Writing-Reviewing and Editing. **Ferhat Tülüce:** Software, Validation.

Conflicts of interest

The authors declare no conflicts of interest.

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