Casting process of gate valve steel based on ProCAST simulation

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Abstract. The sand casting process of 18CrNiMo7-6 gate valve casting was designed in this paper. The molding and core making methods of castings are sodium silicate CO₂ method and self hardening cold box method respectively. The technological parameters of the casting were determined. The middle pouring system and top riser were designed. Using software to draw the assembly and 3D entity of gate valve casting. ProCAST simulation software is used to realize the numerical simulation task of the gate valve casting process. Shrinkage and porosity are the main research objects. It is found that the defects mainly appear in the thick part of the casting and the flange through the simulation experiment feedback parameters. In this paper, from the point of view of reducing and avoiding defects, the casting process is improved and improved. Finally, according to the experimental results, S2 (with chill) is determined as the final scheme.

1. Introduction

Casting production has the advantages of low production cost and high production efficiency, which belongs to the hot working method of producing metal tools[1]. Compared with some developed countries, China's foundry technology and foundry industry are still in a relatively backward position, which needs to be broken through in many technical aspects[2].

The working principle of gate valve is to cut off the flow of fluid by moving up and down the gate which is perpendicular to the direction of fluid flow in the pipeline[3]. Most gate valves are manufactured by casting process. Because the impact force of fluid flow in the pipeline is small, the requirements of erosion resistance, tightness and strength of gate valve are high. In order to make the performance of gate valve reach the standard, 18CrNiMo7-6 low alloy high strength engineering structure steel is used as pouring material[4].

With the development of science and technology, people have realized the simulation of casting process and produced many software for casting. At present, the specific application level of computer simulation in the whole foundry industry is low. Most enterprises still rely on experience and enterprise related systems in production, resulting in low production quality and production efficiency. The computational efficiency of solidification simulation in investment casting process has been studied by X.P.zhang; Ho-Mun Si et al. Proposed a method of combining the finite difference method with the efficient data conversion method in the process of casting simulation[5]. In China, Cheng Jun and others have completed the research on the mechanical properties of materials, and have independently developed the stress field analysis system based on the research[6]; Tang Yong and others explored a
simulation method to study the formation mechanism of liquid metal microstructure in solidification process of metal casting, and confirmed its feasibility[6].

In this paper, UG NX software is used to model the gate valve casting, and ProCAST finite element simulation analysis software is used to realize the whole process simulation of casting process. The analysis can affect the filling speed, solidification speed, temperature field changes and other contents, and at the same time complete the casting defect prediction and prevention. The simulation process in this paper can reflect the problems that may be encountered in the actual casting, and provide a meaningful reference for the development and design of high-quality products.

2. Casting process of gate valve

2.1. Casting material parameters
The selected 18CrNiMo7-6 alloy steel has good corrosion resistance and impact resistance, and its mechanical properties are shown in Table 1. The sand mold was formed by gravity casting. The sand mold was resin self hardening sand and the pattern was wood mold[7]. The pouring temperature is 1600℃ and air cooling.

Table 1 mechanical properties of 18CrNiMo7-6

| Brand     | σ_s (N/mm²) | σ_b (N/mm²) | δ (%) | Ψ (%) | α_k(102J/mm²) |
|-----------|-------------|-------------|-------|-------|--------------|
| 18CrNiMo7-6 | 210~250     | 430~470     | ≥22   | ≥25   | 250~350       |

2.2. Casting process parameters
The parts of the gate valve are shown in Fig. 1. After the steel casting material is set in the software UG NX, the shrinkage rate of the steel casting is set to 1.3%[8]. The mass of casting is 325 kg, and the casting process yield is 70%. The mass of molten steel is 325 × (1 + 70 %) = 450 kg. The ladle capacity is 1000 kg, the number of holes is 1, the diameter of ladle hole is d = 36 mm, and the average pouring speed of each ladle hole is q = 36 kg/s[9~11].

2.2.1. Determination of pouring time. The pouring time is calculated according to formula (1):

\[
\tau = \frac{m}{Nnq}
\]  

(1)
In the formula, $\tau$ is the pouring time; $M$ is the quality of molten steel in the mold; $N$ is the number of ladle poured at the same time; $n$ is the number of ladle holes in a ladle. According to the calculation, the pouring time of $\tau$ is 13 seconds.

2.2.2. Check of rising speed of liquid level in mould. The pouring time is verified by the rising speed of liquid steel in the mold. The rising speed of metal level in the mould is expressed by the following formula:

$$v = \frac{C}{\tau} \tag{2}$$

$C$ is the height of the steel casting; $\tau$ is the pouring time. The height of steel casting is 630 mm, and the formula is used to calculate: $V = 630 \text{ mm}/28 \text{ s} = 22.46 \text{ mm/s}$.

2.2.3. Geometric model and mesh generation. The 3D file of casting process scheme is drawn on UG NX 3D drawing software, and the corresponding solid file is exported into visual mesh for mesh division.

3. Analysis of casting process simulation results

3.1. Analysis of filling process. The filling results of scheme 1 (S1) and scheme 2 (S2) are the same, but the difference lies in the presence or absence of cold iron, which does not affect the filling results.

Figure 2 shows the pouring process of S1 and S2 respectively. The filling velocity of S1 and S2 is about 0.493 ~ 1.232 m/s and 0.892 ~ 1.190 m/s.

![Figure 2](image)
Fig. 3 shows the simulation results of porosity of S1 and S2. The blue part represents the gas existing when the casting is not filled. It can be seen that there is no isolated gas phase zone in the casting cavities of S1 and S2. Therefore, S1 and S2 castings will not have the risk of suffocation and no blowhole defects.

3.2. Simulation analysis of solidification process. From the simulation results of S1 and S2 liquid phase solidification, it can be concluded that there is an isolated liquid region in the casting during cooling and solidification, which makes the molten metal in this position unable to feed through the riser, so the shrinkage defects appear.

Compared with S1, the cold iron at the flange position plays a more obvious local cooling effect. Finally, in the whole solidification process, the hot spot still exists at the flange of the casting. It is necessary to judge whether these isolated liquid phases will form shrinkage defects in the software.

3.3. Defect result analysis. As shown in Figure 4, the shrinkage function of the simulation software shows that the defect risk is filtered to 10% ~ 100%. It can be seen from the figure that the defect risk of shrinkage cavity still exists at the flange position. From the result of filtering to 10% ~ 100%, the defect of S1 flange position can not be eliminated.

According to the results of solidification process of S2, the inner part of the casting is filtered to more than 20%, and there is no shrinkage defect in the casting. The cold iron plays an auxiliary role, which is beneficial to the feeding of the middle riser. S2 solidifies in sequence, which is better than S1.
3.4. Temperature field variation of cold iron. In order to simulate the temperature field of chill and casting in solidification process, two adjacent points (point 1 is the point on the chill and point 2 is the point on the casting) are selected to analyze the temperature field curve.

After 1000 seconds of contact, the temperature of the cold iron starts to rise, while the temperature of the casting decreases with time. After a period of time, the cold iron and the casting are cooled together at the same temperature, as shown in Fig. 5.

Figure 4 Defect simulation results of S1 (a) and (b)
Defect simulation results of S2 (c) and (d)

Figure 5 Simulation results of solidification and defects in S2
4. Conclusion
The filling speed of S1 (no chill) scheme is about 0.493 ~ 1.232 m/s, and there is no gas in the casting cavity and no blowhole defects. However, there are some defects in the solidification region. The defect can't be eliminated when it is filtered to more than 20%.

The filling speed of S2 (with chill) is about 0.892 ~ 1.190 m/s. There are no gas and gas holes in the mold cavity, but there are still a few isolated liquid regions. When the defect is filtered to more than 20%, there is no shrinkage cavity in the casting. The results show that the cold iron disperses the hot spot and is beneficial to the feeding of the middle riser.

S2 (with cold iron) process scheme achieved the expected purpose, in line with the expected effect.

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