Study on the relative feeding efficiency of cast steel riser of low/non-carbon heating and thermal-insulating covering agent

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Abstract. This paper has revised the traditional concept of feeding efficiency of riser, and put forward a new concept of relative feeding efficiency of riser and its characterization method. This paper also introduces the application of two kinds of low/non-carbon type heating and thermal-insulating covering agent in steel castings, and tests relative feeding efficiency of riser with different types of covering agent comparatively. The results show that the new low-carbon heating and thermal-insulating covering agent can make the relative feeding efficiency of riser reach to 60.9\%, and the non-carbon type can reach to 32.2\%. Both of the riser feeding efficiency of two covering agent were better than those of the four typical heating and thermal-insulating covering agent products at home and abroad.

1. Introduction

Due to the large volume shrinkage of molten steel during solidification, which makes it easy to cause shrinkage defects in steel castings, and greatly reduce its mechanical property and service life. In order to prevent shrinkage defects in steel castings effectively, a riser is usually set at suitable points during pouring to compensate for the solidification shrinkage of the castings. At present, the main measures to improve the feeding efficiency of riser are to increase the pressure in the riser (such as the atmospheric riser) and to extend the time for the riser metal to remain liquid (such as insulating riser sleeve and covering agent, etc.). Among them, using the covering agent is the simplest and most effective way to increase the feeding efficiency of the cast steel riser.

In recent years, with the rapid development of domestic nuclear power equipment, high-speed rail and urban rail transit equipment, automobiles, ships, petroleum, natural gas and wind power equipment and other high-end mechanical equipment, and with the substantial increase of casting export, how to improve casting quality, save liquid metal and energy, and improve production environment, is the primary goal of technological innovation in mechanical equipment foundry industry. It also put forward a higher requirement for the quality of covering agent. For this reason, some domestic and abroad research institutions and companies have carried out research and
development of new heating and thermal-insulating covering agent in succession, and have achieved some important results [1-10].

Further development trend of covering agent are as follows: its chemical composition is developing towards the trend of low/non-carbon, and its varieties are developing towards the trend of seriation, which can be used for casting of different kinds of steel and different process conditions.

In order to adapt to the above development trend, according to the principle of aluminium oxidizing and heating reaction and silicate phase-diagram, on the basis of related research results at home and abroad, we use aluminum powder and cheap industrial ferric oxide powder as the main heating material, nitrate-based mixtures as the assistant oxidant, power plant wastes coal flying ash cenosphere and natural mineral products perlite as the main thermal insulation material, moderate fluoride mixture as thermit reaction catalyst and thermal insulation material flux, we only use a little abundant refined agricultural byproducts carbonized rice hull as heating and insulation additives, develop a new low/non-carbon heating and thermal-insulating riser covering agent and serialize them, which can be divided into two types: non-carbon and low-carbon, suitable for casting of low carbon steel and carbon steel, in order to meet the increasing production requirements of foundry industry for domestic high-end mechanical equipment.

In the process of developing a new type riser covering agent, we find that feeding efficiency of riser is difficult to characterize the actual feeding capacity of the riser by using different types of heating and thermal-insulating covering agent.

In order to make up for the deficiency of the concept of feeding efficiency of riser, this paper firstly presents the concept of relative feeding efficiency of riser, and analyze the difference between the relative feeding efficiency and the feeding efficiency of the riser.

In order to evaluate the insulation and feeding effect of new low/non-carbon heating and thermal-insulating riser covering agent, this paper compares the new covering agent with four typical similar covering products at home and abroad, by testing the relative feeding efficiency of the riser.

2. Comparative study on the feeding efficiency and relative efficiency of riser

2.1. Characterization method of feeding efficiency of the riser and its defects

Feeding efficiency of the riser refers to the percentage of the amount of feeding fluid of the total mass of the riser, which means the percentage of the volume of the shrink mark on the top of the riser with the total volume of metal riser. The formula is as follows:

$$\eta = \frac{M_f}{M_R} \times 100\% = \frac{V_f}{V_R} \times 100\%$$

In the formula:
- $\eta$ — feeding efficiency of the riser;
- $M_f$、$V_f$— the amount of feeding fluid of the riser、the volume of the shrink mark on the top of the riser;
- $M_R$、$V_R$— the total mass of the riser、the total volume of riser

As the pouring height of castings depends on the amount of the steel water for pouring, under the same heat retaining conditions of risers, the more the amount of the steel water for pouring, the better the feeding effect will be, the denser the crystallization of casting and riser will be. And there is little or no internal dark shrinkage, the volume of the top shrink mark will be larger. At the same time, the safety height of the riser $H$ is also larger, i.e. the height of the lower part of riser without shrinkage cavity and porosity. At this time, if the feeding efficiency of riser is calculated according to formula [1], as both the numerator and denominator increase, the feeding efficiency of the riser does not necessarily increase correspondingly.

Under the condition that the total volume of riser is the same as the volume of the shrink mark on the top of the riser, if the shrink mark depth on the top of the riser is small, then the safe height of the riser $H$ is larger, and the feeding effect is better, because the leeway for reducing the height and the total volume of the riser is larger. At this time, if the feeding efficiency is calculated according to formula [1], since both the numerator and the denominator remain constant, the calculated feeding efficiency is the same.
Based on the analyses above, it can be seen that the traditional concept and index of feeding efficiency of riser cannot characterize the actual feeding effect of riser.

2.2. Characterization method of relative feeding efficiency of riser
In order to characterize the feeding effect of riser accurately, we first put forward the concept of relative feeding efficiency of riser. The relative feeding efficiency of rise refers to the percentage of the volume of the shrink mark on the top of the riser VF with the volume of the upper riser V_RU corresponding to the top depth of shrink mark. The calculation formula is as follows:

$$\eta_R = \frac{VF}{V_{RU}} \times 100\% = \frac{VF}{VR - V_{RL}} \times 100\%$$  \hspace{1cm} (2)

In the formula:
- $\eta_R$ — relative feeding efficiency of riser;
- $VF$ — the volume of the shrink mark on the top of the riser;
- $V_{RU}$ — the volume of the upper riser corresponding to the top depth of shrink mark;
- $VR$ — the total volume of riser;
- $V_{RL}$ — the volume of the lower riser corresponding to safe height of the riser H.

2.3. Difference between feeding efficiency and relative feeding efficiency of the riser
We believe that the strength of the feeding capacity of the riser depends not only on the size of the total volume of the shrink mark of the riser, but also on whether the top surface of the riser is flat and shrinking. Under the same other riser feeding conditions, the larger the volume of the shrink mark is, which show that the greater the feeding amount of steel water is, the denser the casting is, the less the shrinkage cavity and porosity is.

But when the total volume of the shrink mark of the riser is the same, the flatter shrink mark indicates that the safety height of its riser is greater. However, it has little effect on the internal density of the casting (i.e. the number of shrinkage cavity and porosity defects).

That is to say, the symbol of strong feeding capacity of the riser should be that first of all, the larger the total volume of the shrink mark is, the better; second, the flatter the top surface of the riser is, the better (i.e., the greater the safety height is, the better, so that the space for the reduction of the height of the riser and the overall volume of the riser is wider).

The feeding efficiency of the riser only reflects the influence of the total volume of the shrink mark, but fails to reflect the difference of the safety height of the riser. And the relative feeding efficiency of the riser reflects the comprehensive influence of the total volume of shrink mark and whether the top surface of the riser is flat (i.e. the size of the safe height of the riser). It can represent the actual feeding capacity of the riser more accurately.

2.4. Test method of the feeding efficiency and relative feeding efficiency of the riser
When the casting is cooled, cut the riser with an oxygen-acetylene gas gun, first fill the shrinkage with 100/200 mesh fine quartz sand, weigh the weight of fine quartz sand and calculate the volume of the shrinkage cavity VF. Then use a line cutting machine to cut the riser along its largest longitudinal plane, measure the depth of the shrinkage hole, calculate the upper contour volume of the riser at the same height of the shrinkage cavity VRU, then calculate the feeding efficiency and relative feeding efficiency of the riser according to the formula [1] and formula [2] respectively.

2.5. Experimental verification
In order to prove that the relative feeding efficiency of the riser can accurately characterize the actual feeding capacity of the riser, we selected three kinds of domestic famous companies' riser covering agents sold in the market, and compared its feeding efficiency and relative feeding efficiency under actual production conditions. The results are shown in Table 1.

It can be seen from table 1 that the order of the feeding efficiency of the three kinds of covering agents is parallel to the total volume of the shrinkage cavity. However, since the medium feeding efficiency covering agent II has the highest riser safety height, the relative feeding efficiency is the highest , namely the maximum feeding capacity. While the highest feeding efficiency covering agent
III has the lowest riser safety height, and its relative feeding efficiency is in the middle, namely the feeding capacity in the medium level. It can be seen that the feeding efficiency of the riser only reflects the influence of the total volume of the shrinkage cavity, while the relative feeding efficiency of the riser reflects the combined effect of the total volume of the shrinkage cavity and whether the top surface of the riser is flat, i.e., the size of the safe height of the riser.

Table 1. Comparison of the feeding efficiency and relative feeding efficiency of three kinds of covering agents sold in the market.

| Type of covering agent | The total volume of shrinkage cavity (cm³) | Riser volume within the height of the shrinkage cavity (cm³) | Height of the shrinkage cavity (mm) | Total height of riser (mm) | Safety height of the riser (mm) | Feeding efficiency (%) | Relative feeding efficiency (%) |
|------------------------|------------------------------------------|----------------------------------------------------------|-----------------------------------|---------------------------|-------------------------------|-----------------------|-------------------------------|
| I                      | 115.7                                    | 648.4                                                   | 49                                | 84                        | 35                            | 11.7                  | 17.84                         |
| II                     | 149.3                                    | 302.2                                                   | 24                                | 81                        | 57                            | 16.0                  | 49.41                         |
| III                    | 152.0                                    | 835.8                                                   | 63                                | 79                        | 16                            | 17.8                  | 18.19                         |

3. Comparative study of the relative feeding efficiency of new low/non-carbon heat insulation covering agent

We have developed two kinds of low-carbon and non-carbon heat insulation covering agent by many optimization experiments, which are suitable for low carbon and carbon steel casting respectively. The main properties of the new heating and thermal-insulating covering agent for riser are as follows:

1. Water content: ≤1.5%;
2. Carbon content: ≤5% (carbon steel type), < 0.5% (low carbon steel type);
3. Ignition temperature: ≤1000℃;
4. Melting temperature: 1300～1500℃.

The low carbon steel type heating and thermal-insulating covering agent for riser does not contain carbonaceous material.

In order to evaluate the feeding effect of two kinds of low carbon and carbon steel type heating and thermal-insulating covering agent, we tested the relative feeding efficiency of similar products at foundry production sites of Wuhan Special Industrial Pump Co. Ltd., Ezhou Yuxin Special Casting Co., Ltd. and Ezhou Shiming Machinery Manufacturing Co., Ltd., compared with similar products at home and abroad.

3.1. Experimental method

The same riser of the same casting was selected, and different kinds of covering flux were used respectively to test the influence of the risers covering agent on the shape of the shrinkage cavity, the safety height of the riser and the relative feeding efficiency of the riser.

When the casting is cooled, cut the riser with an oxygen-acetylene airgun, fill the shrinkage cavity of riser with 100/200 mesh fine quartz sand first, weigh the quality of fine quartz sand, calculate the volume of the shrinkage cavity VF, then use a wire cutting machine to cut the riser along its largest longitudinal plane, measure the depth of the shrinkage cavity, calculate the volume of the upper contour of the riser VRU as high as the shrinkage cavity. Then according to the formula [2], the relative feeding efficiency of the riser is obtained.

In order to verify feeding effect of the riser more intuitively, we also obtained photos of the morphology of the shrink mark on the top of riser and the profile of riser.
3.2. **Comparison of application on bearing seat steel castings**

Each piece of bearing seat steel casting weighs about 100Kg, its material grade is ZG230-450 cast carbon steel. Each moulding box can be poured two castings, each casting has an oval shaped open riser, whose size is 180x300mm (BxL). Cenosphere insulating open-sleeve are used on the sides of the riser to insulate, and the same amount (all for 0.9kg) of self-made carbon steel type heating and thermal-insulating covering agent for riser and the same type of heating and thermal-insulating covering agent product of the international famous modeling materials company are used on the top surface to insulate.

Figure 1 and Figure 2 show the morphology of the shrink mark on the top of riser and the profile of riser of the bearing seat steel castings. Table 2 lists out the comparison of the feeding effect of the risers of the bearing seat steel castings.

![Left](image1.png) similar products of a famous international company  
**Figure 1.** The morphology of the shrink mark on the top of riser of the bearing seat steel castings.

![Right](image2.png) self-made carbon steel type covering agent for riser  

![Left](image3.png) similar products of a famous international company  
**Right.** self-made new carbon steel type covering agent for riser  

**Figure 2.** The morphology of the profile of riser of the bearing seat steel castings.

| Type of covering agent                   | The volume of the shrink mark on the top of riser (dm³) | Maximum depth of the shrink mark of riser (mm) | Relative feeding efficiency (%) |
|------------------------------------------|--------------------------------------------------------|-----------------------------------------------|---------------------------------|
| Self-made carbon steel type              | 1.41                                                   | 58                                            | 51.6                            |
| Carbon steel type of a famous international company | 0.73                                                   | 42                                            | 36.9                            |
3.3. Comparison of applications on orbit steel castings

Orbit steel castings is the ship lock gate fittings for the three gorges dam, its material grade is ZG40Mn2 and one piece weighs about 800kg. Each moulding box can be poured one casting, each casting has two identical oval shaped open risers, whose size is 230x330x400mm(BxLxH). Cenosphere insulating open-sleeve are used on the sides of the riser to insulate, and the same amount (all for 1.0kg) of self-made carbon steel type heating and thermal-insulating covering agent for riser and the same type of heating and thermal-insulating covering agent product of the international famous modeling materials company are used on the top surface to insulate.

Figure 3 shows the morphology of the shrink mark on the top of riser and the profile of riser of the orbit steel castings. Table 3 lists out the comparison of the feeding effect of low carbon steel and carbon steel type, these two kinds of heating and thermal-insulating covering agent for riser and four typical similar products at home and abroad on the orbit steel castings.

![Figure 3](image)

**Left.** self-made carbon steel type covering agent for riser. **Right.** carbon steel type covering agent for riser produced by a company in Shanghai.

**Figure 3.** The morphology of the profile of the heating and thermal-insulating riser of the orbit steel castings.

**Table 3.** Comparison of the feeding effects of two kinds of self-made heating and thermal-insulating covering agent for riser and four typical similar products at home and abroad on orbit steel castings

| Serial number | Type of covering agent                                      | The volume of the shrink mark on the top of riser (dm³) | Maximum depth of the shrink mark of riser (mm) | Relative feeding efficiency (%) |
|---------------|-------------------------------------------------------------|--------------------------------------------------------|---------------------------------------------|--------------------------------|
| 1             | Self-made carbon steel type                                  | 3.14                                                   | 80                                           | 60.9                          |
| 2             | Carbon steel type of a company in Suzhou                    | 2.11                                                   | 62                                           | 52.8                          |
| 3             | Carbon steel type of a company in Shanghai                  | 2.30                                                   | 76                                           | 46.9                          |
| 4             | Carbon steel type of a famous international company         | 3.20                                                   | 137                                          | 36.2                          |
| 5             | Self-made carbon steel type                                  | 2.33                                                   | 112                                          | 32.2                          |
| 6             | Low carbon steel type of a company in Shanghai               | 1.24                                                   | 112                                          | 17.2                          |
4. Results and discussions
(1) The comparison test results on the bearing steel castings show that the top section of low carbon steel type heating and thermal-insulating covering agent for riser we developed has a good U-shaped shrink mark, and the depth is large (58mm), the relative feeding efficiency of riser reached 51.6%. However, the U-shaped shrink mark of the top profile of the riser of the same type of the heating and thermal-insulating covering agent for riser of the international famous company is not obvious. And the depth is small (42mm), the relative feeding efficiency of riser is only 36.9%.

(2) The comparison test results on orbit steel castings show that the newly developed carbon steel type heating and thermal-insulating covering agent for riser we developed has a relative feeding efficiency of up to 60.9%, and the new low carbon steel type has a relative feeding efficiency of up to 32.2%.

(3) The feeding effect of the riser is better than the four kinds of contrastive typical heating and thermal-insulating covering agent for riser at home and abroad. The reason is that the ingredients of the two new heating and thermal-insulating covering agent for riser are different, 2~3 exothermic reaction can occur in use continuously, the heat release time is longer and the heat output is bigger. Due to the limited space, this paper does not discuss its causes and mechanisms in detail, additional article will be analyzed and discussed by using the ZH1250 integrated thermal analyzer to test DSC (differential scanning calorimetry), TGA (thermal gravimetric analysis) of these kinds of covering agents.

(4) The feeding efficiency of riser only reflects the influence of the total volume of the shrink mark of the riser, and cannot reflect the difference between safety height of risers. And the relative feeding efficiency of riser we first proposed reflects the comprehensive influence of the volume of the riser shrink mark and whether the top surface of the riser is flat (i.e. the size of the riser’s safety height). It can represent the actual feeding capacity of riser more accurately.

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