Prevention of burn-on defect on surface of hydroturbine blade casting of ultra-low-carbon refining stainless steel

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Abstract: The burn-on sand is common surface defect encountered in CO_2-cured silicate-bonded sand casting of hydroturbine blade of ultra-low-carbon martensitic stainless steel, its feature, causes and prevention measures are presented in this paper. Experiments showed that the burn-on defect is caused by oxidization of chromium in the molten steel at high temperature and can be effectively eliminated by using chromium-corundum coating.

Key words: burn-on defect; ultra-low-carbon martensitic stainless steel; chromium-corundum coatings

CLC number: TG142.71 Document code: A Article ID: 1672-6421(2008)03-0190-04

Electric power is an important national energy source for industrial and agricultural production. At the end of 2005, the total installed power capacity and total generated electricity of China ranked the second in the world. The electricity consumption in China was 2.48×10^{12} kW·h, of which thermal power accounted for 83% and hydropower accounted for 15%. In China, due to the priority policy for hydropower, vast perspective is opened up for the development of hydropower equipment. The strict demands for the surface and internal qualities are put forward for the stainless steel hydroturbine blade castings as a key component. At present, the low-carbon martensitic stainless steel is widely applied for hydroturbine parts because of its high tensile strength and excellent corrosion resistance. But, 13% chromium martensitic stainless steel is not adequate to resist corrosion in strong corrosive medium. The corrosion resistance of martensitic stainless steel increases with the decrease of carbon levels; hence there has been a general trend towards the usage of low-carbon level or ultra-low-carbon level (⩽0.03%C) stainless steel in the world. Up to now the ultra-low-carbon martensitic stainless steel is mainly made using electric arc furnace in China. For electric arc furnace steelmaking, there are certain difficulties in accurate controlling chemical composition, inclusion and temperature of the molten steel.

From metallurgical principle, in atmosphere steelmaking, the higher the temperature of the steel bath, the lower the carbon level equalized with chromium in the molten steel. In electric arc furnace steelmaking, increasing molten steel temperature can be used to prevent oxidization of a large amount of chrome, hence the molten steel temperature can reach 1,800℃. This results in a premature wear of the lining refractory and in the reduction of the lining life, therefore this method is not suitable for making ultra-low-carbon stainless steel.

In recent years, it has been found that the decrease of CO partial pressure in furnace has the same effect as the rise in the temperature of molten steel [1]. AOD-process and VOD-process are widely used in making ultra-low-carbon refining stainless steel both in China and worldwide. In these processes molten steel containing chromium in the furnace is blown with oxygen, or mixture of oxygen and inert gas, when the metal temperature reaches 1,800℃, the carbon concentration can be decreased to ⩽0.035%. However, the temperature above 1,800℃ is not desirable, since too high temperature will result in burn-on defect on casting.

On the other hand, during the melting period of high chromium stainless steel, due to the easy oxidization of chromium on the surface of molten steel [2], inclusions formed may be adhered tightly to the surface of mould and core and form defective surface. Usually such inclusion does not exist in the surface of molten steel above liquidus temperature, but it appears during subsequent cooling. Therefore a higher pouring temperature for the high chromium stainless steel castings is required. Practice has confirmed that the higher pouring temperature of the molten steel containing chromium in combination with fast rising rate in the mould is an effective measure to prevent the surface defect on high chromium stainless steel castings.

Based on above-mentioned analysis, for molten stainless steel with secondary refining it is preferable to pour under the conditions of higher temperature and faster filling rate. Figure 1

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Received: 2008-03-20; Accepted: 2008-06-14

shows the process drawing for hydroturbine blade casting. The maximal hydrostatic head of molten steel reaches more than 3.5 m, pouring temperature is between the range of 1,600–1,650℃, the pouring rate is 30–35 mm/s.

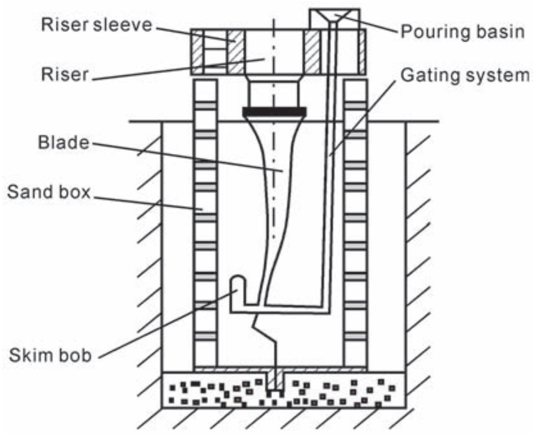
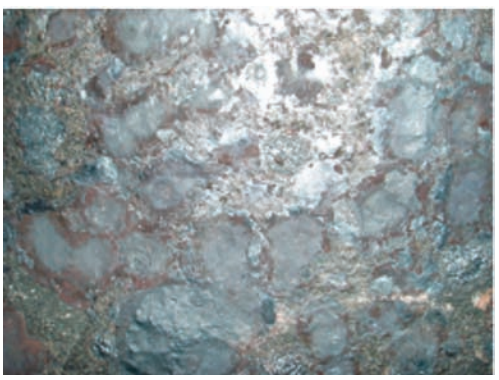
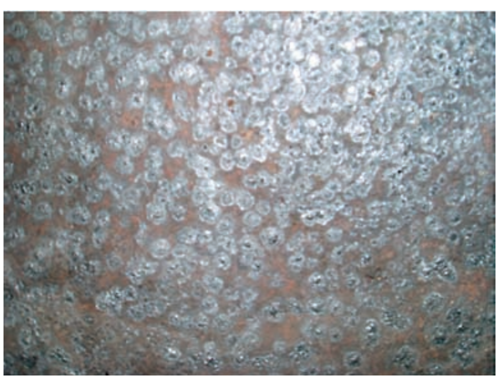


Fig. 1 process drawing for hydroturbine blade casting

It has been found that, when hydroturbine blade castings of ultra-low-carbon refining stainless steel are made using CO_2 cured silicate-bonded sand mould with zircon coating, the burn-on defect mostly occurs on the casting surface closed to the corner and "hot spot" area. This burn-on defect consists of many irregular honeycomb structure, each is about 5 –50 mm long, 3 –10 mm wide and 1.5 – 4 mm thick. Figure 2 (a) and 2(b) show the appearance of the defect. The surface defect is very difficult to be removed by fettling; the castings with the serious defect may lead to scrap. Therefore, a radical solution needs to be found to eliminate the burn-on defects on the surface of hydroturbine blade castings of ultra-low-carbon refining stainless steel.



(a) At the corner of casting



(b) At the "hot spots" of casting

Fig. 2 Burn-on defect on the surface of hydroturbine blade casting

1 Analysis of burn-on defect

Up to now, only a few literatures reported burn-on defects on the surface of hydroturbine blade castings. As early as 1976, И.Н.Примака described a similar casting defect [3]. It was stated that this defect is caused by decomposition of calcium carbonate and magnesium carbonate in chromium sand mould at high temperature. In 2005, Huang Jin reported that "glazing" burn-on defect is different from burn-on defect on the surface of hydroturbine blade castings produced using CO_2-cured silicate-bonded chromite sand mould without coating [4]. The results of our tests indicated that the burn-on defect is easy to form under following conditions:

(1) high chromium content in stainless steel;

(2) high pouring temperature;

(3) oxidation atmosphere in the mould.

Too soft ramming is also favourable for the formation of burn-on defect. Since it is impossible to change steel composition and pouring temperature, the simplest and most effective way to eliminate the burn-on defect on the surface of hydroturbine blade castings is to study and find new coatings used for CO_2 cured silicate bonded sand mould.

2 Experimental procedures

2.1 Preparation of trial coating

Four kinds of alcohol-based coatings containing different refractory materials were prepared. Table 1 lists the composition for each coating.

Table 1 Composition of experimental alcohol-based coatings

<table>
<tr><th>No.</th><th>Zircon</th><th>Chromite</th><th>Chromium-corundum</th><th>Flux</th><th>Li-bentonite</th><th>Phenolic</th><th>PVB</th></tr>
<tr><td>1</td><td>100</td><td></td><td></td><td></td><td rowspan="4">2.0</td><td rowspan="4">2.0</td><td rowspan="4">0.5</td></tr>
<tr><td>2</td><td></td><td>100</td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td>100</td><td></td></tr>
<tr><td>4</td><td></td><td></td><td>90</td><td>10</td></tr>
</table>

For each coating, at first alcohol solvent was mixed with Li-bentonite by stirring for 30 min, and then phenolic resin and PVB were added and continued to mixed for 3 –5 min, finally refractory materials and flux were added and mixed for 10 –15 min. The density of the coatings was adjusted in the range of 1.80–1.90 g/cm^3.

2.2 Pouring test

ZG03Cr13Ni4Mo molten steel was made in an induction furnace and refined in an AOD refining vessel under the production conditions.When the concentration of carbon in the chromium-containing molten steel was in a range of ⩽0.03% and its temperature reached 1,600–1,650℃, the molten steel was poured using ladle into the CO_2 cured silicate-bonded sand mould with different coatings. After trial blade castings (300 kg) cooled down to room temperature, the castings were knocked out; the coating layer and casting surface were investigated by observation and scanning electron microscope (SEM) analysis.

3 Results and analysis

Table 2 shows the surface quality of castings made with different coatings. As shown in Table 2, the casting using the coating 1 and 2 still have poor surface with burn-on defect. Figure 3 shows the burn-on defect on the surface of trial casting when using No. 1 zircon coating.

Table 2 Surface quality of trial blade castings with different coatings

Coating No.	1	2	3	4
Surface of casting	Burn-on	Burn-on	Good	Good

Fig. 3 Burn-on defect on casting surface (No. 1 zircon coating)

The burn-on defect at the corner or "hot spot" area of trial castings is quite serious, and is very difficult to remove. The chemical composition of the coating layer taken from casting surface after shakeout is shown in Table 3, as can be seen from the Table 3, a large amount of chromium exists in the burn-on layer.

Table 3 The chemical composition of the coating layer after shakeout, wt.%

Cr	Fe	Si	Mn	Na	Mg	Al
30	50	8.0	5.0	0.8	0.8	0.6

No. 2 coating also has poor surface quality, this is explained by the fact that the lower refractorihess of coating(⩽1,800℃) isn't suitable for higher pouring temperature of ultra-low -carbon stainless steel.

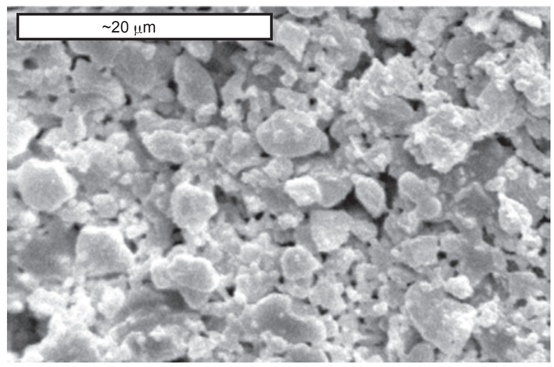
In the case for No. 1 zircon coating, the thermal decomposition of zircon at higher temperature (⩽1,500℃) occurs according to the following equation:

$$ZrSiO_4 \longrightarrow ZrO_2 + SiO_2$$

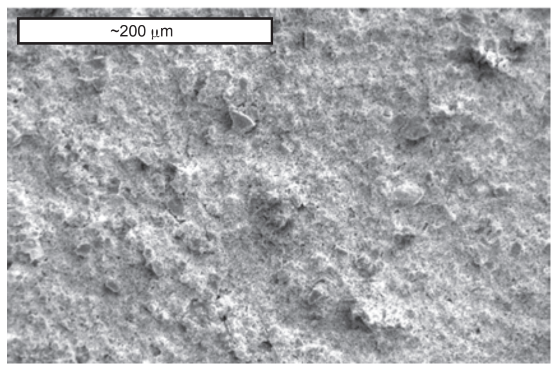
Thermal decomposition of zircon leads to the formation of active SiO_2, which reacts with iron oxide and forms a low-melting compound, thus causes burn-on defect.

When using No. 3 and No. 4 chromium-corundum coatings, in general, the coating layer can be easily separated from the casting surface. For No. 3 chromium-corundum coating, its refractoriness is quite high, ⩾2,000℃, and thermal stability of the chromium-corundum is better than that of chromite; for the No. 4 chromium-corundum-flux coating, the castings have good surface quality because the flux in the coating will help the coating to resist the burn-on defect by the tighter low-melting compound.

Figure 4 shows the electron microscopic photo of the No. 3 and No.4 coating layers taken from the surface of the trial casting.



(a) No. 3 coating layer



(b) No. 4 coating layer

Fig.4 Electron microscopic photo of the No. 3 and No.4 coating layers

The results of tests using different coatings indicated that trial blade castings of ultra-low-carbon refining stainless steel can be successfully produced by using CO_2 cured silicate-bonded sand mould with No.4 corundum-flux coating. The surface quality of casting is very good; no any burn-on defect can be seen on the surface of castings. Figure 5 shows an example of these castings. These tests have proved that using the chromium-corundum coating is an effective measure to eliminate burn-on defect.

4 Conclusions

(1) The main reasons resulting in the formation of burn-on defect on trial blade casting of ultra-low-carbon refining stainless steel are higher chromium content in stainless steel, higher pouring temperature of the molten steel and oxidation atmosphere in the mould.

Fig. 5 Trial blade casting free of surface defects

(2) Using chromium-corundum and/or flux coating to eliminate burn-on defect on trial blade casting of ultra-low-carbon refining stainless steel in CO_2 cured silicate bonded mould is an effective measure.

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