Influence of Casting Temperature of Low Carbon Steel on the Interface Layer of Composite Protective Plate

Hui Gao1, Wenbing Zhang1, Shumei Chen2 and Kuilong Lyu1

1School of Mechanical and Electronic Engineering, Beijing Polytechnic College, Beijing 100042, China
2School of Mechanical Engineering, Jiamusi University, Jiamusi 154007, China
Email: kuilonglv@163.com

Abstract. Based on the liquid/semi-solid bimetal composite casting technology, the low carbon steel/the high chromium casting iron wear-resistant plate was prepared, and the casting temperature of the low carbon steel was investigated on the microstructure and the mechanical properties of the bimetal composite plate. The action of the reasonable casting temperature can make the two kinds of metals play to their excellent properties, and not only has the high wear resistance, but only guarantee to achieve strong match between two kinds of metals. The results showed that the low carbon steel at different casting temperature was poured into the mold, and its upper surface was in the semi-solid state. The semi-solid contact areas between the low carbon steel and the high chromium casting iron have evolved into into the interface layer, and there is no porosity and inclusion in the interface layer. The metallurgical bonding quality is good, and the Rockwell hardness is about 50~52HRC, and tensile strength of is about 550~610MPa.

1. Introduction

The impact crusher can be used to break into pieces on the impact energy. During the equipment operation, rotor with a high speed drive the board hammer breaking the materials pieces, and materials was thrown to the counter-attack board. So the materials once again was rebounded to the zone of action. When the process was carried on over and over again, the materials were completely break into pieces suitable to the demand. This kind of crushing appliance were widely used for the smelting plant, building materials, railway, water conservancy project and chemical plant, and so on[1-3]. In order to enhance the service life of the guard plate, the material of guard board can choose white cast iron which has the high hardness, good wear resistance, easy source and low price, etc[4-7]. However the white cast iron is brittle, easily broken, resulting in the short service life[8-10]. So for enhancing the service life of the guard plate, manganese steel containing more than 12% is often used. ZGMn13 is commonly used which has the good toughness, but not high hardness about 210HB. Although the manganese steel has the characteristics of the work hardening, but its service life is still relatively lower and its price is relatively expensive[11-13].

Aiming at the technical bottleneck of the large plane wear resistant protection plate of the mine counter-attacking crusher, the liquid-semisoluid bimetal casting composite technology is put forward on the basis of the traditional double liquid casting composite technology. And then the effect of the casting temperature of the low carbon steel on the composite plate can be explored, and the generated oxide inclusions after the surface completely solidified can be effectively avoided, so as to achieve the metallurgical combination of the large area of two kinds of materials. It provides a new way for the production and application of the wear-resistant composite board.
2. Experimental Materials and Methods

2.1. Experimental Materials
In this experiment the eutectic high chromium cast iron was selected for the working part, and the low alloy steel was selected for the supporting part. The combination of two kinds of metals can make the metals exert their excellent properties effectively, which not only has high wear resistance, but also can guarantee the process not to break, so as to achieve strength and toughness match each other. The chemical components of the substrate material and the wear-resistant layer material used were shown in Table 1. According to the intermediate value of the chemical components range, the chemical compositions of the low carbon steel and the high chromium cast iron were determined.

| Contents | C     | Cr    | Mn     | Mo       | Si    | Fe     |
|----------|-------|-------|--------|----------|-------|--------|
| HCCI     | 3.1~3.3 | 20~26 | 1.0~1.5 | ≥0.2     | ≤0.4  | Bal.   |
| LCS      | 0.30~0.50 | —     | —      | —        | ≤0.4  | Bal.   |

2.2. Experimental Methods
The medium frequency smelting furnaces of 20kg and 50kg are used to smelt the low carbon steel and the high chromium cast iron respectively. Before pouring the low carbon steel liquid, the rare earth ferrosilicon was used for the inoculation treatment, and a small amount of the aluminum wire was added for the deoxygenation treatment. Firstly, the casting temperature of the low carbon steel respectively take the parameters for the 1510°C, 1520°C, 1530°C, 1540°C and 1550°C. In the process of the experiment, the low carbon steel was preferentially poured into the casting mold. After that the liquid low carbon steel under the action of the cooling medium was reached the required thickness of the solidification layer, then the high chromium cast iron was immediately poured into the upper side of the low carbon steel at 1530°C, as shown in Figure 1.

The obtained composite plate was cut into samples with 10mm×10mm×10mm in linear cutting, as shown in Figure 2, and after that the grinding of the samples section with the abrasive paper such as 400 #, 600 #, 800 #, 1000 # and 1200 # in turn. In the end, the samples using the particle size of the 0.5 diamond polishing paste was polished to a mirror, and cleaned with the ultrasonic in alcohol. After corrosion with the 0.5% saltpeter solution, the metallographic microscope was observed in Olympus GX71 metallographic microscope.

The HR-150A Rockwell hardness meter with proper 150 kgf load was used to determine macro hardness value of the composite board, and then the determination scope was 20~67 HRC. The tensile strength of the cast low carbon steel and high chromium cast iron composite plate was measured by WDT-10 universal testing machine, and therefore the tensile strength of the composite layer was characterized by the tensile strength. So the samples for the tensile strength samples were cut into the sheet through the linear cutting, and then measured on the tensile rate of the 10mm/min.
3. Result and Analysis

3.1. Metallographic Structure
The microstructure of the high chromium cast iron and the low carbon steel was observed, as shown in figure 3. The microstructure of the low carbon steel is mainly α-Fe and P, as shown in figure 3a. The microstructure of the high chromium cast iron is first eutectic carbides and the eutectic lysosomes, as shown in Figure 3b. During the solidification process of the hypereutectic high chromium cast iron, the eutectic carbides were firstly grown preferentially and precipitated in the form of (Fe,C)\(_7\)C\(_3\), presenting the hexagonal prismatic crystals or the hexagonal pyramidal crystals. The hexagonal structure can be observed in the crystal section, which contains the austenite metallic inner cavity. As the hypereutectic high chromium cast iron cools to the eutectic line, the liquid phase gradually changes to \(\gamma\)-Fe + (Fe,C)\(_7\)C\(_3\) eutectic microstructure, and the (Fe,C)\(_7\)C\(_3\) in eutectic takes on the shape of the bands or the bars.

The microstructure of the interface layer of the carbon steel and the high chromium iron was shown in Figure 4.

![Figure 3. Microstructure of the low carbon steel and the high chromium iron](image1)

- a) Low carbon steel
- b) High chromium iron

![Figure 4. Microstructure of the interfacial layer of the composite plate under the different casting temperature of the low carbon steel](image2)

- a) 1510°C
- b) 1520°C
- c) 1530°C
- d) 1540°C
- e) 1550°C
The interface between the low carbon steel and the high chromium cast iron is a good metallurgical bonded interface zone without any porosity or inclusion. According to the microstructure and the distribution of the interface layer, the interface layer and the adjacent area can be divided into three parts, namely, the low carbon steel, the interfacial layer and the high chromium cast iron. The width range of the interface layer is about 30-50μm. With the increase of casting temperature of the low carbon steel, the height of the austenite dendrite gradually decreases in the interfacial layer. In the composite plate prepared under the condition of the cooling medium, the increase of the casting temperature of the low carbon steel can increase the width of semi-solid zone of the low carbon steel, so as to expand the width of the remelting zone of the low carbon steel. However, as the casting temperature of the low carbon steel increases, the chilling effect of the cooling medium is significantly weakened by the high temperature low carbon steel liquid, and then the growth height of the eutectic austenite in the direction perpendicular to the interfacial layer has grown smaller in a relatively small temperature gradient.

3.2. Mechanical Property

3.2.1. Rockwell hardness. To analyze the effect of the casting temperature of the low carbon steel on the Rockwell hardness under the condition of cooling medium, and the selected measured position throughout the low carbon steel and the high chromium casting iron was on the sample surface, and then the measured value of Rockwell hardness was shown in Figure 5. In the low carbon steel side, the hardness value presents the little change between the 30HRC and the 34 HRC. But near the interface layer, the hardness value jumps up from the 50 HRC to the 52 HRC, and the interface layer in the high chromium cast iron side is still a slowly increasing hardness transition area, then the hardness of the high chromium cast iron value tends to be stable, and the highest hardness value is about 64 HRC.

![Figure 5](image.png)

**Figure 5.** Rockwell hardness of composite plate section at different casting temperature of low carbon steel

3.2.2. Tensile strength. In order to verify the bonding strength of the interface layer between the low carbon steel and the high chromium cast iron, the prepared tensile strength test shows the strength performance of the interface layer, as shown in Figure 6. The location of the dotted line position is the position of the composite layer in Figure 6, and the left side is the high chromium cast iron, and the low carbon steel is on the right. From the top to the bottom, the samples of the different casting temperature of the low carbon steel was shown at 1510°C, 1520°C, 1530°C, 1540°C and 1550°C in turn. After the tensile fracture test, all of the fracture location are in the high chromium cast iron side. With the increasing casting temperature, the tensile strength also increases simultaneously, and the range of tensile strength value is from 550MPa to 610MPa, as shown in Figure 7. The fracture positions of the samples were all distributed on the side of the high chromium cast iron, indicating that the high chromium cast iron itself had a higher carbide content, and its tensile strength was
significantly lower than that of the low carbon steel, as well as the strength of the interface between the two materials.

**Figure 6.** The samples of the different casting temperature of the low carbon steel

**Figure 7.** Tensile strength of the different casting temperature of the low carbon steel

4. Conclusions

(1) Influence of the casting temperature of the low carbon steel on the microstructure and properties of the composite interface between the low carbon steel and the high chromium iron was investigated. There were no pores and inclusions in the interface layer between two metals.

(2) The interface layer and the adjacent areas are divided into three parts: low carbon steel, interface layer and high chromium cast iron, and the width of the interface layer is about 30~50 microns.

(3) The tensile strength of the interface layer is better than that of the high chromium cast iron, which indicate that the casting composite interface layer has a good metallurgical bonding performance.

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6. References

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