Influence of process parameters to composite interface organization and performance of liquid/solid bimetal

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Abstract. The liquid-solid composite technique was used to prepare the high carbon high chromium steel (HCHCS) and low alloy steel (LCS) bimetal composite materials by means of insert casting method. The influence of some process parameters such as liquid-solid ratio, preheat temperature, pouring temperature on the interface microstructure and mechanical properties were studied. Interface microstructure and element distribution were analyzed. The results show that the interface microstructure becomes better, and bonding area becomes thicker with the increase of the volume of liquid to solid ratio, preheating temperature and pouring temperature. When the liquid-solid ratio is 8:1, the preheating temperature is 300°C and the pouring temperature is 1565°C, a good metallurgical bonding area without any hole can be obtained with the interface combination of diffusion and fusion. The composite interface structure was composed of a core material diffusion layer, a cooling solidification layer, a direction growth layer and some cell particles. The elements of C, Cr and Mn diffuse from the HCHCS side to the alloy steel side. The microhardness increased in the gradient from the LCS side to the HCHCS. The microhardness of the interface is significantly higher than that of LCS.

1. Introduction

Single wear-resisting materials were unable to meet the requirement of sustained load working conditions [1]. Two liquid bimetal casting technique was worthy for being widely researched and used which provided a feasibility way to the crusher hammer between the LCS and the high chromium white cast iron [2, 3]. During the practical application, the hammer handle due to the soft LCS handle was easy to be wear away [4-6], which decreased the service life and limited the application range of relational bimetal crusher hammers [7, 8]. So a prerequisite to realizing the wear-resisting hammer handle based on liquid-solid composite technology between the LCS and the HCHCS can be proposed in view of the soft hammer handle of the LCS [9].

2. Experimental procedures

The experiment of material was composed of HCHCS and LCS. Chemical components were shown in table 1.

The mold of LCS was ladder structure designed into 2:1, 4:1 and 8:1 of outer/inner volume ratio. First LCS after preparation was polished and coated with a borax layer to increase the wettability.
Table 1. Chemical compositions of HCHCS and LCS (wt%).

| Contents | C    | Cr    | Mn    | Mo    | Si    |
|----------|------|-------|-------|-------|-------|
| HCHCS    | 1.15-1.18 | 11.5-12 | 1.8-2.0 | ≥0.2 | ≤0.4 |
| LCS      | 0.32-0.45 | 0.6-0.8 | 0.6-0.7 | ≤0.2 | ≤0.4 |

Then melted metal by induction furnace was raised to the required pouring temperature with the temperature measuring gun. The processed LCS preheated to room temperature, 300°C and 600°C was placed into the sand mold. The bimetal was cooled to the room temperature after the poured HCHCS in the sand mould.

The casting was cut into 10 mm×10 mm×55 mm for the impact toughness and the microstructure observation. The austenitizing was at 960°C for 2 h, and the isothermal quenching based on the mixed sodium nitrate at 320°C for 1 h. The ZBC-300B automatic metal pendulum tester was used to measure its impact toughness. The Rockwell hardness was tested by the HR-150A durometer. The abrasive resistance was tested by the MLD-10 dynamic load abrasive wear testing machine. The microstructure and composition at the bonding region were examined using the Olympus GX71 optical microscope and the EDAX-FALCON60 energy dispersive spectrometry respectively. The microhardness was tested by the HV-30 Vickers hardness tester.

3. Results and discussion

3.1. Interfacial microstructure

The bonding interface at 1565°C pouring temperature and 300°C preheating temperature was obtained under three kinds of liquid-solid volume ratios, and the interfacial microstructures were seen in figure 1. The overall tendency presented the certain variation from mechanical bonding to metallurgical bonding. The long unbonded region at the interface of that was found in figure 1(a), and curved interface bonded line was detected as shown in figure 1(b). The interfacial microstructure with high

![Figure 1. Interfacial microstructures under the different volume ratios.](image)
quality is investigated without any defect such as the unbonded region or the void on the interface in figure 1(c). So the increase of liquid-solid volume ratio was favorable to form the required bonded interface.

The interfacial microstructure at three preheating temperature under the 4:1 liquid-solid volume ratio and at 1565°C pouring temperature were seen in figure 2.

![Interfacial microstructures of preheating temperature.](image)

Figure 2. Interfacial microstructures of preheating temperature.

The unbonded region and void can be seen in figure 2(a) because of the unpreheated LCS before pouring HCHCS. The casting was easily cracked because the HCHCS had a strong chilling effect by LCS. The quality of interfacial microstructure was significantly improved because of the higher preheated temperature and was shown in figures 2(b) and 2(c). The difference temperature between the HCHCS and the LCS was decreased by the increase of LCS preheating temperature. So the temperature of LCS was easily to increase higher and form metallurgical bonding.

The interfacial microstructure at three pouring temperature under 4:1 liquid-solid volume ratio and at 300°C preheating temperature were seen in figure 3.

The unbonded region was seen in figure 3(a) whose interface quality was better than figure 2(a) because LCS was preheated before poured HCHCS, which decreased the temperature difference. The interface quality was increasingly improved when the pouring temperature reached 1620°C. The increase of pouring temperature was favorable to form desirable bonded interface.

3.2. Interface energy spectrum analysis

The spectrum analysis of the bonded interface region at the liquid-solid volume ratio of 8:1, at the preheating temperature of 300°C and pouring temperature of 1565°C was shown in figure 4.

There were no pores, inclusions, cracks and other defects in the interface bonding region from the scanning electron microscope. There were mutual diffusion and penetration of bimetal in the
Figure 3. Interfacial microstructures of pouring temperature.

composite process because of the different components between HCHCS and LCS. Diffusion of
elements takes place at the interface from the spectrum analysis of bonding interface region. C, Cr,
and Mn element diffuse from the HCHCS to the LCS, and Fe diffuse toward the opposite direction,
which was important to increase the bonding strength. However, the different condition of diffusion
due to the lower temperature of LCS and the characteristic of the different elements. Cr and Mn are
decreased from HCHCS to LCS gradually due to the strong diffusibility and the far distance of
diffusion. C mainly diffuses from HCHCS to the bonding region because of the poor diffusibility, so
the C in bonding region was less. While the element of Si and Mo diffuses from HCHCS to the
bonding region due to its strong diffusibility and the content of Si and Mo in the interfacial bonding
were closer to that of HCHCS and LCS. The elements mainly diffuse from HCHCS to the interface
bonding. The diffusion in the LCS was poor because of the low temperature of LCS. This
phenomenon was consistent with the figure 4.

Figure 4. Interface energy spectrum analysis.
4. Mechanical properties
The major mechanical properties of the HCHCS and the LCS after heat treatment were given in table 2. The wear loss of the HCHCS was obviously higher than that of the LCS, so the “eated handle” phenomenon can be solved through the liquid/solid hammer handle between the LCS and the HCHCS substituted for the original LCS hammer handle.

| Materials | Hardness (HRC) | Impact toughness (J/cm²) | Wear loss (g) |
|-----------|----------------|--------------------------|---------------|
| HCHCS     | 35-38          | ≥80                      | 0.1087        |
| LCS       | 60-62          | 7.9-8.5                  | 0.3325        |

The microhardness under liquid-solid volume ratio of 8:1, at the preheating temperature of 300°C and pouring temperature of 1565°C and 1620°C was shown in figure 5.

![Microhardness at the preheating temperature.](image)

5. Conclusions
- With the increased volume ratio of liquid to solid, preheating temperature and pouring temperature, the interfacial microstructure was becoming better and the thickness of bonding region was becoming thicker.
- Microhardness was gradually increased from the LCS to the HCHCS, and the microhardness of the bonding interface was in between the LCS to the HCHCS. C, Cr, and Mn diffuse from the HCHCS to the LCS, and Fe diffuses towards the opposite direction.
- The good metallurgical bonding interface without any pore was obtained by liquid-solid casting under the volume ratio of 8:1 through the 300°C preheating temperature and the 1565°C pouring temperature.

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