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Diffusion behavior and mechanical properties of high chromium cast iron/low carbon steel bimetal

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ABSTRACT

In the present study, a high chromium cast iron (HCCI) as the high hard and wear-resistant layer was bonded on the surface of low carbon steel (LCS) at 1633 K. The microstructure and mechanical properties of the bimetal were investigated. The results show that the HCCI and the LCS were bonded well, the shear strength value is 539.6 MPa. No defect such as unbonded regions, microvoids and microcracks on the interface was observed. C atoms diffuse from the region of low concentration (LCS) to the region of high concentration (HCCI) across the interface during the diffusion process, which belongs to the uphill diffusion phenomenon. The thickness of the diffusion zone is about 55 µm. The troostite consisting of $M_{23}C_6$ and ferrite showed up instead of M_7C_3 in the diffusion zone. The spacing of $M_{23}C_6$ lamellar is 63 nm in average, and the Fe/Cr atom ratio of $M_{23}C_6$ is approximately 2.4. A certain number of grains formed across the interface, which improved the interface bonding strength effectively. The tensile strength of the bimetal is 447.9 MPa, cleavage fracture appeared in the HCCI side. The bending strength (1208.4 MPa) and impact strength (75 kJ m^{-2}) both enhanced obviously compared with the HCCI.

1. Introduction

High chromium cast irons (HCCIs) are primarily used in mining machinery, wear resistant lining board, crusher jawplate, etc. because of their excellent wear resistance and high hardness [1–3]. But the poor toughness restricts their further development [4,5]. Bimetal materials have been used more and more frequently in a variety of industries to overcome those shortcomings [6–11]. Recently, a high-chromium white cast iron as the wear-resistant part and carbon steel as the ductile part bimetal had been developed [12–22]. Gao et al. [12] developed a hot diffusion-compression bonding process for cladding low carbon steel (LCS) to high chromium cast iron (HCCI) in solid-state. Both rising bonding temperature and reducing bonding strain rate are in favor of improving the bonding strength. The highest interface shear strength was obtained at the bonding temperature of 1150 °C and the bonding strain rate of 0.001 s^{-1}. Oh et al. [13] investigated the correlation of microstructure with wear resistance and fracture toughness in duo-cast materials which consisted of a high-chromium white cast iron and a low-chromium steel as the wear-resistant and ductile parts, respectively. The flexural strengths of duo-cast materials were excellent in the range from 600 to 650 MPa. Kim et al. [14] investigated the effects of heat treatment on wear resistance and fracture toughness in duo-cast materials consisted of a high-chromium white cast iron and a low-chromium steel as a wear-resistant part and a ductile part, respectively. The wear resistance of the bimetallic material had been improved after heat treating. However, the fracture toughness of the heat-treated alloys was lower than the as-cast alloys because of the matrix containing a considerable amount of martensite which could not prevent the crack propagation effectively. Cholewa et al. [15] obtained a bimetal material of high chromium steel or chrome-nickel steel and gray iron by a mould cavity preparation method, both materials free from defects especially in the sensitive area of connection. Xiong et al. [16,17] fabricated the HCCI and medium carbon steel (MCS) bimetal by liquid–solid casting technology with and without electromagnetic. They found the elemental diffusion activity improved with the increase of the liquid–solid volume ratio, resulting in the increased of the interface transition region width. The electromagnetic induction heating is beneficial to achieving metallurgical interface bonding and improving the mechanical properties. Eroglu and Kurt [18] found that the bonding shear strength increased as the bonding temperature and holding time increasing in HCCI/LCS diffusion bonded bimetal. In previous researches, it is mostly interested in the influence of experiment parameters on the joining ability of bimetal. As we know, the interfacial diffusion behavior and the microstructure of diffusion zone make a great contribution to the mechanical properties of bimetals, which had been investigated by few studies. Therefore, these features of the HCCI (16 wt% Cr)/LCS

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Table 1
Chemical compositions of the HCCI and the LCS (wt%).

Material	C	Cr	Si	Mn	Ni	Fe
LCS	0.20	0.20	0.20	0.50	0.10	Balance
HCCI	2.42	16.10	0.79	1.02	1.02	Balance

bimetal fabricated by cladding method were investigated in detail. Electron-probe micro-analysis (EMPA) and transmission electron microscope analysis (TEM) were adopted in this study. Tensile strength and shear strength were measured to evaluate the bonding quality of the bimetal. Bending strength and impact toughness were measured to characterize the abilities of resistance by static and dynamic load.

2. Experimental procedure

For the researches, hypoeutectic HCCI powder and commercial hot-rolled LCS plate were used for the wear-resistant part and ductile part, respectively. The chemical compositions of HCCI and LCS are listed in Table 1. The LCS was machined into a cuboid (100 mm × 100 mm × 10 mm) by wire cutting machine as shown in Fig. 1(a), and the surfaces were cleaned by ethanol. The prepared cuboid was put into a corundum crucible. The HCCI powder was loaded above the LCS cuboid and compacted. The corundum crucible was heated to the temperature of 1633 K in the argon atmosphere furnace, held isothermally 20 min, and then natural cooled to room temperature along with the furnace.

The bimetal specimens were prepared by grinded from 320 to 2000 grit paper and metallographically polished with 1 μm diamond polishing paste subsequently ultrasonically cleaned and etched by a reagent of 4 vol% nital. An optical microscope (OM) OLYMPUS-GX71 and field emission scanning electron microscopy Ultra Plus (ZEISS) were employed for the microstructure examination. The distribution of elements in the diffusion zone was investigated by JXA-8530F EPMA. The phase identification of the HCCI and the diffusion zone were determined by X' Pert Pro PW3040/60 ×-ray diffractometer (XRD) using monochromatic Cu Kα radiation. A TECNAI G20 TEM equipped with an Oxford® Inca EDS detector was utilized and operated at 200 kV.

Microhardness profiles across the interface were obtained by a Vickers hardness tester under a load of 200 g and a dwell time of 10 s. The impact toughness was measured by a JBW-500 screen type impact tester. The three-point bending tests, the tensile tests and the shear tests were conducted in the universal testing machine(IDW-200H) at a crosshead speed of 60 μm min^{-1} at room temperature, the support span of the three-point bending test was 35 mm. All of these specimens were processed by wire cutting, the schematic diagram of mechanics performance testing specimens is shown in Fig. 1. The shear tests were mechanically tested using an apparatus as shown in Fig. 2.

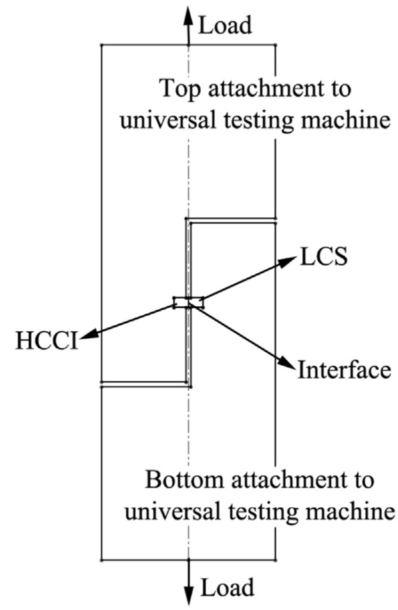

Fig. 2. Schematic illustration of shear strength test apparatus.

The shear strength was measured following:

$$\sigma_b = \frac{F_u}{A_b} \quad (1)$$

Where σ_b is bond strength (MPa), F_u is ultimate load (N), and A_b is bonding area (mm^2). The bending strength is measured following:

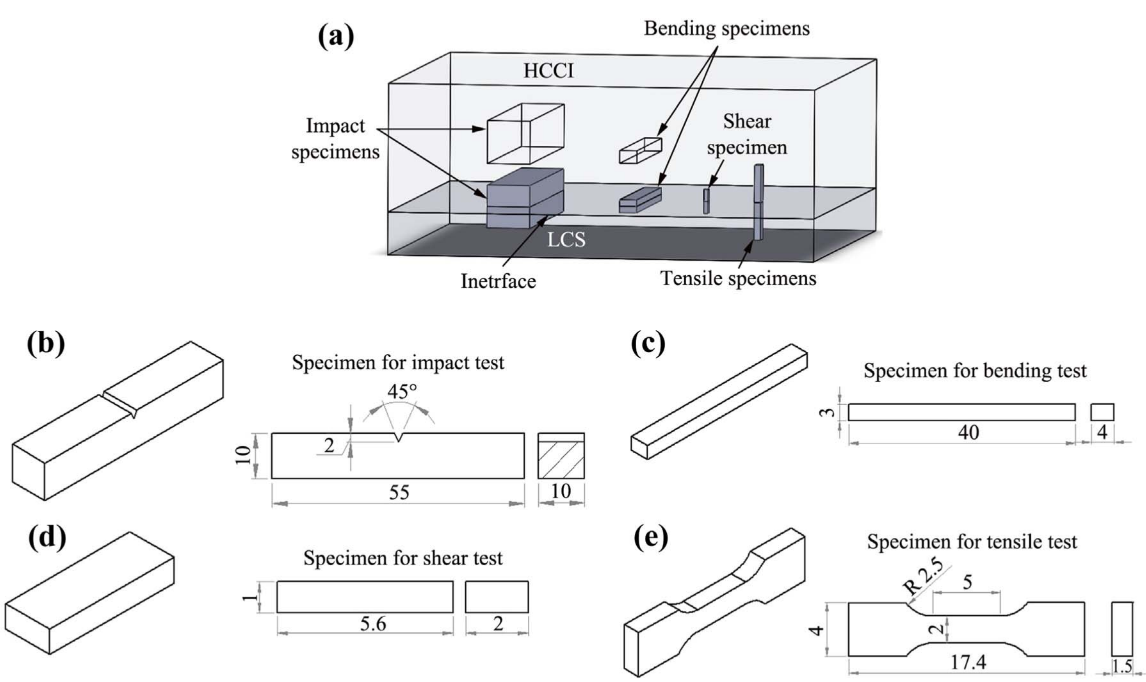

Fig. 1. Positions and dimensions of specimens for tests of mechanical properties.