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Microstructure, mechanical properties and high stress abrasive wear behavior of air-cooled MnCrB cast steels

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ABSTRACT

Three medium carbon low alloyed MnCrB cast steels containing different Cr contents (0.3%, 0.6%, and 1.2%) were designed and the effect of Cr contents on the microstructure, mechanical properties and high stress abrasive wear behavior of the cast steels after 850 °C air-cooling and 220 °C tempering was studied. The results show that the hardenability of the MnCrB cast steels was excellent. The microstructure of the cast steels with low Cr contents (0.3% or 0.6%) consists of granular bainite and lower bainite/martensite multiphase. With increasing of Cr content, the formability of martensite was improved, the hardness and wear-resistance increased, but the impact toughness decreased in that more bainite was replaced by martensite. The air-cooled MnCrB cast steel containing 0.6% Cr, with granular bainite and lower bainite/martensite multiphase, exhibited excellent combination of strength, hardness, ductility, and impact toughness. In addition, its abrasive wear-resistance was 30% more than that of Hadfield cast steel in the high stress abrasive wear condition. This air-cooled MnCrB cast steel by simple alloying scheme and heat treatment has the advantages of high-performance, low cost, and environmentally friendly. It is a potential advanced wear-resistant cast steel for low- or even medium-impact abrasive conditions.

1. Introduction

Cast steels are widely used in civilian industry such as lining board, toothed plate, hammer and other structural parts which require combination of strength, toughness and high stress abrasive wear-resistance. In the application fields of wear-resistant cast steels, Hadfield austenitic cast steel (Fe–1.2%C–13%Mn) is widely employed in that it has high impact toughness and wear-resistance caused by work hardening in high impact wear conditions [1–4]. However, in the fully austenitic solutionised form it is soft and ductile, and it may suffer considerable wear and deformation in that it is not work-harden easily under non- or low- impact wear conditions. The demands for producing higher strength steel castings with high impact toughness and wear-resistance have encouraged some researchers to focus on the martensitic steel [5–9]. Martensitic wear-resistant cast steel is usually employed with high carbon content and has high hardness and wear-resistance. Ball mill lining boards, toothed plates, and hammers made of martensitic cast steel are becoming more competitively than those made of Hadfield austenitic steel. However, the impact toughness of martensitic wear-resistant cast steel is low when the hardness is higher than 50HRC. This is the main obstacle for it to use widely to make wear-resistant steel castings. In addition, most of martensitic wear-resistant cast steels are alloyed with expensive elements (such as nickel, chromium and molybdenum) and oil-quenched in order to obtain high hardness. So, they are expensive and harmful to the environment. With the shortage of natural resources and the demand for sustainable development, research and development of high-performance low-cost wear-resistant cast steels with cheap elements and by environmentally friendly heat treatment are required. However, the elimination of nickel, chromium and molybdenum limits the hardenability of the cast steels, because of the difficulty to obtain martensite when the castings are large in diameter. In the case of steel castings, there is no process of deformation (such as forging and rolling). So the mechanical properties of castings mainly depend on the alloying scheme, cast process and heat treatment.

MnB steel is a kind of high-performance, low cost, and environmentally friendly air-hardened steel which has been researched and developed since 1970s. The former investigations were concentrated on the bainite transformation and the relationship between microstructure and mechanical properties of forged air-cooled MnB steel in low carbon contents [10–13]. The alloying

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elements of manganese and boron have significant effect on the hardenability of the low alloyed MnB steel in that granular bainite can form in the air-cooling process even in the low carbon content. In the MnB steel, the main alloying agent manganese is used to retard the pearlitic transformation and stabilize austenite during cooling, thus allowing a lower critical cooling rate to obtain good hardenability. Also, manganese solution-strengthens the matrix in the microstructure. Boron was used to improve the hardenability. In the low carbon MnB steel, the air-cooled microstructure is ferrite and granule bainite. With the increasing of carbon content, ferrite was replaced by bainite, and martensite comes into being. By this reckoning, one would expect medium carbon MnB cast steel to form bainite/martensite to obtain high wear-resistance. Mn and B are both segregation elements. In order to maintain good hardenability at low contents of Mn and B, a proper amount of Cr can be added to the MnB cast steel.

In the present work, the MnCrB wear-resistant cast steels were based on the design idea of simple alloying scheme and heat treatment. The wear-resistant cast steels were alloyed with manganese, chromium, and a little boron. The heat treatment was simple air-cooling and low temperature tempering. Three medium carbon MnCrB wear-resistant cast steels with differentcontents of Cr (0.3%, 0.6%, and 1.2%) were designed and the effect of Cr on microstructure, mechanical properties and high stress abrasive wear behavior was investigated.

2. Experimental procedures

In this study, the low alloyed MnCrB cast steels were manufactured by vacuum induction melting. Aluminum, titanium, and rare earth (Ce) were added to purify and refine the cast steels. In the addition process, Al, Ti, B, and Ce were added in sequence. The steels were cast into keel blocks. The chemical composition of the tested cast steels is listed in Table 1. The tensile, impact, and wear test samples were all taken form the keel blocks after 850 °C air-cooling (normalizing) and 220 °C tempering. In the heat treatment process, the keel blocks were first heated to 650 °C holding for 60 min, then austenitized at 850 °C for 50 min followed by air-cooling to room temperature, and then tempered at 220 °C for 150 min. The microstructure was characterized by scanning electron microscope (SEM) and transmission electron microscope (TEM). The hardenability of the cast steel was tested in accordance with ISO 642:1999 standards, where the austenization temperature was 850 °C. Ambient temperature uniaxial tensile properties were determined using 60 mm gage length cylindrical tensile bars in accordance with ISO 6892:1998 standards. Impact toughness were determined using standard sized non-notched specimens (10 mm × 10 mm × 55 mm), broken in a pendulum type impact machine of 300 J measurement range at room temperature.

A high stress three-body abrasive wear tester in which the wear mechanism is analogous to that of the lining boards and toothed plates was used to assess the abrasive wear-resistance of the MnCrB cast steels. Its scheme being is shown in Fig. 1. In every test, one test sample made of air-cooled MnCrB cast steel and one standard sample made of Hadfield cast steel were set on the tester at the same time. The load was 1 kg, the worn surface was 5 mm × 10 mm, the abrasive was brown corundum abrasive (aluminum oxide), and the test period was 0.5 h. The values of the wear weight loss of the test samples and the standard samples were determined for each of the test periods under the same conditions. The wear test was repeated three times for each kind of sample and its mean weight loss then calculated. The abrasive wear-resistance was represented by the relative wear-resistance, as weight loss of standard sample divide by weight loss of test sample.

Table 1
Chemical composition of the studied cast steels (in wt.%).

	C	Si	Mn	Cr	S	P	Al	Ti	B	Ce
No. 1	0.44	0.6–0.9	2.5–3.5	0.3	0.01	0.01	0.03–0.04	0.02–0.03	0.003–0.005	0.1–0.2
No. 2	0.43	0.6–0.9	2.5–3.5	0.6	0.01	0.01	0.03–0.04	0.02–0.03	0.003–0.005	0.1–0.2
No. 3	0.43	0.6–0.9	2.5–3.5	1.2	0.01	0.01	0.03–0.04	0.02–0.03	0.003–0.005	0.1–0.2

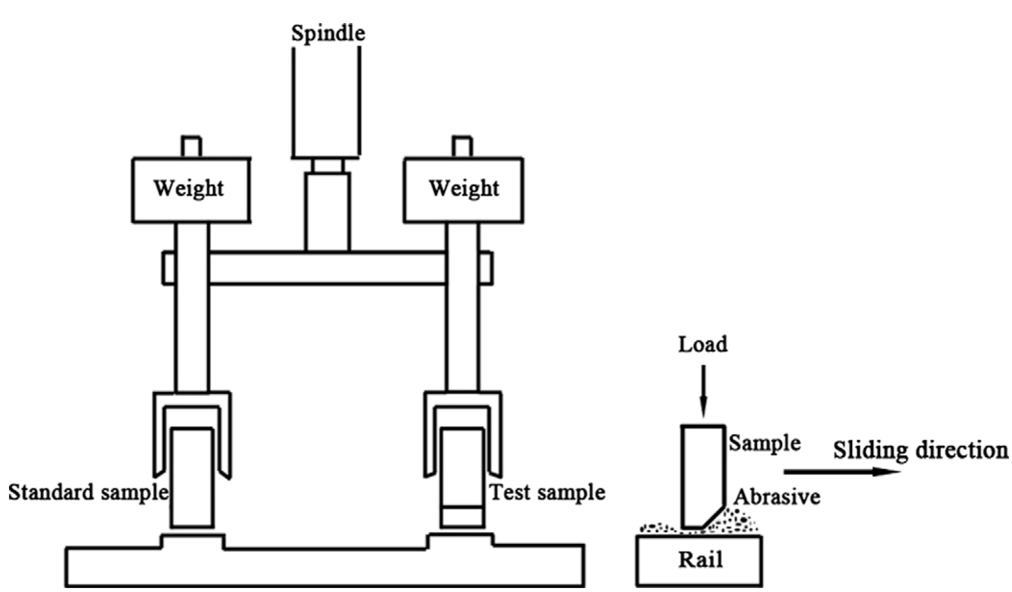

Fig. 1. Schematic diagram of the abrasive wear tester.