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Improvement in erosion-corrosion resistance of high-chromium cast irons by trace boron

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ABSTRACT

Extensive work was carried out to improve the performance of cast irons used for slurry transport in the oil sands industry. Because of complex condition of the multi-phase fluid containing oil sand particles, erosion-corrosion damage has long been an issue. High chromium cast irons (HCCIs) are currently used for slurry pumps, showing high resistance to sand-containing slurry erosion. However, further enhanced HCCIs are highly desired in order to more effectively reduce the damage to oil sand slurry transport facilities caused by erosion-corrosion for prolonged service life.

This study was focused on tailoring an existing HCCI used in the oil sands industry by adding trace boron. Microstructure and relevant properties of the modified cast irons were characterized and evaluated. It was demonstrated that trace boron markedly increased the resistance of the cast iron to slurry erosion. The mechanism responsible for the improvement was analyzed based on observed variations in microstructure and properties.

1. Introduction

Wear is one of the most predominant failure mechanisms for material loss in oil sands industry operations. The extreme wear conditions result from aggressive abrasion and impact caused by the large quantities of silica sand contained in the oil sand and its slurry [1]. In addition to the harsh wearing conditions, corrosion and consequently the synergistic attacks from mechanical and chemical actions considerably shorten the materials lifespan as well [2]. Synergistic erosion and corrosion or erosion-corrosion is the dominant wear mechanism for slurry handling in the oil sand industry [3].

High chromium cast irons (HCCIs) are widely used to resist abrasion and erosion in many industrial processes, such as mining, mineral processing and oil sand operations [4], due to their high hardness and appropriate balance between hardness and toughness, compared to conventional white cast irons [5], as well as high corrosion resistance [6]. The wear resistance of HCCIs results mainly from the high volume fraction of hard M_7C_3 carbides with high hardness and the supporting from tough metallic matrix [7]. HCCIs are classified according to ASTM A532 "Standard Specification for Abrasion-Resistant Cast Irons". Commercially used HCCIs have their compositions usually in the range of 12–27 wt% Cr and 2.4–3.6 wt% C, which process high wear resistance and widely used in slurry transport systems in the oil sands industry [1]. Most HCCIs used in oil sand industry for slurry pump casing and impellers fall into the composition range of 2.4–3.6 wt. % C and 25～27 wt. % Cr. However, this group of HCCIs does not always perform satisfactorily, due to the synergistic attack of oil sand particle erosion and aqueous corrosion [8].

Considerable work has been done to improve the wear resistance of HCCIs. In recent years, the oil sand mining industry intends to push the Cr and C contents to higher levels. The former increases hardness while the latter improves the corrosion resistance. A proper combination of the improvements could be suitable for specific wearing conditions. Such HCCIs with high concentrations of carbon and chromium were previously considered to be non-castable due to high rejection rate (rejected pieces/processed pieces) [9]. However, it has become possible to cast HCCIs with high concentrations of chromium and carbon with the advance in foundry techniques [1]. In our previous studies, HCCIs with 30 wt% to 45 wt% chromium were fabricated and demonstrated to be highly resistant to wear and corrosion [9,10]. Other effective approaches to enhance HCCIs wear and corrosion resistance include appropriate heat treatment and alloying with minor elements, such as boron, nickel, molybdenum, titanium, vanadium, to optimize microstructure [11]. Studies have demonstrated that adding boron is promising to improve the wear resistance of white cast irons [12]. Such improvement is ascribed to both elevated hardness and toughness, resulting from formed

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Table 1
Nominal compositions of HCCIs under study.

Sample no.	%Cr	%C	%B
#1	35	3	0
#2	35	3	0.12
#3	35	3	0.2
#4	35	3	0.4
#5	35	3	0.48
#6	35	3	0.6

boride phases and boron-doped carbide as well as microstructure modification [5,13]. However, few studies have been conducted to investigate the effect of boron on HCCIs' wear resistance, especially on the HCCIs with their chromium concentrations closer to the high end of Cr concentration range.

In this study, an existing HCCI with 35 wt% chromium and 3 wt% carbon for oil sand slurry handling was modified by adding trace boron. The objective of this study is to investigate how the trace boron affects microstructure and relevant properties, including resistance to sliding wear, high speed solid particle erosion, corrosion, erosion-corrosion, of the modified cast irons.

2. Materials and methods

2.1. Materials

Six HCCIs with nominal chemical compositions of 35 wt% chromium, 3 wt% carbon, and various concentrations of boron: 0, 0.12, 0.2, 0.4, 0.48, 0.6 wt%, respectively, balanced by iron were fabricated using an induction furnace. The molten metals were poured into copper molds to produce the samples. Table 1 gives nominal compositions of samples under study.

2.2. Characterization and testing

Microstructures of the samples were examined using a Scanning Electron Microscope (Zeiss Sigma 300 VP-FESEM). Worn surfaces after sliding wear, high-speed particle erosion, and slurry erosion tests were observed under a Scanning Electron Microscope (Tescan Vega 3 SEM, Czech Republic).

Hardness of the samples was measured using a Rockwell hardness tester (Zwick/Roell Rockwell/superficial Rockwell hardness tester, Indentec Hardness Testing Machine Limited, UK) under a load of 60 kgf with a diamond cone indenter.

Sliding wear tests were performed on a pin-on-disc tribometer (CSEM Instruments, Neuchatel, Switzerland) based on ASTM G 99 "Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus". The disc was the sample under study and the pin was a silicon nitride ball with 6mm diameter. All tests were performed at a sliding speed of 1 cm/s along a circle path of 2.0 mm in diameter under a normal load of 10 N for a sliding distance of 36 m. Wear tracks and corresponding volume losses of the samples were determined using a confocal microscope (ZeGage 3D optical profilemeter, Zygo Corp.).

High-speed solid particle erosion tests were carried out using a home-made air-jet erosion tester [14] based on ASTM G 76 "Standard Test Method for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jets" (Fig. 1(a)). The erosion tests were performed at an impingement angle of 90 °and a dry air flow with a pressure of 40 psi was used to eject sand particles to sample surface (corresponding sand flow speed: 55 m/s). Erosion at an impingement angle of 90° usually results in more damage to less tough materials, thus it more or less reflects the toughness of the samples. AFS 50/70 sand (U.S. Silica Company, USA) was used as the erodent particle. The sample mass was measured before and after the tests using a balance with a precision of 0.1 mg. Each test was repeated at least 3 times.

The erosion–corrosion tests were carried out using a home-made slurry-pot tester (Fig. 1(b)). Guidelines for erosion-corrosion tests in slurry can be found in STP946 "Slurry Erosion: Uses, Applications, and Test Methods". The tester had a cylindrical tank of 29 cm in diameter and 22 cm in height. A slurry solution containing 1.5 L silica sand (500 µm in diameter) and 6 L water was placed in the slurry container. Samples were held by a holder, which was rotated during erosion test, thus driving the samples to move in the slurry. The angle between sample surface and the moving direction was kept at 45 °and the moving velocity of samples in the slurry was 8 m/s. For each slurry erosion test, the total distance over which the sample travelled in the slurry was 15 km. After test, corrosion products were removed by rinsing and light brushing, and the samples were finally cleaned by rinsing with distilled water. The weight loss of each sample was then

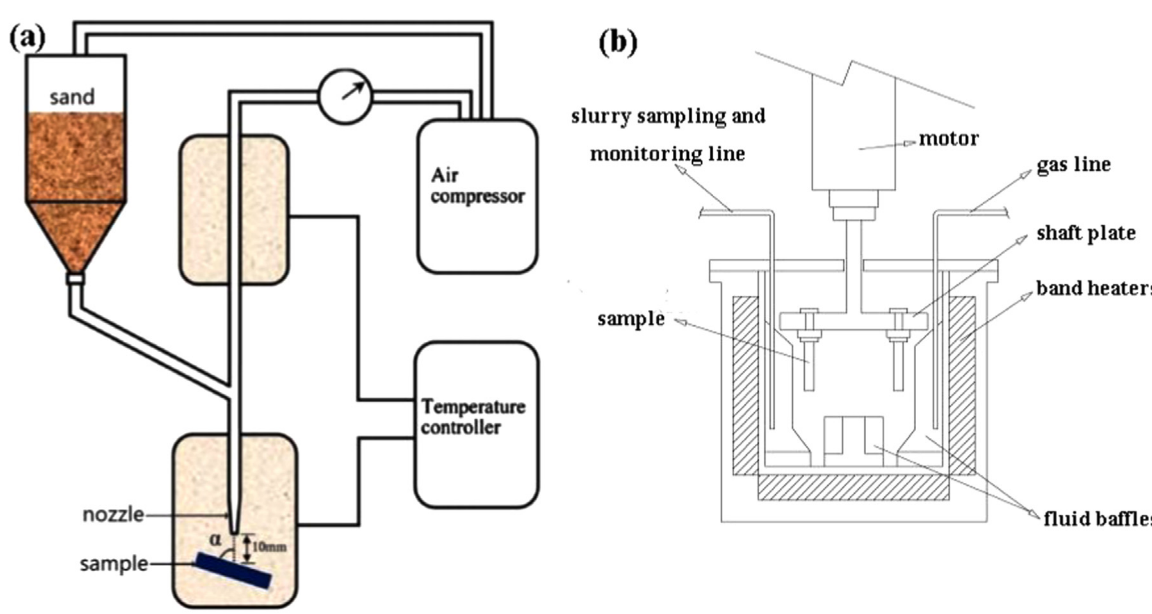

Fig. 1. Schematic illustrations of (a) air-jet erosion tester used for high-speed solid particle erosion tests, and (b) slurry-pot tester used for erosion-corrosion tests.