Abrasion Wear Properties of Low Cement Castable with Boron Addition

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Three low cement castables with silicon carbide and boron compound addition, which are commonly used for the high abrasive resistance applications, were compared by using a hot blast abrasion test at various temperatures. Relative results were compared in terms of physical, mechanical and abrasive properties of concrete. Abrasion wear rate of carbide containing concrete is highly dependent on the dense layer and retards the oxidation of carbide at high temperature. It was concluded that the boron compound containing castable with a layer of dense glassy phase on concrete surface was observed to exhibit the lowest rate of abrasion wear in a hot abrasion test at 1200 °C. The glassy layer on concrete acts also as a barrier for oxidation protection as during the hot abrasion test after several cycles the abrasion rates were progressively reduced by the dense structure on concrete.

1 Introduction

Boron and silicon carbide are important non-oxide ceramic materials, which have diverse industrial applications. They have exclusive properties such as high mechanical strength and erosion resistance over a wide temperature range. All these properties qualify them as a perfect candidate for abrasion resistance applications. Silicon carbide additions to low cement castable were commonly used in steel and cement industry especially where high particulate erosion take places [1].

Abrasion is one of the most deleterious mechanisms for refractory monolithics and it is shortening the life of refractory linings. One of the key properties for high abrasion resistance of refractory is a dense structure. Surface properties are also very important especially for carbide phase containing castables, which may have different surface morphology because of the oxidation in working condition. The surface oxidation rate and penetration depth are related to the bond strength at high temperature. Some researchs were carried out to increase densification of low cement castable by doping of some additives [2–5]. Especially boron compound addition showed promising results for densification of alumina based castable because of the alumina boron glass phase formation at low temperature. [3, 4]. In addition to boron compound, silicon carbide also forms a silicon oxide coating on the low cement castable in air at high temperatures, which improve abrasion resistance at elevated temperatures.

In the present study, properties of low cement castables with boron compound and silicon carbide addition were investigated at various temperatures. Hot abrasion properties of low cement castables with additives were investigated by hot abrasion tests to determine the factors related to refractory erosion at high temperatures. Castables with different additives were also exposured to cyclic hot abrasion tests at 1200 °C to simulate erosion behavior in working conditions.

2 Experimental procedure

SiC and boron compound containing low cement castable were studied in the present work. The samples were prepared by using rotary bauxite as an aggregate with a maximum particle size of 6 mm, and the matrix composed of fine fractions of the rotary bauxite, fused alumina, 4 mass-% of the calcium aluminate cement (Secar 71/Kerneos) and 5 mass-% of fume silica (Elkem 968U). The castable was mixed with 5 mass-% of water (dry basis). 10 mass-% SiC (V 170S) and boron compounds (V 170B) were substituted with rotary bauxite in castable (V 170).

The samples were casted into 230 mm × 115 mm × 65 mm cubic moulds. The casted body were demolded after 24 h at room temperature and then dried for 24 h at 110 °C. The dried samples were cut into 115 mm × 115 mm × 65 mm size, then placed in abrasion test furnace and then heated up to erosion test temperatures at a heating rate of 6 °C/min in air. Blast erosion tests on casted samples were carried out at 110 °C, 400 °C, 800 °C and 1200 °C in air atmosphere according to ISO/TC 33 N 891 standards. The test parameters are given elsewhere [6]. The casted samples after firing were characterized by bulk density (BD), apparent porosity (AP), and cold compression strength (CCS) according to ASTM standard C 830 and C 133.

3 Results and discussion

The AP and CCS of all samples were tested at different temperatures as shown in Fig. 1. The AP of all samples shows similar trends

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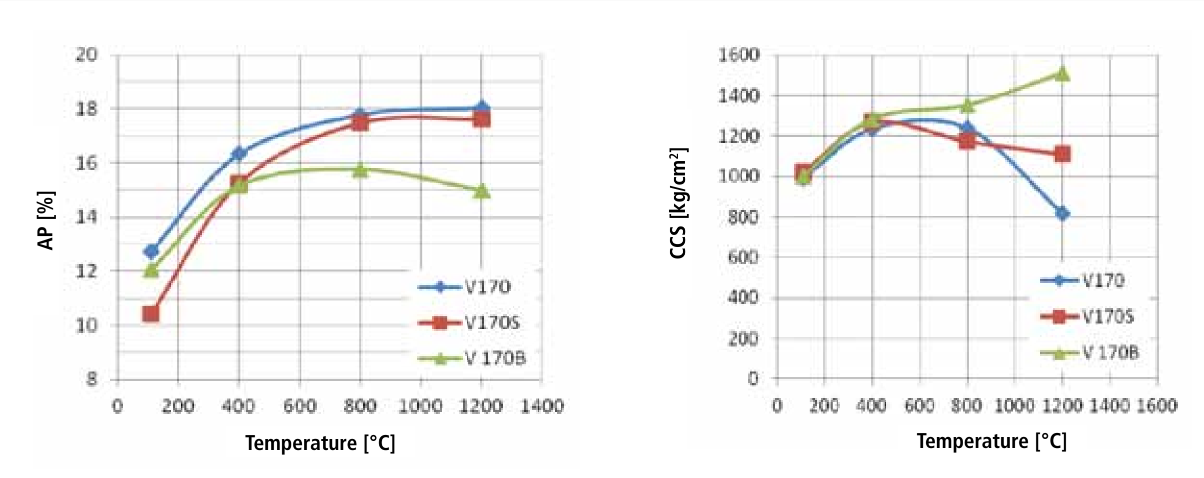

Fig. 1 AP and CCS values of castable after firing at different temperatures

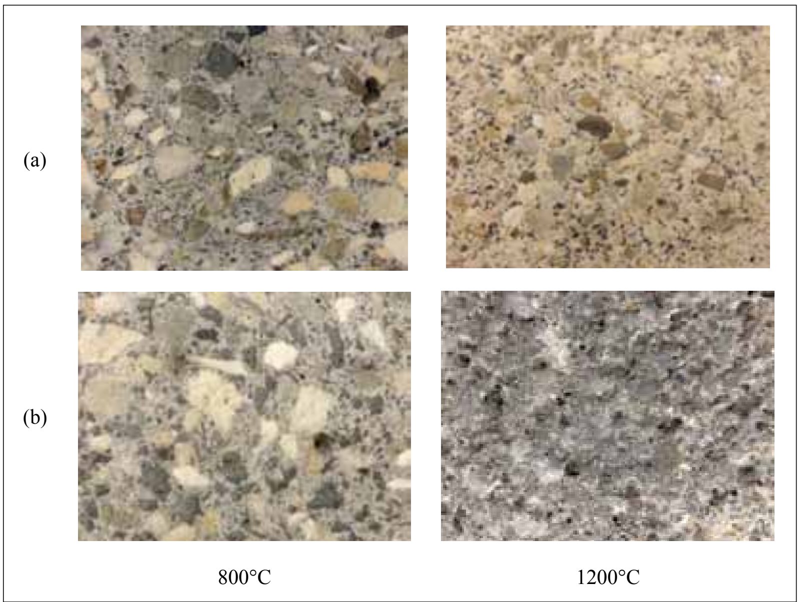

Fig. 2 The eroded surface view of V 170S (a) and V 170 B (b) samples after hot abrasion test at 800 °C and 1200 °C

with increasing temperatures. The V 170B have remarkable decrease in AP after 800 °C. It might be due to do low temperature melting behavior of boron compounds which may behave as pore filler in concrete. The CCS values of all concretes increases with increasing firing temperatures up to 800 °C. V 170B showed higher CCS values than the other samples after 800 °C. This results indicates that boron compound behave as a low temperature sintering agent. Boric acid in boron compounds have low melting temperatures (450 °C) and it may cause low melting alumino borate compounds which are started to form at 600 °C [7]. The similar trend is observed for V 170S but it has lower CCS than V 170 at 800 °C. SiC may adversely affect bonding strength at lower temperatures.

Fig. 2 shows a sample surface view after abrasion test at 800 °C and 1200 °C. After in situ sintering and erosion test at 800 °C, the abrasion surface of all samples shows similar appearance. There are very thin abrasion layers and pinholes, which were flaked off on the eroded surface. Apart from the other samples, V 170B has a dense glassy surface layer was formed after sintering at 1200 °C. The boron compound additive causes boron glass on the surface of V 170B samples.

The cross section view of samples heated at the temperatures 1200 °C for 3 h are shown in Fig. 3. During the hot abrasion test at 1200 °C, the SiC particles on the surface of V 170S were burnt out and decompose to solid SiO_2 and a volatile gaseous CO/CO_2 product [8, 9]. The depth of oxidized area is about 6–8 mm. During oxidation of SiC, free silicon oxide contributes to the development of the silicate bond, which may form a abrasive resistance surface. V 170B samples have a denser glassy surface than V 170S, which is about 0,5–1 mm in depth. The oxidation resistance characteristics of boron compound added castable might be due to the formation of a protective oxidation film rather than to the inherent oxidation resistance of the underlying particles. Boron compounds react with alumina and silica to get glassy phase, which protects from a further oxidation on the surface at high temperatures.

Fig. 4 shows the hot abrasion test results of the samples. All samples showed similar abrasion loss up to 400 °C. It might be due to hydraulic bond strength at low temperatures. V 170 samples with low cement addition have very low abrasion loss at 110 °C. A hydraulic bond is very effective at 110 °C. When the abrasion test temperature was increased from 400 °C to 800 °C, decrease begin in the abrasion loss for all samples due to the ceramic bond formation. However, there is a sharp decrease in the abrasion loss for V 170B sample showed 1,32 cm^3 abrasion loss at 800 °C.

It might be due to the formation of a dense phase at the surface. The hot abrasion test results of V 170, V 170S and V 170 B samples showed 1,48, 1,24 and 0,96 cm^3 abrasion losses respectively at 1200 °C. The V 170S sample with SiC addition showed higher abrasion resistance than V 170 at 1200 °C.

Apparent porosity is related to the sintering degree and densification of the material. The lower porosity refers to high crushing strength and low abrasion resistance. Generally, there is a linear correlation between mechanical properties and abrasion wear [10]. However, the correlation depends on the bond type of concrete in the certain temperature ranges. The erosion rate is decreasing with the decreasing CCS value for V 170 and V 170S at high temperatures. It might be due to the transformation from hydraulic to ceramic bond in the concrete with increasing temperature. Samples have high values of CCS characteristics at low temperatures (<400 °C) due to formation of a hydraulic bond. However, samples treated at high temperatures (>800 °C) have lower CCS but show higher abrasion resistance due to the formation of a ceramic bond. The cement bond could not develop enough strength to bond refractory aggregates in castables at low temperatures. This could be reduced by interface bonding between aggregates. The SiC containing sample behaves similarly to the V 170 samples because of the oxidation of the outer surface at high temperatures. But concrete with boron compound addition showed a different behavior. V 170B has the lowest AP and highest CCS values with the lowest abrasion loss at 1200 °C. It might be due to the alumino borate formation, which tends to form needle-shaped crystals [11, 12]. The micro structural characteristics of alumino borate phase suggest that it could be helpful for low abrasion resistance at higher temperature. Furthermore, boron glass has low melting temperatures and forms a liquid state during the abrasion test at 1200 °C and may behave like a shock absorber during abrasion test at elevated temperatures.

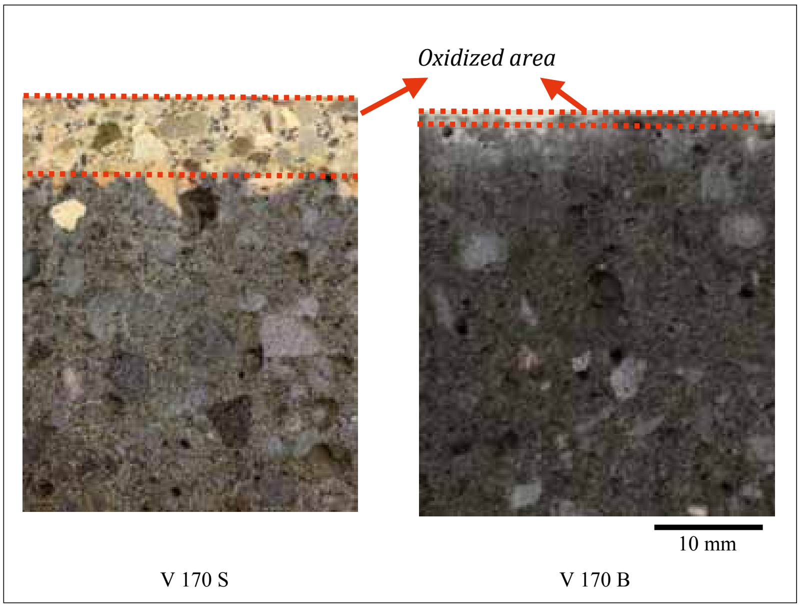

Fig. 3 Cross section views of samples after blast abrasion test at 1200 °C

The abrasion wears of carbide containing castables with repeated abrasion cycles is shown in Fig. 5. The boron compound added sample (V 170B) shows very stable abrasion resistance after a first cycle at 1200 °C. During first abrasion test, the glassy surface was broken and then a denser and strengthened matrix shows higher erosion resistance. There might be also a self sealing effect due to the formation of a boron glass phase. Whereas, the SiC containing castable shows decreasing abrasion loss with increasing cycles. The effect of SiC on the abrasion resistance is obscured by the oxidation of SiC in hot abrasion cycles.

4 Conclusions

Hot abrasion wear properties of low cement castable with silicon carbide and boron compound addition were investigated. The bond type and strength is very important for particle hardness in the castable for high abrasion resistance. A ceramic bond shows higher abrasion resistance than a hydraulic bond. Low temperature sintering agents are helpful to get high abrasion resistance at lower temperature. The results show that the

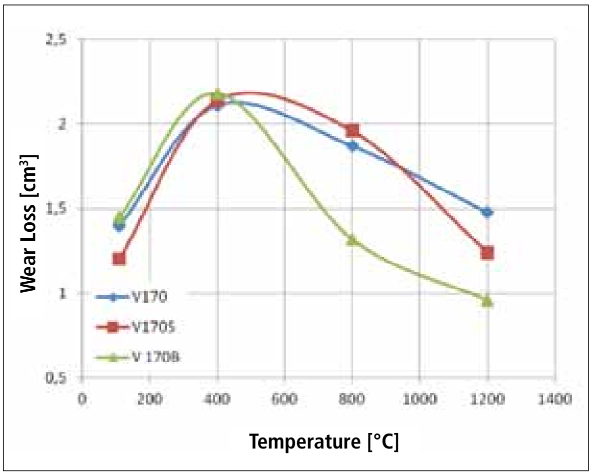

Fig. 4 In situ hot abrasion loss of samples at different temperatures

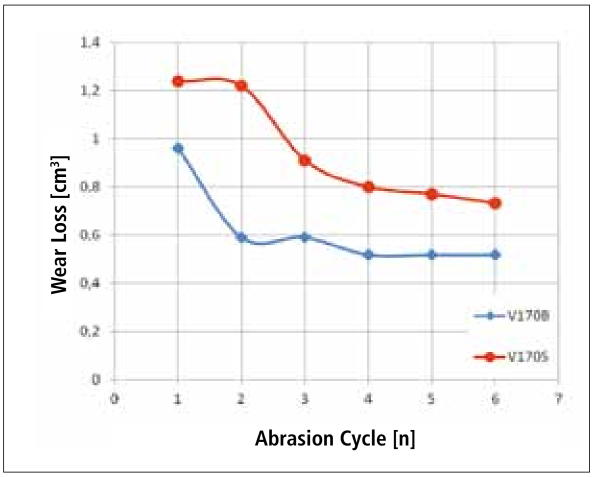

Fig. 5 Hot abrasion loss of samples with abrasion cycles at 1200 °C

concrete strength and abrasion resistance was increased at lower temperatures by the addition of boron compounds in concretes. Boron compound addition to castables causes dense structure in the concrete. This study shows that the addition of silicon carbide and boron compounds to low cement castable is able to increase abrasion resistance at elevated temperatures. However the effect of SiC particles on the abrasion resistance is obscured by oxidizing SiC particles on the surface. Boron compound addition to the SiC containing castable may help to prevent surface oxidation of SiC in concretes at elevated temperatures.

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