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Incorporating Zr combined Si and C to achieve self-repairing ability and enhancement of silica sol bonded SiC castables

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ABSTRACT

SiC based refractory is an environment-friendly lining material for high-temperature solid waste gasifier and urgently required longer service life. In this paper, the efficiency of silica sol bonded SiC castables introducing different amounts of Zr combined Si and C was evaluated by considering their sintered properties, mechanical performance, isothermal oxidation behavior, microstructure, and thermodynamics. It was found that the oxidation of SiC castables follows a two-stage kinetic model, controlled by oxidation (rate constant k_c) at an earlier period and diffusion (rate constant k_d) at a later period. Incorporating Zr distinctly slower oxidation rate of the Si containing SiC castables and the k_c and k_d were reduced by 18.9% and 9.2% with addition of 0.6 wt% Zr, respectively, compared to the unmodified sample. The Zr-modified SiC castables exhibited good mechanical behavior, increased bulk density, and reduced porosity. The oxidation of Zr to ZrO_2 reduced the diffusion path and concentration of O_2, which prevented the loss of SiC and C by forming SiC fibers and reducing CO(g) to graphite, helped absorb SiO_2 to form $ZrSiO_4$. It made the SiC castable a self-repairing and enhanced refractory material.

1. Introduction

A high-temperature solid waste gasifier is preferred for the treatment of solid hazardous wastes [1] (e.g., medical and electronic wastes) as it avoids the formation of noxious chemicals such as heavy metals [2,3], polycyclic aromatic hydrocarbons [4], and dioxins [5,6] in the ash owing to its high operating temperature (over 1500 °C around the torch) [7]. However, such high operating temperatures impose strict demands on the lining refractory of the gasifier such as the requirement of high thermal stress and slag resistances. Silicon carbide (SiC) is an important ceramic material which possesses many excellent properties such as a high melting point (2827 °C), high hardness, high abrasion resistance, good chemical and radiation resistance, high thermal conductivity with a low thermal expansion coefficient, and an excellent thermal shock resistance [8–15]. Compared to a spinel castable containing 20 wt% of Cr_2O_3, the silica sol bonded SiC castable exhibits excellent properties at high temperature and has demonstrated potential for application in a high-temperature solid waste gasifier as a refractory lining material [16]. However, SiC is easily oxidized to SiO_2 at a high temperature and the mismatch of thermal expansion coefficients of SiC and SiO_2 is likely to cause cracks under frequent thermal cycling conditions. Furthermore, the presence of the extra glass state SiO_2 has a negative effect on the mechanical behavior of the material. Thus, the loss of SiC as SiO_2 in the castable generally results in its degradation.

Therefore, it is necessary to improve the oxidation resistance of SiC materials for use in a high-temperature solid waste gasifier. Borosilicates have been used as an oxidation resistance coating to improve the anti-oxidation ability of the SiC materials. B_2O_3 possesses good fluidity at 600–1000 °C, which can fill the pores to prevent the diffusion of O_2. However, this strategy fails owing to the strong volatility of B_2O_3 at temperatures higher than 1100 °C [17–19]. Wu et al. [20] have coated Cr_3Si-Cr_7C_3 on the surface of C/SiC composite materials, as Cr_2O_3 is formed at high temperatures and helps prevent further oxidation. Nevertheless, it is a significant step towards development if refractories are “chrome-free”. Xiang et al. [21] have prepared a ZrC/SiC coating on the surface of C/SiC materials to improve the anti-oxidation ability of the refractory lining. In this case, ZrC was oxidized to ZrO_2 to reduce ignition lost obviously. Based on thermodynamic analysis, this article focuses on preventing the depletion of SiC through the reducing of oxygen. The diffusion path of oxygen into the inner structure of a silica sol

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Table 1
Experimental formula.

Raw materials (wt%)		A0	A1	A2	A3
SiC	5-3 mm	15	15	15	15
	3-1 mm	32	32	32	32
	1-0 mm	23	23	23	23
	≤0.088 mm	25	25	25	25
Si		1	1	1	1
Carbon black		1	1	1	1
SiO_2 micropowder		3	3	3	3
Zr (extra)		0	0.3	0.6	0.9
Silica sol (extra)		8	8	8	8

bonded SiC castable can be reduced by introducing a combination of Zr, Si, and C into the material. The mechanical performance and oxidation behavior of SiC castables containing different amounts of Zr were evaluated and it was expected that such a SiC refractory lining would be enhanced and achieve self-repairing ability.

2. Materials and methods

Silica sol bonded SiC castables containing different amounts of Zr was prepared. SiC (5-3 mm, 3-1 mm, 1-0 mm and ≤0.088 mm, Henan Ming Maite New Material Technology Co., Ltd., China), Zr

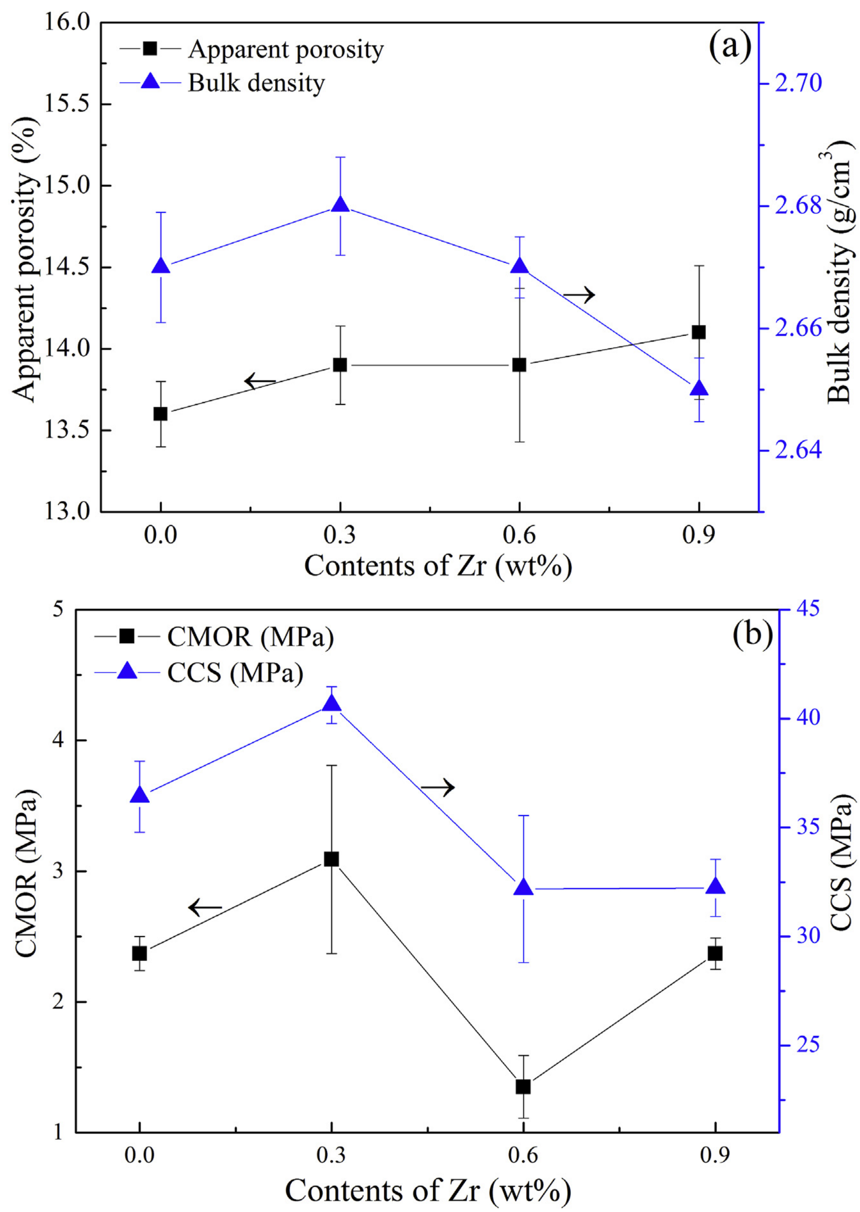

Fig. 1. Properties of castables after curing at 110 °C for 3 h. (a) Apparent porosity and bulk density and (b) CMOR and CCS values.