EFFECTS OF MICROSILICA CONTENT ON THE PERFORMANCES OF LIGHTWEIGHT CASTABLES CONTAINING POROUS PERICLASE-SPINEL AGGREGATES

WEN YAN#, NAN LI, BINGQIANG HAN, XUANMING FANG AND GUANGPING LIU

The Key State Laboratory Breeding Base of Refractories and Ceramics,
Wuhan University of Science and Technology, China

#Corresponding author, e-mail: yanwenref@yahoo.com.cn

Submitted May 21, 2010; accepted October 16, 2010

Keywords: Microsilica, Castable, Porous periclase-spinel, Strength, Slag resistance

Five lightweight castables containing the same porous periclase-spinel aggregates and different matrices were fabricated successfully. Effects of microsilica content on the porosity, strength and slag resistance of lightweight castables were investigated through the mercury porosimetry measurement, XRD, SEM, EDAX, and so on. It's found that microsilica makes the matrix more densification and induces the pore growth through increasing the sinterability, and makes the penetrated slag high viscosity through reacting with slag, and then strongly affects the performances. When the microsilica content is 3.2 wt.%, the castable containing porous periclase-spinel aggregates has the best performance, which has a porosity of 24 %, a crushing strength of 90 MPa, a flexural strength of 22 MPa and a high slag resistance.

INTRODUCTION

Users and manufacturers of refractories traditionally devote much attention to the reaction between the refractory and slag, in order to improve slag resistance and prolong the service life of the refractory [1]. Recently, with increased demand for saving energy, more attention has been paid to lightweight refractories. Traditionally lightweight refractories are mainly consisted of Al_2O_3–SiO_2 materials, which are acidic and have low strength, can't be used as working line in ladle [2, 3]. Basic lightweight refractories with high strength and high slag resistance are required.

Al_2O_3-MgO refractories castables have been widely used as work line in ladle due to its excellent properties and easy installation [1, 4-9], and the lightweight Al_2O_3–MgO refractories have been studied [10, 11]. Usually, increasing strength of aggregates is beneficial to increasing strength of castable. The porosity and the pore size distribution affect the strength of aggregates. Smaller pore size and homogenous pore distribution are thought to be helpful to improve the strength of aggregates. Yan et al optimized pore structures to improve the mechanical properties of the porous periclase spinel, spinel, and corundum-spinel ceramics, and prepared high-strength lightweight castables containing the porous corundum-spinel aggregates [10, 11].

The corrosion mechanisms of traditionally dense alumina-magnesia refractories by slag have been studied. The corrosion and penetration resistance of the castables depend on the castables' composition distribution and microstructure and the reaction between the slag and the castables. [1, 4-9]. Diaz et al [5] found that the reaction between the slag and the high alumina castables made the slag SiO_2 rich and more viscous, thus inhibiting the slag further penetration.

The slag resistance of lightweight alumina-magnesia refractories could be enhanced through changing their phase composition distribution and microstructure and the reaction between the slag and the refractories [12-14]. The corrosion and penetration resistances of porous spinel with small pore size were investigated and the porous spinels with high slag resistance were obtained [12]. The slag resistances of castables containing porous corundum-spinel aggregates were studied, and the lightweight castables with high slag resistance were prepared [13, 14].

Monolithic refractories are now widely used in steel-making, and microsilica is a common binder since it can reduce water demand for placement, improve matrix sintering and increase the viscosity of the penetrating slag [11, 13, 15-17]. All these effects have been proved beneficial to the improved slag resistance and the enhanced strength of castables using dense aggregates and porous corundum-spinel aggregates. But the effects of microsilica on the slag resistance and the strength of castables using porous periclase-spinel aggregates still have not been fully understood. These will be addressed in the present paper.

EXPERIMENTAL

Five kinds of lightweight periclase-spinel castables containing different microsilica content were prepared by using lightweight periclase-spinel as aggregate and white corundum powder, spinel powder (90 wt.% Al_2O_3), magnesia powder, α-Al_2O_3 micropowder and microsilica as matrix. The chemical compositions and properties of aggregate were listed in Table 1. The microstructure of aggregate was shown in Figure 1. Microsilica contents in the samples were listed in Table 2. Compositions of the matrices in samples and the slag were listed in Table 3. Particle-size distribution of aggregates, aggregate content (66.6 wt.%), matrix content (33.4 wt.%) and water content (9.0 wt.%) were similar for all batches of castables. Five castables were named as A, B, C, D and E according to their different matrices, respectively. The rectangle parallelepiped specimens with the size of 125 mm length × 25mm width × 25 mm thickness were casted for the porosity, density and strength measurement. The cubic crucibles in which there is a hole with diameter of 30 mm and depth of 40 mm were casted for the slag resistance testing. The castables were cured for 24 h at room temperature, dried at 110°C for 24 h. And then the rectangle parallelepiped specimens and the crucibles filled with 30 g slag were heated at 1600ºC for 3 h, and then furnace-cooled.

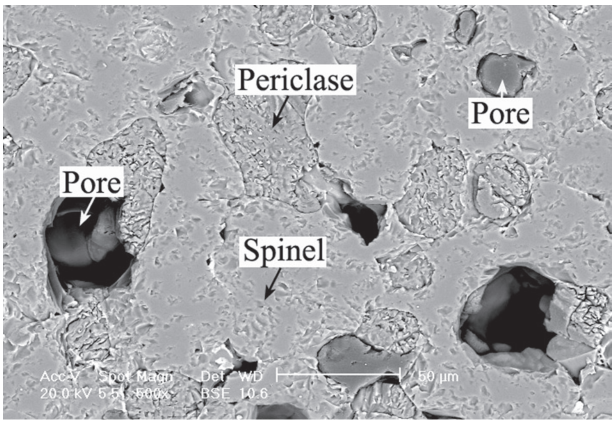

Figure 1. Microstructure of porous periclase-spinel aggregate.

Table 2. Microsilica content added in the samples (wt.%).

A	B	C	D	E
0.8	1.6	2.4	3.2	4.0

Table 3. Compositions of the matrices in the samples and the slag.

	Chemical compositions of five matrices and the slag (wt.%)					
Matrix	Al_2O_3	MgO	SiO_2	CaO	TiO_2	Fe_2O_3
A	80.93	16.69	2.07	0.15	–	0.16
B	79.43	16.39	3.88	0.15	–	0.15
C	77.99	16.09	5.63	0.14	–	0.15
D	76.60	15.80	7.31	0.14	–	0.15
E	75.26	15.53	8.93	0.14	–	0.14
Slag	9.04	9.18	31.50	44.83	1.15	3.86

After corrosion testing, crucibles were cross-sectioned perpendicularly to the slag-refractory interface. The actual corroded and penetrated areas in each sample were measured by counting pixels method. Corrosion here is defined as regions of refractory completely replaced by slag. The corrosion index I_C and penetration index I_P are obtained by following equation: $I_C(_P) = S_C(_P)/S_O \times \times 100$ (%); S_O is the original section area of the crucible inner chamber; S_C is the section area of refractory completely replaced by slag; S_P is the penetrated section area.

Apparent porosity and bulk density of castables was detected by Archimedes' Principle with kerosene as medium. The crushing strength and flexural strength at room temperature were measured. The flexural strength (25 mm × 25 mm × 125 mm) were measured with a span length of 100mm and crosshead speed of 1 mm/min. Phase analysis was carried out by X-ray diffractometer (Philips Xpert TMP) with a scanning speed of 2º per minute. Cumulative porous volume and average pore size of matrices were measured by the mercury porosimetry measurement (AutoPore IV 9500, Micromeritics Instrument Corporation). The liquid phase content of matrices was calculated from the Equilib mode of MgO–Al_2O_3––SiO_2–CaO–Fe_2O_3 system by the FactSage 6.1 thermochemcial software. Microstructure and glass phase composition were measured by scanning electron microscopy with EDAX (Philips XL30). The viscosities of penetrated slag are calculated from model Riboud [18] based on the glass phase composition obtained by EDAX.

Table 1. Chemical compositions, mineral phases, properties of porous periclase-spinel aggregate.

Chemical composition (wt.%)					Average pore size (μm)	Bulk density (g/cm^3)	Apparent porosity (%)	Mineral phases
Al_2O_3	MgO	SiO_2	CaO	TFe				
57.63	39.66	0.69	0.32	0.16	13.26	2.97	16.1	Periclase, Spinel

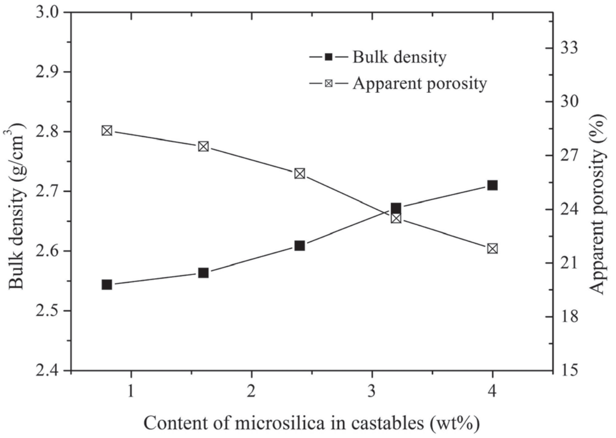

Figure 2. Bulk density and apparent porosity versus microsilica content in castables sintered at 1600°C.

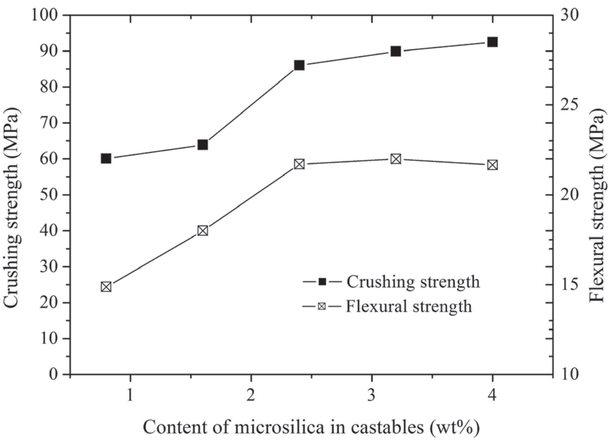

Figure 3. Crushing strength and flexural strength versus microsilica content in castables.

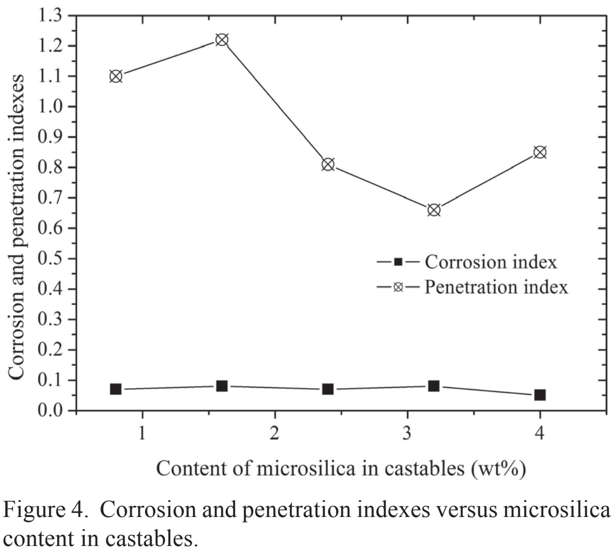

Figure 4. Corrosion and penetration indexes versus microsilica content in castables.

RESULTS

The apparent porosity and bulk density of castables sintered at 1600°C is given in Figure 2. With an increase in microsilica content, the apparent porosity decreases, and the bulk density increases. The crushing strength and flexural strength of castables sintered at 1600ºC is shown in Figure 3. With an increase in microsilica content from 0.8~2.4 wt.%, the crushing strength and flexural strength increases obviously. But with a further increase from 2.4~4.0 wt.%, the crushing strength and flexural strength changes slightly.

The slag corrosion and penetration indexes are shown in Figure 4. It can be seen, with an increase in microsilica content, the corrosion index changes little. But with an increase in microsilica content from 0.8~3.2 wt%, the penetration index decreases, and the penetration index is the minimum when the microsilica content is 3.2 wt.%; with a further increase in microsilica content to 4.0 wt.%, the penetration index increases sharply.

Comprehensive considering the porosity, strength and slag resistance, the castable containing 3.2 wt.% microsilica has the best performance, which has a porosity of 24 %, a crushing strength of 90 MPa, a flexural strength of 22 MPa and a high slag resistance.

DISCUSSION

Microsilica increases the strength and the slag resistance through promoting sinterability and resulting in high viscosity slag penetrated.

Figure 5 gives the XRD analysis of five castables and Figure 6 shows the liquid content of matrices in castables at 1600°C. It can be seen, some microsilica reacts with MgO to form olivine, and other microsilica reacts with refractory to form liquid phase at 1600°C.

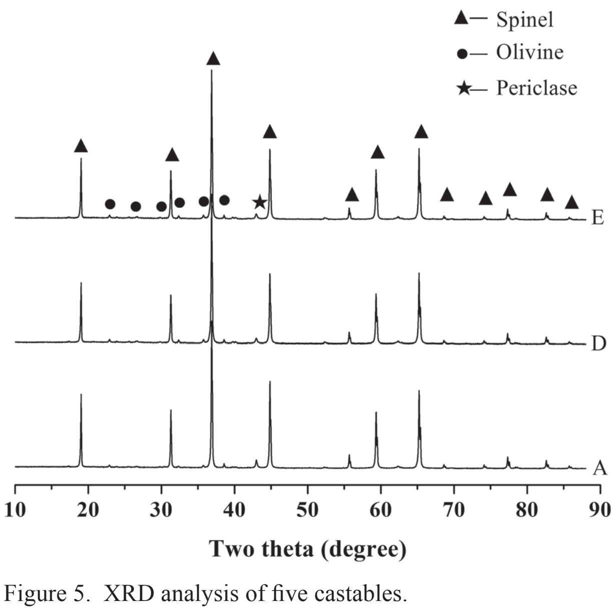

Figure 5. XRD analysis of five castables.

With an increase in microsilica content, the liquid phase content of matrices in castables increases sharply. More liquid phase is formed, more densification the matrix becomes, as shown in Figure 7. These are why the strength increase sharply with the increase in microsilica content from 0.8~2.4 wt.%. The strength changes little with the further increase in microsilica content from 2.4~4.0 wt.%, which may be attributed to the increasing average pore size of matrix, as shown in Figure 8, because bigger pore size are thought to be adverse to improve the strength of aggregates [10].

The changing slag resistance of castables affected by microsilica content is attributed to three factors:

1. Microsilica increases the sinterability, and makes the matrix more densification (Figure 7), which inhibits the slag penetration.
2. Microsilica increases the sinterability, and makes the pore growth (Figure 8), which facilitate the slag penetration.
3. Microsilica reacts with penetrated slag, and makes the slag high viscosity. As shown in Figure 9 and Table 4, at the same depth from hot face to inside of matrices in castable A and D, the viscosity of slag penetrated in castable A is obviously lower than those in castable D, because the microsilica content and the liquid content (Figure 6) in matrices A are less than those in matrices D.

When the microsilica content is less than 3.2 wt.%, the factors (1) and (3) are more significant than the factor (2), the slag resistance increases with the increase in microsilica content. But when the microsilica content is more than 3.2 wt.%, the factor (2) is predominant, and then the penetration resistance of castable E decreases. Thus the castable D with 3.2 wt% microsilica content has the best slag resistance.

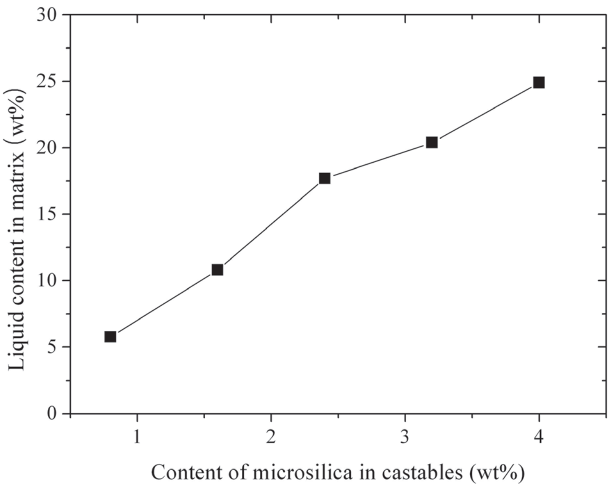

Figure 6. Content of liquid phase in matrices.

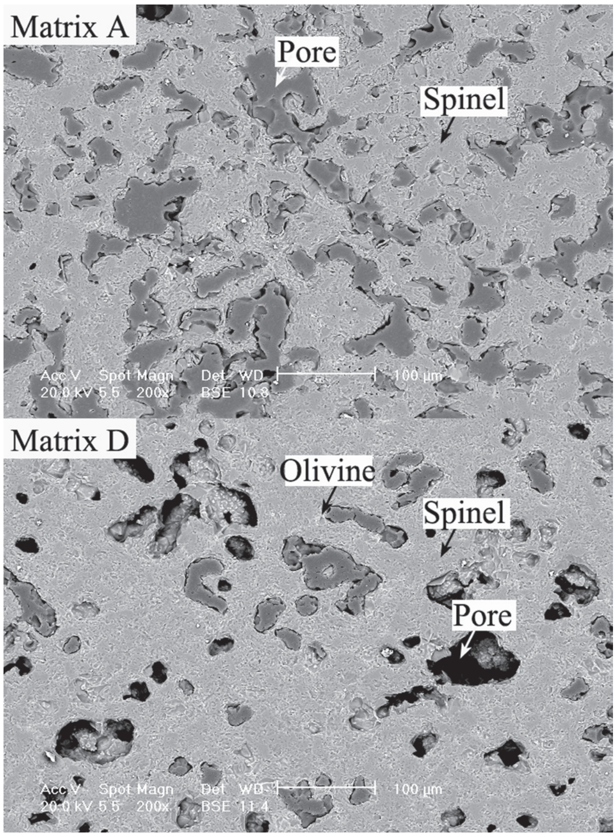

Figure 7. Typical microstructures of matrix A and D.

Table 4. EDS results and viscosities at 1600°C of glass phase in Figure 9.

		1	2	3	4	5	6	7	8
EDS result (wt.%)	Na_2O	0.84	1.15	0.68	0.51	0.00	0.00	0.97	0.44
	MgO	2.12	2.29	2.61	7.13	2.90	1.77	3.06	2.49
	Al_2O_3	31.53	28.21	26.85	9.35	25.19	27.12	25.01	16.45
	SiO_2	26.77	27.18	31.08	26.54	37.93	37.53	39.33	40.70
	CaO	38.74	41.18	38.77	38.54	31.97	32.04	29.01	32.21
	TiO_2	0.00	0.00	0.00	14.18	0.00	0.00	0.00	4.52
	Fe_2O_3	0.00	0.00	0.00	3.73	0.00	0.00	2.63	3.19
	MnO	0.00	0.00	0.00	0.00	2.01	1.54	0.00	0.00
Viscosity (Pa·s)		0.53	0.36	0.51	0.19	1.05	1.31	1.24	0.93

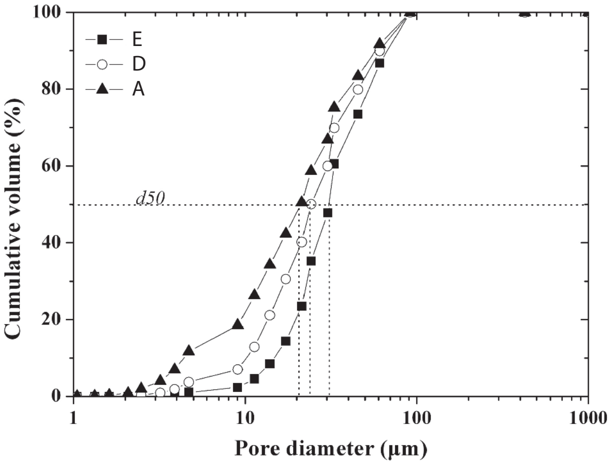

Figure 8. Cumulative porous volume (%) of matrix A, D and E as a function of pore size.

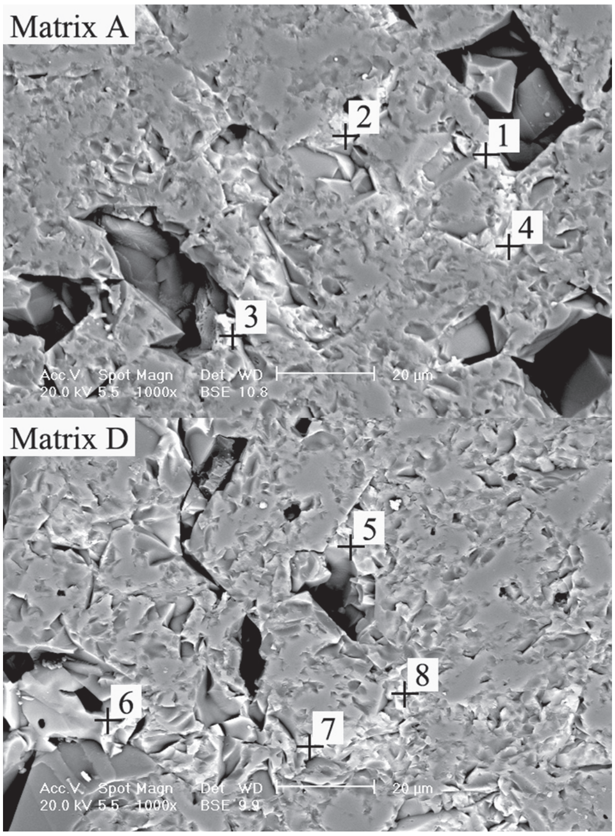

Figure 9. Typical SEM micrographs of matrices of corroded castables A and D at the same depth from hot face to inside.

CONCLUSIONS

Five lightweight castables containing same porous periclase-spinel aggregates and different microsilica content were fabricated successfully. It's found that microsilica makes the matrix more densification and induces the pore growth through increasing the sinterability, and makes the penetrated slag high viscosity through reacting with slag, and then strongly affects the performances. The castable containing 3.2 wt.% microsilica has the best performance, which has a porosity of 24 %, a crushing strength of 90 MPa, a flexural strength of 22 MPa and a high slag resistance.

Acknowledgements

We wish to express our thanks to the Puyang Refractories Co., Ltd for financially supporting this work.

References

1. Li N., Li H.L., Wei Y.W.: Brit. Ceram. Trans. *102*, 175 (2003).
2. Charles, G.W., Lesar A.R.:US Patent, 3 010 835, 1961.
3. Dunaeva M.N.: Refract. Ind. Ceram. *47*, 199 (2006).
4. Goto K., Argent B.B., Lee W.E.: J. Am. Ceram. Soc. *80*, 461 (1997).
5. Díaz L.A., Torrecillas T., Aza A.H., Pena P.: J. Eur. Ceram. Soc. *27*, 4623 (2007).
6. Sarpoolaky H., Zhang S., Argent B.B., Lee W.E.: J. Am. Ceram. Soc. *84*, 426 (2001).
7. Ko Y.: J. Am. Ceram. Soc. 83, 2333 (2000).
8. Ma X., Wang Z., He Q., Xu Y.: China's Refract. *7*, 25 (1998).
9. Korgul P., Wilson D.R., Lee W.E.: J. Eur. Ceram. Soc. *17*, 77 (1997).
10. Wen Y., Nan L., Han B.Q.: Am. Ceram. Soc. Bull. *84*, 9201 (2005).
11. Yan W., Li N., Han B.: Sci. Sinter. *41*, 275 (2009).
12. Yan W., Li N.: Proc. the 5th International Symposium on Refractories, p.215-219, Beijing, China, 2007.
13. Yan W., Li N., Han B.: Int. J. Appl. Ceram. Technol. *5*, 633 (2008).
14. Yan W., Li N., Han B.: Interceram: Refractories Manual, p.25 (2009).
15. Goberis S., Pundene I., Shpokauaskas A., Wala T.: Refract. Ind. Ceram. *44*, 205 (2003).
16. Li N., Wei Y., Wu H., Myhre B., Ødegård C.: Proc. UNITECR'99, p.97-102, Berlin, Germany, 1999.
17. Sandberg B., Myhre B., Holm J. L.: Proc. UNITECR'95, p.173-180, Kyoto, Japan, 1995.
18. Mills K. C., Keene B. J.: Int. Mater. Rev. *32*, 1(1987).