Available online at www.sciencedirect.com

ScienceDirect

Ceramics International 35 (2009) 359–362

CERAMICS INTERNATIONAL

www.elsevier.com/locate/ceramint

Mechanical properties up to 1100 °C of Al_2O_3–MgO-extruded graphite pellets castables reinforced with steel fibres

K. Sankaranarayanane [a,*], K. Balamurugan [b], Michel Rigaud [b]

[a] Calderys Research Centre, 38070 Saint Quentin Fallavier, France

[b] École Polytechnique de Montréal, Que., Canada H3C 3A7

Received 23 April 2007; received in revised form 9 October 2007; accepted 4 November 2007

Available online 1 February 2008

Abstract

The influences of adding 19, 25 and 50 mm carbon steel and 19 mm stainless steel fibres in the range of 0–3 volume percentages on the mechanical properties of alumina–magnesia-extruded graphite pellet castables have been studied at intermediate temperatures between 800° and 1100 °C, in argon atmosphere, as well as at room temperature. Wedge splitting test results at room temperature have shown that both carbon and stainless steel fibres increases work of fracture. Same tests at 1100 °C have shown decrease in strength with all length and volume percentage of carbon steel fibre while improving work of fracture values as 50% over fibre-free castables. Strength degradation is caused by the defect generation in the castable structure.

Keywords: B. Fibres; D. Carbon; D. Al_2O_3; Spinels

1. Introduction

Usage of alumina–MgO based monolithic is gaining popularity in steel making application since a decade [1,2], but cannot challenge yet the performance of MgO–C brick in slag line zone. The degradation mechanisms such as corrosion/erosion, penetration, oxidation and spalling of refractories at slag line demand material having very high resistance to such conditions. The works on alumina–MgO-extruded graphite pellets (EG pellets) have shown fruitful results in terms of corrosion resistance with steel making slags. The results of the carbon based (EG pellet) castables are very much comparable to MgO–C bricks in terms of corrosion resistance even with 6 wt% EG pellet addition only but susceptible to cracking at cold face (800–1100 °C) due to lack of sintering at that temperature [2,3]. This problem may be tackled by reinforcing the alumina–MgO–C castables with fibres. Very few publications have appeared on fibre reinforced castables, since two decades [4–6]. With this background, this investigation focuses on the effect of different types, lengths and vol.% of steel fibres, into an alumina–MgO–EG pellet containing castables, on their thermomechanical behaviour between 800° and 1100 °C in Argon atmosphere.

2. Experimental

Alumina–MgO–EG Pellets (AMC) self-flowing castable containing 0 vol.% steel fibres, has been developed and the details of castable used in the present investigation is given in Table 1. The particle size distribution (PSD) analysis of fine matrix ingredients were carried out using a particle size analyzer (COULTER LS200, USA). The PSD of the castable mixes was designed according to Andreasen's model [7] using the following equation;

$$\mathrm{CPFT} = \left(\frac{d}{D_{\max}}\right)^q \times 100 \qquad (1)$$

where, CPFT is the cumulative percentage finer than, d is the particle size, D_{max} is the largest particle size and q (0.24 in the present study) is the distribution modulus. Two types of steel fibres with different chemistry and lengths were used (Table 2). Castable and steel fibres were volumetrically mixed and the nomenclatures of castables designed with steel fibres are given in Table 3. For each castable dry mixing of the constituents was

* Corresponding author.
E-mail address: kannansankar2004@gmail.com (K. Sankaranarayanane).

0272-8842/$34.00
doi:10.1016/j.ceramint.2007.11.005

Table 1
Composition and details of alumina–MgO–EG pellet castable

Ingredients	Details	AMC (wt%)
White fused alumina (mesh) 3–8, 8–14, 14–28, 28–48, −48, −100, −200	CE minerals, USA	71
MgO fines, −325 mesh	DSP, Israel	6
Reactive alumina, RAC 45B	Alcan Canada, $d_{50} = 0.5$ μm	6
Extruded graphite	CIREP, Canada Appaeant porosity: 15% Bulk density: 1.5 g/cm^3 Diameter: 0.7 mm Length: 2–4 mm	6
Calcined alumina, C90LSB	Alcan Canada, $d_{50} = 2$ μm	6.5
Microsilica	Elkem, Norway, $d_{50} = 0.15$ μm	0.5
Calcium aluminate cement, CA14S	Alcoa, USA	4
Dispersant, MELFLUX	Degussa, USA	0.2
Water (%)	–	5.65

Table 2
Details of steel fibres

Property	SS406 fibre	Carbon steel fibre
Density (g/cm^3)	7.47	7.86
Tensile strength (MPa)	519	420–840
Melting range (°C)	1371–1477	1516
Length used (mm)	19	19, 25, 50
Thickness (mm)	0.36	0.36
Modulus of elasticity (GPa)	28	29
Thermal expansion coefficient (10^{-6} K^{-1})	15	–
Manufacturer	Fibercon international, USA	

performed using Hobart mixer for 3 min, followed by 6 min of wet mixing with required amount of water. Samples of dimensions of 160 mm × 40 mm × 40 mm for modulus of rupture (MOR) and 100 mm × 100 mm × 75 mm for wedge splitting were cast and covered with plastic bags in order to avoid moisture loss from the surface and cured for 24 h at room temperature. After curing the samples were demoulded and dried at 110 °C for 24 h. Dried samples were pre-fired at 800° and 1100 °C for 3 h in a furnace. Coke powder was used to cover the samples to prevent the oxidation of both EG and steel fibres. Samples prefired at 800° and 1100 °C, were used for MOR testing (ASTM-C133-97) at 800° and 1100 °C in argon atmosphere using Instron machine (model 5581). Wedge splitting test was used to evaluate the force–displacement curves, and work of fracture (γ_{wof}), at 110 °C and 1100 °C in argon atmosphere. The details of wedge splitting technique can be found elsewhere [8,9].

3. Results and discussion

The force–extension curves obtained form the wedge splitting tests at room temperature for AMC 19 family and AMC at room temperature are shown in Fig. 1. While the castable cracks and fails abruptly after peak load, when there is no fibre (AMC), once fibres are present (AMC191, 192, 193), the composites display elastic, non-linear and fibre pull-out domains. At 3 vol.% of fibres (AMC 193), after the matrix cracks, more fibres present in the structure start carrying the increased loads. At 1100 °C, the fibre-free castable, AMC (Fig. 2), shows certain degree of deformability due to the presence of graphite in the structure. Graphite can cause crack branching, it may act as a plate like reinforcement, absorbing energy either through pull-out or actual flake fracture [2,3]. With fibres, the peak load decreases in all cases but with more

Table 3
Details of steel fibre containing castables

Type	Length (mm)	Volume % of fibre	Volume % of castable	Nomenclature	Family	Water (%)
AMC	–	No fibre	100	AMC	–	5.65
AMC + stainless steel fibre	19	1	99	AMC SS406 191	AMC SS40619	5.75
		2	98	AMC SS406 192		
		3	97	AMC SS406 193		
AMC + Carbon steel fibre	19	1	99	AMC 191	AMC19	
		2	98	AMC 192		
		3	97	AMC 193		
	25	1	99	AMC 251	AMC25	
		2	98	AMC 252		
		3	97	AMC 253		
	50	1	99	AMC 501	AMC50	
		2	98	AMC 502		
		3	97	AMC 503		

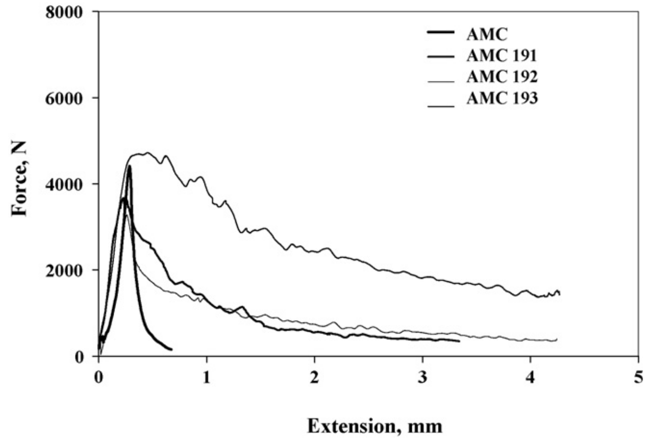

Fig. 1. Force–extension curves for AMC 19 family at RT.

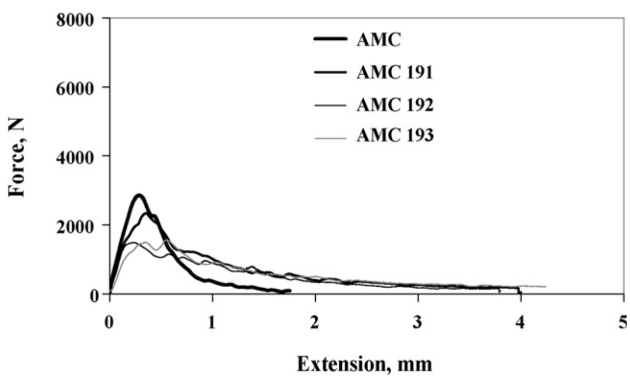

Fig. 2. Force–extension curves of AMC 19 family at 1100 °C.

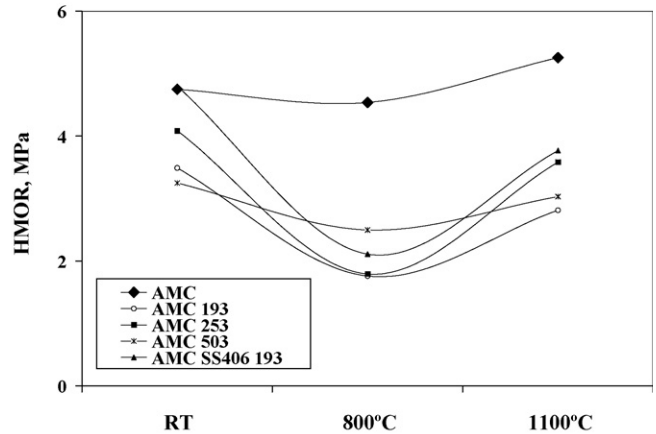

Fig. 3. Comparison of HMOR for different length and types of fibres.

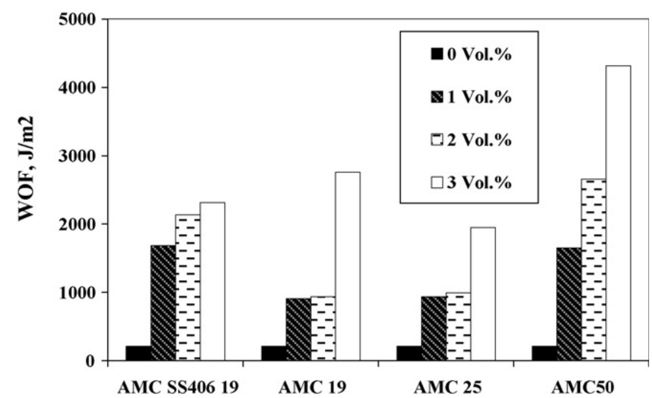

Fig. 4. Comparison WOF at RT (after drying at 110 °C).

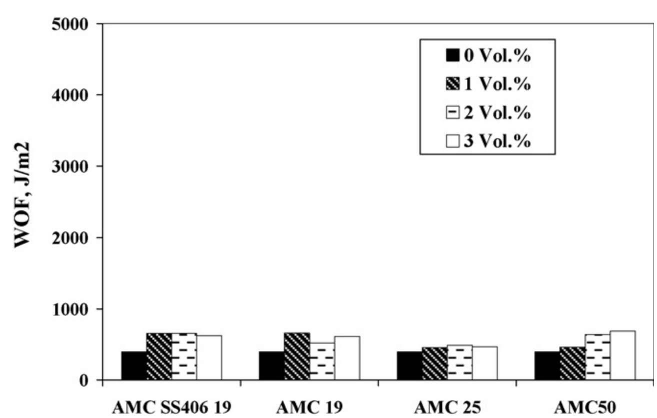

Fig. 5. Comparisons WOF at 1100 °C.

post peak deformation. The extraction load after the debonding peak consist of two components [6,10]. One is the fretting pressure at the test temperature and another arises from radial fibre contraction due to the Poisson effect. Development of fretting pressure generally leads to increased load level for debonding and friction level. But, in this investigation, there is no increase in the load level, rather reverse behaviour has been observed.

The hot MOR (HMOR) data of AMC 19 castables are presented in Fig. 3. The HMOR of AMC is reduced slightly at 800 °C and then shows an increase at 1100 °C. Strength reduction at 800 °C for AMC corresponds to the loss of bond in the structure and further degradation with fibre addition is attributed to the formation of structural defects at interfaces. The increase in HMOR values at 1100 °C in all cases is due to contribution from spinel formation. Stainless steel fibres have shown significant improvement strength of castables. Figs. 4 and 5 show the γ_{wof} at RT and 1100 °C, respectively. At RT, the castable with fibres display more γ_{wof} compared to no fibre castable. The γ_{wof} of castable at 1100 °C is 50–65% improved with fibre addition almost in all cases. There is no significant role played by either increasing the amount or changing the type of fibre in all cases. This is attributed to the presence of structural defects with fibre addition and degradation of fibres themselves at elevated temperatures [11]. With the use of stainless steel fibre up to 2 vol.%, it is possible to increase the work of fracture without strength degradation. SS406 fibres are more recommended than carbon steel fibre.

4. Conclusions

At room temperature, steel fibre additions (from 1 to 3 vol.%, length of 19, 25, 50 mm) leads to an increase in work of fracture values for all the castables tested, over the same composition of castable without fibre. However, the strength is slightly affected negatively for the fibre containing castables. At high temperature (1100 °C), with carbon steel fibres the strength of castables is degraded much more significantly, in comparison to the fibre-free castable and also to the stainless steel fibre containing castables. For the work of fracture the net effect of adding fibres is detectable going from 395 J/m^2, for fibre-free mix to 690 J/m^2 with both types of steel fibres, but is not as spectacular as what was observable at room temperature (moving upward by a factor of 10- to 20-fold). In fact, based upon the results so fare obtained it is beneficial to use stainless steel fibre at 2 vol.%, to have better work of fracture for equivalent strength, and in so doing improving the characteristics of the AMC castables at 1100 °C. This was the goal, but further improvements are yet to be looked at by adjusting the nature of the fibre, with a lower thermal expansion, yet flexible rather than brittle, able to create an in situ bonding with the matrix at higher temperatures.

References

[1] H. Nishio, Steelmaking Refractory Trends in Japan, in: Proceedings of UNITECR, 2003, pp. 23–26.

[2] N. Zhou, M. Rigaud, Different approaches to incorporating natural flake graphite into Al_2O_3–SiC–C castables, China's Refract. 7 (4) (1998) 3–10.

[3] H. He, Optimisation of antioxidant additives in carbon containing Castables, Ph. D Thesis, Ecole Polytechnique, Montreal, Canada, 2002.

[4] L.W. Marson, R. Rooney, The effect of fibre dosage levels on the performance of castable refractory materials, Refract. Eng. (January) (2005) 11–16.

[5] K. Anan, Application of fibres to monolithic refractories, Taikabustu Overseas 14 (3) (1994) 3–9.

[6] T. Cutard, E. Caileux, G. Bernhart, Pull out of metallic fibres from a ceramic refractory matrix composites: Part A, Appl. Sci. Manufact. 33 (10) (2002) 1461–1466.

[7] J.E. Funk, D.R. Dinger, Predictive Process Control of Crowded Particulate Suspensions: Applied to Ceramic Manufacturing, Kluwer Academic Publishers, USA, 1994.

[8] H. Harmuth, K. Rieder, M. Krobath, E. Tschegg, Investigation of the nonlinear fracture behaviour of ordinary ceramic refractory materials, Mater. Sci. Eng. A 214 (1996) 53–61.

[9] K. Balamurugan, Steel fibres reinforced carbon bonded alumina–MgO castable, M.Sc Thesis, Ecole Polytechnique, Montreal, Canada,2005.

[10] D.J. Pinchin, D. Tabor, Inelastic behaviour in steel wire pull-out from Portland cement mortor, J. Mater. Sci 13 (1978) 1261–1266.

[11] R.D. Veltri, F.S. Galasso, High temperature strength of boron, SiC coated boron, SiC, stainless steel, and tungsten fibres, J. Am. Ceram. Soc. 54 (6) (1971) 319–320.