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Effect of spinel content on the properties of Al_2O_3–SiC–C based trough castable

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Abstract

Effect of addition of spinel on the various refractory properties of Al_2O_3–SiC–C based trough castable is studied with both cement and sol bonding systems. Graphite as C source varied between 2 and 4 wt% and spinel between 5 and 10 wt%. Different castable compositions were processed as per conventional processing and heat treated at 900 and 1500 °C. Increasing amount of graphite resulted in reduced densification and strength properties for both the bonding systems at all the processing temperatures. An increasing amount of spinel and sol bonding were found to improve the corrosion resistance. Lime, silica and iron oxide were found to be the main corroding and penetrating components of blast furnace slag.

Keywords: Trough castable; Spinel; Sol and cement bonding; Corrosion; Phase analysis; Microstructure

1. Introduction

Blast Furnace (BF) Troughs convey the molten iron and slag to their respective transfer ladles after tapping. They also have the function to separate molten iron and slag while flowing. Thus the trough refractory is under the effect of corrosion and wear of molten iron and slag. Again the troughs are required to meet the demands of the blast furnace operations, like, long and predictable campaign lives, ease of installation, mechanized dismantling and installation processes, safe working conditions, rapid drying capability, reduced intermittent repairs and above all reduced operating costs. To meet these challenges, the evolution in blast furnace trough refractories has reached today in an alumina based castable formulations containing both carbon and silicon carbide as must components.

Trough castables are exposed to different wear mechanisms during operation, the propagation of metal/slag into it causes corrosion and erosion to the refractory. Some of these wear mechanisms include thermal shock, iron erosion, and slag corrosion. Sudden and rapid changes in temperature, which relates to thermal shock, may cause the stresses to develop within the refractory castable. These stresses reduce the service life of refractory due to the formation of cracks. Molten iron may also attack the castable constituents after oxidation and may form low melting compounds, thus deteriorating the properties of the castable [1]. Slag attacks the trough castable by forming various low-melting phases through several chemical reactions, causing corrosion and wear to the castable. Trough castables are required to be designed to resist these wear mechanisms through the compositional adjustments and batch formulations.

The trough castable formulations are designed in such a way that alumina acts as the primary constituent [2]. High density and low porosity of alumina aggregates provide excellent mechanical properties with good resistance to metal and slag attack [1]. Carbon is added as a non-wetting compound to avoid adhesion of molten iron and slag to the castable and imparting corrosion resistances [3]. Silicon carbide is also added for similar reasons and also due to better oxidation

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resistance amongst the non-oxide components [4]. Due to the strong covalent bonding, carbon and silicon carbide have low diffusivity and so inhibit sintering in the oxide compositions. Therefore, the strength like MOR, CCS and HMOR were found to decrease with increasing SiC content [5]. Silicon carbide also acts as a volume stabilizer to minimize linear change when in service and increases the thermal conductivity of the refractory [5,1]. The volume stability and higher conductivity characteristics of the silicon carbide help to minimize damage from thermal shock. Fine alumina and or silica (in cement containing compositions) are typically added to help and promote good flow properties. Metal powders, such as silicon or aluminum, are also added as antioxidants to protect the carbon particles from oxidation at high temepratures, to aid in dry-out and to enhance the hot strength of the refractory material [2,1]. Incorporation of all these additive components, mainly present in the matrix phase, increases the corrosion, oxidation and thermal shock resistance of the trough castables [6,7].

The main trough is usually designed with a zonal lining, which implies that the composition and properties of the refractories in different zones, namely the slag zone and metal zone, are different due to different corrosive environments. Higher amount of SiC improves the corrosion and thermal shock resistances of the compositions but also enhances the chance of oxidation and corrosion by FeO. Addition of spinel prevents such effect and provides a higher FeO corrosion resistance [8]. SiC is effective to reduce slag penetration and spinel is effective to improve slag corrosion resistance [9].

In the present work, comparison between sol and cement bonding systems is studied for the Al_2O_3–SiC–C based trough castable with the addition of spinel. Variation in physical and mechanical properties, phase analysis, corrosion resistance against and microstructural developments were studied with the variation in C and spinel content. Use of 15 wt% SiC was maintained for all the compositions, as found optimum in earlier study [10].

2. Experimental procedure

The starting materials used in the study are white tabular alumina (WTA) of different fractions, alumina fines (RA), silicon carbide (SiC), graphite (C), magnesium aluminate spinel, Al metal powder as anti-oxidant and calcium aluminate cement (HAC) or silica sol as binder. The details of the raw materials are given in Table 1.

Castable formulation was done using the particle size distribution (PSD) formula, as proposed by Dinger and Funk [11]

$$CPFT = \left[\frac{(D^q - D_s^q)}{(D_l^q - D_s^q)}\right] \times 100$$

where CPFT: cumulative percent finer than, D: particle size, D_s: minimum particle size, D_l: maximum particle size, q: distribution coefficient / modulus. In the present work, a q value of 0.21 is taken and the plot for PSD, used in the study, is shown in Fig. 1. 1 wt% Al metal powder was used in all the compositions as anti-oxidant. For cement containing compositions 4 wt% cement and 4 wt% fume silica (as flow modifier), 0.3 wt% ammonium polymethacrylate as deflocculant 0.1 wt% citric acid as set retarder and 0.05 wt% of polypropylene fiber were used.

All the raw materials were first dry mixed as per batch composition (Table 2) in a Hobart mixer. SiO_2-sol or water was added to the dry mixed batches while mixing in the sol or cement-bonded castable compositions respectively at an amount of 6–7 volume to weight percent. Mixing was continued thoroughly till proper consistency was attained. Mixed batches were then cast into 50 mm cube-shaped lubricated molds on a vibratory table with 3200–3600

Table 1
Physico-chemical properties of the starting materials chemical analysis (oxide percent).

Constituent Source	WTA grain Almatis, India	Alumina fines Almatis, India	Fume silica Elkem, India	HAC Almatis, India	SiC St-Gobain, India	Silica sol Dr. Khan's Lab, India	Spinel Almatis, India
SiO_2	0.03	0.03	96.2	0.21	0.35	29.8	0.10
Al_2O_3	99.34	99.3	0.4	71.64	0.22		≥ 74
Fe_2O_3	0.035	0.03	0.1	0.11	0.1		0.15
TiO_2		Trace					
CaO		0.02	0.2	26.91			0.24
MgO		0.01	0.1	0.32			22.5
Na_2O+K_2O	0.15	0.1	0.4	0.27			0.09
SiC					98.1		
LOI						70.1	

Physical properties

Property	WTA Grain	Alumina fines	Fume silica	HAC	Silica sol	Spinel
Particle size, μ		$D_{50}=2.5$	> 99% < 45		~ 0.02	
Bulk density	3.61 g/cc					3.3 g/cc
Apparent porosity	3.93%					1.8%
Sp. Surface area		3.1 m^2/gm	20 m^2/gm	4400 cm^2/gm		
Phase analysis	Corundum	Corundum	Amorphous	CA_2, CA		Spinel