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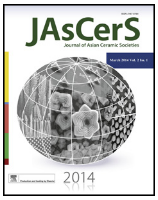

Implementation of industrial waste ferrochrome slag in conventional and low cement castables: Effect of calcined alumina

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ABSTRACT

A new class of conventional and low-cement ferrochrome slag-based castables were prepared from 40 wt.% ferrochrome slag and 45 wt.% calcined bauxite. Rest fraction varied between high alumina cement (HAC) acting as hydraulic binder and calcined alumina as pore filling additive. Standard ASTM size briquettes were prepared for crushing and bending strengths evaluation, and the samples were then subjected to firing at 800, 1100 and 1300 °C for a soaking period of 3 h. The microstructure and refractory properties of the prepared castables have been investigated using X-ray diffraction (XRD), scanning electron microscopy (SEM), cold crushing strength, modulus of rupture and permanent linear changes (PLCs) test. Castables show good volume stability (linear change <0.7%) at 1300 °C. The outcomes of these investigations were efficacious and in accordance with previously reported data of similar compositions. High thermo-mechanical and physico-chemical properties were attained pointing out an outstanding potential to increase the refractory lining working life of non-recovery coke oven and reheating furnaces.

1. Introduction

The development of refractory castables is important due to their increasing applications in the cement, non-recovery coke ovens, chemical, metallurgical industries, ceramics, chemicals, oil/petrochemicals, etc. [1,2]. Unshaped monolithic refractories have been increasingly used instead of the shaped refractory bricks of the same class due to their easier replacement, lower cost, more efficient installation and lower material consumption, especially in steel-making applications such as the production of steel ladles and the linings of tundishes [2,3]. The addition of fine calcined alumina in castables improves the refractory properties, has a high melting point (2072 °C) and has good mechanical properties that are suitable for high-temperature applications [4,5]. High alumina cement (HAC), one of the most widely used as refractory binders in monolithic refractories, promotes initial hardening and mechanical strength before firing [6–10].

Every year, more than 300 million tons of industrial solid wastes are being produced by various industries in India and government is seeking ways to reduce the dual problems of disposal and health hazards from the accumulation of by-products. In recent years, the use of waste materials in the construction industry has become an important option, as it offers cost reductions, energy savings, and reduced CO_2 emissions from the production of Portland cement, as well as reduced environmental impacts of construction materials. The predominant industrial byproducts that can be effectively used include chemical gypsum, fly ash, lime sludge and ferrochrome slag [11–14].

Out of the different waste materials being generated, the use of byproduct ferrochrome slag is significant in the production of monolithic refractories. Ferrochrome slag is a waste material obtained from the manufacturing of high carbon ferrochromium alloy, which is usually dumped. Global ferrochrome production is totaled around 8.9 million tons in the year 2011 [15]. Utilization of dumped ferrochrome slag in refractory castables reduces the cost of the product and is friendly to the atmosphere. This material is being used for brick manufacturing, and recently has been tried in cement industry and base layer material of road pavements because of its excellent technical properties as well as chemical stability [13–15].

This slag is formed as a liquid at 1700 °C and its main components are SiO_2, Al_2O_3 and MgO. Additionally it consists of chrome, ferrous/ferric oxides and CaO [16,17]. The smelted products obtained from the smelting furnaces are ferrochrome alloy and slag, and the slag production is 1.1–1.6 ton/ton ferrochrome alloy [17]. Binary compound (magnesium-aluminate spinel) formed by interaction of MgO and Al_2O_3 present in the slag offers good mechanical, chemical and thermal properties both at ambient

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Table 1
Particle size and chemical composition of the raw materials.

	FC slag (wt.%)	Calcined bauxite (wt.%)	HAC (wt.%)	Calcined alumina (wt.%)
Al_2O_3	22.21	85	72	99.0
SiO_2	27.14	8	–	0.007
Fe_2O_3	4.01	3	–	0.016
CaO	5.13	–	28	0.005
MgO	24.88	–	–	0.001
TiO_2	–	4	–	0.002
Cr_2O_3	12.57	–	–	–

FC, ferrochrome slag; HAC, high alumina cement.

Table 2
Batch composition of ferrochrome slag-based castables.

Sample code	FC slag (wt.%)	Calcined bauxite (wt.%)	HAC (wt.%)	Calcined alumina (wt.%)
CA 0	45	40	15	00
CA 5	45	40	10	05
CA 10	45	40	5	10
CA 12	45	40	3	12

FC, ferrochrome slag; HAC, high alumina cement.

and elevated temperatures [18–20]. MA spinel is now extensively applied in high performance refractory castables [21,22].

Evaluated effects of fine calcined alumina addition in castables reduce the permanent linear change. Mullite ($3Al_2O_3$–$2SiO_2$), which is another binary component of this slag-based system, is formed by reactions of silica glass melt and alumina present in bauxite. It is a thermodynamically most stable product in the high-temperature solid-state reaction between silica and bauxite [23,24]. In situ formed, elongated needle-like mullite crystals grow with increasing temperature and lock the structure to create a strong refractory bond system improving the mechanical properties of the castable [25,26].

The aim of this work is to prepare conventional castable and low cement castables by utilizing this waste ferrochrome slag, calcined bauxite and fine calcined alumina. Use of secondary resources makes it possible to solve problems of materials availability; it reduces cost for their extraction, processing and their industrial discharge in the atmosphere thereby providing economic and financial benefits to the country as well.

2. Materials and experimental procedure

2.1. Materials

Calcined bauxite (Shiva Minerals Pvt. Ltd., Rourkela) along with ferrochrome slag (byproduct of TATA Ferroalloy, India) was used as aggregate. Details of particle grading and chemical composition are included in Table 1. High alumina cement CA-270 (Almatis Kolkata, India) is introduced as a hydraulic binder. Fine calcined alumina (Shiva Minerals Pvt. Ltd., Rourkela, India) was used as superfine additive. The percentage of aggregates was kept constant at 85% throughout the study. The fine calcined alumina content with respect to high alumina cement (HAC) varied from 0 to 15 wt.%.

2.2. Preparation of castables

Conventional and low cement refractory castables are generally prepared using approximately 15–10 and 3–5 wt.% HAC, respectively. The ferrochrome slag and calcined bauxite were used in castable formulation in the present study with small additions of fine calcined alumina. The formulation (Table 2) shows the detailed composition with their names. In the first step for castable formulation, ferrochrome slag was oven dried, crushed and ground for grading into three groups of coarse (6–2 mm), medium (1–0.5 mm) and fine (<0.5 mm). The jar and grinding media were of titanium-coated stainless steel material. At one time 250 g of ferrochrome slag material was taken in the jar and ground in a high-energy ball mill for 30 min at 400 rpm. Similarly, it was processed to complete the grinding of complete material. The ground material was then kept in various selected sieves and set up on the motorized vibro-sieving equipment for grading. The same technique was used for grinding and grading calcined bauxite material. The particle size distribution has an important role in the properties of refractory castable. Incorrect particle size distribution may cause militancy or the excess water required by the castables. The particle size distribution of the fine fraction is generally a representation of the flow characteristics. The trials of aggregate proportions were taken in a 1000 cm^3 flask filled up to 250 cm^3 and vibrated for 30 s and the packing density calculations were carried out for each trial. Aggregate having highest packing density was chosen for further analysis. The materials were dry mixed in a plastic container for 10 min with a spatula and then were taken for sample preparation. Generally, conventional and LCCs require less than 12 and 5 wt.% of water respectively to achieve the desired rheology; therefore, water was added in two steps. The casting was done by adding the first two-thirds proportion of water at a time. Then, one-third of water was added slowly to get a homogeneous mixing. The wet mixing was performed for up to 5–6 min to achieve proper flow. Immediately after wet mixing, the castable mix was filled into a cubic mold (50 mm) made of hard steel. The mold was placed on the vibrating table filled with the wet mixed castable and the mixes were vibrated for 10 min, showing better compactness. For each composition, several samples were prepared for laboratory test. The samples were cured in a moisture-saturated environment (95% RH) in a humidity chamber at room temperature for different time periods. For firing the samples, they were first oven dried at 110 °C for 24 h. Fig. 1 shows the pictorial representation of the ferrochrome slag castables. The test samples were fired at 1100 and 1300 °C with dwell time of 3 h, using an electric furnace at a heating rate of 5 °C/min. The furnace was equipped with SiC heating element and a programmer PID528, manufactured by Selectron Process Controls Pvt. Ltd, India. The programmer has the temperature control accuracy of ±1 °C.

2.3. Characterizations of prepared castables

Preparation of 50 mm cubic and 25 mm × 25 mm × 150 mm castable briquettes had been the same as published in our previous