Use of castables and high alumina refractories for lining reheating furnaces

M. C. Kundra & K. K. Singh
National Metallurgical Laboratory, Jamshedpur

There is an increasing demand of castables and high alumina refractories for lining reheating furnaces. In view of the present requirements of improved quality refractories for lining such furnaces to obtain better service performance, attempts have been made to formulate some suitable batch compositions of castables and high alumina refractories to be used in different zones of reheating furnaces. Physical as well as high temperature properties of the products made from above compositions have been studied and results discussed in this paper. Consequent upon the findings of the above results, certain broad recommendations have been made for the use of such refractories in different zones of reheating furnaces Castable developed at N. M. L. has also been used for repairing the inverted arch brick roof of a reheating furnace operating at 1320 °C at Rourkela Steel Plant. It has shown encouraging results.

Introduction

Reheating furnaces are used for intermediate heating of steel blooms, ingots, billets and slabs during their final finishing process. These furnaces are of two types i. e. batch type and continuous type. Batch furnaces are generally simple box type used for heating prior to forging and shaping. Such furnaces should be able to withstand required operating temperature, frequent heating and cooling and abrasion due to stock handling.

Continuous type reheating furnaces are used for heating of small ingots for rolling and forging but more usually for reheating semi-finished products for further deformation i.e. billets and slabs into bars, rods and strips etc. The range of operating temperature in such furnaces varies from 1050 °C to 1320 °C. Continuous type reheating furnaces are mostly of one, two, three or four zone type. The recent one is of five zone type mainly used for large scale heating. These multizone furnaces are of both pusher and rolling hearth type.

Factors responsible for the selection of refractory materials for lining reheating furnaces are as follows :

a) Maximum operating temperature.

b) Frequent heating and cooling cycles

c) Extent of flame impingment on the refractory

d) Abrasion due to the movement of stock in the hearth region

e) Effect of oil firing

f) Effect of Mill scale in the hearth.

In the light of the above factors, castables and high alumina refractories are playing a great roll as lining materials used in modern reheating furnaces.

Castables

Use of castables in the roof of reheating furnaces has given better service performance by speeding up intermediate repairs, decreasing number of joints to save heat losses and reducing the range of roof shapes as described elsewhere[1]. Use of castable results in lower initial cost and provides faster installation. In order to obtain improved service performance, castables should possess adequate cold crushing strength, dimensional stability at operating temperatures, good thermal shock resistance and high refractoriness. Castables are also used for making burner blocks to resist the reducing effect of oil firing near the burners and localised over heating caused by carbon build up on the burner blocks. They are also finding greater application in the linings of sidewalls to obtain better support by using ceramic anchors. This gives more satisfactory lining than conventional brick work.

High-alumina refractories

Earlier sillimanite bricks were being used for lining roofs of reheating furnaces. But recent trend is to use 60—61% Al_2O_3 (bauxitic material) for getting better service performance. Due to severe service conditions prevailing in modern reheating furnaces, there is an increasing tendency to use more and more of high alumina bricks in place of conventional fireclay bricks. High alumina refractories are also being used in burner blocks to combat the effects of oil firing. Moreover oils with high Na_2O and V_2O_5 contents reduce the refractoriness[3]. In the sidewalls where conditions are severe, high alumina refractories are being used. Hearths of reheating furnaces are lined with 70% Al_2O_3 bricks to resist abrasion and lessen the effect of mill scale attack. 73% fusion cast alumina bricks are now used to resist abrasion more effectively in the hearth. It is interesting to note that 85% Al_2O_3[4] brick is the only other alternative to chrome bricks apart from water cooled or refractory skids.

Based upon the present requirements of improved quality refractories for lining reheating furnaces to obtain better service performance, attempts have been made at National Metallurgical Laboratory to formulate some suitable batch compositions of castables and high alumina refractories to be used in different zones of such furnaces.

Raw materials

The raw materials used for making

castables during this investigation were exportable grade Maharashtra kyanite and N. M. L. made high alumina cement. The chemical analysis of raw and calcined Maharashtra kyanite used have been given in Table I and that of high alumina cement in Table II. This exportable grade kyanite was received from Dahegaon kyanite mines of Maharashtra The material was lumpy ranging from boulders of about 14″ across (largest dimension) to lumps of approximately 4—6″ across. Physical properties of raw and calcined kyanite lumps have been shown in Table III

Raw materials used for making high alumina refractories are Bommuru plastic fireclay and Saurashtra bauxite. Their chemical analyses are given in Table IV. This fireclay was received from Andhra Pradesh Mining Corporation Ltd. (APMC). It was a highly plastic fire clay. Properties of this clay have been given in Table V. Saurashtra bauxite was in lump form. Its size varied from 3″ to 6″.

Experimental

Kyanite lumps were calcined in a conventional gas fired D. D. kiln at a temperature of 1600 °C with 5 hours soaking. These calcined lumps were crushed in jaw and roll crushers to pass through 5 mesh B. S. S. A part of this material was dry ball milled using charge to ball ratio as 1:2 to pass through 52 mesh B. S. S. Sieve analyses of both the fractions of kynaite have been reported in Table VI. Five batches of castables were made using both the fractions of calcined kyanite and different proportions of high alumina cement. Sieve analysis of the cement used is shown in Table VII. These batches were mixed thoroughly in simpson mixer with 18% water and pressed into 2″ dia buttons under 30 tons hydraulic press at a pressure of 5000 psi. These buttons were cured at room temperature for 24 and 72 hours and their properties such as apparent porosity, bulk density and C. C. S. etc. were determined as per standard procedures. Specimens after 72 hours curing were further heat treated at 110, 300, 600, 900 and 1200 °C with a soaking of 3 hours. Properties such as apparent porosity, bulk density, CCS and percent linear shrinkage of these heat treated specimens were determined as shown in Table VIII-A and VIII-B. These values indicate the average of minimum five specimens.

Saurashtra bauxite lumps were calcined in gas fired Brayshaw furnace at a temperature of 1600 °C with 4 hours soaking. These calcined lumps were crushed in jaw and roll crushers to pass through 5 mesh B.S.S. and a part of this material was dry potmilled with charge to ball ratio as 1:1.5 to pass through 72 mesh B. S. S. Bommuru fireclay lumps were crushed through jaw and roll crushers and dry ground in a rubber lined ball mill with charge to ball ratio as 1:1 to pass through 350 mesh B. S. S. Particle size analysis of this clay was carried out as per Andreasen's pipette method[5] and the values are shown in Table IX. Three different batches were prepared using above ground bauxite and fireclay in the proportions (by weight) of 50:50, 60:40 and 70:30. These batches were mixed thoroughly with 10% water in the simpson mixer. Buttons of 2" dia were made under 30 tons hydraulic press at a pressure of 750 kg/cm^2. These buttons were dried at 110°C in an electric oven and their dimensions (dia & ht) were noted down. These buttons were than fired in Brayshaw furnace at a temperature of 1625 °C for a soaking period of 3 hours. Their properties such as apparent porosity, bulk density, apparent specific gravity, percent linear shrinkage and spalling resistance were determined as shown in Table X. The values reported here are the average of 4 to 5 samples.

Results and discussion

Castables : Table I indicates the chemical analyses of raw and calcined kyanite. Here, Al_2O_3 and SiO_2 contents are of the order of 60% and 36% respectively. After calcination at 1600 °C Al_2O_3 and SiO_2 contents remains more or less same. It has also been observed that after calcination Fe_2O_3 increases from 0.71 to 0.9%. Similarly Na_2O content increases from 0.18 to 0.54 and K_2O from 0.27 to 0.63% after calcination. Probable cause for the increase of Fe_2O_3, Na_2O and K_2O contents in the kyanite rock as noticed may be due to the contamination from the flue gases. Table II indicates the chemical analysis of high alumina cement which is of secar type having less impurities and good refractoriness. Its P. C. E. as determined is cone 20 (Orton). Table III indicates the properties of raw as well as calcined Maharashtra kyanite. It shows that calcination at 1600 °C has brought a considerable apparent porosity in its wake. Moreover on calcination bulk density has decreased from 3.21 to 2.44 g/cc and apparent sp. gravity from 3.36 to 2.96 due to the formation of mullite.

Table VI shows the sieve analyses of coarse and fine calcined kyanite powders. It indicates that in coarse fraction 70% of the kyanite grog is+25 mesh B.S.S. whereas in fine fractions 83% of the material passes through 100 mesh B.S.S. Similarly Table VII indicates the sieve analysis of high alumina cement. Here 85.5% of material passes through 100 mesh B. S. S. leaving 0.4% as the residue on 72 mesh B. S. S.

Table VIII.A and VIII-B indicate the properties of the castables cured at 110 °C and fired to various temperatures i. e. 300, 600, 900 and 1200 °C. Apparent porosities of the specimens cured at 110 °C increased with the decrease of cement content in the batches but its trend is reverse at all other temperatures of heat treatment. Apparent porosities of all the batches increase with the increase of firing temperature. This increase is maximum i. e. of the order of 60% in the castable C1 (where cement content is maximum) when fired to 1200 °C but its magnitude decreases gradually from batch C1 to C5 where cement content decreases and is minimum in case of castable C5.

Bulk density : In all the castables C1 to C5 cured at 110 °C bulk density decreases from 2.9 to 1.93 gm/cc with the decrease of cement content. Specimens heat treated upto 900 °C show a decrease in bulk density values whereas the specimens heat treated at 1200 °C show increase. This is as per expectation.

Cold crushing strength : Cold crushing strength increases with the increase of cement content in the specimens. It is maximum in C1 batch and minimum in C5 batch at all the temperatures of heat treatment. In general, all the specimens gain strength on heating to 1200 °C after suffering a fall at 900 °C. Modulus of rupture values for the specimens heated to 600, 900 and 1200 °C follow the same trend as that of cold crushing strength. Percentage loss in weight on heat treatment bears approximately linear relationship with the cement content as well as temperature of heat treatment. This may be due to the formation of more quantity of hydrates and their consequent dehydration[6] between the heat treatment temperatures ranging from 600 to 1000 °C. Percent linear shrinkage values at different temperatures of heat treatment is of the order of 0.3 to 0.4% as expected.

High alumina refractories : It is seen from the chemical analysis of Bommuru fireclay (Table IV) that its alumina and silica contents are very near to the corresponding values of pure china clay. Its SiO_2/Al_2O_3 ratio is 1:219. Overall fluxes are also under permissible limits. Its P. C. E. is cone 34 (Orton) which indicates that it is a good refractory clay. Moreover, Bommuru fireclay is highly plastic in nature as is clear from the values of percent water of plasticity and Atterberg's number (Table V). It is slightly acidic in nature as the pH value is 6.8. This clay gives a strong green bond and fired strength to these refractories due to its high plasticity and fineness of particles (Table IX). The average particle size of Bommuru plastic is calculated to be 5.44 microns.

The chemical analysis of raw bauxite (Table IV) shows that it is a good refractory grade variety. On calcination at 1600 °C, it gives approximately 90% of Al_2O_3. It is one of the best refractory grades of bauxite available in India. Its SiO_2, Fe_2O_3 and TiO_2 contents are also at low levels. This bauxite is most suitable for making high-alumina refractories with outstanding properties. Though many Indian refractory manufacturers utilise bauxites containing 54% and more of alumina, 1—6% SiO_2, upto 4% Fe_2O_3 and a maximum of 10% TiO_2.

Table X gives an account of different properties of fired high-alumina buttons studied during this investigation. Bulk density increases with increasing amount of bauxite content in the buttons.

Apparent porosity varies betwen 13 to 15%. From these values, it is apparent that all buttons are well sintered. This is required for attaining both good resistance to abrasion and slag penetration. The values of percent linear change on reheating at 1650 °C for 5 hours show slight expansion and are in good agreement to those as reported by previous workers[8—10]. This expansion is caused by the penetration of liquid silicates into the bauxite grains and due to mullite formation. As such, these high alumina buttons seem to be quite volume stable because no significant expansion was recorded. Thermal shock resistance values of these buttons are also appreciably high taking their fired porosity values into consideration. Service performance of high alumina refractories has a direct relationship with their volume stability and thermal shock resistance properties. Cold crushing strength values are also high and increase with increasing amount of alumina content. This makes the buttons to bear more load during use

Uses : Based on the data discussed, castables had been developed and used in the following furnaces. Their performance reports as discussed further have been quite satisfactory in the different zones of reheating and heat treatment furnaces.

Wear and heat resistant base for heat treatment furnace

Two castable slabs of size 36″ x 20″ x $1\frac{1}{2}$″ had been made and fitted as base of a batch type gas fired reheating furnace in the MMT division of NML for reheating steel ingots at a temperature of 1300 °C. This furnace had been working intermittently for 6 years and these slabs have given very good service performance. It is interesting to note that bottom of these slabs forms the roof of the combustion chamber where the temperature is of the order of 100—150 °C higher than the actual furnace temperature.

Use in reheating furnace at HSL, Rourkela

600 kg of C4 type castable made at NML was supplied to M/s. Hindustan Steel, Rourkela. It was used in the 1st instance near the soaking zone of one of their reheating furnaces where the temperature was round 1300 °C ±20 °C. It was also used to repair the inverted arch brick work. This remained in tact even after 4 months of continuous operation. But owing to collapse of SMS roof, production of the plant considerably fell down and two of their reheating furnaces were closed down. Thus performance reported can be taken as quite satisfactory.

Use in electrical type reheating furnace (190 ft. long)

Castable of type C2 has been used to line sidewalls and roof of a 190 ft long electrical tunnel kiln operating at the carbon plant of NML. For the construction of roof, slabs of size 40″ x 18″ x $1\frac{1}{2}$″ were casted, cured and placed on the roof. For sidewalls the pellets made of castable were used to hold heating elements of nichrome and kanthal type. This castable is giving very good service in such type of continuous heating furnace. Castable has proved quite satisfactory in other places such as lining of kiln cars and saggers for heat treatment of refractories as well as carbon bricks where atmosphere is of reducing nature.

Conclusions and recommendations

Based upon the findings of above results, certain conclusions have been drawn and recommendations suggested.

i) Castables have been designed at N. M. L. to suit different temperatures of firing ranging from 1200 to 1600 °C.

ii) Actual service performance of these castables in electrical and gas fired reheating furnaces in different zones ranging from 1200 to 1600 °C has been found quite satisfactory.

iii) These castables behaved well under both oxidising and reducing conditions of firing and withstood the ill effects of oil firing.

iv) High alumina (65—75%) refractories made at N. M. L. are quite strong, dense, volume stable aud thermal shock resistant.

v) They can withstand maximum operating temperature, flame impingement and combat the effects of oil firing etc.

vi) Hence these castables and high alumina refractories could very well be used for lining roofs, burner blocks, sidewalls and hearths of reheating and heat treatment furnaces.

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TABLE—I

Chemical analysis of raw and calcined Maharashtra Kyanite

Ingredients	Mahatashtra Kyanite Raw (wt %)	Calcined at 1600 °C (wt %)
Loss at 110 °C	0.20	0 16
L. O. I.	1.70	0.10
Al_2O_3	60.00	60.14
SiO_2	36.00	37.12
Fe_2O_3	0.71	0.90
TiO_2	0.42	0.40
CaO	0.13	Traces
MgO	Traces	Traces
Na_2O	0.18	0.54
K_2O	0.27	0.63

TABLE—II

Chemical analysis and P. C. E. of NML made high alumina cement

Ingredients	Wt (%)
Loss of Ignition	0.43
Al_2O_3	65.32
CaO	30.16
SiO_2	1.14
Fe_2O_3	1.02
MgO	1.21
TiO_2	Traces
Na_2O	0.25
K_2O	0.02
P. C. E.	Cone 20 (Orton)

TABLE—III

Physical properties of raw and calcined Maharashtra Kyanite (lumps)

Properties	Kyanite	
	Raw	Calcined at 1600 °C
Apparent porosity (%)	4	17
Bulk density (gms/cc)	3.21	2.44
App. sp. gravity	3.36	2.96

TABLE—IV

Chemical analysis of raw Bommuru Plastic Fireclay raw & calcined Saurashtra Bauxite

Ingredients	Raw Bommuru Plastic Fireclay (wt %)	Saurashtra Bauxite Raw (wt %)	Saurashtra Bauxite Calcined (1600 °C wt %)
L. O. I.	11.04	30.04	—
SiO_2	46.26	2.08	2.10
Al_2O_3	37.92	62.86	90.48
Fe_2O_3	2.40	2.46	3.56
TiO_2	1.50	2.35	2.40
CaO	Traces	Traces	0.72
MgO	Traces	0.20	0.74
Alkalies	0.87	Traces	Traces
SiO_2/Al_2O_3	1.219	—	—

TABLE—V Properties of Bommuru Plastic Fireclay

Properties	Bommuru Plastic Fireclay
Colour	Pinkish to light violet. When wetted with water the colour darkens.
Shaking time	8 minutes.
Moisture at 110 °C	1.0 %
Water of plasticity	38.0 %
Atterberg's Number	22
Specific gravity	2.664
pH	6.8
Dry linear shrinkage	0.14 %
P. C. E.	34 (Orton cone)

TABLE—VI Sieve analysis of kyanite powders

Sieve No. B. S. S.	Coarse fractions (wt %)	Fine Ball milled fractions (wt %)
— 5 + 7	20	—
— 7 + 14	34	—
—14 + 25	16	—
—25 + 52	11	—
—52 + 72	3	4
—72 + 100	4	13
—100 + 200	12	32
—200 + 300		40
—300		11

TABLE—VII Sieve analysis of NML made high alumina cement

Sieve B. S. S.	% age by weight
+ 72 NSS	0.4
— 72 + 100 BSS	14.1
— 100 + 200 BSS	62.2
— 200 + 300 BSS	19.8
— 300 BSS	3.5

TABLE—VIII-A Properties of the castables cured at 110 °C and fired to various temperatures

Batch No.	Cement content %	Apparent Porosity (%) after heat treatment at 110 °C	300 °C	600 °C	900°C	1200°C	Bulk density (gms/cc) after heat treatment at 110 °C	300 °C	600°C	900°C	1200°C	Cold crushing strength (psi) after heat treatment at 110°C	300°C	600°C	900°C	1200°C
C1	25	26.0	36.9	36.4	39.2	42.4	2.09	1.97	1.90	1.86	1.87	2885	2890	3500	2880	3250
C2	20	28.3	34.7	36.0	41.5	41.0	2.05	1.97	1.91	1.84	1.88	2410	2030	2907	2397	2250
C3	15	29.0	35.4	35.8	38.5	38.7	2.03	1.97	1.91	1.85	1.87	1566	1240	1500	1555	1300
C4	10	31.4	30.0	36.2	37.8	36.3	1.98	1.99	1.90	1.85	1.86	891	800	894	965	1088
C5	5	33.0	30.2	—	36.3	34.4	1.93	2.04	1.94	1.85	1.93	268	210	216	275	578

TABLE—VIII-B Properties of the castables cured at 110°C and fired to various temperatures.

Batch No.	Cement content %	Modulus of rupture (psi) after heat treatment at 110°C	300°C	600°C	900°C	1200°C	% loss in weight after heat treatment at 110°C	300°C	600°C	900°C	1200°C	% linear shrinkage after heat treatment at 110°C	300°C	600°C	900°C	1200°C
C1	25	—	—	569	387	480	—	6.4	8.1	9.1	10.5	—	0.27	0.28	0.28	0.34
C2	20	—	—	442	282	433	—	6.0	7.2	8.0	9.1	—	0.25	0.30	0.33	0.37
C3	15	—	—	371	315	410	—	5.1	5.4	6.1	7.3	—	0.30	0.31	0.32	0.33
C4	10	—	—	343	301	452	—	4.0	4.5	5.0	5.6	—	0.31	0.34	0.39	0.36
C5	5	—	—	ND	ND	ND	—	2.2	2.5	2.7	3.0	—	ND	ND	ND	ND

TABLE—IX

Particle size analysis of Ball Mill Fines (—45 microns)
Bommuru Plastice Fireclay

% Finer Bommuru Plastic Fireclay	(E.S.D.) in microns of Bommuru Plastic Fireclay
99.5	34.5
84.5	11.0
77.0	7.5
72.0	5.5
69.5	4.0
66.0	3.5
50.0	1.5
47.0	1.0
34.5	0.75
31.0	0.50
Avg. Particle size	5.44 microns

TABLE—X

Properties of fired (1625 °C, 3 hours) buttons of different mixes prepared from raw Bommuru fireclay and calcined Bauxite

Properties	Mix I 50:50 B C	Mix II 60:40 B C	Mix III 70:30 B C
Bulk Density (gms/cc)	2.50	2.63	2.82
Apparent porosity (%)	14.69	13.17	12.89
Apparent Sp. gr.	2.84	3.00	3.09
% Linear shrinkage (from dry to fired stage)	6.27	5.82	5.24
C. C. S. (kg./cm^2)	475.0	535.5	580.0
P. L. C. (%) (on reheating at 1650 °C with 5 hrs soaking)	+0.15	+0.10	+0.05
Spalling Resistance (cycles) (0—100 °C)	21+	20+	20+
Al_2O_3 (%)	64.20	69.45	71