Development and Application of Andalusite-Based Bricks for the Rotary Hearth Furnace of a Wheel and Axle Plant

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High alumina bricks with superior RUL (refractoriness under load), high thermal shock resistance and high volume stability have been developed as an alternate refractory material to imported semi-silica bricks to use in sprung arch type roof of rotary hearth furnace of the wheel and axle plant of Durgapur Steel Plant/IN. This has been developed at first in laboratory and then manufactured in industrial scale. Laboratory investigations reveal that adequate mullite phase content and absence of free quartz are major contributors to its superior quality. In the second phase, around 100 t of developed quality bricks were produced in IFICO plant of SAIL Refractory Unit (SRU) and were applied in the furnace roof. Several field trials were conducted and finally the plant switched over to this quality bricks for its encouraging performance. In addition to this, it is being an import-substitution and in-house developed product; it leads to substantial economic benefit to the organization.

1 Introduction

Wheel and Axle plant (WAP) of Durgapur Steel Plant (DSP) under Steel Authority of India Limited (SAIL) mainly caters to the demand of wheel and axle sets of Indian Railways. This plant is equipped with a Rotary Hearth Furnace with a capacity of reheating 300 Diesel Locomotive Wheels (DLW) and 330 Broad Gauge Wheels (BGW) per day. The furnace is gas fired with a heating cycle of 6 h. Three definite zones such as preheating zone, heating zone and soaking zone with temperature ranges of 920 ± 50 °C, 1150 ± 20 °C and 1280 ± 20 °C, respectively are prevailing. The performance of roof lining in heating zone and soaking zone are found to be deteriorating over the time. The rotary hearth furnace was commissioned in 1961–62 by Stein & Atkinson/GB. Since its inception, semi-silica bricks manufactured from quartz, pyrophilite, clay and mineralisers, were traditionally used for roof lining and it was considered to be the most suitable for this type of roof due to its high Refractoriness under load (RUL), volume stability at operating temperature, imperviousness to molten scales, high emissivity and reasonable thermal shock resistance. Nowadays, quality of imported bricks has been drastically deteriorated due to non-availability of pyrophilite. On the other hand, improved thermal shock resistance has become most important property due to enhanced productivity. Andalusite belonging to the sillimanite group with composition approximately 60 % Al_2O_3, 38 % SiO_2 containing least amount of iron and alkalis was thought to be a good option for this purpose. This easily forms mullite at elevated temperatures. Mullite is an attractive bonding phase in high alumina bricks because of its high melting point i.e. 1850 °C. As a refractory material, mullite provides high thermal shock resistance properties to high alumina bricks due to its superior mechanical properties such as low thermal conductivity and low thermal expansion.

Several studies [1–8] reported on the mullitisation of the andalusite. Xiong et al. [1] narrated that andalusite forms mainly as needles crystals in host rocks composed mainly of quartz and micas. The nature and size of the andalusite crystals limits the maximum size of the andalusite grain, and makes it very difficult to produce coarse sizes of pure andalusite [1]. During investigation with refractory solutions for rotary hearth furnaces, Tasso et al. [2] postulated that main stresses are very intensive in a rotary hearth furnace and mechanical change in the new developed products allow them to reach a good performance and also to deliver a good availability of the furnace. In order to prolong the life of the furnace, the authors [2] also developed a repair technology that allowed them in a 6-months frequency to postpone a new investment. Anggono [3] investigated the structure-property relationship of mullite ceramics. It is suggested that some outstanding properties of mullite are low thermal expansion, low thermal conductivity, excellent creep resistance, high-temperature strength and good chemical stability. The mechanism of mullite formation depends upon the method of combin-

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Tab. 1 Properties of roof bricks of semi-silica quality (typical values)

Imported Semi-Silica Bricks – Characterized in the RDCIS Lab.		
Chemical Composition	**Recent Supply**	**Old Supply**
SiO_2 [%]	85–90	84,22
Al_2O_3 [%]	4–8	12,15
Fe_2O_3 [%], max.	1,95–2,5	1,45
CaO [%], max.	1–4	0,49
Physical Properties		
BD [g/cm³], min.	1,90	–
AP [%], max.	21–24	–
CCS [kg/cm²], min.	170–200	–
RUL, ta [°C]	1550	1600
PLC [%], max. 1500 °C/2 h	–0,5 to +2,0	–
Th-Shock, Cycles [%], min. 1200 °C, Small Prism Test	3–5	–
XRD (Semi-quantitative Analysis) [%] of Phase	Mullite –4 Tridymite –21 Cristobalite –15 Free Quartz –58	Mullite –17 Tridymite –38 Kyanite –16

Tab. 2 Composition of developed high alumina bricks

Ingredients	[mass-%]
Brown Fused Alumina Grains	30–35
Calcined Fireclay	18–22
Andalusite	30–35
Calcined Alumina	4–5
Raw Kyanite	4–5
Plastic Clay	10–12

Tab. 3 Properties of developed HA-HTS quality

Chemical Composition	Developed HA-HTS Bricks
SiO_2 [%]	–
Al_2O_3 [%]	62
Fe_2O_3 [%], max.	1,5
CaO [%], max.	–
Physical Properties	
BD [g/cm³], min.	2,5
AP [%], max.	18,0
CCS [kg/cm²], min.	400
RUL, ta [°C]	1550
PLC [%], max. 1500 °C/2 h	±0,2
Th-Shock, Cycles [%], min. 1200 °C, Small Prism Test	30
XRD (Semi-quantitative Analysis) [%] of Phase	Mullite –54 Corundum –26 Cristobalite –25 Kyanite –16

ing the alumina and silica-containing reactants. It is also related to the temperature at which the reaction leads to the formation of mullite (mullitisation temperature). Mullitisation temperatures have been reported to differ by up to several hundred degrees Celsius depending on the synthesis method used. Some other investigations [4–8] also focussed on the structure-property relationship of mullite.

Since suitable quality semi-silica bricks are not anymore available in the global market, development of an alternate quality bricks for this purpose became inevitable.

This paper reports the effort pertaining to laboratory development of andalusite based high hot strength alumina bricks followed by industrial scale manufacturing and its application in roof lining of rotary hearth furnace of the wheel and axle plant of DSP.

2 Experimental

2.1 Laboratory-scale brick development

Imported semi-silica bricks' samples were collected from the steel plant for characterization. The properties are given in Tab. 1.

Taking into account the service environment of heating and soaking zones of rotary hearth furnace, high thermal shock resistant high alumina bricks were considered to be suitable for this application. Moreover, this quality was falling in the existing line of production in IFICO. Since the roof lining is of sprung arch type, bricks should have high volume stability i.e. low Permanent Linear Change (PLC) and high hot strength i.e. Refractoriness Under Load (RUL). To attain this combination of important properties, effort was directed towards high mullite phase content high alumina bricks. It, therefore, prompted to incorporate optimum quantity of andalusite in the material composition. The range of weight percentage of different compositions tried in laboratory is given in Tab. 2.

The composition was dry mixed in an intensive mixer in batches of 5 kg for 10 min. Thereafter, 4–5 % green binder (molasses + slurry of plastic clay) was added and again mixed for another 20 min. The green mix was then pressed in laboratory by 100 t Carver press at a specific pressure of 0,8 t/cm². The green bricks were dried in an oven at 110 °C for 24 h. The samples were fired in chamber furnace at 1600 °C. The temperature was raised in 6 h and soaking was provided for another 4 h. The properties of developed bricks were evaluated in laboratory and shown in Tab. 3.

2.2 Plant scale brick production

For plant-scale trials, the final composition was mixed in a Muller mixer in the batches of 1000 kg. The mix was pressed in 600 t hydraulic press (Laeis Bucher/DE) at a specific pressure of 1,0 t/cm². After 24 h of air drying followed by another drying in a tunnel drier at 110 °C, the bricks were fired in tunnel kiln at 1600 °C with total heating cycle of 6 days in which soaking was provided for 12 h. Total 100 t bricks was manufactured and supplied to DSP. The properties of the bricks were evaluated in laboratory and found to be conforming to the quality as given in Tab. 3.

2.3 Sample characterization

The XRD analyses of samples of imported semi-silica bricks and developed high alumina bricks were carried out for identification of various phases. The sample was crushed for XRD analysis and the distinct phases have been analysed by a Bruker make D8 ADVANCE X-ray diffractometer. The morphology of the developed bricks was also characterized using field emission scanning electron microscope (FESEM, S-4800, Hitachi). Very small amount of the refractory samples in powder form were pasted on a conducting carbon tape and mounted on the sample holder of the FESEM equipment. Prior to scanning, a very thin Pt layer was coated on the samples to avoid any possible charging effects during scanning.

2.4 Plant trials

This type of bricks was applied for the first time and its suitability was judged by conducting trials in the rotary hearth furnace roof of Wheel and Axle Plant. The entire soaking zone roof was relined with around 35 t of developed bricks.

3 Results and discussion

The XRD analysis has been carried out to obtain the evolution of various phases of both imported semi-silica bricks and developed high alumina bricks. The obtained diffraction patterns of imported semi-silica bricks are presented in Fig. 1, while those of developed high alumina bricks are presented in Fig. 2. It is clearly revealed from Fig. 2 that in developed high alumina bricks, mullite phase is present along with other phases; while mullite phase is absent in case of imported semi-silica bricks as shown in Fig. 1.

The properties of imported semi-silica bricks is shown in Tab. 1. It indicates the deterioration of quality of imported bricks over the time. The poor quality is mainly attributed to depletion of mullite phase and presence of very high free quartz in the bricks. These results in falling of main mechanical properties such as RUL and thermal shock resistance under elevated temperatures and shows enhanced performance. Whereas, the properties of developed bricks as depicted in Tab. 3 are much superior compared to imported semi-silica bricks.

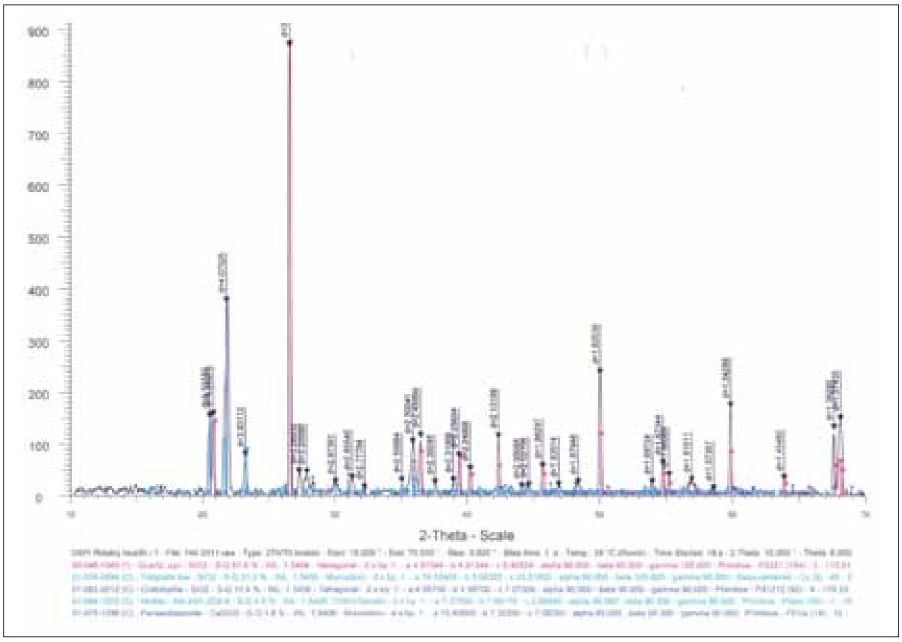

Fig. 1 XRD analysis of imported semi-silica bricks

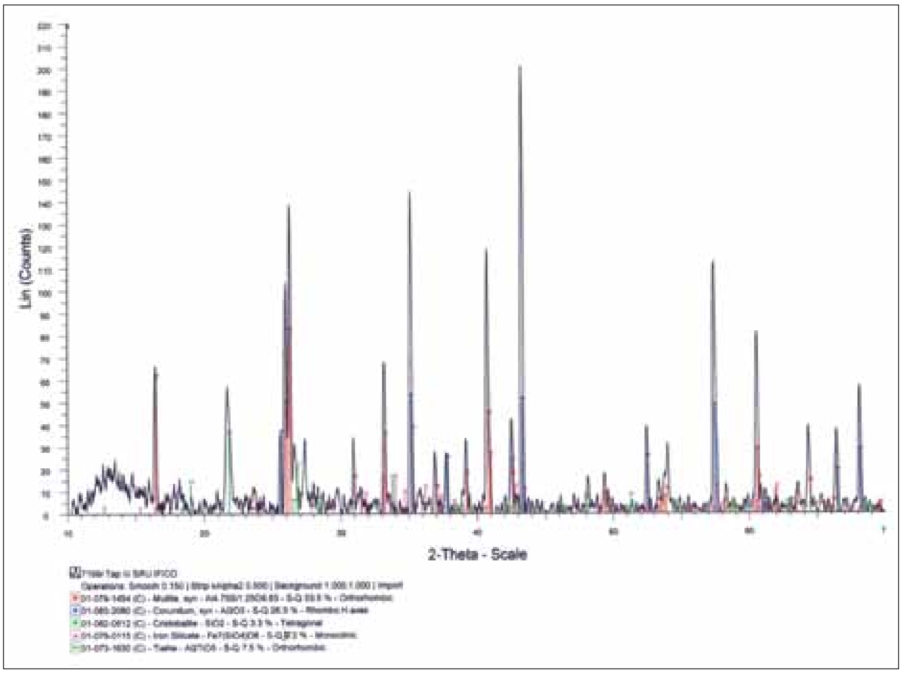

Fig. 2 XRD analysis of developed high alumina bricks

In order to have a better identification of the different phases in the microstructures, the developed bricks were examined under field emission scanning electron microscope (FESEM), and the photomicrograph is presented in Fig. 3. It clearly reveals the presence of mullite phase. Actually inside the andalusite grains, the transformation takes place through a dissolution-precipitation process starting from the mineral inclusions and the grain borders. The mineral

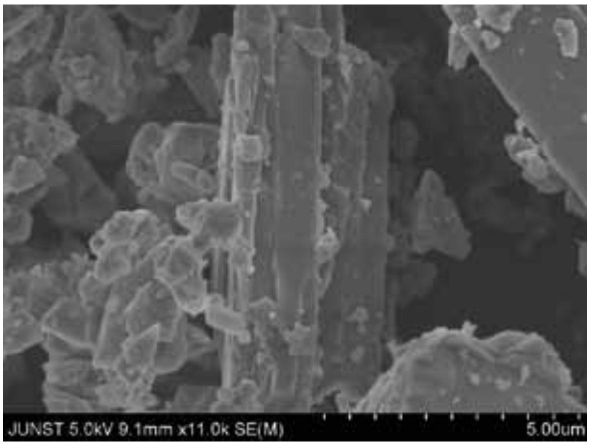

Fig. 3 FESEM of developed high alumina bricks

Fig. 4 Condition of relining with developed bricks two years after capital repair

Fig. 5 Condition of lining with semi-silica bricks two years after capital repair

inclusions seem to play a role creating local melting which promotes the mullite formation. During the process, mullite precipitates and the excess silica creates a liquid phase. Above 1280 °C, this mineral yields 80 % mullite phase and 20 % silica glass phase and decomposes as Andalusite ($Al_2O_3{\cdot}SiO_2$) → Mullite ($3Al_2O_3{\cdot}2SiO_2$) + Quartz (SiO_2) + ΔV (volume expansion), here, ΔV is ~3 –5,4 %. It is maintainable here that volume expansion caused by decomposition and subsequent phase transformation of quartz which in turn results in micro cracks within the matrix and this is responsible for thermal shock resistance [1].

The performance of developed bricks in entire soaking zone of furnace, and also in door arch and adjacent roof areas of the furnace was found to be highly encouraging. Performance of developed bricks in entire soaking zone roof lining of rotary hearth furnace was monitored time to time by visual inspection. Developed bricks are found to be performing very well and still intact. The condition of roof lining lays with developed bricks two years after its lining in the capital repair can easily be compared with that of the heating zone laid with semi-silica bricks as depicted in Fig. 4–5.

In fact, this remarkable improvement could be effected in spite of thermal cycling faced in several cold repairs held during two years of operation after the capital repair. This has contributed to increase in production of wheels. Looking at its encouraging performance, DSP has switched over to this quality for some other vulnerable areas of WAP. This development has primarily enhanced availability of furnace and thereby production of wheels. It has also lessened dependence on external sources. Moreover, an import-substitution product being manufactured in-house at SRU lead to substantial economic benefit to SAIL.

4 Conclusions

Andalusite based high alumina high thermal shock resistant refractory bricks were developed in laboratory. Investigations showed the phase constituents vis-a-vis hot strength of bricks showed good potential. Based on this, bricks were manufactured in SRU for plant scale application. This type of bricks were used for the first time in most vulnerable areas of rotary hearth furnace roof and showed improved performance. Developed bricks may also be effectively used in other vulnerable areas of different reheating furnaces.

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