Improving roof life of the twin hearth furnaces at Bhilai Steel Plant

There has been a gradual decrease in the lining life of the roofs of the Twin Hearth furnaces at Bhilai Steel Plant due to a combination of operating practice and quality of refractory materials. This paper focuses on the interventions carried out to improve the roof life which have increased the campaign life from an average of 368 heats in 2010-11 to an average of 436 heats with a record life of 545 heats in 2011-12.

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BHILAI Steel Plant at Bhilai, Chhattisgarh State, India is a unit of the Steel Authority of India Ltd. It is an integrated steel plant of capacity 5.4Mt/y of crude steel. Production of steel is through two routes – an ingot route of capacity 2.5Mt of crude steel using four twin open hearth furnaces (THF) and an oxygen converter (BOS) – continuous caster route of annual capacity 3Mt.

Steel Melting Shop-1 (SMS-1) houses the four twin hearth furnaces (THFs) each of 2 x 250t capacity. At any one time, only three of the THF are operating as one is kept in cold reserve. SMS-1 is equipped with six charging machines each of 10t capacity and five overhead hot metal cranes each of capacity 125/30t.

The Twin hearth furnace consist of two hearths separated by a bridge wall with a common roof. The Twin hearth furnace is worked by synchronizing operations in the two hearths such that each are at different stages of operation as they proceed. While one is in the solid period the other hearth will be in liquid period. Oxygen lances through ports in the roof are used to accelerate processing the charge. In the recent past there has been a falling trend in the life of the roof refractories as indicated in **Figs 1 & 2**.

The decrease in roof life led to a decrease in productivity of the steel shop and an increase in refractory consumption. To investigate the root cause of this various investigations were carried out to find out how the furnace operating parameters affect roof life. The quality of brick used and procedure of manufacture were also studied and necessary modifications carried out to improve the brick quality. The present paper focuses on the different technological intervention carried out to stabilize and improve the furnace campaign.

Few Twin hearth furnace operate today as only 1.2% (18.16Mt) of global steel was produced in open hearth furnaces in 2011, mainly in CIS countries. In 2011, India produced just under 1Mt of steel by this method. From a literature survey of past and present operations, roof life is reported to vary from plant to plant and depends upon furnace design (principally the height of the roof), operating conditions, and furnace maintenance. Deviation from the optimum parameters may lead to a reduction in roof life.

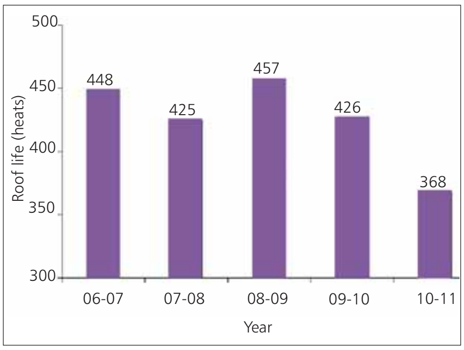

Fig 1 Average annual life of the roof from 2006 to 2011

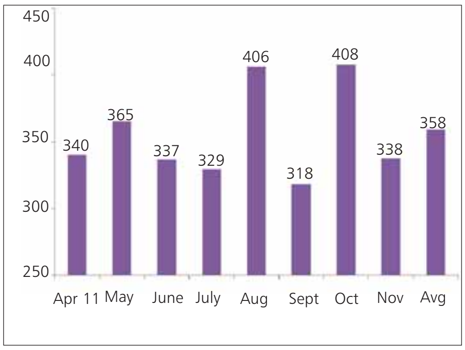

Fig 2 Average life of the roof from Apr 2011 to Nov 2011

One of the main causes for shortened roof life is the corrosive action from dust evolving from the bath during oxygen blowing. Blowing of metal with oxygen is always accompanied by an abundant release of dust from the bath. This dust consisting mainly of iron oxides (magnetite, hematite, wustite), and settles on the working surface of the roof in large quantities. The dust, thereby enriches the basic phases in the refractory brock (periclase and chromite) with iron oxide which lowers the melting point by 300 to 400ºC, and leads to rapid fusion and wear of the roof[1].

The roof of twin hearth furnace is lined with a magnesite chromite brick. This refractory is very sensitive to temperature fluctuations which cause sudden changes in thermal stress during processing the charge. Structural stresses also act on the roof. Thus forces are constantly changing on the magnesite chromite roof depending on the temperature of the roof and duration of melting. Short period changes in the temperature of the roof which arise from the regular reversal of the flue gases between chambers also cause changes in these thrust forces. The roof brick spalls when there is a sudden and prolonged change in the value of the thrust force (such as during repairs, charging of burden, and hot patching of the furnace)[2].

The life of the roof also depends to a considerable extent on the workmanship in building the structure. Too dense and non-uniform laying in the bricks in the walls of the roof arches can lead to a maximum concentration of thrust forces in a section[3].

Summarizing the various factors which can affect the life of the roof are:

– Changes in roof configuration resulting from thermal expansion as the temperature rises causing unevenness in the roof wear so leading to loss of static stability.

– Thermal stability and open porosity of the roof refractories. Also a substantial lack of physical and chemical uniformity in the refractories through the thickness of the roof may also lead to variable thrust forces because of differential expansion of bricks. The photographs in **Figs 3 & 4** illustrate the deterioration of the roof brickwork.

– Overcooling of the roof during hot repairs, hearth repairs, emergency cut off fuel and during charging (especially when working with solid charges), and also when the burner flame is reversed.

– Duration of charging, heating and pouring of molten pig iron. Also, the thermal load dur-

Fig 3 Twin hearth furnace roof during dismantling

Fig 4 Brick failure: Slag Infiltration & Thermal Spalling

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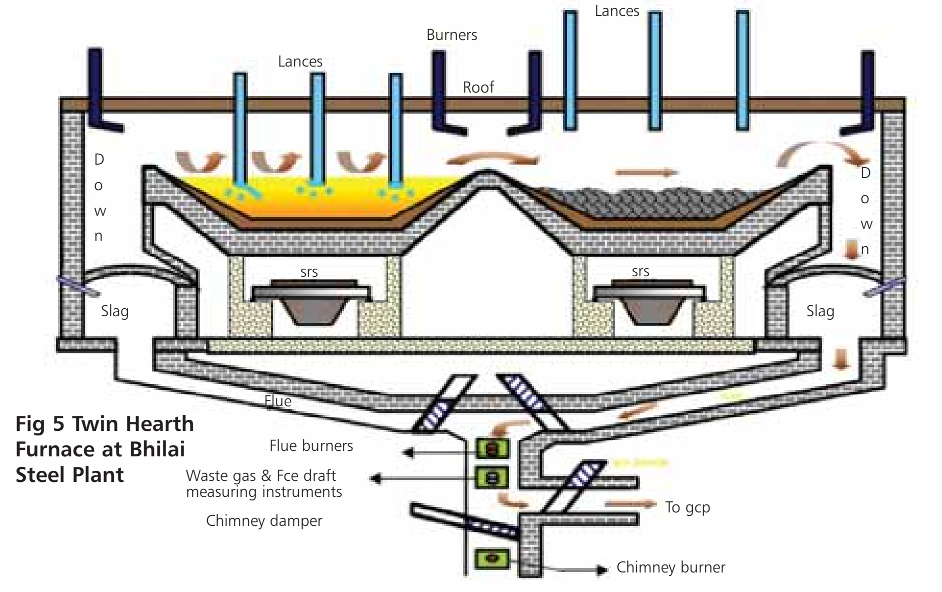

Fig 5 Twin Hearth Furnace at Bhilai Steel Plant

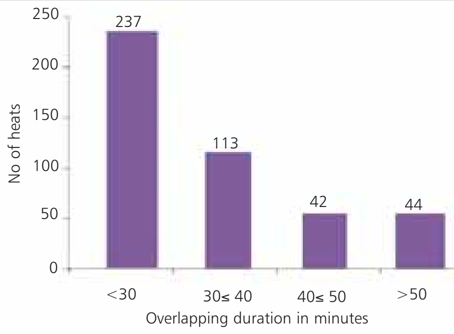

Fig 6 Restriction of oxygen blow overlap duration to decrease gas load on roof

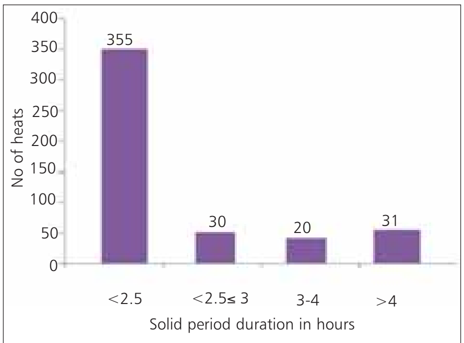

Fig 7 Reduction in charging time for solids to reduce overcooling of roof bricks

ing the period of charging, heating and pouring of pig iron.

– Melting and refining time and the intensity of the oxygen blow during the refining period.

THF operation

The Twin-bath furnace is a modified version of the traditional open hearth (Siemens Martin) furnace. The Twin hearth furnace is a double bath furnace without regenerators. It is designed to operate with intensive oxygen blowing into the bath through multiple roof lances (**Fig 5**). The fundamental principle of its operation is the utilization of the physical and chemical heat from the gases evolved from the bath during blowing to heat the solid charge in the adjoining hearth. To achieve this there is a gap between the two hearths and the common roof for the transfer of combustion products from one hearth to the other.

The first operation after tapping is fettling the refractories which is carried out using sintered dolomite or magnesite. When fettling is completed the hearth is charged first with part of the scrap load, then with limestone and then again with the remaining scrap. Thus, limestone is sandwiched between the scrap. Around 40-50t of scrap in total and 10-12t of limestone are charged. After charging this solid material, this hearth is preheated by directing the combustion gases from the adjacent hearth which is in its oxygen blowing refining stage, across the solid charge. These gases impart both their heat content and chemical heat, by ensuring post combustion of the CO present, to the solids. When heating is completed, liquid iron (around 200-220t) from the blast furnace is poured into the charged bath and oxygen blowing is commenced to refine the metal. The direction of the gases in the furnace are reversed by gate valves at this stage, and the second bath is tapped. The cycle is then repeated.

Measures for operational improvement

Reversal of gas flow

A twin hearth steelmaking furnace is the first industrial structure representing a proper steelmaking unit without regenerators, designed for operation with intensive oxygen blowing in the bath. The fundamental principle of its operation is the utilization of the physical and chemical heat of gases formed during blowing the adjacent hearth to heat the solid charge materials in the hearth's twin. In normal practice the latent and chemical heat of the flue gas is used to preheat the cold charge in the adjacent hearth and then sucked out through the opposite down-take.

Improper reversal practice will lead to cooling of the hearth roof above where the cold charge is located. During the trial it was ensured that the gases generated during blowing should be reversed to the adjacent hearth for proper heating of the scrap and fluxes.

Overlapping of oxygen blow

Overlapping in the twin hearth furnace means that both the hearths of the furnace contain metal in liquid form. While one hearth contains metal in almost a refined condition, the other hearth contains hot metal where the refining process has just started. During overlapping of hearths the overall gas load on the furnace roof increases and corrosive action of iron oxide dust in the gas affects the roof bricks. During the trial the period of overlap of the oxygen blow was restricted to a maximum of 30 minutes (**Fig 6**).

Furnace draft

The primary requirement in improving twin hearth furnace operation is to substantially cut down leakage of air into the furnace chamber. This will greatly increase efficiency in post combustion of carbon monoxide to further heat the charge. This will also help in extending the roof life and increasing the yield of the furnace[4]. The furnace damper is used for reversing the flue gas and the draft is controlled by an ID fan. Under regular plant operation, the furnace draft was slightly negative in the range of (-)32 to 34mmWC (millimetre of water column) and in some cases as high as (-)38mmWC. To avoid ingress of cold air, which adversely affects the roof life by cooling down the roof, the furnace draft was reduced to (-)28-29mmWC. A more negative furnace draft will also have implication on the movement of the furnace gases. The increased wear of the roof brickwork can be attributed to an increase in the rate of movement of these gases, which contain a large amount of melting dust and slag.

Solid period/charging period

Overcooling of the roof occurs during the charging period, especially during charging of solid charge ie scrap, limestone and iron ore. This causes sharp fluctuations in the roof temperature over a prolonged period leading to the redistribution of thrust forces in the deeper layers of the roof brick. As a result, cracks and spalling of the roof bricks occurs from areas at contact between the softened and the hard layers of brick. An increase in the time taken to charge will lead to overcooling of the roof bricks, and thus affect the performance of the roof. To avoid overcooling of the roof during charging the solids, emphasis was given on keeping the time taken to less than 2.5 hours (**Fig 7**).

Measures to improve brick quality

Input raw material & brick making

Around 420t of Mag-Chrome bricks are required for one set of roof lining of the twin hearth furnace at Bhilai Steel Plant. The bricks are made at the SAIL Refractory Unit (SRU) at Bhilai, India from Dead Burnt Magnesia (DBM) and Chromite ore in various proportions and bonded with molasses and dextrin as additives. The other materials used are salvaged Mag-Chrome and Chrome – Mag brick-bats (commonly known as Blast) generated from the steel plant in varying quantities.

Samples of all input raw materials ie dead burnt magnesia, chromite, and blast material were tested with respect to chemical analysis. The analysis of blast material indicated SiO_2, 11.57% to 11.73% and Fe_2O_3, 6.96% (**Table 1**). Higher SiO_2 and Fe_2O_3 in the matrix contribute to formation of low melting compounds resulting in faster erosion of the bricks.

Phase analysis of normal bricks

The phase analysis study of Mag-Chrome normal roof bricks was carried out using XRD and

Parameters %	MgO	CaO	SiO_2	Fe_2O_3	Cr_2O_3
DBM	91.15	1.51	6.55	0.57	-
Chromite	10.46	-	5.54	15.69	51.47
Salvaged Brick Bats	66.46	1.32	11.57	6.96	9.90
Brick Sample-1	66.52	1.68	8.20	6.86	11.65
Brick Sample-2	68.54	1.4	6.8	6.62	11.14

Table 1 Chemical analysis of input materials and brick samples (wt%)

Samples	Periclase (MgO)	Spinel ($MgO.Cr_2O_3$)	Forsterite ($2MgO,SiO_2$)	Chronium Oxide (Cr_2O_3)	Donahite (Fe.Mg) ($CrFe_2O_4$)
Fresh Bricks (Hot Face)	91.9	2.3	2.0	NIL	3.8
Fresh Bricks (Cold Face)	83.7	3.1	3.7	0.2	9.3
Blast Material	81.1	-	7.0	-	11.8

Table 2. Phase Analysis of Mag-Chrome Bricks and Input Materials

the results showed that the presence of the desirable phases ie Spinel ($MgCr_2O_4$) was very low at 1.0 to 3.1% and Forsterite ($2MgO.SiO_2$) was low at around 2.0-3.7%, whereas the undesirable Donahite (Fe.Mg)($CrFe_2O_4$) phase was present at 2.3 to 10.2% as indicated in **Table 2**. The silica in the bricks if not combined to form a high melting point phase (eg Forsterite – $2MgO.SiO_2$) will instead form low melting compounds with MgO such as Donahite. Similarly, the iron oxide will also form an undesirable phase.

Formulation of modified brick composition

The study of the mag-chrome brick used in the twin hearth showed that the bricks are made using Grade-III and Grade –IV Dead Burnt Magnesia (DBM) which has higher amount of SiO_2 (6.5-7.5%) and thus the resulting brick cannot meet specification. Further, the higher SiO_2 in the brick matrix will contribute to the formation of a low melting point compound causing further erosion of the bricks[5]. Mag-Chrome blast material, which is a mixture of crushed, used Mag-Chrome bricks from THF, BSP and of rejected bricks from the SAIL Refractory Unit (SRU), Bhilai, has SiO_2 in the range of 11-11.5%. This was used in manufacturing of 20-30% of the roof bricks.

Based on the study of brick making practices at SRU, and the analysis of both fresh and used bricks and input raw materials, it was proposed that the following procedure be adopted for the manufacture of Mag-Chrome roof bricks:

– Use DBM of grade III with a SiO_2 content of 6.07-6.55% to avoid formation of low melting point phases which may arise with grade IV and grade V type DBM which have SiO_2 contents of 7.5 to 8.5%.

– Continue using grade I type chromite fines (Cr_2O_3-52-54%, SiO_2-5%).

– Avoid using blast material in the brick com position, which may contribute to higher SiO_2 (11.57-11.73%) and Fe_2O_3 (6.96%) and results in the formation of unwanted Donahite phase (6.6-10.2%).

– Replacement of 10% DBM micro fines with purer magnesia (SWM); and

– Bricks to be fired with extended soaking times of 5 hours 20 minutes minimum at 1600°C.

Experimental

Trials were conducted after modification of operational factors (as discussed above) using the modified brick composition A few sets of bricks were made to the following composition.

Result and discussion

The new formulation helped in decreasing the porosity as well as improved the spalling resistance of the bricks (**Table 4**):

Improvement in operational practices in combination with improvement in brick quality helped in increasing the roof life form an average of 368 heats to 436 heats with a maximum lining life of 545 heats during the FY year 2010-11. This resulted in an increased furnace availability to 73.0%. Refractory consumption was also decreased by 15% ie 4.3kg/t from the previous level of 5.09kg/t. All these factors eventually led to increase in productivity of the furnaces from 101.22 t/h to 107.54 t/h.

The improved practice led to large monetary benefits because of the increase in productivity and decrease in refractory consumption.

Conclusions

– A decrease in the roof life of THF may be attributed to deviations from standard operating practices as well to a deterioration in brick quality.

– Frequent and prolonged deviation from the optimum level of overlapping in which solid charge remains in both furnaces, will adversely affect the roof life.

– Furnace draft is an important parameter which also affects the roof performance. Regular analysis of waste gas will help in maintaining an optimum draft.

– Brick quality especially porosity and thermal stability are important refractory characteristic for obtaining good furnace roof life.

– Both the silica (SiO_2) and iron oxide (Fe_2O_3) content in the refractory raw materials must be controlled to promote the formation of the desirable phases, spinel and forsterite in the fired bricks.

– Use of salvaged mag–chrome brick is detrimental to the quality of the brick due to contamination with free iron, SiO_2 etc, but;

– To promote the formation of desirable phases, the use of around 10% of salvaged mag-chrome bricks is preferable. In such cases purity level of other raw material viz dead burnt magnesia (DBM) and chromite must be increased. ■

References

1 M B Zil'bershtein, M G Kostyanoi et al 'Protection of the Main Roof of Open- Hearth Furnaces by Means of Air (Under Conditions of Intensification of Melting by Compressed Air), Translated from Metallurg, No 1, pp 20-22, January,1969 2 G T Tu'K, A A Mukhlynin et al, 'Increasing the Life of Roofs of Open–Hearth Furnaces', Translated from Metallurg, No 3, pp 16-21, March,1969
3 I P Gerasimenko, 'Öperation of Open Hearth Furnace Roofs', Translated from Metallurg, No 3, pp 20-23, March, 1974
4 K M Trubetskov, L M Efimov, and M M Privalov, 'The Present Situation and Future Prospects for Twin-Bath-Furnace Steel Production' Translated from Metallurg, No 11, pp 32-34, November, 1974 5 0 J Mosser, G Brchebner, K Dosinger, RHI Refractories

Raw material	Composition (%)
DBM (Grade-III)	40-45
Chinese DBM	16-20
Purer Magnesia (SWM)	8-12 (as micro fines)
DBM (Grade-III)	8-12 (as micro fines)
Chromite	18-22
Fired at 1610°C and soaked for 5 hours	

Table 3 Composition of Bricks For Trial

Properties	Earlier	Modified
Bulk Density (gm/cc)	2.82-2.86	2.82-2.95
Apparent Porosity (%)	20.7-22.6	18.0-22.2
Ref. Under Load (oC)	1590	1600-1640
CCS (kg/cm2)	450 – 500	455 – 830
PLC (%) 1600 X 3 hrs	-0.03 to +0.14	+0.06 to +0.26
Spalling (1000oC), Air	-	+ 35 cycles, hairline crack

Table 4 Properties of Modified bricks v/s Normal Bricks