Refractories for reheating and heat treatment furnaces

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After describing the type of furnacess and the service conditions encountered in different types of reheating and heat-treatment furnaces the authors illustrates the different types of refractories used in various zones of the furnaces e. g. walls, roofs, hearth, combustion chamber etc. The importance of insulation and conservation of energy in various types of furnaces has also been emphasied. Refractories for soaking pits has also been discussed.

Introduction

The group of furnaces used for reheating and heat-treatment covers a wide field in the processing of both ferrous and non-ferrous metals. A "re-heating" furnace is utilised to raise the temperature of the metal to prepare it for hot working (shaping), while the "heat-treatment" furnaces are used for stress relieving and for changing the physical properties of the metal after the product has attained its final shape.

The above type furnaces may be grouped as follows :

1. Re-heating furnaces.
   These are divided into general classes :—
   a) Batch type
   b) Continuous type, which may be pusher-type, walking beam type, rotary hearth type and roller-hearth type.
2. Soaking pits.

The "heat-treating" furnaces encompass a wide range of furnaces varying in size, design and operating conditions.

In re-heating and heat-treatment furnaces the essential criteria for refractory performance is uninterrupted service life and minimum maintenance cost. Unscheduled breakdowns are extremely undesirable since it would upset the entire production programme of the mill.

The selection of the refractories to achieve a successful performance would depend upon the areas of application in the furnace and the service conditions. One of the major criteria influencing the choice would be the overall cost so as to achieve the optimum economic performance.

In general the refractories, are required to withstand any of the following conditions during service. The severity of any of these conditions would greatly influence the choice of refractory.

1. High temperature depending on furnace operational requirements.
2. Localised overheating due to flame misalignment or radiation from the flame.
3. Abrasive action due to nature of the fuel e. g. where solid or pulverised fuel is used.
4. Effect of fuel ash etc.
5. Load due to the brick work.
6. Structural stresses.
7. Stresses due to temperature gradient.
8. Temperature fluctuations and cycling.
9. Effect of fumes etc. prevailing in the furnace atmosphere.
10. Reactions due to scales, slags etc.
11. Load due to charge in the furnace.
12. Mechanical abuses either due to movement of the charge or any other factor.

The temperature conditions in service is the major factor to determine the quality of the refractory required for any particular application. Here the distinction is to be made for refractories which are used in the immersed state i. e. where it is exposed to temperature on all sides such as checkers, partition walls etc. On the contrary where the refractory is subjected to high temperature on one face only, which is the more usual condition encountered in furnaces, the relatively cooler rigid portion of the brick on the cold face side of the brick work can take most of the load.

Insulation and conservation of energy

Conservation of energy is also one of the important feature which would influence the choice of refractories. The refractory quality i. e. the thermal conductivity and the lining thickness would determine the amount of heat flow through any structure. Usually the facing lining which has to withstand the abrasive actions and other mechanical abuses of the furnace, is a dense refractory material backed up by hot face and cold face insulation bricks. However, over insulation is also not beneficial since it would raise the intereface temperature, which would require a better grade of refractory to withstand the relatively more intense temperature conditions.

In recent years, with the development of superior quality hot face refractories increasing use is being made of such refractories for the construction of furnaces. If other operating parameters are suitable, these refractories can be used as the working face of the lining which in addition to the lower heat losses provide the advantage of the lighter construction.

In continuous furnaces, the losses through the walls is insignificant compared to the total energy consumption[1].

In case of the batch type furnaces the conditions are distinctly different. Construction with insulating refractories results in a relatively lower thermal mass of the furnace brickwork. Such constructions have the advantage of reducing the heat losses due to heat flow through the refractory structures as well as reduction in the residual heat content between heating cycles due to the lower thermal capacity. These are ideally suited for the construction of the low inertia rapid heating furnaces where relatively quicker cycles become possible to be achieved. The introduction of ceramic fibres which can withstand quite high temperatures have immensely increased the possibility of the extensive use of such materials in furnace constructions.

Refractories for re-heating furnaces

In addition to the suitable refractory quality required to adequately withstand the furnace operational environments, the following aspects are equally important to achieve success :

a) Design of suitable refractory structure

b) Provision of expansion allowance

c) Laying of the refractory brick work.

The common areas of all furnaces are usually i) Walls ii) Roof iii) Combustion chambers iv) Hearth, which are dealt separately from the design view point. The designers' concern is not only to achieve a structurally stable construction, but also to ensure that the structures would withstand the stress/strain influences during operation.

Walls

The quality of the refractory as well as the wall thickness would depend on the operating environment of the furnace, wall height as well as the degree of conservation of heat desired.

In the continuous reheating furnaces the walls have to usually accommodate other important elements of the furnace such as combusion chamber, the load of the roof in some types of constructions and doors etc. However less severe conditions are in general experienced in the walls than in the roof and combustion chambers. The introduction of oil firing and high output rates has resulted in replacement of the usual medium and high duty fireclay bricks by higher alumina (50—60% Al_2O_3) bricks, specially in the bottom part of the furnace where lower shrinkage, higher resistance to creep in compression and greater resistance to thermal shocks are necessary. A particular damage to side walls in bottom fired furnaces is the effect of flame impingement, which being below charge level, is not easily detected before serious damage has been effected.

The compressional load at the bottom brick for a 4 meter wall would be about 1.5 Kg/cm^2. However, complication arises due to the surface irregularities, within the tolerance limits allowed and present day manufacturing practices, which may result in point loading at the contact of two brick interfaces. This results in development of stresses which far exceeds the compressional crushing strength of the bricks. The stresses however can be more uniformly redistributed by provision of suitable mortar joints. In case of bowed bricks, transverse cracks and failure would result due to point contacts where the load would exceed the strength of the bricks[2].

Mouldable refractories are being increasingly used for insitu construction of furnace walls with suitable anchors. These are being extensively used in USA and other countries advantageously with satisfactory performance.

In a 22 meter long continuous strip annealing furnace operating at 950°C the firebricks lining backed up by hot face and cold face insulation bricks, used to collapse frequently On the spot enquiry by the authors and follow up by intensive laboratory trials and estimates of temperature gradients in the wall revealed that the brick quality used was not suitable to withstand the operating conditions. It was more so since the walls also have to withstand the load of the sprung arch roof. Replacement with proper grade high alumina refractories to meet the operating conditions was ruled out since the operators were equally concerned with conservation of the expensive LPG fuel being used for heating. The proposed high alumina lining would obviously increase the heat losses, through the walls and also increase the outside wall temperature where buckling of the steel shell had already occured with the previous campaigns. Since suitable grade hot face insulation bricks were not available indigenously, it was developed in the authors laboratory with utmost urgency and translated into actual plant scale production with the minimum lead time. The specification of the hot face insulation brick used in the furnace is given below :

Maximum service Temperature	...	1300°C
SiO_2	...	80—85
Refractoriness	...	1500°C
Bulk Density (gms/cc)	...	0.9—1.1
Apparent Porosity (Vol. %)	...	55—60
C C S (Kg/cm^2)	...	30—40
% PLC at 1300°C (8 Hrs.)	...	±0.5
Thermal conductivity in	...	400°C—2.0
Btu/in/hr/°F at hot face		600°C—2.3
temperature of		800°C—2.8

The furnace has now been operating successfully without any interruption since over a year. The savings on the fuel cost alone has already paid back the refractory prices several times over.

Roof

The furnace roof is usually made with sprung arch or suspended construction. Suspended roof construction is more in practice in recent years, particularly for large furnaces.

Thermal spall resistant and volume stable fireclay shapes have been successfully used in furnaces with moderate operating conditions. Semi silica bricks, which posesses relatively better spalling resistance, have also been used. Typical data of fireclay refractories which has proved to be suitable for roof construction is given in Table I.

However, the severe operating conditions in large furnaces of high output mills have exposed the limitations of these refractories. The introduction of oil firing has further aggravated the situation due to faster heating rates particularly in the lower temperature range and there is a greater risk of flame misalignment with risk of localised over heating. The alkalis and vanadium oxide in the fuel ash may have a strong corrosive effect on the refractories.

The present trend, particularly in USA and other western countries, is to replace shaped bricks in the roof by fully monolithic roofs installed insitu or use of large precast blocks. Besides good thermal shock resistance, use of such refractories have the advantage of the inherent lower conductivity over equivalent grade of dense bricks.[3]. Some typical properties of refractory concretes for reheating furnace roof blocks (Hardy and Titterington)[4] are given below :

Recommended service temperature range — 0 to 1550°C

Cold crushing strength, Kg/cms^2 — 475

Thermal expansion (20—1550°C) — 0.25%

Permanent linear change, % (Shrinkage) — 0.47

Refractoriness — Orton Cone 32

In case of the sprung arch constructions conditions of point loading due to surface irregularity may occur. Similarly with bowed bricks transverse fracturing may also develop which partly explains the slabbing off of the hot face of the roof during furnace heating up.

The creep properties also play a significantly important role in the performance of roof refractories. On the hot face such expansion is partially off-set by the creep. But immediately behind the hot face stresses develop in the relatively rigid portion of the brick which would crack due to its failure to yield to the resultant stresses. These difficulties may be eliminated to great extent by provision of suitable expansion allowance in the construction.

In case of the suspended roof construction several design with proven

TABLE—I

Refractories for use in roof of reheating furnaces

Thermal shock resistant and volume stable firebrick		
% Al_2O_3	....	35—37
% % Fe_2O_3	...	2.0
Refractoriness	....	SK—32
Bulk Density (gm/cc)	..	2.15
App. Porosity (Vol. %)	....	18
C C S (Kg/cm²)	....	380
R U L (2Kg/cm²) + ta °C	....	1435
% P L C at 1450 °C	....	± 0.2
Spalling Resistance 1200°C—water	....	+ 15 Cycles

performance over the years are in existance. The essential features are provision of suitable anchors and their protection against over-heating, proper design of the bricks and thermal spall resistant characteristics.

In the construction of the sprung arch furnace roofs the authors have experienced that provision of adequate expansion joints provided with meticulous care, through half the length of the arch brick on the hot face side, have shown promising results. The expansion allowance provided should be just adequate so as to allow for the arch rise during heating up. In such a case the stresses are uniformly distributed and the arch is less prone to cracking or sagging. It has also been observed that the problems related to flame impingement on the roof due to misalignment or any other reason and subsequent collapse can be eliminated to a great extent by providing a recess for the toe of the arch over the furnace wall. In extreme cases where temperature cycling and other mechanical abuses are characteristic of the particular furnace, provision of suitably designed tongue and groove arrangements in the design of sprung arches has given improved performances.

Combustion Chambers

The combustion chambers usually comprise of the burner quarls and the nose arch. The burner quarls are subjected to the destructive influence of rapid heating and cooling as well as severe over-heating due to radiation and flame impingement. During operation, carbon build up is frequently encountered which tend to effect the direction of the flames. High alumina refractories in 60—80% Al_2O_3 range are conventionally used. The typical problems encountered are cracking and sagging of the burner quarls. In severe operating conditions where the burner quarls are to perform at continuous high temperature, even 90% alumina refractories have been used advantageously to avoid saggingand deformations. Recently both precast blocks and insitu castings are being used for installation of burner quarls. The following material has given successful result in several applications in the burner quarls, which was specifically developed for this purpose in the authors laboratory, and is given in Table II :

The nose arch is also exposed to more or less similar operatinng condition viz severe localised over heating due to flame impingement and continuous high temperature by flame radiation and possible misalignment. In case of self supporting arches, the stress/strain conditions and failure due to fracturing occur similar to the roof arches. High alumina refractories are recommended where the nose arch has to support the load of the roof and

TABLE—II

Typical data of Ramming mass Burner quarl

Quality	...	High alumina
Max. Service Temperature	....	1700°C
Refractoriness	....	+ 1780°C
Al_2O_3 %	....	70—75
Fe_2O_3	....	2.5—3
Setting	....	Chemical
Sintering temperature	....	800°C
Crading mm	....	0-5

Linear change %

After drying at 110 °C — 0.2
After heating at 500 °C — 0.2
After heating at 1000 °C — 0.2
" " at 1450 °C — +0.8
" " at 1550 °C — +0.2

C C S Kg/cm²

After drying at 110 °C — 200—250
" Heating at 500 °C — 300—300
" " at 1000 °C — 350—400
" " at 1450 °C — 400—420
" " at 1550 °C — 350—370

wall super structures since higher hot strength and resistance to compressional creeps are highly desirable.

In a walking beam furnace operating at moderate temperature of about 1100°C, it was unfortunately exberienced that the furnace has to be shutdown in a few days after the light up due to complete collapse of the combustion chamber arches due to cracking. After intensive testing in the authors laboratory it was noticed that the refractory quality used were suitable to serve the purpose adequately and the failure was mainly due to other reasons. During the subsequent repairs, expansion allowances were provided on the hot face and also grannular refractory material were used over the arch to have the flexibility to marginally accommodate the arch rise (Fig. 1). The problem have been satisfactorily solved since then.

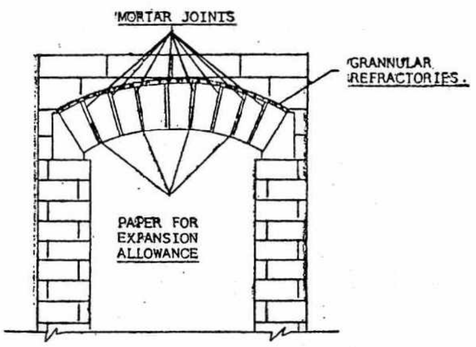

Fig. 1 Provision of expansion allowance on the burner arch

Similarly in a furnace operating continuously over 1500 °C, sagging of the combustion chamber arches was a recurring problem since these arches have also to withstand the thrust of the roof arch. Subsequently additional rider arches were provided to relieve the burner arches from the direct thrust of the roof arch. The performance since then have improved appreciably (Fig. 2).

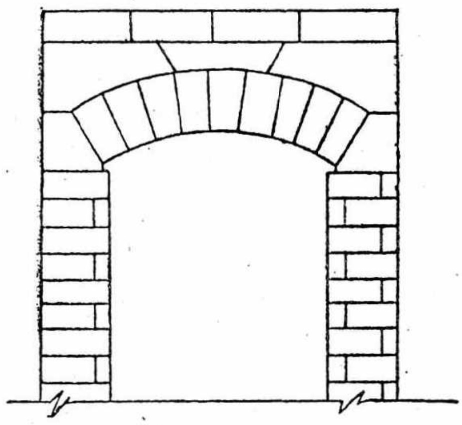

Fig. 2 Rider arch to relieve the load on the burner arch.

Hearth

The hearth of the reheating furnaces is the total area available to carry the stock and is subjected to the maximum mechanical abuse, slag and scale attacks, load at high temperatures etc.

In pusher type furnaces the preheating zone hearth is either solid through out with skid rails to give protection against abrasion or have water cooled skids supported by ordinary fireclay bricks as in the bottom fired pusher type furnaces. In the soaking zone the hearth is subjected to abrasion and attack by oxide scale which may result in severe fluxing of the refractory under the prevailing high temperature condition. In this area both basic and

TABLE—III

Properties of refractories for lining of reheating furnace hearth

	BRL—88	BRL—88X	BRL—90	BRL—95X	BRL—CMN
% Al_2O_3	87	88	90.1	95	—
% Fe_2O_3	1.5	0.9	0.8	0.9	—
% MgO	—	—	—	—	37.2
% Cr_2O_3	—	—	—	—	24.5
	—	—	—	—	—
Refractoriness :	Over SK—36	Over RK—36	Over SK—36	Over SK—36	Over SK—36
Bulk Density (gm / c.c.	3.16	3.14	3.05	3.5	2.90
App. Porosity (Vol. %)	15.1	16.0	16.7	20.2	24.0
C. C. S. (Kg / cm^2)	1050	975	920	980	250
R. U. L. ($2Kg / cm^2$) : t_a °C	1480	1550	+1700	+1700	1640
% P. L. C. at	1500 °C, 2 Hrs. —0.3	1500 °C, 2 Hrs. —0.2	1600 °C, 1 Hr. +0.2	1600 °C, 1 Hr. +0.4	1600 °C, 1 Hr. +1.0
Spalling Resistance 1200 °C—Water	+12 Cycles	+12 Cycles	+12 Cycles	+10 Cycles	+10 Cycles
Creep with 4 Kg/cm^2 load for 4 hrs. at	1300 °C —0.02%	1300 °C .0	1400 °C .0	1400 °C .0	— .0

high alumina (80-90% Al_2O_3) refractories have been successfully used. Fusion cast bricks give better performance, but the relatively high cost precludes its use extensively. Dense (80-90% Al_2O_3) fused grain rebonded brick developed indigenously has given highly promising results. These bricks have been successfully used in the skids and hearth of a pusher type reheating furnace in an integrated steel plant. A record ingot production of over 1.5 million tonnes has been achieved without any necessity of repair of the hearth with the BRL-88 brick (item I, Table III). The typical data of the materials suitable for the reheating furnace hearths are given in Table III.

In the walking beam furnaces the refractories are required to have high impact resistance, resistance to thermal shock and scaling. High alumina bricks (80% Al_2O_3) and a high strength castable refractory specially developed for the purpose have performed well in service after careful attention was paid to the design of the brick shapes. The typical data of 80% Al_2O_3 brick is given in Table IV and that of the castable is given below :

Typical data of castable used in walking beam furnace :

Max. Service Temperature	—	1450 °C
P C E	—	+ 1600 °C
Al_2O_3	—	42—45%
Fe_2O_3	—	1—1.5%
CaO	—	4.8—5.5%
Setting	—	Hydraulic
Sintering tem.	—	1200 °C
Grading	—	(0—5) mm

	Linear change	CCS Kg/cm^2
After drying at 110 °C	± 0	250—300
After heating at 500 °C	± 0	280—310
After heating at 1000 °C	± 0	200—230
Aftre heating at 1200 °C	± 0	240—260

Refractories for soaking pits

In the soaking pits, although the operating temperatures are relatively moderate (1250 to 1400 °C) the service conditions to which refractories are exposed are frequently severe. The recent trend in the refractory practices being adopted in the various important areas of the soaking pits are briefly reviewed below :–

Hearth—This has to support heavy load of ingots and also to resist the attack of molten scale. Earlier, fireclay bricks were used for lining the the hearth, but these were attacked vigorously by iron scales with the formation of liquid slag. The top refractory layer of the hearth in the present day soaking pits is usually magnesite, chrome magnesite or high Al_2O_3 bricks (70—80% Al_2O_3) with a covering of coke breeze. The main requirements are high impact and load resistance, and also resistance to iron oxide attack at the operating temperature.

In the **lower walls**, the refractories are subjected to corrosive action of

TABLE—IV

Properties of indigenous brands of refractories for use in soaking pits

	Hearth & Lower Sidewalls		Bottom & Lower sidewalls		Upper sidewalls		Pit Cover
	BRL—MGR	BRL—CMN	BRL—70	BRL—80(WB)*	BRL—HGD	BRL—SGD	Special quality fireclay
% Al_2O_3	—	—	70.5	80 5	36	38	38
% Fe_2O_3	—	—	1.5	2.0	1.5	1.5	1.7
% MgO	88	37.2	—	—	—	—	—
% Cr_2O_3	—	24.5	—	—	—	—	—
% SiO_2	6.0	—	—	—	—	—	—
Refractoriness :	Over SK—36	Over SK—36	Over SK—36	Over SK—36	SK—31—32	SK—33	SK—32—33
Bulk Density (gm/cc)	2.87	2.80	2.35	2.60	2.22	2.25	2.15
App. Porosity (Vol. %)	20.2	24.0	22	22	12.5	14.7	20—25
C. C. S. (Kg / cm^2)	400	250	400	450	600	620	200—300
R.U.L. (2Kg/cm^2) : t_a °C	1620	1640	1560	1660	1480	1500	1490
% P. L. C. at	1600 °C, 1 Hr., ±0.7	1600 °C, 1 Hr., ±1.0	1600 °C, 1 Hr., ±0.8	1600 °C, 1 Hr., ±0.8	1450 °C 2 Hrs., ±0.3	1450°C 2 Hrs., ±0.2	1450 °C 2 Hrs., ±0.5
Spalling Resistance 1200 °C—Water	—	—	10 Cycles	10 Cycles	10 Cycles	12 Cycles	15 Cycles
Resistance to iron oxide scale	Good	Good	Good	Good	Good	Good	Good
Creep with 4 Kg/cm^2 load for 4 hrs. at	—	—	1400 °C —0.32%	1400 °C —0.20%	—	—	—

* Successfully used in the hearth of walking beam furnace.

molten iron oxide scale. The lower courses may be constructed of the same materials as hearth i. e., magnesite, chrome-magnesite or high alumina, backed by fireclay and insulation bricks. For upper walls, high grade firebricks suitable to resist the impact of the resting ingots, and to resist the thermal shock due to change in temperature during loading and unloading are normally used. Sometimes semisilica bricks are also used in the upper walls.

Pit cover—The refractories used as cover of soaking pits have to withstand frequent thermal shocks, and attack of iron oxide vapours. The refractories used must have the following properties-high thermal shock resistance, minimum attack by iron oxide vapour, volume stability and high mechanical strength. Table IV gives the properties of the various refractories used in the soaking pits.

In order to achieve quicker repair time at the end of campaign and to reduce labour cost, large precast or moulded blocks are being used for construction of upper side-walls of soaking pits in Western countries. Also monolithic 'in situ' constructions of side walls as well as covers of soaking pits is becoming popular in other countries. The refractory materials which may be suitable for these purpose are properly formulated fireclay or high alumina bodies—which may be either hydraulically, chemically or ceramically setting types.

Conclusion

The successful performance of refractories in the reheating and heat treating furnaces is dependent on the selection of suitable quality of refractories to withstand the environmental conditions as well as proper design of the refractory structures. Besides, provission of adequaate expansion allowances located judiciously to suit specific service conditions and also good workmanship in laying the bricks are equally important.

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