Properties of Refractories

1.5.1 Physical properties

A. Melting point, B. Size and dimension stability, C. Apparent porosity, D. water absorption, E. Bulk density .

1.5.2 Chemical properties

Reaction and corrosion of Refractories

1.5.3 Mechanical properties

a. Modulus of rupture (MOR), b. Hot modulus of rupture (HMOR)
c. Cold crushing strength , d. Hardness e. flexural strengths

1.5.4 Thermal properties

a. Thermal Shock Resistance b. thermal conductivity
c. thermal expansion and spalling, slag resistance.
d. Refractoriness, pyrometric cone equivalent (refractoriness) under load.
e. Thermal diffusivity

1.5.5 Electrical Properties

a. Dielectric Properties

1) Melting Point:

Melting temperatures (melting points) specify the ability of materials to withstand high temperatures without chemical change and physical destruction.

The melting point of few elements that constitute refractory composition in the pure state varies from 1716°– 3482°C as indicated in the table below:

REFRACTORY ELEMENT	MELTING TEMPERATURES (°C)
Graphite C Pure	3482
Thoria, ThO_2 Pure Sintered	3000
Magnesia, MgO, Pure Sintered	2800
Zirconia, ZrO_2 , Pure Sintered	2700
Lime, CaO	2570
Beryllia, BeO, Pure Sintered	2550
Silicon Carbide, SiC, Pure	2250
Magnesia, 90-95%	2193
Chromite, FeO-Cr_2O_3	2182
Chromium Oxide	2138
Alumina, Al_2O_3, Pure Sintered	2050
Chromite, 38%, Cr_2O_3	1970
Fireclay	1870
Titania, TiO_2	1850
Kaolin	1816
Silica, SiO_2	1716

The melting point serves as a sufficient basis for considering the thermal stability of refractory mixtures and is an important characteristic indicating the maximum temperature of use.

2) Size and Dimensional Stability:

- The size and shape of the refractories is an important feature in design since it affects the stability of any structure.

- Dimensional accuracy and size is extremely important to enable proper fitting of the refractory shape and to minimize the thickness and joints in construction.

- The contraction or expansion of the refractories can take place during service. Such permanent changes in dimensions may be due to:

1. The changes in the allotropic forms which cause a change in specific gravity.
2. A chemical reaction which produces a new material of altered specific gravity.
3. The formation of liquid phase.
4. Sintering reactions.
5. It may also happen on account of fluxing with dust and slag or by the action of alkalies on fireclay refractories, to form alkali-alumina silicates, causing expansion and disruption.


Silica
L3597
9
Calcium carbonate
L3593E
9
Pyrophyllite
L3593C
9
Dolomite
M3593F
9
Talc
Calcined kaolin

- The linear change can be calculated on basis of volume change by the following relationships:

- $$Volume\ change\ \% = \frac{final\ volume - original\ volume}{original\ volume} .100$$

- $$Linear\ change\ \% = \frac{final\ length - original\ length}{original\ length} .100$$

- **3) Porosity and Slag permeability:**
- The porosity of refractory is expressed as the average percentage of open pore space in the overall refractory volume. The molten metal, slag, fluxes, vapors etc. can penetrate and thereby contribute to eventual degradation of the structure.
- Decrease in porosity increases strength and thermal conductivity.

- High porosity materials tend to be highly insulating as a result of high volume of air they trap, because air is a very poor thermal conductor.
- Refractory materials with high porosity are usually NOT chosen when they will be in contact with molten slag because they cannot be penetrated as easily.

- **True porosity** of a refractory brick is the percentage of the volume of combined open and close pore space of its total volume.
- Density of a refractory brick is controlled by both open and close pores while its permeability is affected by only open (i.e., interconnected) pores.

- **With increase in the porosity of the refractory bricks, its**

1. Thermal conductivity **decreases** because the air which fills the pores acts as an insulator, which is why insulating bricks have higher porosity.
2. Resistance to the penetration of metal, molten slag and flue gases **reduces** due to increased permeability.
3. Temperature fluctuation sensitivity **reduces** as pores can accommodate the thermal expansion due to heat.
4. Strength **reduces** due to decreased compactness obviating their usage in taller structure demanding higher strength.

- **Porosity determination:**
- In raw/green refractory materials the pores are all open. When these materials are fired some liquid formation due to fusion takes place and as a result some pores will be sealed. The apparent porosity as such takes the open pores and not the closed pores. True porosity is defined as:
- ***True porosity***

$$= \frac{volume\ of\ open\ pores + volume\ of\ closed\ pores}{External\ volume}.100$$

- ***Apparent porosity***

$$= \frac{volume\ of\ open\ pores}{External\ volume}.100$$

- **Boiling Point Method for Porosity Determination**
- The apparent porosity of a clean small sample (measuring 6.5 x 6.5 x 4 cm) is measured by making three weighings. The first is dry specimen. The second is saturated specimen immersed in water and third the saturated specimen suspended in air. To ensure that the specimen is thoroughly saturated, it should be boiled in water for two hours. The apparent porosity is determined from these weighings by the equation:
- $$A.P\% = \frac{W - D}{W - A} .100$$

where, A.P% = The apparent porosity.

W = Weight of saturated specimen in air

D = Weight of dry specimen in air (dried at 110°C in an oven)

A = Weight of saturated specimen submerged in water.

- The total porosity present can be found by relating the theoretical density (ρth), to the calculated density (ρ). The total porosity (T.P) of the sintered samples is also calculated from the following equation:

- $$T.P\,\% = \frac{\rho_{th} - \rho}{\rho_{th}}\,.100$$

- **4) Water Absorption:**
- Water absorption can be indicative of open pores due to the weight of moisture in the pores compared to the weight of sintered body.
- Water absorption depends on the properties of the raw materials, grain size, and the conditions of shaping process and firing temperatures. Water absorption (W.A %) is calculated as follows:

- $$W.A\,\% = \frac{W - D}{D}\,.100$$

- **5) Density:**
- The bulk density is generally considered in conjunction with apparent porosity. It is a measure of the weight of a given volume of the refractory.
- For many refractories, the bulk density provides a general indication of the product quality; it is considered that the refractory with higher bulk density (low porosity) will be better in quality.
- An increase in bulk density increases **the volume stability**, the **heat capacity**, as well as the resistance to **abrasion** and **slag penetration**.
- True density is the weight per unit volume of the refractory including the volume of its open and close pore space.

- **Determination of Bulk Density**:
- The bulk density of any refractory is measured by the equation:
- $$Bulk\ density = \frac{total\ wight}{total\ volume}\ of\ refractory$$
- Bulk density is measured using either :
- direct measurement method
- or direct volume determination method.

- **Direct Measurement Method**.
- The rectangular refractory test specimen brick is accurately weighed (to nearest 50 g) and its dimension is noted using a hook rule for calculating its volume. The bulk density is calculated using the formula:
- $$B = \frac{W}{V}$$
- where, B = Bulk density of brick, g/cc,
- W= Weight of the test specimen, g
  V = Volume of the test specimen, cc.

- **Direct Volume Measurement Method**.

- $B = \frac{D}{W-A}$

- The direct volume determination method (generally used for deeply branded and irregular refractories) gives more accurate results than the direct measurement method (used for rectangular shapes of refractory only). This is one of the main criteria for assessing the quality aspect of the particular brick.

- ***<u>H.W:</u>***
- Volume of a cubic refractory brick has been expanded from all dimensions in equal amounts, when it was heated. The new volume of the brick at high temperature becomes 1000 cm^3. The initial length of the brick becomes equal 90% of the final length. Find the ratio of volume change to linear change of the brick?