CHAPTER 3

3.REFERACTORIES

3.1. Definitions

Refractory is a class of materials which are produced from **non-metallic materials**.

Any material can be described as a ‘refractory, if it can **withstand** the action of abrasive or corrosive solids, liquids or gases at high temperatures, without softening or suffering a deformation in shape.

Main Objective	
1-	To confine heat e.g. to resist loss of heat.
2-	To resist abrasive and corrosion action of molten metals, slags and gases at high temperatures, without undergoing softening or distortion in shape.

Uses	
1-	Construction of the linings of the furnaces, tanks, converters, Kilns, crucibles, ladles etc.
2-	Manufacture of metals (Ferrous or non-ferrous), cement, glass, ceramics, paper, steel etc.

The various combinations of operating conditions, in which refractories are used, make it necessary to manufacture a range of refractory materials with different properties.

Refractory materials are made in varying

1-Combinations and,
2- Shapes depending on their applications.

3.2. General requirements of refractory material

General requirements of a refractory material are:	
1-	Withstand high temperatures
2-	Withstand sudden changes of temperatures
3-	Withstand action of molten metal slag, glass, hot gases, etc
4-	Withstand load at service conditions
5-	Withstand load and abrasive forces
6-	Conserve heat
7-	Have low coefficient of thermal expansion

8-	Should not contaminate the material with which it comes into contact
Characteristics of Refractories	
A good refractory possess the following characteristics:	
1-	Be infusible at the temperature to which it is liable to be exposed.
2-	Chemically inert towards corrosive action of gases, metallic liquids, and slags.
3-	Resist the abrasive action of flue gases, flames, etc.
4-	Be able to withstand the overlying load of structures at the operating temperature.
5-	No crack
6-	No loss in size.
7-	Expand and contract uniformly, with temperature rise and fall respectively

3.3 Classification of Refractories

Refractories are classified into number of ways on the basis of chemical composition (properties) of their constituent substances, their refractoriness, method of manufacture and physical form.

3.3.1-Classification Based on Chemical Composition

Refractories are typically classified on the basis of their chemical behavior, i.e. their reaction to the type of slags (خبث). Accordingly the refractory materials are of three classes - Acid, Basic & Neutral.

I-Acid Refractories (e.g. silica bricks):

Acid refractories are those which are attacked by alkalis (basic slags). These are used in areas where slag and atmosphere are acidic. Examples of acid refractories are:

1-	Silica (SiO_2).	2-	Zirconia (ZrO_2).	3-	Alumina silicate.
4-	fireclay refractories				

II-Basic (Alkaline) Refractories (e.g. magnetia bricks):

Basic refractories are those which are attacked by acid slags but stable to alkaline slags, dusts and fumes at elevated temperatures. Since they do not react with alkaline slags, these refractories are of considerable importance for furnace linings where the environment is alkaline; for example non-ferrous metallurgical operations.

The most important basic raw materials are:

1-	Magnesia (Mg O) - caustic, sintered and fused magnesia
2-	Dolomite (CaO. MgO) - sintered and fused dolomite
3-	Chromite -main part of chrome ore **by**

III-Neutral Refractories (e.g. karborundum bricks):

(made from weakly acid/basic)

Neutral Refractories are chemically stable to both acids and bases and are used in areas where slag and atmosphere are either acidic or basic. The common examples of these materials are: Alumina

1-	Carbon graphite (most inert)	2-	Chromite (Cr_2O_3)	3-	Zirconia (ZrO2)
4-	(Fe O. CrO2),	5-	carborundum (SiC) refractories		

Out of these graphite is the least reactive and is extensively used in metallurgical furnaces where the process of oxidation can be controlled.

Melting point of some pure compounds used to manufacture refractory Melting

Compounds	**point (℃)**
MgO (pure sintered)	2800
CaO (limit)	2571
SiC pure	2248
MgO (90-95%)	2193
Cr2O3	2138
Al2O3 (pure sintered)	2050
Fireclay	1871
SiO2	1715

Note

Chemical characteristics of the furnace process usually determine the type of refractory required. Theoretically, acid refractories should not be used in contact with basic slags, gases and fumes whereas basic refractories can be best used in alkaline environment. Actually, for various reasons, these rules are often violated

3.3.2 Classification Based on Method of Manufacture

The refractories can be manufactured in either of the following methods:

a-	Dry Press Process.
b-	Fused Cast (إنصهار بالصب).
c-	Hand Molded.
d-	Formed (Normal, Fired or chemical bonded).
e-	Unformed (Monolithic (متألفه) – Plastics, Ramming (صدمة) mass, Gunning, Cast able, Spraying).

3.3.3 Classification Based on Physical Form

Refractories are classified according to their physical form. These are the shaped and unshaped refractories. The shaped is commonly known as refractory bricks and the unshaped as "monolithic" refractories. They are produced in Special shapes and are custom made to suit the requirements of the various industries

I-Shaped Refractories (Refractory bricks):

Shaped refractories are those which have fixed shaped when delivered to the user. These are what we call bricks. Brick shapes may be divided into two: standard shapes and special shapes.

Standards shapes have dimension that are conformed to by most refractory manufacturers and are generally applicable to kilns and furnaces of the same type. Special shapes are specifically made for particular kilns and furnaces. This may not be applicable to another furnaces or kiln of the same type. Shaped refractories are almost always machine-pressed, thus, high uniformity in properties are expected. Special shapes are most often hand-molded and are expected to exhibit slight variations in properties.

II-Unshaped Refractories:

Unshaped refractories are without definite form and are only given shape upon application. It forms joint less lining and are better known as monolithic refractories. These are categorized as Plastic refractories, ramming mixes, castables, gunning mixes, fettling mixes and mortars.

3.4. Properties of Refractories

Important properties of refractories are**:** chemical composition, bulk density, apparent porosity, specific gravity and strength at atmospheric temperatures. These properties are often among those which are used as control points in the manufacturing and quality control process. So, refractories have physical and thermal and properties**:**

3.4.1 Physical Properties of Refractories

Important physical properties of refractories are:

Physical Properties	
1-	**Refractoriness**
2-	**Strength or Refractoriness-under load**
3-	**Size & Dimensional Stability**
4-	**Chemical Inertness**
5-	**Porosity**
6-	**Resistance to abrasion or corrosion**
7-	**Texture**
8-	**Permeability**
9-	**Bulk density (kg/m3):**
10-	**Cold crushing strength**
11-	**Creep at high temperature**
12-	**Electrical conductivity**

1. Refractoriness

Is the ability of a material to withstand the heat, without appreciable deformation or softening under particular service conditions.

In general, measured as the softening or melting temperature of the material. As most of the common refractory materials are mixtures of metallic oxides, so they do not have a sharp fusion (إنصهار) temperature.

Pyrometric Cones Test (Segar Cones Test)

The softening temperature of the refractory material are, generally, determined by using Pyrometric cones test. Expressed in terms of Pyrometric cone Equivalents (PCE).

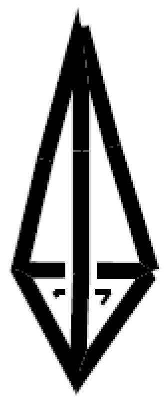
Softening temperature

(Material to be used as refractory) **>>** **Operating temperature**

Pyrometric Cones Test (Segar Cones Test)

The refractoriness is, usually, determined by comparing the behavior of heat on cone of material to be tested with that of a series of Segar cones of standard dimensions.

Segar	Cones Number Fusion temperature
1	1110
2	1120
3	1140
4	1160
5	1180
6	1200
7-	1230
8-	1250
9-	1280

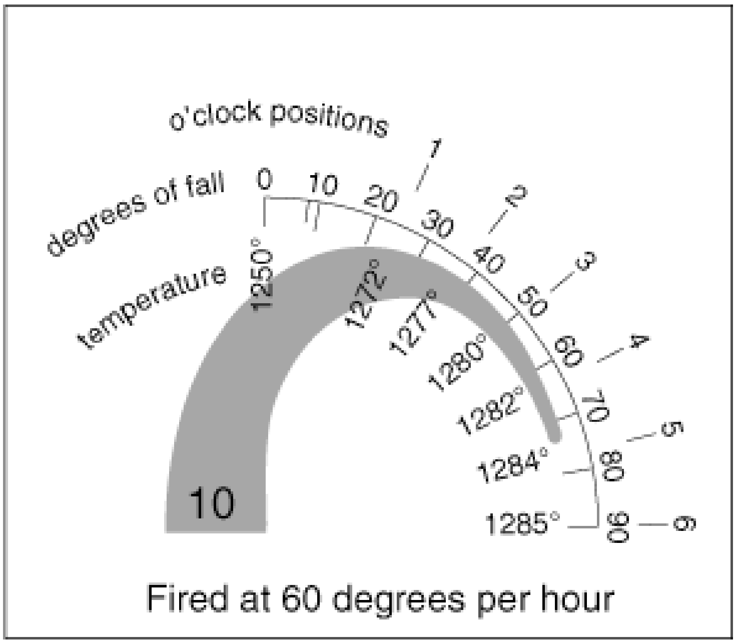


Segar Cone

Pyramid Shaped having triangular base 38 mm high and 19 mm long sides

Segar cones melt or fuse at definite temperature when heated under standard conditions of 10°C/min. So, the temperature at which the fusion or softening of the test cones occurs is indicated by its apex (رأس - قمة) touching the base.

The PCE value of the given refractory is taken as the no. of the standard cone, which fuses along with the test cone.



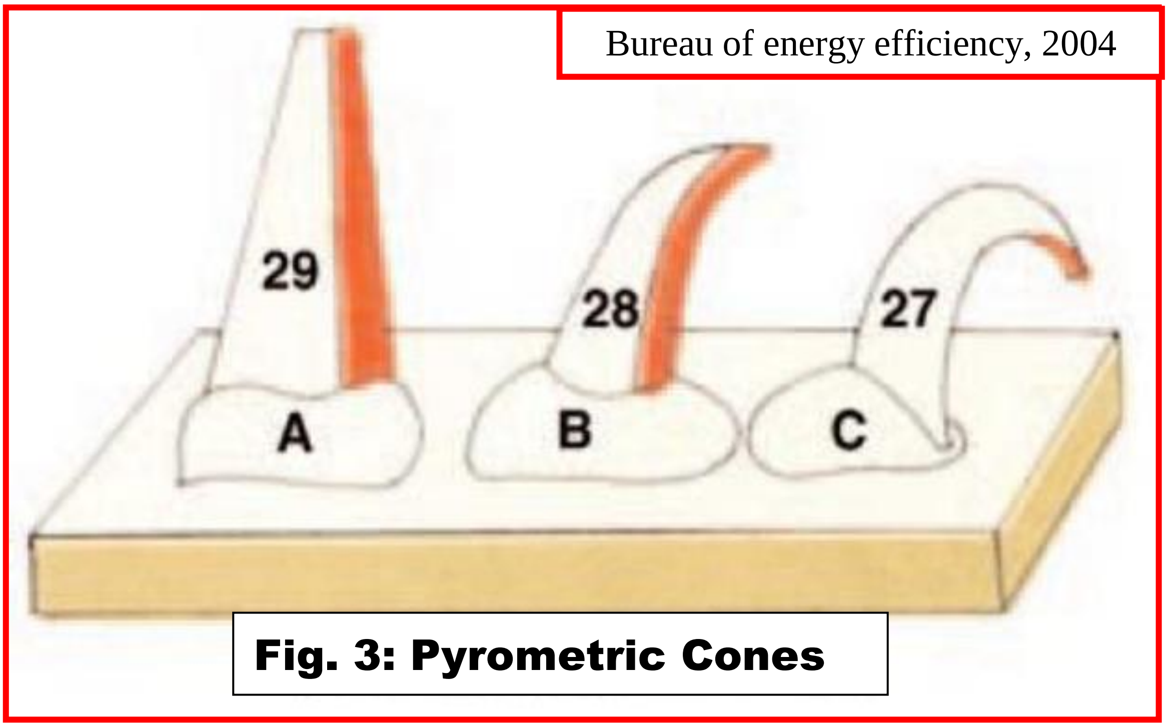


Fig. 3: Pyrometric Cones

Pyrometric cones and Pyrometric cones equivalent (PCE):

A standard method of evaluating the high temperature softening behavior of alumina-silica and fireclay compositions is the determination of their Pyrometric Cone Equivalent, abbreviated PCE (ASTM C24).

Pyrometric cone equivalent (PCE):

- Temperature at which a refractory will deform (Soften) under its own weight is known as its softening temperature which is indicated by PCE.

  Softening temperature → indicated by PCE

♦	Refractories, due to their chemical complexity, melt progressively over a range of temperature.
♦	Hence refractoriness or fusion point is ideally assessed by the cone fusion method.
♦	Refractoriness = fusion point = cone fusion method.
♦	The equivalent standard cone which melts to the same extent as the test cone is known as the pyrometric cone equivalent.
♦	The 'refractoriness' of (refractory) bricks is the temperature at which the refractory bends because it can no longer support its own weight.
♦	Thus in the Figure 3 refractoriness of Sample A is much higher than B and C.
♦	The pyrometric cone equivalent (PCE) indicates only the softening temperature. PCE → Softening temperature
♦	This is the temperature range in (°C) above which the refractory cannot be used
♦	This is known as Pyrometric Cone Equivalent temperatures.
♦	But, in service the refractory is subjected to loads which would deform the refractory at a much lower temperature than that indicated by PCE.
♦	With change in the environmental conditions, such as reducing atmosphere, the P.C.E. value changes drastically.

PCE Experiment	
♦	A sample of the material to be tested is molded into the form of test cones and mounted in a ceramic plaque (صينية) with a series of standard pyrometric cones having known their high temperature softening values.
♦	The plaque is heated at a fixed rate until the test cones soften and bend. The number of the standard cone whose tip touches the plaque at the same time as the tip of the test cone is reported as the PCE value of the test cone.

Note	
♦	Pyrometric cones are used in ceramic industries to test the refractoriness of the (refractory) bricks.
♦	The PCE does not indicate a definite melting point or fusion point because the test is not a measurement, but merely a comparison of the thermal behavior of the sample to that of standard cones. PCE = comparison not measuring
♦	The test is used in evaluating the refractory quality of clays and the softening temperature of slags, as well as in the manufacture and quality control of fire clay products. PCE → Refractory quality → Quality control of fire clay products.
♦	PCE values of alumina-silica refractories are given in Table 3.3

Table 3.3 : Typical Pyrometric Cone Equivalents of Refractory		
Types of brick	Minimum (PCE) (ASTM C24)	Typical (PCE)
Fireclay		
Super duty	**33**	**33 to 34**
High-Duty	**31.5**	**31.5 to 33**
Medium-Duty	**29**	**29 t0 31**
Low-Duty	**15**	**15 to 27**
Semi-Silica	---	**27 to 31**
High-Alumina		
50% Alumina Class	**34**	**35**
60% Alumina Class	**35**	**36 to 37**
70% Alumina Class	**36**	**37 to 38**
80% Alumina Class	**37**	**39**
90% Alumina Class	---	**40 to 41**
Mullite Class*	------	**38**
Corundum Class*		**42 Minus**

* Estimated and shown for convenience. It is generally impractical to obtain the PCE values of high-alumina brick above the 50% or 60% alumina class.

In reporting PCE values, the word "to" is used between two standard cone numbers to indicate that different lots of the given material have a range of softening from the lower to the higher value. A dash (-) between two standard cone numbers does not indicate a range, but shows that the material has a position as to softening approximately midway between the two pyrometric cone values.

2. Strength or Refractories-under load (RUL):

Refractories used in industrial furnaces have invariably to withstand varying loads of the products, being manufactured at high operating temperature.

It is, therefore, essential that refractory materials must also possess **high mechanical strength,** even at operating temperature, to bear the maximum possible load, without breaking.

Some refractories like FIRECLAY, High Alumina Bricks softens gradually over the range of temperature, but under appreciable load, they collapse (إنهيار), far below their true fusion point, as determined by segar cones.

On the other hand, other refractories, such as Silica Bricks softens over a relatively narrow range of temperature and exerts good load bearing characteristics close to their fusion points.

Refractories-under load Test (R.U.L. Test)

R.U.L. test is performed by applying a constant load of 3.5 or 1.75 kg/cm2 to the refractory specimen (of size 5 cm2 and 75 cm high) and heating in a carbon-resistance furnaces at a standard rate of 10°C / min.

The record of the height of the specimen vs. temperature is made by a plot, until the test-piece deforms or collapses by 10%.

The R.U.L. is expressed as the temperature at which 10% deformation takes place.

3. Size & Dimensional Stability

3.1-Size Stability

The size and shape of the refractories is a part of the design of the furnace, since it affects the ❶stability of the furnace structure. ❷Accurate size is extremely important to properly fit the refractory shape inside the furnace and to ❸minimize space between construction joints.

3.2-Dimensional Stability

Resistance of a material to any volume changes, which may occur on its exposure to high temperature, over a prolonged (فترة طويلة) time.

These dimensional changes may be permanent (irreversible) or reversible.

Irreversible changes may result either in the contraction or expansion of a refractory. The permanent contraction is due to the formation of increasing amounts of liquid from the low fusible constituents of the refractory brick, when it is subjected to a long period of soaking (بلل) at the high temperature.
The liquid gradually fills the pores of the refractory body, causing a high degree of vitrification (تزجيج) and shrinkage.

4. Chemical Inertness (خمول)

A refractory should be selected that is chemically inert in use and does not form fusible products with slags (خبث), fuel ashes, furnace gases, etc. usually, the environment in most furnaces are either acidic or basic.

It is not recommended to employ Acid refractory in contact with an alkaline (basic) product or vice-versa.

5. Porosity

The apparent porosity is the volume of the open pores (مسام), into which a liquid can penetrate, as a percentage of the total volume of the refractory.

All refractories contain pores, either due to manufacturing methods or deliberately (عن عمد) made (by incorporating saw-dust or cork during manufacture).

Porosity is the ratio of its pore's volume to the bulk volume.

$$P = \frac{W - D}{W - A} \times 100$$

W = Wt. of saturated specimen.
D = Wt. of Dry specimen.
A = Wt. of saturated specimen submerged in water.

Porosity is an important property of refractory bricks, because it affects many other characteristics, e.g. chemical stability, strength, abrasion-resistance and thermal conductivity.

In a porous refractory, molten charge, slags, gases etc. are likely to enter more easily to a greater depth and may react and reduces the life of the refractory material

Porosity decreases ➔	Strength ,	resistance to abrasion
	resistance to corrosion	penetration by slags, gases.
Porosity increases ➔	resistance to thermal spalling (i.e. thermal shock-resistance	

The densest and least porous brick have the highest thermal conductivity, owing to the absence of air-voids. In porous bricks, the entrapped air in the pores, acts as a non-heat conducting material.

least porous brick (absence of air-voids) ➔ highest thermal conductivity➔
porous bricks (present of air-voids) ➔ non-heat conducting material

The volume of the open pores (مسام) / liquid which can penetrate, as a percentage of the total volume of the refractory.

This property is important when the refractory is in contact with molten charge and slag. A low apparent porosity prevents molten material from penetrating into the refractory. A large number of small pores is generally preferred to a small number of large pores.

A good refractory, in general, should have low porosity.

6. Resistance to abrasion or erosion

good refractory must show a good resistance to abrasion or erosion.

7. Texture (نسيج- بنية- تلاحم)

Course or light –textured bricks (الطوب المحكم), because of their large porosity, are light in weight and hence, they are more resistant to sudden changes in temperature.

However, their crushing strength is low. Such bricks are more susceptible (سريع التأثير) to the action of abrasion and corrosion.

On the other hand, fine or dense-textured bricks possess low porosity and hence are light in weight. These are not so resistant to sudden changes in temp. However, such bricks are less susceptible (سريع التأثير) to action and corrosion.

8. Permeability (β)

Measure of rate of diffusion of gases, liquids, and molten solids through a refractory. Permeability depends upon the size and number of connected pores.

$$\beta = \frac{1}{\text{Viscosity of molten material}}$$

9-Bulk density (kg/m3):

The bulk density is useful property of refractories, which is the amount of refractory material within a volume (kg/m3). An increase in bulk density of a given refractory ①increases its volume stability, ②heat capacity and ③resistance to slag penetration.

Note	An increase in bulk density of a given refractory increases :	
	1-	its volume stability,
	2-	heat capacity and
	3-	resistance to slag penetration

10-Cold crushing strength:

The cold crushing strength is the resistance of the refractory to crushing, which mostly happens during transport. It only has an indirect relevance to refractory performance, and is used as one of the indicators of abrasion resistance. Other indicators used are bulk density and porosity.

11-Creep at high temperature:

Creep is a time dependent property, which determines the deformation in a given time and at a given temperature by a refractory material under stress.

12. Electrical conductivity

Good refractory must show a low electrical conductivity. Except graphite, all other refractories are poor conductors of electricity.

3.4.2 Thermal Properties of Refractories

Important thermal properties of refractories are:

Thermal Properties	
1-	Melting point
2-	Thermal Conductivity
3-	Thermal Diffusivity
4-	Thermal Expansion
5-	Thermal Shock
6-	Thermal Spalling (Spall=شظية)
7-	Heat capacity
8-	Electrical conductivity

1-Melting point:

Pure substances melt instantly at a specific temperature. Most refractory materials consist of particles bonded together that have high melting temperatures. At high temperatures, these particles melt and form slag.

The melting point of the refractory is :
The temperature at which a test pyramid (cone) fails to support its own weight.

OR

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:

Melting point of some pure compounds used to manufacture refractory Melting	
REFRACTORY ELEMENT	**MELTING TEMPERATURES (°C)**
Graphite C Pure	3482
Thoria, ThO2 Pure Sintered	3000
Magnesia, MgO, Pure Sintered	2800
Zirconia, ZrO2 , Pure Sintered	2700
Lime, CaO	2570
Beryllia, BeO, Pure Sintered	2550
Silicon Carbide, SiC, Pure	2250
Magnesia, 90-95%	2193
Chromite, FeO-Cr2O3	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.

Melting point ➔	thermal stability of refractory mixtures
	maximum temperature of use

2. Thermal Conductivity

In industrial operations, refractory materials of both high thermal conductivity and low thermal conductivity are required, depending upon the type of the furnaces. In most cases, furnaces are lined with refractories of low heat conductivities to reduce the heat losses to the outside by radiation; otherwise maintenance of high temperature inside furnaces will become difficult.

A good **heat conductivity** of the refractory material is desirable for effective heat transmission in furnace construction.

i-High Density Brick

The densest (الأكثر كثافة) and least porous (الأقل مسامية) brick have the highest thermal conductivity, owing to the absence of air-voids.

ii-Low Density Brick (light weight Brick)

On the other hand, in porous bricks, the entrapped air in the pores, acts as a non-heat conducting material. (يسمى طوب خفافى)

صناعة الطوب الخفافى(Light weight Brick)

For making porous refractory bricks (سمى طوب خفافى), the refractory material is mixed with a liberal amount of carbonaceous (كربون) material, then mold into bricks and burnt. The carbonaceous material burns off; leaving behind minute voids (فراغ), which enhances the insulating quality.

3. Thermal Diffusivity (α)

Thermal diffusivity is the thermal conductivity divided by density and specific heat capacity at constant pressure. It measures the ability of a material to conduct thermal energy relative to its ability to store thermal energy. It has the SI unit of m^2/s or m_2/hr. The formula of thermal diffusivity (a) is:

$$a = \frac{thermal\ conductivity}{heat\ storage\ capacity} = \frac{k}{C_p\ \rho}$$

Where:

k : Thermal conductivity (W/(m·K)) or (Kcal/m.hr.°C)

ρ: Density (kg/m^3)

C_p: Specific heat capacity (J/(kg·K)) or (Kcal/kg.°C)

4. Thermal Expansion

This is a measure of the refractory about its linear stability when it is exposed to different ranges of high temperatures and then cooled to room temperatures. It is defined as a permanent linear change (ASTM C-113) and is measured by the changes in the longest linear dimensions. Most refractory materials expand when heated. Hence, when refractories are installed at room temperatures, the whole structure tightens up when heated.

Linear Thermal Expansion of ceramic:

When the temperature of a ceramic changed ΔT, the change of its length ΔL is very nearly proportional to its initial length multiplied by ΔT.

The Linear Expansion equation is:

$$\Delta L = \alpha L_0 \Delta T$$

Where:

α: the Coefficient of linear expansion.

L_0: Initial length of the object.

ΔL: Length change of the object.

ΔT: Temperature change of the object.

Area Thermal Expansion:

When the temperature of a surface changed ΔT, the change of its area ΔA is very nearly proportional to its initial area multiplied by ΔT. The Area Expansion equation is:

$$\Delta A = \gamma A_0 \Delta T$$

Where: γ: the Coefficient of Area expansion. A_0: Initial area of the object. ΔA: Area change of the object. ΔT: Temperature change of the object.

Volume Thermal Expansion:

When the temperature of a volume changed ΔT, the change of its volume ΔV is very nearly proportional to its initial volume multiplied by ΔT. The Volume Expansion equation is:

$$\Delta V = \beta V_0 \Delta T$$

Where:

β: the Coefficient of volume expansion
V_0: Initial volume of the object
ΔV: Volume change of the object
ΔT: Temperature change of the object.

Thermal expansion of ceramic materials depends on bonding strength between atoms. Ceramic with high degree of ionic bond have high thermal expansion (behavior similar to metals). As the bond strength increases or as the percent of covalent bond increases, the thermal expansion decreases. Both melting temperature and thermal expansion are controlled primarily by bond strength and the magnitude of thermal vibration. As the bond strength increases, the melting temperature increases and thermal expansion coefficient decreases.

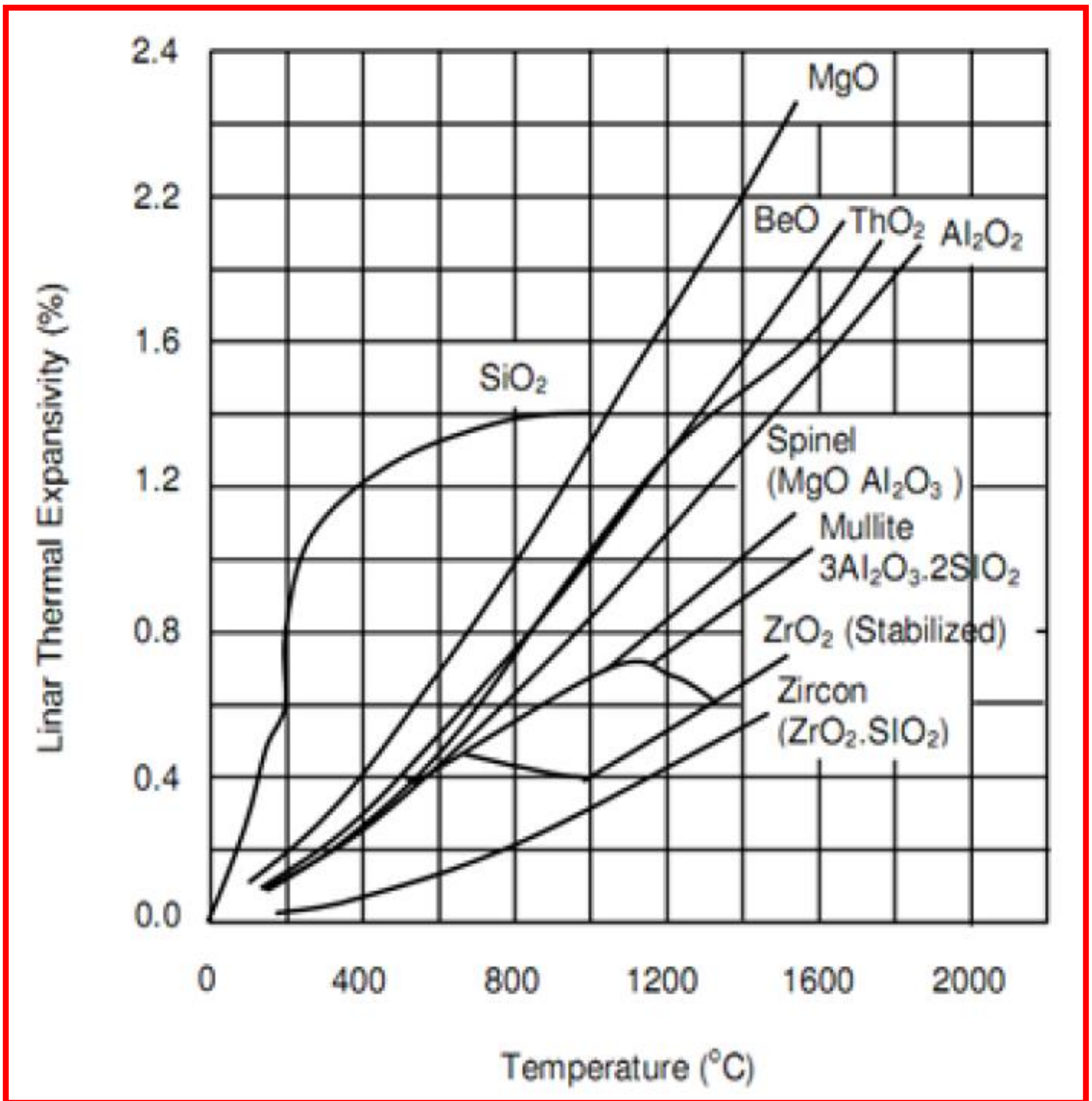


Fig. : Thermal Expansion of Refractory Oxides as Function of Temperature

The expansion characteristic correlates with the nature of the structure, and the atomic bonding. Al_2O_3, TiO_2 and mullite have moderately close packed structures and atomic bond strength. As result, they have moderate thermal expansion. Within the graphite layers, the atomic bonding is very strong (C-C covalent bond) and the coefficient of expansion is low ($1X10^{-6}$ /°C). The atomic bonding between layers is very week (van der waal's bonds) and the thermal expansion coefficient is high ($27X10^{-6}$/°C).

Important of thermal expansion: many ceramic applications expose to a range of temperature. Mismatch in thermal expansion behavior between two adjacent materials, can result high enough stresses to fracture. Moderate close thermal expansion match is necessary to minimize thermal stress. Some application required very low thermal expansion. A well-known domestic application is the use of (LAS) based polycrystalline ceramic ($LiAlSi_2O_6$) for heat-resistant cooking ware.

5- Thermal Shock

Thermal shock is the fracture of a body resulting from thermal stresses induced by rapid temperature changes. Because ceramic materials are brittle, they are especially susceptible to this type of failure. The thermal shock resistance of many materials is proportional to the fracture strength and thermal conductivity, and inversely proportional to both the modulus of elasticity and the coefficient of thermal expansion.

Thermal shock is an important property for a refractory material. Most high-temperature processes experience heating and cooling. Thermal shock can be indicated by the number of cycles to withstand such temperature fluctuations. Thermal shock resistance can be defined as partial or complete fracture of material due to gradient temperature. The factor that affects the thermal shock resistance includes the shaping methods and the firing temperatures.

Thermal shock refers to the thermal stresses that occur in a component as a result of exposure to temperature difference between surface and interior of the component. Thermal stress occurs at the surface during cooling refers to the following equation:

$$\sigma_{th} = \frac{E\ \alpha\ \Delta T}{1 - \nu} \qquad (1)$$

Where:

σ_{th} **:** thermal stress,

E: the elastic modulus,

α: the coefficient of thermal expansion,

ΔT: the temperature difference and

υ: Poisson's ratio.

Equation (1) indicates that the thermal stress increases as the elastic modulus and thermal expansion coefficient of the refractories increases. The temperature difference ( ) can be decreased by increasing the thermal conductivity of the refractories.

Thermal shock resistance (R) of refractories can be calculated from the following equation:

$$R = \frac{\sigma\,(1-\nu)}{E\,\alpha} \qquad (2)$$

Where:

α: The symbol stands for the strength of the ceramic material.

As ceramic materials subjected to thermal shock generally fail in tension rather than in shear or compression, the tensile strength is generally used as the criterion for failure rather than the compressive or shear strength. As the thermal shock resistance of a ceramic material is governed mainly by its mechanical and thermal properties, as indicated above, an improvement of the thermal shock resistance of the high Young's modulus of ceramics.

6- Thermal Spalling

Spalling (تقشير) is defined as the fracture of the refractory brick or block due to any of the following causes**:**

	A temperature gradient in the brick due to uneven heating or cooling that sets up stresses causing failure. (Thermal Spalling).
	Compression in a structure of refractories due to expansion of the whole from a rise of temperature causing shear failure.
	Variation in coefficient of thermal expansion between the surface layer and the body of the brick, due to the surface **slag penetration** or to structural changes in service resulting in shearing off the surface layer. As a general rule, those with a lower thermal expansion coefficient are less susceptible to thermal spalling
	Spalling may also be due to slag penetration into the refractory brick, thereby causing variation in the coefficient of expansion.

Breaking, cracking, peeling off (تقشير), or fracturing of, a refractory brick or block, under high temperature. So, good refractory must have a good resistance to thermal spalling. Spalling is caused by rapid changes in temperature, which causes uneven expansion and contraction within the mass of refractory, thereby leading to development of internal stresses and strains.

Thermal Spalling can be reduced by:	
1-	Using high porosity, low coefficient of expansion and good thermal conductivity refractory bricks.

2-	Avoiding sudden temperature changes.
3-	Using materials with low coefficient of expansion and avoiding sudden temperature fluctuation for example addition of alumina in small quantities decreases expansion to a large extent.
4-	Using high porosity bricks.
5-	By designing the furnace such that stress is alienated.
6-	By over firing the refractories at high temperature for a sufficiently long time, whereby mineral inversion et. takes place making the material less susceptible (سريع التأثير) to uneven (غير متساوى) expansion or contraction, when heated

7. Heat capacity

Heat capacity of any substance depends on
(a) Thermal conductivity
(b) Specific heat
(c) Specific gravity

8. Electrical conductivity

Good refractory must show a low electrical conductivity. **Except graphite**, all other refractories are poor conductors of electricity.