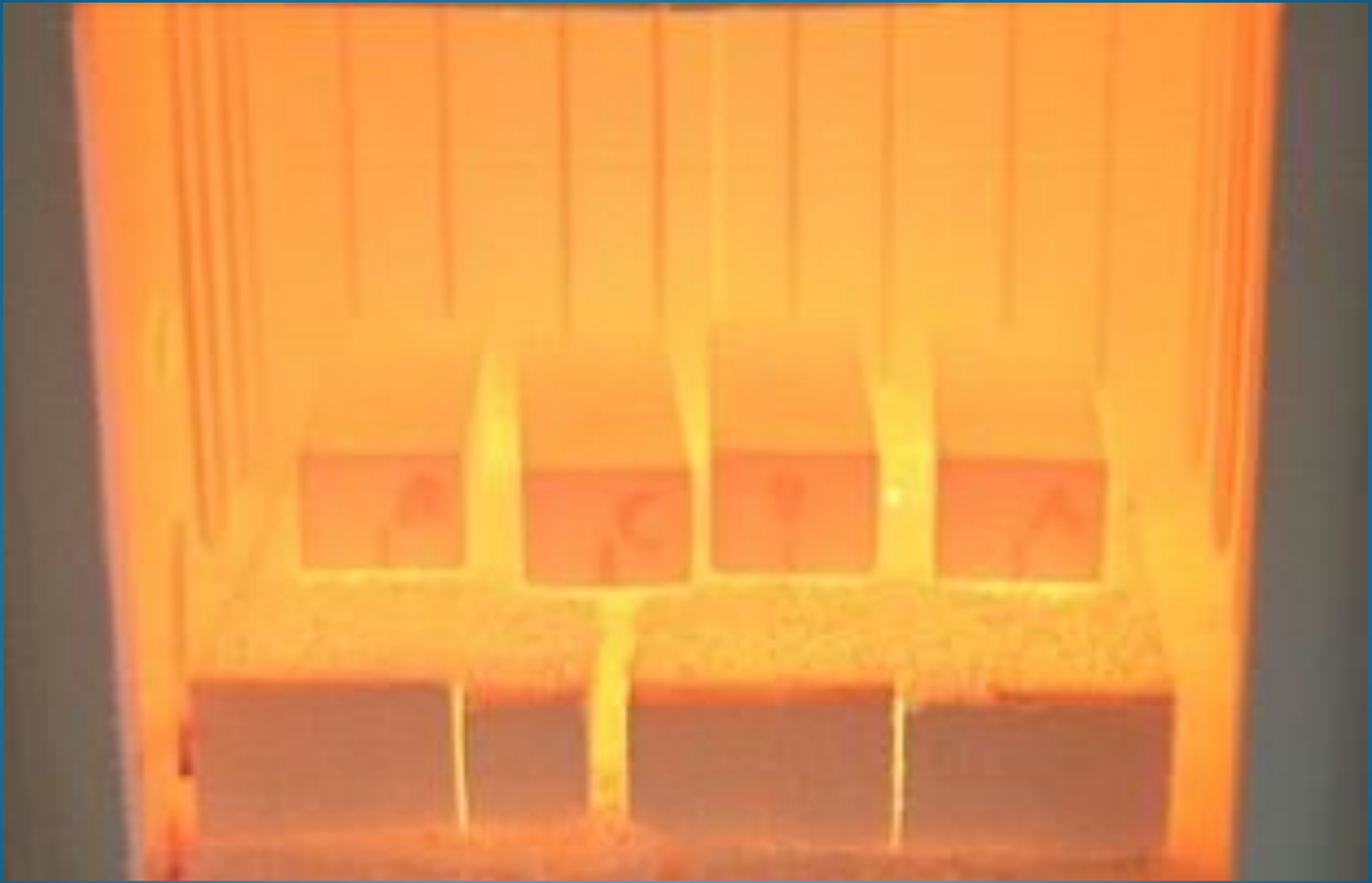
Thermal Properties of Refractories



4) Thermal Diffusivity

- 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. The formula of thermal diffusivity (a) is:

$$a = \frac{thermal\ conductivity}{heat\ storage\ capacity} = \frac{k}{C_p\ .\ \rho} \qquad \left(\frac{m^2}{s}\right)$$

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)

- **5) 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, the change of its length **ΔL** is very nearly proportional to its initial length **L_o** multiplied by **ΔT**. The Linear Expansion equation is:

$$\Delta L = \alpha\, L_o\, \Delta T$$

- Where:
  α: the Coefficient of linear expansion.
  L_o: 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, the change of its area **ΔA** is very nearly proportional to its initial area **A_o** multiplied by **ΔT**. The Area Expansion equation is:

$$\Delta A = \gamma A_o \Delta T$$

Where:
γ: the Coefficient of Area expansion.
A_o: 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, the change of its volume **ΔV** is very nearly proportional to its initial volume **V_o** multiplied by **ΔT**. The Volume Expansion equation is:

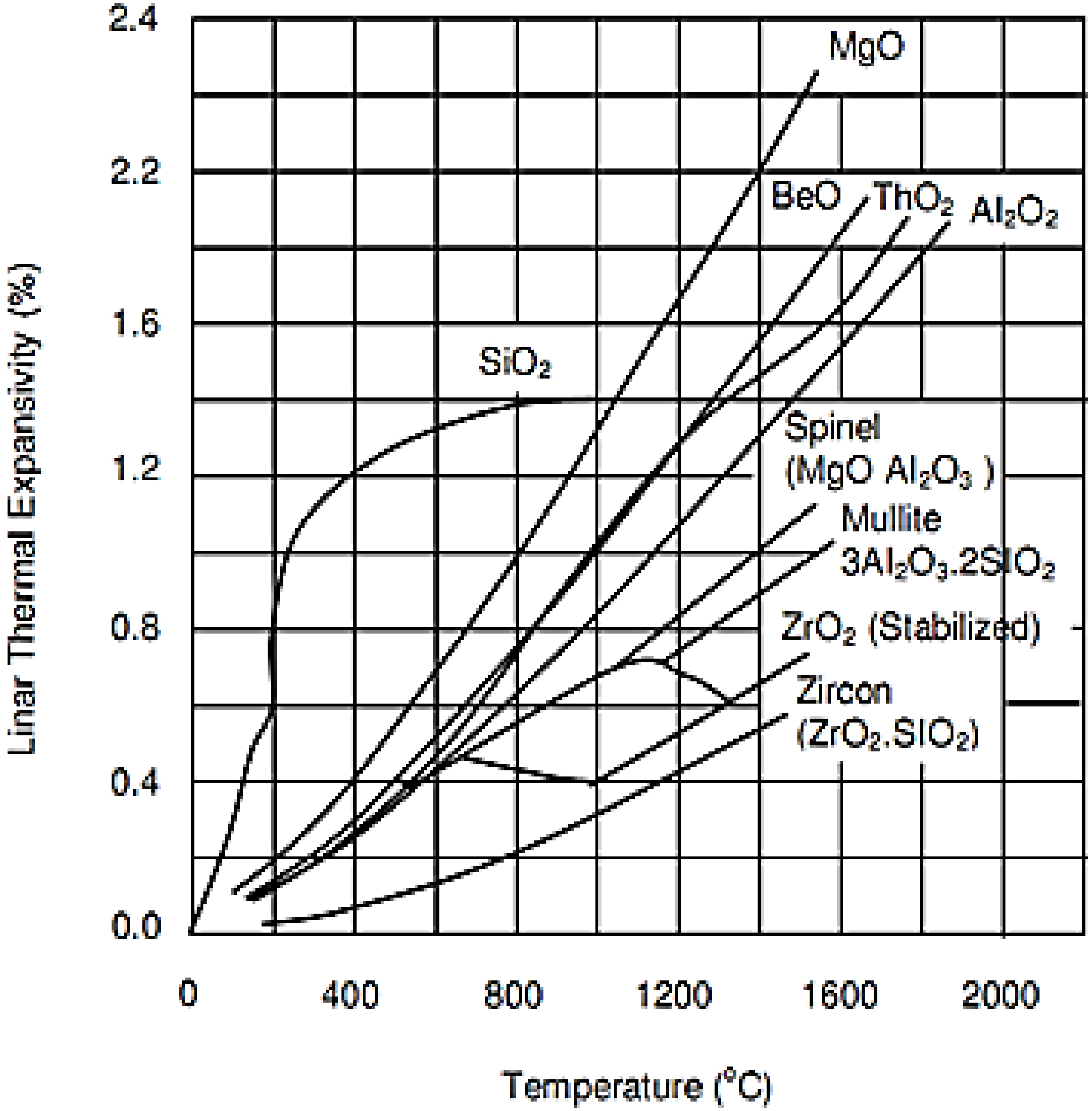
$$\Delta V = \beta V_o \Delta T$$

Where:
β: the Coefficient of volume expansion
V_o: 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.



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).

- **6) Thermal Shock**

Thermal shock is the fracture of a body resulting from thermal stresses induced by rapid temperature changes.

Thermal shock resistance can be defined as partial or complete fracture of material due to gradient temperature.

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 shock can be indicated by the number of cycles to withstand such temperature fluctuations.

Thermal shock is an important property for a refractory material. 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. Also the shaping methods and the firing temperatures affected on the thermal shock resistance of refractories.

- 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 ν: 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 (ΔT) 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: σ: 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.

7) Thermal Spalling

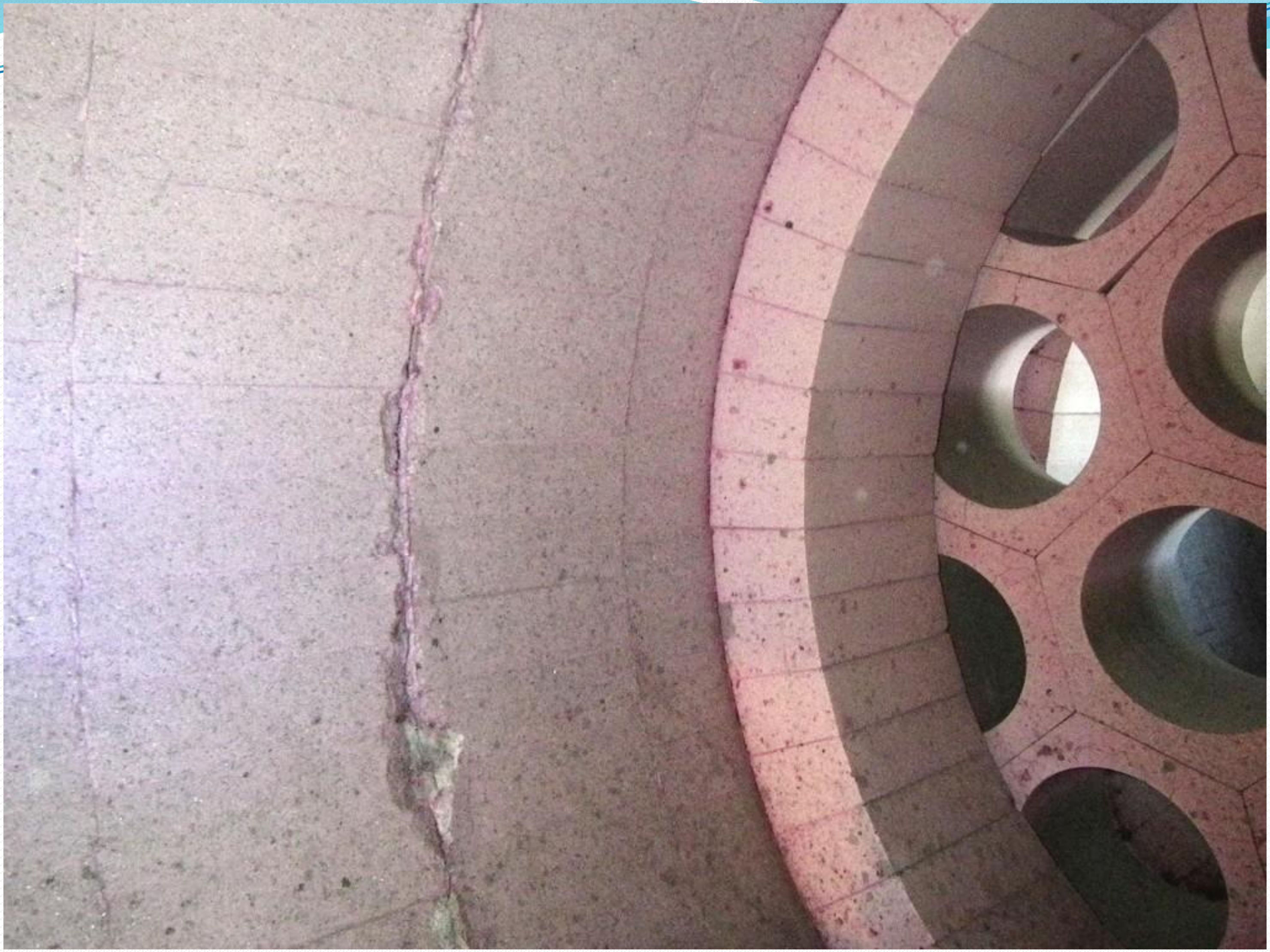
Spalling is defined as the fracture of the refractory brick due to any of the following causes:

1. A temperature gradient in the brick due to uneven heating or cooling that sets up stresses causing failure. (Thermal Spalling).
2. Compression in a structure of refractories due to expansion of the whole from a rise of temperature causing shear failure.
3. 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 co-efficient are less susceptible to thermal spalling**.

Thermal Cycling

Cause: repeated thermal cycling causes cracking at surface of brick



Thermal Mechanical Spalling

Cause: excessive thermal expansion at refractory hot face results in pinch spalling at refractory joints

Thermal Spalling can be reduced by:

1. 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.
2. Using high porosity bricks.
3. By designing the furnace such that stress is alienated.