21 GLASSES AND CERAMICS

Glass is an amorphous, hard, brittle, transparent or translucent, super-cooled liquid of infinite viscosity, obtained by fusing a mixture of a number of metallic silicates, most commonly of Na, K, Ca and Pb. It possesses no sharp melting-point, definite formula or crystalline structure. Within certain limits, it may be represented as $x\,R_2O \cdot y\,MO \cdot 6\,SiO_2$, where R is an atom of *monovalent* alkali metal like Na, K, etc., M is an atom of a *bivalent* metal like Ca, Pb, Zn, etc., x and y are *whole numbers*. Thus, approximate composition of ordinary glass (called *soda-lime glass*) is $Na_2O \cdot CaO \cdot 6\,SiO_2$. In some glasses, SiO_2 *may be* replaced by $Al_2O_3 \cdot B_2O_3 \cdot P_2O_5$, etc.

General properties of glass : Glass : (1) is *amorphous*, (2) has no definite melting-point, (3) can absorb, reflect or transmit light, (4) can take high polish, (5) is a *good* electrical insulator, (6) is affected by alkalis, (7) is not affected by air, water or acids or chemical *reagents, except HF*, which converts its silica into SiF_4, (8) can be formed into articles, even of intricate shapes, (9) is *very* brittle, (10) softens on heating, (14) is light, because it has homogeneous internal structure similar to *liquids*, (15) has *no* crystal structural and hence, no slippage between planes can occur. Hence, glass has a high compressive strength.

Ceramics (from Greek *keramos* meaning burnt stuff) *are inorganic, non-metallic materials that are processed and/or used at high temperatures.* They include silicates, metallic *oxides*, and their combination. Ceramics can be grouped into *three* broad divisions–clay products, refractories and glasses, according to their common characteristic features. Clay products can be sub-divided into *three* main types, namely :

1. **The structural clay products,** all of which contain *iron oxides*. They are used for *bricks, tiles* and similar products.

2. **The whitewares,** which are *paler substances* such as *Porcelain,* and *China,* and

3. **Chemical stonewares,** which have been *specially-treated* to be hard, resilient and non-porous.

Closely related to ceramics, in chemical composition, are natural rocks and their disintegration products such as clay, sand and gravels.

Clay : The term **clay** *denotes certain earths, which are highly plastic, when wet and which, when heated to redness, loses their plasticity and are converted into a hard mass, which is unaffected by water. Clays are formed by the weathering of igneous,* (*e.g.*, granite), *and felspathic rocks by various agencies through time and are composed essentially of hydrated aluminium silicates* (such as $Al_2Si_2O_7 \cdot 2H_2O$), together with other substances such as *mica* and *quartz,* which were present with the feldspar in the original rocks (*e.g.*, granite).

$$\underset{\text{Potash feldspar}}{2\,KAlSiO_8} + 2\,H_2O + CO_2 \longrightarrow K_2CO_3 + \underset{\text{Clay}}{Al_2O_3 \cdot 2\,SiO_2 \cdot 2H_2O} + 4SiO_2$$

The alkali is *leached-out* by water.

If the clay remains at the original location, it is a **primary clay,** *usually white with a low content of iron, so that it 'burns' white : and it is called 'Kaolin' or 'China clay'.* If in the course of geological changes, the clay has been *transported* (by water, glacier or wind) to *another location,* it is a **secondary clay ;** it now contains limestone powder, hydrated oxides, mud and organic impurities in varying amounts.

22 MANUFACTURE OF GLASS

Raw materials : Chief *source* of incorporating :

(*a*) *Sodium* is soda, Na_2CO_3. (*Soft glass*)

(*b*) *Potassium* is potash, K_2CO_3. (*Hard glass*)

(*c*) *Calcium* are limestone, chalk and lime.

(*d*) *Lead* are litharge, and red lead. (*Flint glass*)

(*e*) *Silica* are quartz, white sand, and ignited flint.

(*f*) *Zinc* is zinc oxide. (*Heat and shock-proof glass*)

(*g*) *Borate* are borax, and boric acid, (*Heat and shock-proof glass*)

(*h*) *Cullets* or pieces of broken glass to *increase the fusibility.*

(i) *Colours* : *Yellow*–ferric salt ; *Green*–ferrous and chromium salts ; *Blue*–cobalt salts ; *Purple*–manganese dioxide ; *Red*–nickel salts or Cu_2O; *Lemon-yellow*–CdS. ; *Fluroescent greenish-yellow*–uranium oxide ; *Opaque milky-white*–cryolite (Na_3AlF_6) or calcium phosphate.

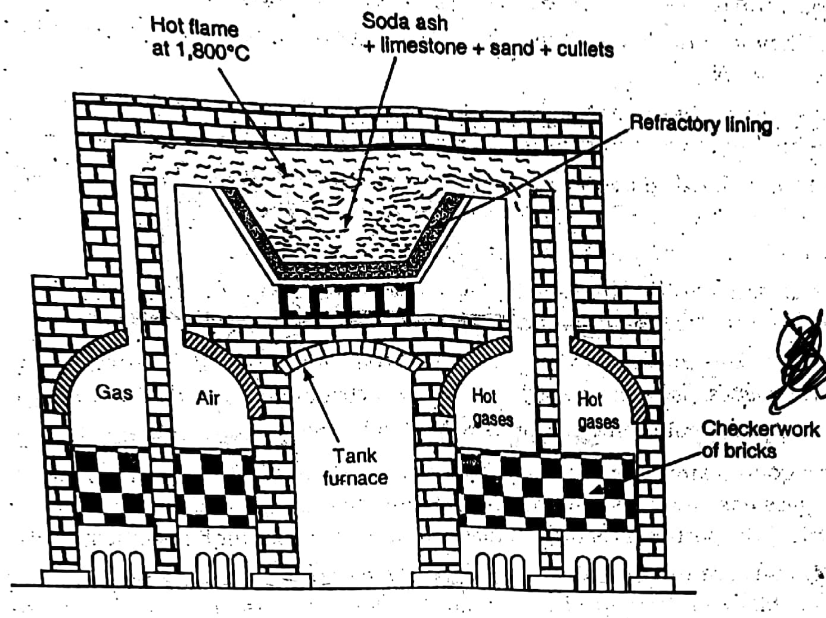

Fig. 7. Manufacture of glass.

Manufacturing steps : (i) *Melting* : Raw materials, in proper proportions (*e.g.*, sand, soda ash and limestone for *common glass*) mixed with cullets, are finely powdered and intimate mixture (called '*batch*') is fused in either *fireclay pots* (in case of *high-grade glass*) or *tanks* that form part of an open-hearth furnace, in which heating is done by burning *producer gas* and *air* mixture over the charge. At high prevailing temperature (about 1,800°C), the charge melts and fuses. The melting process in case of ordinary *soda-glass* involves the following series of reactions :

$$CaCO_3 + SiO_2 \longrightarrow CaSiO_3 + CO_2 \uparrow$$

$$Na_2CO_3 + SiO_2 \longrightarrow Na_2SiO_3 + CO_2 \uparrow$$

When all the carbon dioxide has escaped out of the moten mass, *decolorizers* (such as MnO_2 or nitre) are added to do away with ferrous compounds and carbon, if present. *If a coloured glass is desired, the colouring salts are added at this stage.* Heating is continued, till the moten mass is free from bubbles and glass-balls ; and then cooled to about 800°C.

(ii) *Forming and shaping* : Molten glass is then worked into articles of *desired shapes* by either blowing or moulding or pressing between rollers.

(iii) *Annealing* : Glass articles are then allowed to *cool gradually* to room temperature by passing through different chambers with *descending* temperatures. *If allowed to cool rapidly, glass being bad conductor of heat, the superficial layer cools down first ; leaving the interior portion in a state of strain. Owing to this unequal expansion, the articles are likely to crack to pieces.* The *longer* the annealing period, the *better* the quality of the glass.

(iv) *Finishing* : All glass articles, after annealing, are subjected to finishing processes such as cleaning, grinding, polishing, cutting, sand-blasting, etc.

23. TYPES OF GLASSES

Commercial glasses can be *classified* as follows :

(1) **Soda-lime or soft glass :** The raw materials are *silica* (sand), *calcium carbonate* and *soda ash*. Their approximate composition is $Na_2O \cdot CaO \cdot 6\,SiO_2$. They are low in cost, resistant to devitrification and relatively resistant to water. They *melt easily* and hence, can be hot-worked easily. Such glasses are, however, *attacked by common reagents like acids.*

Uses : They are widely used as *window glasses, electric bulbs, plate-glasses, bottles, jars, building blocks, and cheaper tablewares,* where high temperature-resistance and chemical-stability are not required.

(2) **Potash-lime or hard glass** *is obtained from silica (sand), calcium carbonate, and potassium carbonate.* Their approximate composition is $K_2O \cdot CaO \cdot 6\,SiO_2$. They possess *high melting-point, fuse with difficulty* and *are less acted upon by acids, alkalis and other solvents than ordinary glasses.*

Uses : These glasses (*costlier* than soda-lime glasses) are used for *chemical apparatus, combustion tubes,* etc., which are to be used for heating operations.

(3) **Lead glass or flint glass** *is made by using lead oxide, instead of calcium oxide, for fusing together with silica.* For *dense optical glasses,* as much as 80% of PbO is incorporated. In addition, K_2O is used, instead of sodium oxide. So, its approximate composition is $K_2O \cdot PbO \cdot 6\,SiO_2$.

Lead glass is a good deal *more expensive* to make than ordinary lime-soda glass, but much *easier to shape and work with.* Lead glass has a lower softening temperature than soda-glass and also a *higher refractive-index.* It has excellent electrical properties. It is bright, lustrous and possesses high specific gravity (3 to 3.3).

Uses : Lead glasses are used widely for *high-quality tablewares, optical purposes* (like lenses, etc.) ; *neon sign tubings, cathode-ray tubes, electrical insulators* and *in art objects,* because of their high lustre. High lead-content glasses are used for *extra-dense optical glasses* for windows and shields to protect personnel from X-rays and gamma-rays in medical and atomic energy fields respectively.

(4) **Borosilicate glass or pyrex glass or jena glass** *is the most common of the hard glasses of commerce.* Such glasses contain virtually *only silica and boron,* with a small amount of alumina and some alkali oxides. A typical formula for such a glass would be following :

Percentage	80.5	13	3	3	0.5
Component	SiO_2	B_2O_3	Al_2O_3	K_2O	Na_2O

The substitution for alkali (Na_2O) and basic alkaline-earth oxides (CaO) of the soda-lime glasses by boron and aluminium oxides, results in a glass of *low thermal coefficient of expansion, and high chemical-resistance.* Borosilicate glasses have *very high softening points* and excellent resistivity (*i.e., shock-proof*).

Uses : They are used extensively in industry for pipelines for corrosive liquids, gauge glasses, superior laboratory apparatus, kitchenwares, chemical plants, television tubes, electrical insulators, etc.

(5) **Aluminosilicate glass :** A typical analysis of such a glass would be following :

Percentage	55	23	7	9	5	1
Component	SiO_2	Al_2O_3	B_2O_3	MgO	CaO	$Na_2O + K_2O$

This type of glasses possess *exceptionally high softening temperatures.*

Uses : For high-pressure *mercury discharge tubes, chemical combustion tubes, certain domestic equipments, etc.*

(6) **99.5% silica glass** or **vitreosil** *is produced by heating pure sand* (SiO_2) *to its melting point* (*or about 1,750°C*). Because of absence of fluxing agents, it is extremely difficult to get rid of all air-bubbles. Moreover, owing to the *high viscosity of this glass at its working temperature, shaping is rather difficult.* The final product is *translucent.* Its softening-temperature is about 1,650°C. Its thermal expansion is *lowest,* namely, only 0.55×10^{-6} cm cm^{-1} °C^{-1}.

3. **Emery** *is fine-grained, opaque, massive mineral, dark-grey to black in colour*. It is found chiefly in Greek. *It is an aggregate of 55 to 75 percent crystalline alumina, 20 to 40 percent magnetite* (Fe_3O_4), *and about 12 percent other minerals, of which the chief is tourmaline*. Its hardness is about *8 on Moh's scale*. The grinding power of emery depends almost entirely *on the proportion of alumina it contains*, and on the effect of the other ingredients in determining true hardness of this mineral. Emery is used as tips of bits of cutting, and drilling tools, etc. Artificial emery (used for buffing and polishing) is a graded combination of alumina and magnetite.

4. **Garnets** *are trisilicates of alumina, magnesia and ferrous oxide*. The common garnet used as an abrasive is a complex calcium-aluminium- iron silicates with the approximate formula : $Ca_3Al_2(SiO_4)_3 \cdot Ca_3Fe_2(SiO_4)_3 \cdot Fe_3Al_2(SiO_4)_3$ Hardness of garnets ranges from *6 to 7.5 on Moh's scale*. Garnets *are too soft for grinding steel and iron*, but when glued to paper or cloth, they are used for *finishing hard woods*. They are also used for bearing pivots in watches, glass-grinding, and polishing metals.

5. **Quartz** *is composed of silica* (SiO_2). An impure grey, sometimes hydrated form of quartz, is the abrasive *flint* that is used on good quality *sand-paper*. It is almost a hard as garnet. Grinding and other sharpening stones are cut from *sandstone*. This rock consists of *quartz particles cemented together with feldspars, clays, carbonates and other minerals*. It is used for grinding floor, pigments, ores, etc.

3 ARTIFICIAL ABRASIVES

1. **Carborundum** or **silicon carbide** (SiC) is a bluish-black crystalline artificial mineral with hardness between corundum and diamond. *It is made by subjecting a mixture of silica and carbon (coke or coal) to high temperature* (1,650–2,200°C) *in an electric furnace*.

$$SiO_2 + 3\,C \longrightarrow SiC + 2\,CO\uparrow$$

It is very hard (*Moh's scale* = 9.3), chemically unreactive, can withstand the action of high temperature without damage, but is not tough and is somewhat brittle. It is mainly used in cutting-wheels, abrasive papers, and clothes. It is extensively used for *grinding of materials of low tensile-strengths* like cast iron, brass, bronze, porcelain, marble, finishing of leather, glass and optical grinding of lenses.

2. **Alundum** (Al_2O_3) *is prepared by subjecting a mixture of calcined bauxite, coke, and iron to high-temeperature (about 4,000°C) in an electric arc furnace*. The iron, titanium, and silica impurities settle to the bottom of the furnace and after solidification, the hard crystalline alumina is separated, crushed, and graded. It is sold under a number of trade names, including *aloxite*. Alundum (or *artificial corundum*) is not as hard as carborundum, but is also less brittle, and tougher. It is, therefore, used in preference to carborundum, for grinding hard steels and other material of high tensile-strengths. On an abrasive paper and cloth, it is used for finishing woodworks.

3. **Boron carbide** or **norbide** (B_4C) *is inert and one of the hardest (about 9 Moh's) of all artificial abrasives, and made by heating boron oxide with coke in an electric furnace to approximately 2,700°C*

$$2\,B_2O_3 + 7\,C \longrightarrow B_4C + 6\,CO\uparrow$$

It is used on hard materials for making grinding dies, and for cutting and sharpening hard high-speed tools.

4 REFRACTORIES

Broadly speaking, *refractory is any material that can withstand high temperatures, without softening or suffering a deformation in shape*. Refractories are the essential materials of construction in metallurgy, engineering and chemical industries and without their use, it is impossible to maintain required high temperatures. The main objective of a refractory is to *confine heat* (*i.e.*, to resist loss of heat) and at the sametime to *resist the abrasive and corrosive action of molten metals, slags and gases* at high operating temperatures, without undergoing softening or distortion in shape.

Uses :—

Refractories are mostly used for the construction of the linings of the furnaces, tanks, converters, kilns, crucibles, ladles, etc., employed for the manufacture of metals (ferrous as well as non-ferrous), cement, glass, ceramics, paper, steel, etc.

Characteristics : A good refractory possesses the following characteristics : It should : (1) be *infusible* at the temperature to which it is liable to be exposed ; (2) be *chemically inerts* towards corrosive action of gases, metallic liquids and slags, produced in its immediate contact in furnaces ; (3) *resist the abrading action* of flue gases, flames, etc. ; (4) be able to *withstand the overlying load* of structure, at operating temperatures ; (5) *not crack and suffer loss in size*, at the operating temperatures ; (6) *expand and contract uniformly*, with temperature rise and fall respectively.

Classification of refractories : Refractories are classified into *three* main types, on basis of the *chemical properties* of their constituent substances ;

1. **Acid refractories** are those which consist of *acidic materials* like alumina (Al_2O_3) and silica (SiO_2). *They are not attacked by acidic materials, but easily attacked by basic materials.* Important members of this group are *alumina, silica* and *fireclay* refractories. examples

2. **Basic refractories** are those which consist of *basic materials* like CaO, MgO, etc. *These are not attacked by basic materials, but easily attacked by acidic materials.* Important members of this group are *magnesite* and *dolomite* refractories. examples

3. **Neutral refractories** are made from *weakly acid/basic materials* like carbon, chromite (FeO . CrO_2), zirconia (ZrO_2), etc. Important members of this group are *graphite, chromite, zirconia,* and *carborundum* (SiC) refractories. examples

5 PROPERTIES OF REFRACTORIES

More important *characteristics* of refractories are :

(1) **Refractoriness** is *the ability of a material to withstand the heat, without appreciable deformation or softening under particular service conditions.* Refractoriness is, generally, measured as the *softening or melting temperature* of the material. As most of the common refractory materials are mixtures of several metallic oxides, so they *do not have a sharp fusion temperatures.* It is common practice to determine *softening temperature,* rather than fusion temperature. The softening temperatures of refractory materials are, generally, determined by using "**pyrometric cones** (also called *Seger cones*) test". It is *necessary that a material, to be used as refractory, should have a softening temperature much higher than the operating temperature of the furnace in which it is to be used.* It is, however, notworthy that the inner refractory lining in a furnace is at a much higher temperature than the outer ones. So, unless the refractory melts away completely, it can, usually, be employed to withstand a temperature higher than its softening temperature, since the outer end of refractory is at a lower temperature and still in solid state and it provides requisite strength.

Measurement : Refractoriness is, usually, determined by comparing the behaviour of heat on *cone of material to be tested* with that of a series of *Seger cones* of standard dimensions. The refractoriness is expressed in terms of *Pyrometric cone equivalent* (PCE). These cones are small pyramid-shaped, 38 mm high and have a triangular base, with 19 mm long sides. They melt or fuse at definite temperatures, when heated under standard condition of 10°C per minute. The temperature at which the fusion or softening of the test-cone occurs is indicated by its *apex touching the base* (*see* Fig. 1). The PCE value of the given refractory is taken as the number of the standard cone, *which fuses alongwith* the test-cone. If the test cone softens earlier than one standard cone, but latter than the next cone, the PCE value of the test sample is approximately measured as the average value of the two.

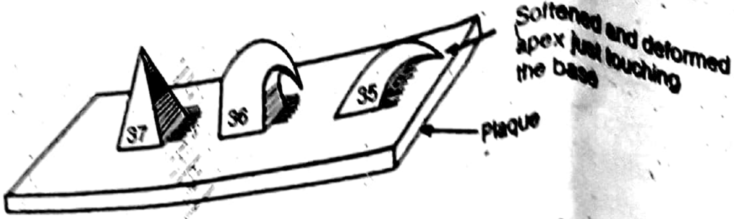

Fig. 2. Seger cone-test.

Table 1 : *Seger-cone number and fusion temperature.*

Seger-cone number	*Temperature °C*	*Seger-cone number*	*Temperature °C*	*Seger-cone number*	*Temperature °C*
1	1,110	12	1,350	27	1,610
2	1,120	13	1,380	28	1,630
3	1,140	14	1,410	29	1,650
4	1,160	15	1,435	30	1,670
5	1,180	16	1,460	31	1,690
6	1,200	17	1,480	32	1,710
7	1,230	18	1,500	33	1,730
8	1,250	19	1,520	34	1,760
9	1,280	20	1,530	35	1,770
10	1,300	23	1,550	36	1,790
11	1,320	26	1,580	37	1,825
				38	1,850

(2) Strength or refractiorines-under-load : Refractories in use, in industrial furnaces, have invariably to withstand varying loads of the products, being manufactured at high operating temperatures. *It is, therefore, essential that refractory materials must also possess high mechanical strengths, even at operating temperatures, to bear the maximum possible load, without breaking.* Some refractories, like fireclay and high-alumina bricks, soften gradually over a range of temperature, but under appreciable load, they collapse, far below their true fusion point, as determined by Seger cones. On the other hand, other refractories like silica bricks soften over a relatively narrow range of temperature and exert good load-bearing characteristics close to their fusion points.

R.U.L. test *is performed by applying a constant load (of 3.5 or 1.75 kg/cm^2) to the refractory specimen (of size 5 cm^2 and 75 cm high) and heating in a carbon-resistance furnace at a standard rate (of 10°C/minute).* 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. Under a load of 3.5 kg/cm^2 : (*i*) *a high heat-duty brick should not deform a great deal (i.e., more than 10%) at 1,350°C* ; (*ii*) *an intermediate heat-duty brick at 1,300°C* and (*iii*) *a moderate heat-duty brick at 1,100°C.* Most of the applications of refractories find use only under *compressive* load ; and in rare cases, they may be subjected to tension or shear alone.

(3) Dimensional stability is *the resistance of a material to any volume changes, which may occur on its exposure to high temperature, over a prolonged 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 constituent of the refractory brick, when it is subjected to a long period of soaking at the high temperature.*

The liquid gradually fills the pores of the refractory body, causing a high degree of vitrification and shrinkage. A typical example of such a behaviour as *fireclay brick*. The **shrinkage** of a refractory can also be caused by the transformation of one crystalline form of material into another more dense form. For example, *in a magnesite brick, amorphous* MgO, *which is relatively light* (*sp. gr* = 3.05), *is gradually converged to a more dense crystalline form; periclase* (*sp. gr.* = 3.54). *With the increase in density, there is a natural shrinkage of the material.* On the other hand, *the transformation of quartz (sp. gr.* = 2.65) *in silica bricks to tridymite (sp. gr.* = 2.26) *and cristobalite (sp. gr.* = 2.32) *at high service temperature is accompanied by a considerable increase in volume.* This thus accounts for *permanent* expansion of silica bricks in service.

(4) **Chemical inertness :** A refractory should be selected that is *chemically inactive in use and does not easily form fusible products with slags, fuel ashes, furnace gases,* etc. Usually, the environment in most furnaces is either acidic or basic. *It is inadvisable to employ* ***an acid refractory in contact with an alkaline product or vice-versa.***

(5) **Thermal expansion :** In a furnace design, *allowance has to be made for* ***thermal expansion****, since practically all solids expand, when heated and contract, when cooled.* The expansion affects all dimensions (*i.e.*, length, area and volume) of a body. So, it is necessary that *a refractory material should have least possible thermal expansion*, because : (*i*) expansion of a refractory *decreases the capacity of* the furnace ; (*ii*) repeated expansion and contraction contribute much towards *rapid breakdown*, and wear and tear of the refractory material structure.

(6) **Thermal conductivity :** In industrial operations, refractory materials of both high thermal conductivity and low thermal conductivity are required, depending upon the type furnace. In most cases, furnace is lined with refractories of ***low heat conductivities*** *to reduce the heat losses to the outside by radiation ;* otherwise maintenance of high temperatures inside the furnace will become difficult. However, ***a good heat conductivity*** *of refractory is desirable for effective heat transmission in some furnace construction*, as in muffle furnace walls, coke-oven batteries, in which *charge is separated from the flame.*

The ***densest and least porous*** *brick have the* ***highest*** *thermal conductivity, owing to the absence of air-voids.* On the other hand, *in porous bricks, the entrapped air in the pores, acts as a non-heat conducting material.* For making *porous* refractory bricks, the refractory material is mixed with a liberal amount *of carbonaceous* material, then moulded into bricks and burnt. The carbonaceous material burns off ; leaving behind *minute voids, which enhances the insulating quality.*

(7) **Porosity :** All refractories contain pores, either due to manufacturing methods or deliberately (by incorporating saw-dust or cork during manufacture). The pores may be *open* or *closed*, the latter are encountered in an oven-fired refractory. ***Porosity*** *in the ratio of its pore's volume to the bulk volume.* Thus, porosity,

$$P = \frac{W-D}{W-A} \times 100 \quad \text{where} \quad \left[\begin{array}{l} W = \text{Wt. of saturated specimen.} \\ D = \text{Wt. of dry specimen.} \\ A = \text{Wt. of saturated specimen submerged in water.} \end{array}\right.$$

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 *reduce the life of* refractory material. *Porosity* ***decreases*** *the strength, resistance to abrasion, resistance to corrosion/penetration by slags, gases etc., but* ***increases*** *resistance to thermal spalling (i.e., thermal shock-resistance).* Moreover, *the* ***densest and least porous bricks 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.* A good refractory, in general, should have *low porosity*.

[A good refractory should have low porosity]

(8) **Thermal spalling** *is breaking, cracking, peeling off or fracturing of a refractory brick or block, under high temperature.* So a good refractory must show a good resistance to thermal spalling. Spalling is, generally, due to *rapid changes in temperature*, which cause uneven expansion and contraction within the mass of refractory, thereby leading to development of internal stresses and strains. Spalling may also be due to *slag penetration* into the refractory brick, thereby causing *variation in the coefficient of expansion*. It has been found that *spalling can be decreased by* : (*a*) *using high porosity, low coefficient of expansion and good thermal conductivity refractory bricks*, since all these resist the development of internal stresses ; (*b*) *avoiding sudden temperature changes* ; (*c*) *by overfiring the refractories* (during manufacture) at high temperatures for a sufficiently long time, whereby *mineral inversion*, etc., takes place, making the material less susceptible to uneven expansion or contraction, when heated ; (*d*) *by modifying the furnace design* so that stresses are not set up, when the furnace is heated.

(9) **Resistance to abrasion or erosion** : *For a refractory to last longer, it is desirable that it is least abraded by descending hard charge, flue gases escaping at high speeds, particles of carbon or grit, etc.*, Resistance to erosion is very important for such constructions as by-product coke-oven walls, and linings of the discharge-ends of rotary cement kilns, etc.

(10) **Electrical conductivity** : Refractories to be used for lining *electric* furnaces should have *low electrical conductivity*. Except *graphite*, all other refractories are poor conductors of electricity. *However, electrical resistance of refractories decreases rapidly with temperature rise.*

(11) **Heat capacity** of furnace depends on : (*a*) *thermal conductivity* ; (*b*) *specific heat*, and (*c*) *specific gravity of refractory. In case of intermittently-operated furnaces, light-weight brickwork has an advantage*, since the working temperature can be achieved *in less time with less fuel*. Conversely, *the dense and heavy fire-bricks would be best* for regenerators, checker-works as in coke ovens, glass furnaces, and stoves for blast furnaces.

(12) **Texture** : *Coarse or light-textured bricks, because of their large porosity, are light in weight and hence, they are more resistant to sudden changes in temperatures.* However, their *crushing strength is low*. Such bricks are *more susceptible to the action of abrasion and corrosion*. On the other hand, *fine or dense-textured bricks* possess low porosity and hence, are heavier in weight. These are not so resistant to sudden changes in temperature. However, such bricks are less susceptible to action of abrasion and corrosion.

(13) **Permeability** *is a measure of rate of diffusion of gases, liquids and molten solids through a refractory*, Permeability depends upon the *size* and *number of connected pores*. With the rise of temperature, the permeability increases, since the viscosity of molten metals decreases with an increase of temperature. An increase in *bulk-density* (*i.e.*, ratio of weight to its volume) of a refractory increases the resistance to slag-penetration and spalling.

Conditions leading to failure of a refractory material : (*i*) Using a refractory of refractoriness less that of the operating temperature. (*ii*) Using *lower-duty* refractory bricks in a furnace than the actual load of raw materials and products. (*iii*) Using bricks of *higher* thermal expansion. (*iv*) *Rapid changes* in temperature of the furnace. (*v*) Using *heavy-weight* refractory bricks. (*vi*) Using refractory bricks which are *not properly fired*. (*vii*) Using bricks which *undergo considerable volume changes* during their use at high temperatures. (*viii*) Using *acidic/basic refractory* in a furnace in which *basic/acidic reactants* and/or products are being processed.

6 MANUFACTURE OF REFRACTORIES

Manufacture of refractories consists of the following *steps* :

1. **Crushing** : The raw materials in the form of big lumps are crushed to about 25 mm size.

2. **Grinding** : The crushed materials are ground, in suitable grinding machine, down to 200 mesh size.