

THEORY & **O**BJECTIVE

BUILDING MATERIAL

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BRICKS

THEORY

- A brick is rectangular in shape and size that can be conveniently handled with one hand. Brick may be made of burnt clay or mixture of sand and lime or of Portland cement concrete. Clay bricks are commonly used since these are economical and easily available. The length, width and height of a brick are interrelated as below:

$$\text{Length of brick} = 2 \times \text{width of brick} + \text{thickness of mortar}$$

$$\text{Height of brick} = \text{width of brick}$$

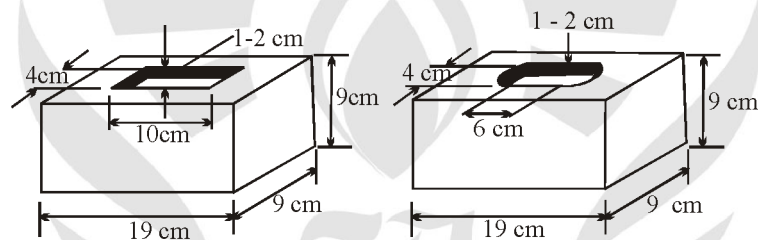
Size of a standard brick (also known as modular brick) should be

$$19 \times 9 \times 9 \text{ cm and } 19 \times 9 \times 4 \text{ cm.}$$

When brick placed with mortar then

size of brick

$$20 \times 10 \times 10 \text{ cm}$$



Bricks

- An indent called frog, 1–2 cm deep, as shown in figure, is provided for 9 cm high bricks. The size of frog should be $10 \times 4 \times 1$ cm. The purpose of providing frog is to form a key for holding the mortar and therefore, the bricks are laid with frogs on top. Frog is not provided in 4 cm high bricks and extruded bricks.

Classification of Bricks

- Clay bricks are classified as first class, second class, third class and fourth class based on their Physical and mechanical properties.

First Class Bricks

- These are thoroughly burnt and are of deep red, cherry or copper colour.
- The surface should be smooth and rectangular, with parallel, sharp and straight edges and square corners.
- These should be free from flaws, cracks and stones.
- These should have uniform texture.
- No impression should be left on the brick when a scratch is made by a finger nail.
- The fractured surface of the brick should not show lumps of lime.
- A metallic or ringing sound should come when two bricks are struck against each other.
- Water absorption should not be more than 20% of its dry weight when immersed in cold water for 24 hours.
- The crushing strength of the brick should not be less than 10 N/mm^2 .

- ❖ First class bricks are recommended for pointing, exposed face work in masonry structures, flooring and reinforced brick work.

➤ **Second Class Bricks :**

- ❖ Small cracks and distortions are permitted.
- ❖ A little higher water absorption of about 22.5 % of its dry weight is allowed.
- ❖ The crushing strength should not be less than 7.0 N/mm².
- ❖ Second class bricks are recommended for all important or unimportant hidden masonry works and cantering of reinforced brick and reinforced cement concrete (RCC) structures.

➤ **Third Class Bricks :**

- ❖ **These are Underburnt :**
- ❖ They are soft and light-coloured producing a dull sound when struck against each other. Water absorption is about 25 per cent of dry weight. The crushing strength should not be less than 5.0 N/mm².
- ❖ It is used for building temporary structures.

Classification of Bricks on The Basis of Strength :

- ❖ The Bureau of Indian Standards (BIS) has classified the bricks on the basis of compressive strength and is as given in Table below :

Class	35	30	25	20	17.5	15	12.5	10	7.5	5	3.5
Average Compressive Strength not less than (N/mm ²)	35.0	30.0	25.0	20.0	17.5	15.0	12.5	10.0	7.5	5.0	3.5

Note: The burnt clay bricks having compressive strength more than 40 N/mm² are known as heavy duty bricks and are used for heavy duty structures such as bridges, foundation for industrial building and multi-storey buildings.

➤ **Characteristics of Good Bricks:**

- ❖ The essential requirements for building bricks are sufficient strength in crushing, regularity in size, a proper suction rate, and a pleasing appearance when exposed to view.
 - ❖ **Size and shape:**
- ❖ The bricks should have uniform size and plane, rectangular surfaces with parallel sides and sharp straight edges.
 - ❖ **Colour:**
- ❖ The brick should have a uniform deep red or cherry colour as indicative of uniformity in chemical composition and thoroughness in the burning of the brick.
 - ❖ **Texture and compactness:**
- ❖ The surfaces should not be too smooth to cause slipping of mortar. The brick should have pre compact and uniform texture. A fractured surface should not show fissures, holes grits or lumps of lime.
 - ❖ **Hardness and soundness:**
- ❖ The brick should be so hard that when scratched by a finger nail no impression is made. When two bricks are struck together, a metallic sound should be produced.
 - ❖ **Water absorption** should not exceed 20 per cent of its dry weight when kept immersed in water for 24 hours.
 - ❖ **Crushing strength** should not be less than 10 N/mm².

➤ **Ingredients of Good Bricks :**

❖ The proportions of various ingredients are as follows:

❖ Silica	50–60%
❖ Alumina	20–30%
❖ Lime	10%
❖ Magnesia	< 1%
❖ Ferric oxide	< 7%
❖ Alkalis	< 10%
❖ Carbon dioxide, Sulphur trioxide and Water:	- very small amount

COMPOSITION BRICK EARTH

❖ Following are the constituents brick earth :

➤ **ALUMINA : (20-30%)**

- ❖ It is the chief constituent of every kind of clay. A good brick earth should contain about 20% to 30% of alumina. This constituent imparts plasticity to the earth so that it can be moulded.
- ❖ If alumina is present in excess, with inadequate quantity of sand, the raw bricks shrink and warp during drying and burning and become too hard when burnt.

➤ **SILICA :**

- ❖ It exists in clay either as free or combined. As free sand, it is mechanically mixed with clay and in combined form, it exists in chemical composition with alumina. A good brick earth should contain about 50 percent to 60 per cent of silica.
- ❖ The presence of this constituent prevents cracking, shrinking and warping of raw bricks. It thus imparts uniform shape to the bricks.
- ❖ The durability of bricks depends on the proper proportion of silica in brick earth. The excess of silica destroys the cohesion between particles and the bricks become brittle.

➤ **LIME :**

- ❖ A small quantity of lime not exceeding 5 per cent is desirable in good brick earth .It should be present in a very finely powdered state because even small particles of the size of a pin-head cause flaking of the bricks.
- ❖ The lime prevents shrinkage of row bricks. The sand alone is infusible. But it slightly fuses at kiln temperature in presence of lime. Such fused sand works as a hard cementing material for brick particles.
- ❖ The excess of lime causes the brick to melt and hence its shape is lost. The lumps of lime are converted into quick lime after burning and this quick lime slakes and expands in presence of moisture. Such an action results in splitting of bricks into pieces.

➤ **OXIDE OF IRON :**

- ❖ A small quantity of oxide of iron to the extent of about 5 to 6 per cent is desirable in good brick earth. It helps as lime to fuse sand. It also imparts red colour to the bricks.
- ❖ The excess of oxide of iron makes the bricks dark blue or blackish. If on the other hand, the quantity of iron oxide is comparatively less, the bricks will be yellowish in colour.

➤ **MAGNESIA :**

- ❖ A small quantity of magnesia in brick earth imparts yellow tint to the bricks and decreases shrinkage. But excess of magnesia leads to the decay of bricks.

HARMFUL INGREDIENTS IN BRICK EARTH:

- ❖ Following are the ingredients which are undesirable in the brick earth :
- **Lime :**
- ❖ Excess of lime cause the bricks to melt and hence its shape is lost.
- **Iron pyrites :**
- ❖ If iron pyrites are present in brick earth, the bricks are crystallized and disintegrated during burning because of the oxidation of the iron pyrites.
- **Alkalies :**
- ❖ These are mainly in the form of soda and potash. The alkalies act as a flux in the kiln during burning and they cause bricks to fuse, twist and warp. As a result, the bricks are melted and they lose their shape.
- ❖ Further, the alkalies remaining in bricks will absorb moisture from the atmosphere, when bricks are used in masonry.
- ❖ Such moisture, when evaporated, leaves behind grey or white deposits on the wall surface. The appearance of the building as a whole is then seriously spoiled.
- **Pebbles :**
- ❖ The presence of pebbles or grits of any kind is undesirable in bricks earth because it will not allow the clay to be mixed uniformly and thoroughly which will result in weak and porous bricks. Also, the brick containing pebbles will not break regularly as desired.
- **Vegetation and organic matter :**
- ❖ The presence of vegetation and organic matter in brick earth assists in burning. But if such matter is not completely burnt, the bricks become porous.
- ❖ This is due to the fact that the gases will be evolved during the burning of the carbonaceous matter and it will result in the formation of small pores.
- ❖ Hence it is necessary to see that all these gases are removed during the process of burning for getting bricks of good quality.

MANUFACTURING OF BRICKS

- ❖ In the process of manufacturing bricks, the following four distinct operations are involved :
 - ✧ Preparation of clay
 - ✧ Moulding
 - ✧ Drying
 - ✧ Burning.
- **Preparation of clay :** The clay for bricks is prepared in the following order :
 - ✧ Unsoiling
 - ✧ Weathering
 - ✧ Digging
 - ✧ Blending
 - ✧ Cleaning
 - ✧ Tempering.
- ❖ **Unsoiling :** The top layer of soil, about 200 mm in depth, is taken out and thrown away. The clay in top soil is full of impurities and hence it is to be rejected for the purpose of preparing bricks.
- ❖ **Digging :** The clay is then dug out from the ground. It is spread on the levelled ground, just a little deeper than the general level of ground. The height of heaps of clay is about 600 mm to 1200 mm.

- ❖ **Cleaning** : The clay, as obtained in the process of digging, should be cleaned of stones, pebbles, vegetable matter, etc. If these particles are in excess, the clay is to be washed and screened. Such a process naturally will prove to be troublesome and expensive. The lumps of clay should be converted into powder form in the earth crushing roller.
- ❖ **Weathering** : The clay is then exposed to atmosphere for softening or mellowing. The period of exposure varies from few weeks to full season. For a large project, the clay is dug out just before the monsoon and it is allowed to weather throughout the monsoon.
- ❖ **Blending** : The clay is made loose and any ingredient to be added to it, is spread out at its top. The blending indicates intimate or harmonious mixing. It is carried out by taking small portion of clay every time and by turning it up and down in vertical direction. The blending makes clay fit for the next stage of tempering.
- ❖ **Tempering** : In the process of tempering, the clay is brought to a proper degree of hardness and it is made fit for the next operation of moulding. The water in required quantity is added to clay and the whole mass is kneaded or pressed under the feet of men or cattle. The tempering should be done exhaustively to obtain homogeneous mass of clay of uniform character.
- ⇒ **Moulding** : Following are the two ways of moulding :
 - ⊗ Hand moulding
 - ⊗ Machine moulding.
- ❖ **Hand moulding** : In hand moulding, the bricks are moulded by hand i.e., manually. It is adopted where manpower is cheap and is readily available for the manufacturing process of bricks on a small scale. The moulds are rectangular boxes which are open at top and bottom.
- ❖ The bricks prepared by hand moulding are of two types :
 - ⊗ Ground-moulded bricks
 - ⊗ Table-moulded bricks.
- ❖ The lower faces of ground moulded bricks are rough and it is not possible to place frog on such bricks. A frog is a mark of depth about 10 mm to 20 mm which is placed on raw brick during moulding. It serves two purposes :
 - ⊗ It indicates the trade name of the manufacturer.
 - ⊗ In brickwork, the bricks are laid with frog uppermost. It thus affords a key for mortar when the next brick is placed over it.
- ❖ **Machine Moulding** : In machine moulding, the bricks are moulded by machine. It proves to be economical when bricks in huge quantity are to be manufactured at the same spot in a short time
- ⇒ **Drying** :
 - ⊗ Artificial drying
 - ⊗ Circulation of air
 - ⊗ Drying yard
 - ⊗ Period for drying
 - ⊗ Screens

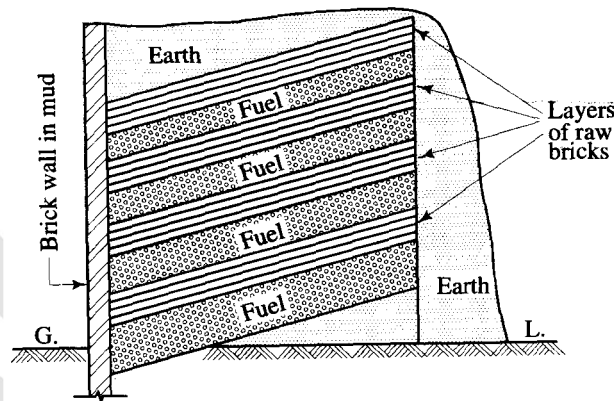
Burning :

- ❖ This is a very important operation in the manufacturing of bricks. It imparts hardness and strength to the bricks and makes them dense and durable. The bricks should be burnt properly.
- ❖ If bricks are overburnt, they will be brittle and hence break easily. If they are underburnt, they will be soft and hence cannot carry loads.

BURNING OF BRICKS IS DONE IN CLAMPS AND KILNS**Clamps**

➤ **Procedure :** A typical clamp is shown in Fig. Following procedure is adopted in construction of clamp :

- ❖ A piece of ground is selected. Its shape in plan is generally trapezoidal. The floor of clamp is prepared in such a way that short end is slightly in the excavation and wider end is raised at an angle of about 15° from ground level.
- ❖ The brick wall in mud is constructed on the short end and a layer of fuel is laid on the prepared floor. The fuel may consist of grass, cow dung, litter, husks of rice or ground nuts, etc. The thickness of this layer is about 700 mm to 800 mm. The wood or coal dust may also be used as fuel.



Clamp

- ❖ A layer, consisting of 4 or 5 courses of raw bricks, is then put up. The bricks are laid on edges with small spaces between them for the circulation of air.
- ❖ A second layer of fuel is then placed and over it, another layer of raw bricks is put up. Thus alternate layers of fuel and raw bricks are formed. The thickness of fuel layer gradually decreases as the height of clamp increases.
- ❖ The total height of a clamp is about 3 m to 4 m. When nearly one-third height is reached, the lower portion of the clamp is ignited. The object for such an action is to burn the bricks in lower part when the construction of upper part of clamp is in progress.
- ❖ When clamp is completely constructed, it is plastered with mud on sides and top and filled with earth to prevent the escape of heat. If there is any sudden and violent outburst of fire, it is put down by throwing earth or ashes.
- ❖ The clamp is allowed to burn for a period of about one to two months.
- ❖ It is then allowed to cool for more or less the same period as burning.
- ❖ The burnt bricks are then taken out from the clamp.

- **Advantages of clamp burning :** Following are the advantages of clamp burning :
- ✧ The burning and colling of bricks are gradual in clamps. Hence the bricks produced are tough and strong.
 - ✧ The burning of bricks by clamps proves to be cheap and economical.
 - ✧ No skilled labour and supervision are required for the construction and working of clamps.
 - ✧ The clamp is not liable to injury from high wind or rain.
 - ✧ There is considerable saving of fuel.
- **Disadvantages of clamp burning :** Following are the disadvantages of clamp burning :
- ✧ The bricks are not of regular shape. This may be due to the settlement of bricks when fuel near bottom is burnt and turned to ashes.
 - ✧ It is a very slow process.
 - ✧ It is not possible to regulate fire in a clamp once it starts burning and the bricks are liable to uneven burning.
 - ✧ The quality of bricks is not uniform. The bricks near the bottom are overburnt and those near sides and top are underburnt.

KILNS

- ❖ A kiln is a large oven which is used to burn bricks. The kilns which are used in the manufacture of bricks are of the following two types :
 - ✧ Intermittent kilns
 - ✧ Continuous kilns.
- **Intermittent kilns :**
 - ❖ These kilns are intermittent in operation which means that they are loaded, fired, cooled and unloaded. Such kilns may be either rectangular or circular in plan. They may be over ground or underground. They are classified in two ways :
 - ✧ Intermittent up-draught kilns
 - ✧ Intermittent down-draught kilns.
- **Continuous kilns :**
 - ❖ These kilns are continuous in operation. This means that loading, firing, cooling and unloading are carried out simultaneously in these kilns. There are various types of the continuous kilns.
 - ✧ Bull's trench kiln
 - ✧ Hoffmann's kiln
 - ✧ Tunnel kiln.

COMPARISON BETWEEN CLAMP-BURNING AND KILN-BURNING

- ❖ In order to bring out points of differences between similar items of clamp burning and kiln-burning of bricks, a table is prepared.

COMPARISON BETWEEN CLAMP-BURNING AND KILN-BURNING

No.	Item	Clamp-burning	Kiln-burning
1.	Capacity	About 20000 to 100000 bricks can be prepared at a time.	Average 25000 bricks can be prepared per day.
2.	Cost of fuel	Low as grass, cow dung, litter, etc. may be used.	Generally high as coal dust is to be used.
3.	Initial cost	Very low as no structures are to be built.	More as permanent structures are to be constructed.
4.	Quality of bricks	The percentage of good quality bricks is small about 60% or so.	The percentage of good quality bricks is more about 90% or so.
5.	Regulation of fire	It is not possible to control or regulate fire during the process of burning.	The fire is under control throughout the process of burning.
6.	Skilled supervision	Not necessary throughout the process of burning.	The continuous skilled supervision is necessary.
7.	Structure	Temporary structure.	Permanent structure.
8.	Suitability	Suitable when bricks are to be manufactured on a small scale and when the demand of bricks is not continuous.	Suitable when bricks are to be manufactured on a large scale and when there is continuous demand of bricks.
9.	Time of burning and cooling	It requires about 2 to 6 months for burning and cooling of bricks.	Actual time for burning of one chamber is about 24 hours and only about 12 days are required for cooling of bricks.
10.	Wastage of heat	There is considerable wastage of heat from top and sides and hot flue gas is not properly utilized.	The hot flue gas is used to dry and pre-heat raw bricks. Hence the wastage of heat is the least.

FACTORS AFFECTING QUALITY OF BRICKS

- ❖ Following factors affect the quality of bricks :
 - ✱ composition of bricks earth;
 - ✱ preparation of clay and blending of ingredients;
 - ✱ nature of moulding adopted;
 - ✱ care taken in drying and stacking of raw or green bricks;
 - ✱ type of kiln used including type of fuel and its feeding;
 - ✱ burning and cooling processes; and
 - ✱ care taken in unloading.
- ❖ It is thus obvious that not only the bricks of different bricks fields will have different strengths, but in the same brick field, the bricks of the same batch may have different strengths.
- ❖ The average crushing strength and tensile strength of hand moulded bricks are 60000 kN/m² and 2000 kN/m² respectively. The shearing strength of bricks is about one-tenth of the crushing strength.

TESTING OF BRICKS :

- **Dimension test (IS: 1077)** is used to check the proper size of bricks.
- **Water absorption test (IS: 3495 part (2)):** to find the amount of water absorbed by the brick water absorption test is done. There are two popular methods are available to find the water absorbed which are

↗ **24 hours immersion cold Water Test:**

- ❖ Dry bricks are put in an oven at a temperature of 105° to 115°C till these attain constant mass. The weight (w_1) of the bricks is recorded after cooling them to room temperature. The bricks are then immersed in water at a temperature of 27° ± 2°C for 24 hours.
- ❖ The specimens are then taken out of water and wiped with a damp cloth. Three minutes, thereafter it is weighed again and recorded as w_2 .

⊗ The water absorption in $\% = \frac{w_2 - w_1}{w_1} \times 100$

- ❖ The average water absorption shall not be more than 20 per cent by weight upto class 12.5 and 15 per cent by weight for higher classes.

↗ **Five Hours Boiling Water Test:**

- ❖ The weight of the oven dried bricks (w_1) is recorded as above.
- ❖ Then the specimen is immersed in the water and boiled for five hours, followed by cooling down to 27° ± 2°C by natural loss of heat within 16–19 hours. The specimen is taken out of water and wiped with a damp cloth and the weight is recorded as w_3 .

⊗ The water absorption in $\% = \frac{w_3 - w_1}{w_1} \times 100$

↗ **Compressive Strength Test:**

- ⊗ For testing bricks for compressive strength from a sample the two bed faces of bricks are ground to provide smooth, even and parallel faces. The bricks are then immersed in water at room temperature for 24 hours. These are then taken out of water and surplus water on the surfaces is wiped off with cotton or a moist cloth.
- ❖ The frog of the brick is flushed level with cement mortar and the brick is stored under damp jute bags for 24 hours followed by its immersion in water at room temperature for three days. The specimen is placed in the compression testing machine with flat faces horizontal and mortar filled face being upwards.
- ❖ Load is applied at a uniform rate of 14 N/m² per minute till failure. The maximum load at failure divided by the average area of bed face gives the compressive strength.

⊗ Compressive strength $(\text{N/mm}^2) = \frac{\text{maximum load at failure (N)}}{\text{avg area of bed face (mm}^2\text{)}}$

- ❖ The average of results shall be reported. The compressive strength of any individual brick tested in the sample should not fall below the minimum average compressive strength specified for the corresponding class of brick by more than 20 percent.

FIRE-BRICKS

- ❖ These bricks are made from fire-clay. The process of manufacture is the same as that of ordinary clay bricks. The burning and colling of fire-bricks are done gradually.
- ❖ These bricks are usually white or yellowish white in colour. The weight of a fire-brick is about 30 to 35 N. The fire-bricks can resist high temperature without softening or melting. Hence they are used for linings of interior surfaces of furnances, chimneys, kilns, ovens, fireplaces, etc.
- ❖ The compressive strength of these bricks varies from 200 to 220 N/mm². The percentage of absorption for these bricks varies from 5 to 10.
- ❖ Following are the *three* varieties of fire-bricks :

- ⊗ Acidic bricks
- ⊗ Basic bricks
- ⊗ Neutral bricks.

⇒ **Acidic bricks :**

- ❖ These bricks are used for acidic lining. Following are the types of acidic bricks :
 - ⊗ **Ordinary fire-bricks** : These bricks are prepared from natural fire-clay and they provide a good material for acidic refractory lining.
 - ⊗ **Silica bricks** : These bricks contain a very high percentage of silica to the extent of about 95 to 97 per cent. A small quantity of lime, about 1 to 2 per cent, is added to work as binding material. These bricks are moulded under pressure and burnt at high temperature. The silica bricks can stand a high temperature upto about 2000°C. The compressive strength of such bricks is about 15 N/mm².

⇒ **Basic bricks :**

- ❖ These bricks are used for basic lining and basic refractory materials are used in the manufacture of such bricks. The magnesia bricks are prepared from lime and magnesia rocks. The dolomite may also be adopted for the manufacture of these bricks.

⇒ **Neutral bricks :**

- ❖ These bricks are used for neutral lining. They offer resistance to the corrosive action of slags and acid fumes. As compared to the basic bricks, the neutral bricks are more inert to the slags. Following are the types of neutral bricks :
 - ⊗ **Chromite bricks** : These bricks are prepared from a mixture of chrome, iron ore, ferrous oxide, bauxite and silica. Such bricks are unaffected by acidic or basic actions.
 - ⊗ **High alumina bricks** : These bricks contain a high percentage of alumina and they are found to be more inert to the slags.

⇒ **Heavy Duty Burnt Clay Bricks :**

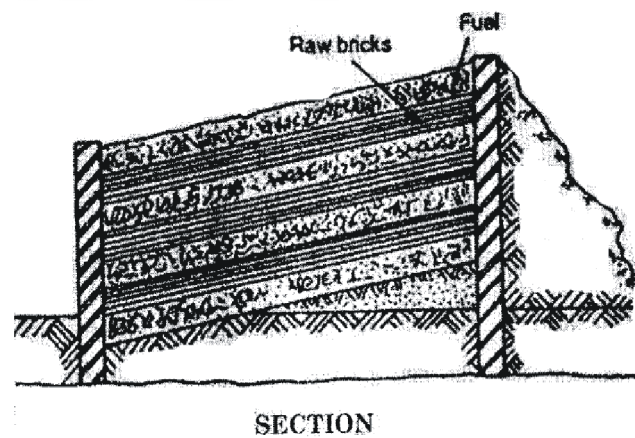
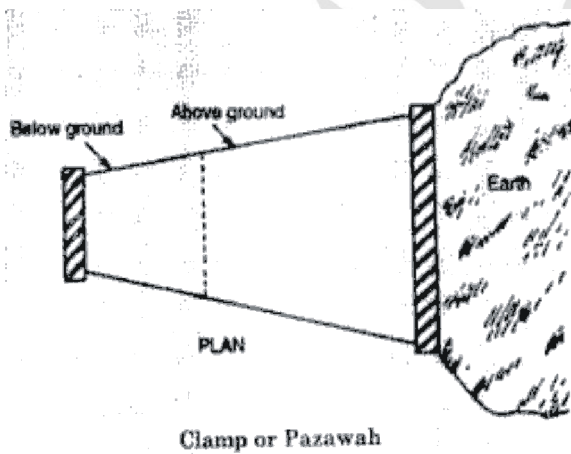
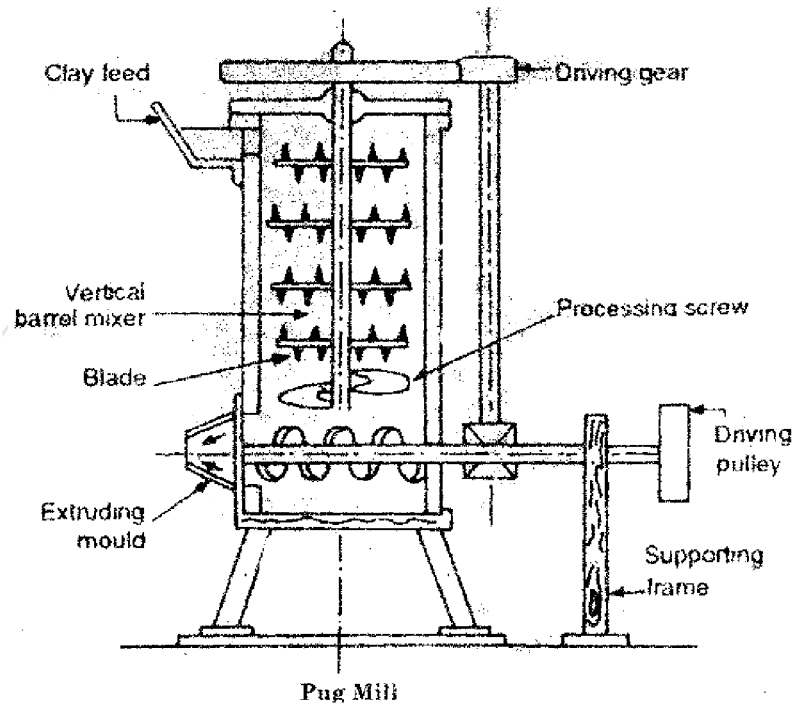
- ❖ These are similar to burnt clay bricks and of the same size but with high compressive strength.

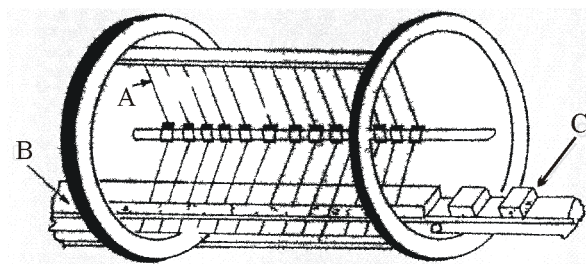
CLASSIFICATION :

- ❖ **Class 400** : Compressive strength not less than 40.0 N/mm² but less than 45.0 N/mm².
- ❖ **Class 450** : Compressive strength not less than 45.0 N/mm²

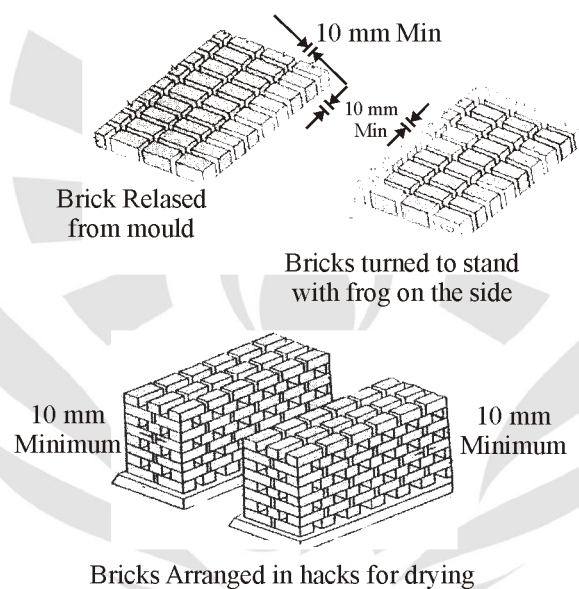
⇒ **Burnt Clay Perforated Bricks :**

⇒ **Burnt clay Paving bricks :**





A. Wire; B. Column of pressed clay passing through die; C. Wire cut brick
Brick cutting wire machine



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CEMENT

THEORY

- ❖ Cements in a general sense are adhesive and cohesive materials which are capable of bonding together particles of solid matter into a compact durable mass.
- ❖ Cements used in construction industry may be classified as hydraulic and non-hydraulic. The latter does not set and harden in water such as non-hydraulic lime or which are unstable in water, e.g. Plaster of Paris.
- ❖ The hydraulic cement set and harden in water and give a product which is stable. E.g. Portland cement.

PORTLAND CEMENT

- ❖ It is a cementing material resembling a natural stone quarried from Portland in U.K. Portland cement may be defined as a product obtained by finely pulverizing clinker produced by calcining to incipient fusion, an intimate and properly proportioned mixture of argillaceous and calcareous materials.
- ❖ The ordinary Portland cement has been classified as 33 Grade (IS269:1989), 43 Grade (IS 8112:1989), and 53 Grade (IS 12669-1987). The physical requirements of all these three types of cement are almost same except for compressive strength and are as follows:

Physical Requirement	Method of Testing	Grade		
		33	43	53
Fineness (Sp. Surface in cm^2/gm)	Blaine's air permeability	2250	2250	2250
Soundness from lime	Le Chatelier	10mm	10mm	10mm
Soundness from magnesia	Autoclave	0.8%	0.8%	0.8%
Setting time in minutes initial (min)	Vicat apparatus	30	30	30
Final (max)		600	600	600
Compressive strength	UTM machine (70.6 × 70.6 × 70.6) mm			
72 ± 1 hour		16	23	27
168 ± 2 hour		22	33	37
672 ± 4 hour		33	43	53

Chemical Composition of Raw Material :

- ❖ The three constituents of hydraulic cements are lime, silica and alumina. In addition, most cements contain small proportions of iron oxide, magnesia, sulphur trioxide and alkalis.
- ❖ An increase in lime content beyond a certain value makes it difficult to combine completely with other compounds. Consequently, free lime will exist in the clinker and will result in an unsound cement.
- ❖ An increase in silica content at the expense of alumina and ferric oxide makes the cement difficult to fuse and form clinker.

OXIDE	FUNCTION	COMPOSITION (%)
CaO	Controls strength and soundness. Its deficiency reduces strength and setting time	60 – 65
SiO ₂	Gives strength. Excess of it causes slow setting.	17 – 25
Al ₂ O ₃	Responsible for quick setting, if in excess, it lowers the strength.	3 – 8
Fe ₂ O ₃	Gives colour and helps in fusion of different ingredients	0.5 – 6
MgO	Imparts colour and hardness. If in excess, it causes cracks in mortar and concrete and unsoundness.	0.5 – 4
Na ₂ O + K ₂ O	These are residues, and if in excess cause efflorescence and cracking	0.5 – 1.3
TiO ₂		0.1 – 0.4
P ₂ O ₅		0.1 – 0.2
SO ₃	Makes cement sound	1 – 2

Composition of Cement Clinker :

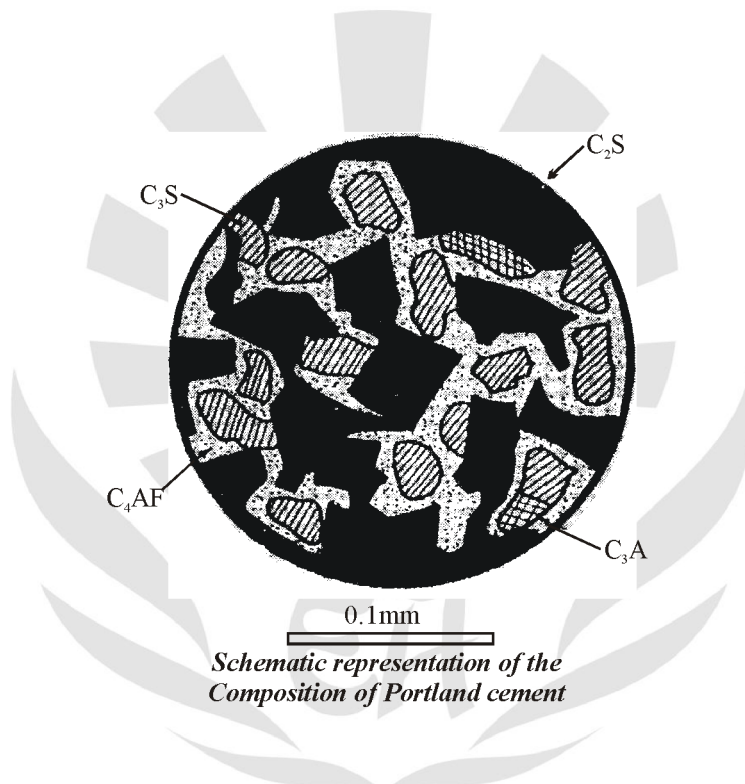
- ❖ The various constituents combine in burning and form cement clinker. The compounds formed in the burning process have the properties of setting and hardening in the presence of water.
- ❖ They are known as *Bogue compounds* after the name of Bogue who identified them. Le-Chatelier and Tornebohm have referred these compounds as Alite (C₃S), Belite (C₂S), Celite (C₃A) and Felite (C₄AF). The following Bogue compounds are formed during clinkering process.

The principal mineral compounds in Portland Cement	Formula	Name	Symbol
Tricalcium silicate	3CaO.SiO ₂	Alite	C ₃ S
Dicalcium silicate	2CaO.SiO ₂	Belite	C ₂ S
Tricalcium aluminate	CaO.Al ₂ O ₃	Celite	C ₃ A
Tetracalcium alumino ferrite	4CaO.Al ₂ O ₃ .Fe ₂ O ₃	Felite	C ₄ AF

Functions of Bogue's Compound

- **Tricalcium silicate** is supposed to be the best cementing material and is well burnt cement. It is about 25-50% (normally about 40 per cent) of cement. It renders the clinker easier to grind, increases resistance to freezing and thawing, hydrates rapidly generating high heat and develops an early hardness and strength.
- ❖ However, raising of C₃S content beyond the specified limits increases the heat of hydration and solubility of cement in water. The hydrolysis of C₃S is mainly responsible for 7 day strength and hardness. The rate of hydrolysis of C₃S and the character of gel developed are the main causes of the hardness and early strength of cement paste. The heat of hydration is 500 J/g.
- **Dicalcium silicate** is about 25-40% (normally about 32 per cent) of cement. It hydrates and hardens slowly and takes long time to add to the strength (after a year or more). It imparts resistance to chemical attack.
- ❖ Raising of C₂S content renders clinker harder to grind, reduces early strength, decreases resistance to freezing and thawing at early ages and decreases heat of hydration. The hydrolysis of C₂S proceeds slowly.
- ❖ At early ages, less than a month, C₂S has little influence on strength and hardness. While after one year, its contribution to the strength and hardness is proportionately almost equal to C₃S. The heat of hydration is 260 J/g.

- **Tricalcium aluminate** is about 5-11% (normally about 10.5 per cent) of cement. It rapidly reacts with water and is responsible for flash set of finely grounded clinker.
- ❖ The rapidity of action is regulated by the addition of 2-3% of gypsum at the time of grinding cement. Tricalcium aluminate is responsible for the initial set, high heat of hydration and has greater tendency to volume changes causing cracking.
- ❖ Raising the C_3A content reduces the setting time, weakens resistance to sulphate attack and lowers the ultimate strength, heat of hydration and contraction during air hardening. The heat of hydration of 865 J/g.
- **Tetra calcium alumina ferrite** is about 8–14% (normally about 9 per cent) of cement. It is responsible for flash set but generates less heat.
- ❖ It has poorest cementing value. Raising the C_4AF content reduces the strength slightly. The heat of hydration is 420 J/g.



HYDRATION OF CEMENT:

- ❖ The chemical reaction between cement and water is known as *hydration* of cement.
- ❖ The reaction of compound C_3A with water is very fast and is responsible for flash setting of cement (stiffening without strength development) and thus it will prevent the hydration of C_3S and C_2S . However, calcium sulphate ($CaSO_4$) present in the clinker dissolves immediately in water and forms insoluble calcium sulphoaluminate.
- ❖ It deposits on the surface of C_3A forming a colloidal membrane and consequently retards the hydration of C_3A . The amount of $CaSO_4$ is adjusted to leave a little excess of C_3A to hydrate directly. This membrane in the process breaks because of the pressure of the compounds formed during hydration and then again C_3A becomes active in the reaction.
- ❖ The hardening of C_3S can be said to be catalysed by C_3A and C_3S becomes solely responsible for gain of strength up to 28 days by growth and interlocking of C-S-H gel. The increase in strength at later age is due to hydration of C_2S .