Program : **B.Tech**

Subject Name: **Basic Civil Engineering & Mechanics**

Subject Code: **BT-204**

Semester: **2nd**

Unit: 01

BUILDING MATERIALS:

1. Bricks: Manufacturing, field and laboratory test, Engineering properties.

2. Cement: Types, physical properties, laboratory tests

3. Concrete and Mortar Materials: Workability, Strength Properties of Concrete, Nominal proportion of Concrete, Preparation of Concrete, Compaction Curving.

Mortar: Properties and Uses.

Bricks:

Properties:

All properties of brick are affected by raw material composition and the manufacturing process. Most manufacturers blend different clays to achieve the desired properties of the raw materials and of the fired brick. This improves the overall quality of the finished product. The quality control during the manufacturing process permits the manufacturer to limit variations due to processing and to produce a more uniform product. The most important properties of brick are 1) durability, 2) color, 3) texture, 4) size variation, 5) compressive strength and 6) absorption.

Durability

The durability of brick depends upon achieving incipient fusion and partial vitrification during firing. Because compressive strength and absorption values are also related to the firing temperatures, these properties, together with saturation coefficient, are currently taken as predictors of durability in brick specifications. However, because of differences in raw materials and manufacturing methods, a single set of values of compressive strength and absorption will not reliably indicate the degree of firing.

Color

The color of fired clay depends upon its chemical composition, the firing temperatures and the method of firing control. Of all the oxides commonly found in clays, iron probably has the greatest effect on color. Regardless of its natural color, clay containing iron in practically any form will exhibit a shade of red when exposed to an oxidizing fire because of the formation of ferrous oxide. When fired in a reducing atmosphere, the same clay will assume a dark (or black) hue. Creating a reducing atmosphere in the kiln is known as flashing or reduction firing. Given the same raw material and manufacturing method, darker colors are associated with higher firing temperatures, lower absorption values and higher compressive strength values. However, for products made from different raw materials, there is no direct relationship between strength and color or absorption and color.

Texture, Coatings and Glazes

Many brick have smooth or sand-finished textures produced by the dies or molds used in forming. Smooth textures, commonly referred to as a die skin, results from pressure exerted by the steel die as the clay passes through it in the extrusion process. Most extruded brick have the die skin removed and the surface further treated to produce other textures using devices that cut, scratch, roll, brush or otherwise roughen the surface as the clay column leaves the die (see Photo 6).

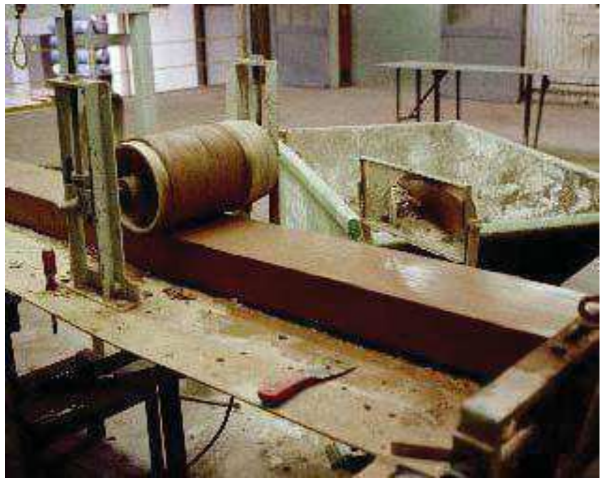


Figure: Some Brick Textures are applied by Passing under a Roller after Extrusion

Size Variation

Because clays shrink during both drying and firing, allowances are made in the forming process to achieve the desired size of the finished brick. Both drying shrinkage and firing shrinkage vary for different clays, usually falling within the following ranges:

- Drying shrinkage: 2 to 4 percent
- Firing shrinkage: 2.5 to 4 percent

Firing shrinkage increases with higher temperatures, which produce darker shades. When a wide range of colors is desired, some variation between the sizes of the dark and light units is inevitable. To obtain products of uniform size, manufacturers control factors contributing to shrinkage. Because of normal variations in raw materials and temperature variations within kilns, absolute uniformity is impossible. Consequently, specifications for brick allow size variations.

Compressive Strength and Absorption

Both compressive strength and absorption are affected by properties of the clay, method of manufacture and degree of firing. For a given clay and method of manufacture, higher compressive strength values and lower absorption values are associated with higher firing temperatures. Although absorption and compressive strength can be controlled by manufacturing and firing methods, these properties depend largely upon the properties of the raw materials.

Rail kilns

In modern brickworks, this is usually done in a continuously fired tunnel kiln, in which the bricks are fired as they move slowly through the kiln on conveyors, rails, or kiln cars, which achieves a more consistent brick product. The bricks often have lime, ash, and organic matter added, which accelerates the burning process.

Bull's Trench Kilns

In India, brick making is typically a manual process. The most common type of brick kiln in use there is the Bull's Trench Kiln (BTK), based on a design developed by British engineer W. Bull in the late 19th century.

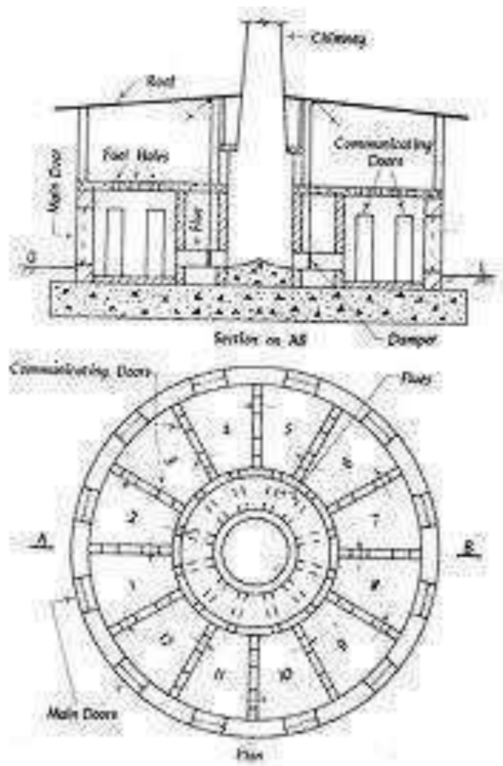


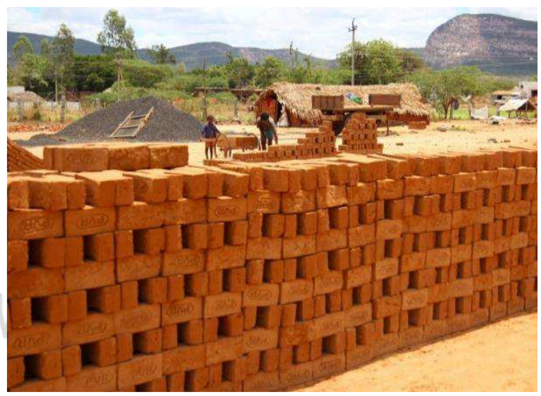
Figure 2: Bull's Trench Kiln

An oval or circular trench is dug, 6–9 meters wide, 2-2.5 meters deep, and 100–150 meters in circumference. A tall exhaust chimney is constructed in the centre. Half or more of the trench is filled with "green" (unfired) bricks which are stacked in an open lattice pattern to allow airflow. The lattice is capped with a roofing layer of finished brick. In operation, new green bricks, along with roofing bricks, are stacked at one end of the brick pile; cooled finished bricks are removed from the other end for transport to their destinations. In the middle, the brick workers create a firing zone by dropping fuel (coal, wood, oil, debris, and so on) through access holes in the roof above the trench. The advantage of the BTK design is a much greater energy efficiency compared with clamp or scove kilns. Sheet metal or boards are used to route the airflow through the brick lattice so that fresh air flows first through the recently burned bricks, heating the air, then through the active burning zone. The air continues through the green brick zone (pre-heating and drying the bricks), and finally out the chimney, where the rising gases create suction which pulls air through the system. The reuse of heated air yields savings in fuel cost.

As with the rail process above, the BTK process is continuous. A half dozen laborers working around the clock can fire approximately 15,000–25,000 bricks a day. Unlike the rail process, in the BTK process the bricks do not move. Instead, the locations at which the bricks are loaded, fired, and unloaded gradually rotate through the trench.

Use

Bricks are used for building, block paving and pavement. Bricks in the metallurgy and glass industries are often used for lining furnaces, in particular refractory bricks such as silica, magnesia, chamotte and neutral (chromo magnesite) refractory bricks. This type of brick must have good thermal shock resistance, refractoriness under load, high melting point, and satisfactory porosity. Engineering bricks are used where strength, low water porosity or acid (flue gas) resistance are needed.



Cement

Cement is the product obtained by burning a well-proportioned mixture of silicious, argillaceous and calcareous materials and crushing the same into a fine powder. In the most general sense of the word, cement is a binder, a substance that sets and hardens independently, and can bind other materials together. The word "cement" traces to the Romans, who used the term opus caementicium to describe masonry resembling modern concrete that was made from crushed rock with burnt lime as binder. The volcanic ash and pulverized brick additives that were added to the burnt lime to obtain a hydraulic binder were later referred to as cementum, cimentum, cäment, and cement.

Cements used in construction can be characterized as being either hydraulic or non-hydraulic. Hydraulic cements (*e.g.,* Portland cement) harden because of hydration, a chemical reaction between the anhydrous cement powder and water. Thus, they can harden underwater or when constantly exposed to wet weather. The chemical reaction results in hydrates that are not very water-soluble and so are quite durable in water. Non-hydraulic cements do not harden underwater; for example, slaked limes harden by reaction with atmospheric carbon dioxide.

The most important uses of cement are as an ingredient in the production of mortar in masonry, and of concrete, a combination of cement and an aggregate to form a strong building material. In 1824, Joseph Aspdin patented a material, which he called Portland cement, because the render made from it was in color similar to the prestigious Portland stone.

Types of cement

1. Ordinary Portland cement (OPC – IS 269): Cement is made by heating limestone (calcium carbonate) with small quantities of other materials (such as clay) to 1450 °C in a kiln, in a process known as calcination, whereby a molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix. The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to make 'Ordinary Portland Cement', the most commonly used type of cement (often referred to as OPC). Portland cement is a basic ingredient of concrete, mortar and most non-specialty grout. The most common use for Portland cement is in the production of concrete. Concrete is a composite material consisting of aggregate (gravel and sand), cement, and water. As a construction material, concrete can be cast in almost any shape desired, and once hardened, can become a structural (load bearing) element. Portland cement may be grey or white.

The Portland cement consists of the following components:

1) Lime 60% to 67%.
2) Silica 17% to 25%.
3) Alumina 03% to 08%.
4) Iron oxide 0.50% to 06%.
5) Magnesia 0.10% to 04%.
6) Soda and Potash 0.20% to 01%.

7) **Sulphur Trioxide 01% to 2.75%.**
8) **Free Lime 0% to 1%.**

Cement is a complicated mixture of chemical compounds. Ordinary Portland cement contains the following compounds:

1) **Tri calcium silicate $(CaO)_3 SiO_2$ denoted by C_3S.**
2) **Di calcium silicate $(CaO)_2 SiO_2$ denoted by C_2S.**
3) **Tri calcium Aluminate $(CaO)_3 Al_2O_3$ denoted by C_3A.**
4) **Tetra calcium Alumino ferrite $(CaO)_4 Al_2O_3 Fe_2O_3$ denoted by C_4AF.**

About 70% to 80% of cement is contributed by C_3S and C_2S which are responsible for the strength of cement. These compounds provide to cement the property to resist the attacks of acids and alkalis and make the cement durable. Tri calcium silicate has the property of hydrating rapidly and is responsible to provide not only early strength but also ultimate strength. Di calcium silicate has the property of hydrating less rapidly and provides the strength after duration of 7 days. Tri calcium Aluminate gets hydrated rapidly and is also responsible to provide early strength but is found to slightly retard the ultimate strength. The compound is susceptible to be attacked by alkalis and salts. Tetra calcium Alumino ferrite appears to be redundant not known to provide any strength and is at times considered as an undesirable compound which gets into cement.

2. **Rapid hardening Portland cement**

This type of cement is manufactured in a manner similar to that of ordinary Portland cement, but it differs in respect of chemical composition, degree of burning and grinding. This contains greater lime content than ordinary Portland cement. This requires a better control of burning the ingredients over a longer period of time. The clinker is ground to a much finer extent than the ordinary Portland cement. The quick rate of gain of strength is due to a higher content of Tri calcium silicate and finer grinding of clinker. For the same water cement ratio, it gains strength in 3 days what the ordinary Portland cement gains in 7 days; and it gains a strength in 7 days what the ordinary cement gains in 28 days. The main advantage in using rapid hardening Portland cement is that the shuttering may be struck considerably earlier, thus saving considerable time and expenses. This cement is particularly satisfactory under conditions of frost. This cement can also be used for road work, so that the road can be open to traffic with least delay.

3. **Low Heat Portland cement**

During the process of setting and hardening of cement, an appreciable rise of temperature occurs. The heat generated in ordinary cement at the end of 3 days may be at the order of 80 calories per gram of cement. In massive constructions like abutments, retaining walls, dams etc. the rate at which the heat can be lost at the surface is lower than at which the heat is initially generated. The temperature rise is an important factor, because the shrinking which

may take place during the cooling processes introduces tensile stresses in concrete. This will therefore affect the water tightness of the structure and may lead to deterioration. In low heat cement the heat involved is less. As per the code the heat of hydration for low heat cement shall not exceed 65 calories per gram of cement at 7 days, 75 calories per gram of cement at 28 days. The strength of this cement is a little lower than that of ordinary cement during the first two or three months, but its strength after this period is practically the same as that of ordinary cement. This cement offers better resistance to chemical deterioration than ordinary Portland cement.

Low heat cement is obtained by increasing Di calcium silicate content, decreasing Tri calcium silicate content and considerably bringing down Tri calcium Aluminate. The lesser rate of gain of strength in the initial period is due to the reduction of Tri calcium silicate and Tri calcium Aluminate. However, in order the rate of gain of strength may be ensured sufficiently, the IS code recommends a specific surface requirement of 3200 cm^2/gm.

4. **Portland Blast Furnace cement (IS 455)**

This is the cement obtained by inter grinding Portland cement clinker with blast furnace slag. The blast furnace slag content shall not exceed 65%. The property of cement is not detracted by the above blending. On the contrary, the blending provides some advantages. The granulated slags possess latent hydraulic properties which are activated to a great extent when the slag is catalyzed and inter ground with Portland cement clinker. This cement can be used at all places where OPC is used. In addition due to low heat evolution it can be used in huge mass concrete structures like dams, retaining walls, foundations and abutment of bridges. This cement has a good Sulphate resistance and is very suitable for use in construction in sea water.

5. **Portland Pozzolana cement (IS 1489)**

This cement is made either by inter grinding Portland clinker and pozzolana or uniform blending Portland cement and fine pozzolana. Inter grinding does not present any difficulty whereas, blending tends to produce a non-uniform product. The IS code has suggested that the latter method may be confined to factories where intimate blending can be guaranteed through mechanical means.

The pozzolana content varies from 10% to 25% by weight of cement. Pozzolanas do not possess cementing value themselves but have the property of combining with lime to produce a stable lime Pozzolana compound which possesses cementing property. Since the free lime which is readily attacked chemically is removed, the pozzolana concretes have a greater resistance to chemical agencies. They can also resist attack by sea water better than OPC since pozzolana cement has a lower heat evolution and is properly used in the construction dams. The pozzolana used in the manufacture of cement in India consists of burnt clay of shale or flyash. The pozzolana must satisfy very strictly certain requirements in order to use it successfully. The following table shows the compressive strengths reached by ordinary Portland cement and Portland pozzolana cement.

Age in days	Compressive strength in N/mm^2.	
	Ordinary Portland cement	Portland Pozzolana cement
1	8	8
3	19	16
7	26	25
14	31	30
15	38	38

6. **White cement:**

White cement has practically the same composition and has the same strength as OPC. To obtain the white color the iron oxide content is reduced considerably (about 1%). The raw materials for this cement are lime stone, and china clay with low iron content. Sometimes cryolite (Sodium alumino fluoride) is added as a flux to aid in burning. The cement is burnt in rotary kiln with coal as fuel. This cement is used as a base for colored cement. It is used for interior and exterior decorative works, facing works, flooring works, ornamental concrete products, paths of garden, swimming pools etc.

7. **Colored cement:**

Colored cement is obtained by adding 5% to 10% of ground pigments to OPC. The following table gives the pigments generally used to get different colors.

Desired color	Pigment used
Green	Chromium oxide or greenish blue ultra-marine
Blue	Ultra marine
Blue black	Carbon black
Black	Black oxide of Manganese
Red	Red oxide of iron.

8. **Sulphate resisting cement:**

This cement is similar to OPC, but in this case it contains greater proportion of Tri calcium silicate and Di calcium silicate and a low content of Tri calcium Aluminate and tetra calcium Alumino ferrite. The chemical combination of Tri calcium Aluminate and tetra calcium Alumino ferrite renders the cement resistant to Sulphate. This type of cement is particularly useful in the airid western regions of India where the water deposits a large amount of sulphates in the soil.

9. Hydrophobic cement:

This is special type cement manufactured by the Associated Cement Company (ACC) which is claimed to have the property of repelling water. Hence the cement stored or transported does not spoiled even during the monsoons. This cement is made by adding water repellant chemicals to ordinary Portland clinkers in the process of grinding. The chemicals added form a molecular coating over every grain of cement and thus prevent any absorption of moisture from air by the cement. In concreting process, in the mixer, the coating gets removed by abrasion.

10. Oil well cement:

After the oil well is dug, it is necessary to fill the clearance between the steel lining and the wall of the well. It is necessary to grout the porous strata so that the wall of the well is prevented from collapse. It is also necessary to keep the ground waters out of the shaft of the well. Oil wells are dug to great depths (1000 m to 5000 m) and at high temperatures. Thus in such conditions the cement used for sealing the oil wells be in such a state, the slurry if pumped into the well casing will remain in the fluid state for a few hours before it can harden. For such a condition ACC have manufactured the oil well cement which is designed to be best suited for sealing the deep oil wells at temperature not exceeding 100 °C.

11. Air entrant cement:

In this case indigenously air entraining agents like glues, resins, sodium salts etc. are added while grinding the clinker. This cement provides greater workability of concrete at lesser water cement ratio. This cement increases the frost resisting capacity of concrete.

Physical requirements for cement (IS 269, 455, 1489)

The following table gives the physical requirements for cement.

Type of cement	Ordinary Portland cement	Rapid hardening PC	Low heat PC	Blast furnace slag cement	Portland pozzolana cement
Fineness-Residue by weight on 90µ IS sieve minimum specific surface cm^2/gm	≤ 10% 2250	≤ 5% 3250	--- 3200	≤ 10% 2250	≤ 5% 3000
Soundness expansion (Le Chatelier)	≤ 10 mm	≤ 10 mm	≤ 10 mm	≤ 10 mm	≤ 10 mm
Setting time Initial Final	≤ 30 min ≤ 600 min	≤ 30 min ≤ 600 min	≤ 60 min ≤ 600 min	≤ 30 min ≤ 600 min	≤ 30 min ≤ 600 min

Minimum compressive strength (N/mm^2) 1 day 3 days 7 days 14 days 28 days	 --- 16 22 --- ---	 16 28 --- --- ---	 --- 10 16 --- 35	 --- 16 22 --- ---	 --- --- 18 25 ---
			Heat of hydration not to exceed 65cal/gm at 7 days and 75cal/gm at 28 days		Average drying shrinkage of mortar is not to exceed 0.15%.

Chemical requirements for cement (IS 269, 455, 1489)

The following table gives the physical requirements for cement.

Type of cement	Ordinary and rapid hardening Portland cement	Low heat PC	Blast furnace slag cement	Portland pozzolana cement
	Maximum	Permissible value		
Insoluble residue	15%	15%	1.5%	x+{1.5(100-x)/100} x=declared percentage of pozzolana in the cement.
Magnesia (MgO)	6%	6%	8%	5%
Sulphor as SO_3	2.75%	2.75%	3%	2.75%
Sulphor as sulphide	--	--	1.5%	--
Oxide of Manganese (Mn_2O_3)	--	--	2%	--
Ignition loss	4%	4%	4%	5%

Role of various ingredients of cement

The various ingredients in cement have their characteristic functions.

Silica provides strength to cement. Excess silica may enhance the strength but increases the setting time.
Lime also provides strength to cement. Excess of lime is resulting in objectionable expansion. Insufficient lime reduces the strength and decreases the setting time.
Alumina makes the cement quick setting. It brings down the clinking temperature acting as a flux. Excess of this ingredient lowers the strength.
Iron oxide provides colour to the cement. This also imparts strength and hardness to the cement.
Magnesia when present in small extent provides hardness and colour. Excess of this ingredient seriously affect the soundness of cement.
Alkalies in excess are disadvantageous as they may cause alkali aggregate reaction, efflorescence and staining of concrete and brickwork. Generally alkalies present in the raw materials get removed by the flue gases in the burning process.

Harmful ingredients in cement:

i. Excess of Alumina reduces the strength.
ii. Magnesia content should not exceed 8%. This will affect soundness of cement.
iii. Excess of lime produces objectionable expansion leading to disintegration.
iv. Excess of alkalies produces alkali aggregate reaction, efflorescence.

Manufacturing of cement:
The three distinct operations involved in the manufacture of cement are:\

(i) Mixing of raw materials.
(ii) Burning.
(iii) Grinding.

Mixing of raw materials: The raw materials of cement are lime stone and clay are mixed in dry condition or wet condition. Accordingly the process of mixing is called dry process or wet process.
Dry process: This is an outdated process. In this process lime stone and clay are broken into pieces of nearly 25 mm size by crushers. An air draft is passed over the crushed materials. Now these are ground to a fine powder in the grinding mills. Each ingredient is separately stored in separate hoppers.
The powdered materials are now mixed in the required proportion. The raw mix so obtained is stored in the storage tank. From the storage tank the raw mix is passed on to the granulator consisting to a sloping rotating drum. Water about 15% is sprinkled and powdered material to become nodules. These are now burnt in the kiln.
Wet process: The raw materials viz. limestone and clay are taken in the right proportion and crushed to a fine powder in jaw crushers. The crushed materials in the proper proportionare conveyed into the ball mill. Water is added and the mixture is ground to form a slurry. The slurry is conveyed into the correcting silos in which the chemical composition of the slurry is examined. Now the slurry is passed on to the rotary kiln.
Burning: The slurry is burnt in a rotary kiln. The rotary kiln consists of a long cylinder 50 m to 100 m long supported on roller bearings provided over masonry pillars at intervals of 15 m to

20 m. The inner surface of the cylinder is lined with fire bricks. The cylinder is placed at a slope of 1 in 30. The cylinder rotates at1 revolution per minute. The heating is done by injecting pulverized coal using hot air blast from the lower end, while the slurry from hopper is supplied at the upper end. The slurry soon changes into nodules which roll down the kiln reaching hotter zones. As the nodules are heated to a very high temperature (1600°C), they are changed into hard clinkers. The white hot clinkers discharged out of the kiln are cooled in coolers by passing cold air.

Grinding: The clinkers are now ground in the ball mills and finally in the Tube mills. About 2% to 4% of gypsum is added to control the setting time of cement. After completion of grinding the cement is sieved and packed in bags.

Testing of Portland cement:

Field tests for cement:

When cement is received at a construction site, a few field tests can be made to ascertain its quality. They are

1) Cement should be uniform in colour. Portland cement should be greenish grey in colour.
2) When a small sample of cement is rubbed between fingers, it should feel smooth.
3) The cement mass must feel cool when touched by hand.
4) There should be no lumps in the cement. Lumps indicate cement that has already set.

Figure 4: The cement (left) and clinker (right)

Laboratory tests for cement: To ascertain the qualities of cement correctly, a number of tests are performed in the laboratory as suggested by IS codes. They are;

1) Sampling: A sample meant for testing shall be drawn from at least 12 different bags or barrels or containers or from 12 different positions in heap if the cement is loose. The final sample shall weigh at least 5 kg. The sample is placed in a dry metal can closed with tight cover to exclude external air and moisture.
2) Chemical Composition: The IS specified tests are;
    i. *Ignition loss*: One gram of sample is heated in a porcelain crucible continuously for a period of 1 hour at 900°C to 1000°C. If platinum crucible is used, it is enough to heat the sample for 15 minutes. After heating the sample, it is cooled and again weighed. The percentage loss of weight should not exceed 4%.
    ii. *Insoluble residue*: one gram of cement is weighed and put in a 40 cc of water and stirred. Then 10 cc of hydrochloric acid of specific gravity 1.18 should be

added and stirred. Any lumps present shall be carefully broken and the mixture is boiled for 10 minutes. The mixture, now, shall be filtered. Using hot water the container should be rinsed 5times and the filter should be washed 10 times. Now the residue left on the filter should be washed in a beaker containing 30 cc of hot distilled water. This is boiled for a duration of 10 minutes with 30 cc of sodium carbonate solution of twice the normal strength. The solution obtained is again filtered through the same filter paper. The filter paper is now washed 5 times with water. Now it is washed with hydrochloric acid solution of twice the normal strength and then with water so that it is free from chlorides. The filter paper is dried, then ignited and weighed. The insoluble residue shall not exceed 1.5%.

iii. *Lime and alumina*: The ratio of percentage alumina to the percentage of iron oxide shall not be less than 0.66. The percentage of lime to silica. Alumina and iron oxide when determined by the formula in percentage

$$(CaO - 0.7SO_2) / (2.8SiO_2 + 1.2\ Al_2O_3 + 0.65Fe_2O_3)$$

Should not exceed 1.02 nor be less than 0.65.

iv. *Magnesia*: Free magnesia shall not be present at more than 5 percent.

v. *Sulphur*: This shall not exceed 2.75%.

3) Fineness: Sieve test: 100 grams of cement is weighed accurately and placed on IS sieve No. 9. Any air set lumps are broken using fingers. Now gentle sieving is done continuously for fifteen minutes. The residue left is weighed. This shall not exceed 10% by weight of the sample.

Air permeability test: In this test specific surface in square cm per gram of cement is measured. The permissible values as given below:

Sl. No.	Type of cement	Specific surface area requirement in cm^2/gm
1	Ordinary Portland cement	2250
2	Portland blast furnace slag cement	2250
3	Rapid hardening Portland cement	3250
4	Low heat Portland cement	3200
5	Portland pozzolana cement	3000

Figure 3: Vicat Apparatus with plunger and needle.

4) **Consistency: This is a test conducted to estimate the quantity of water to be mixed with cement to form a paste of normal consistency for use in other tests. 300 grams of cement is mixed with 25% of water and a paste is prepared. The paste obtained should be filled in the mould of the Vicat's apparatus. The interval of time between the instant of adding water to the dry cement and the instant of common cement of filling the mould is called the time of gauging. The time of gauging must be 4±0.25 minutes.**
   The plunger, of diameter 10 mm is lowered gently on the paste in the mould. Now the settlement of plunger is noted. If the settlement is between 5 and 7 mm from the bottom of the mould, the amount of water added is correct. If this condition is not satisfied, the test must be repeated again by changing the percentage of water until the stipulated extent of penetration of the plunger is reached.

5) **Test for setting time: The object of this test is to make a distinction between normal setting and quick setting types of cement and also to detect deterioration due to storage.**
   Weigh 300 grams of cement and add the percentage of water required to have normal consistency. The paste obtained is filled in the mould. In the Vicat's apparatus, attach the needle of square section i.e. 1 mm x 1 mm to the Vicat's rod. Lower the system so that the needle just touches the surface of the paste and gently release. Find out if the needle pierces into the paste fully. If it does, again observe whether the needle pierces fully into the paste. This is repeated till the needle does not pierce into the paste completely. Now the interval of time between this instant and the instant at which water was added to the cement is called the initial setting time.

Now change the needle to the third one which has a projecting sharp point in the centre with an annular attachment. Now release the needle as before on the same paste. The needle as well as the attachment will make their impressions on the paste. Repeat this process till only the needle makes the impression but not the attachment. The interval of time between this instant and the instant at which water was added to the cement is called the final setting time.

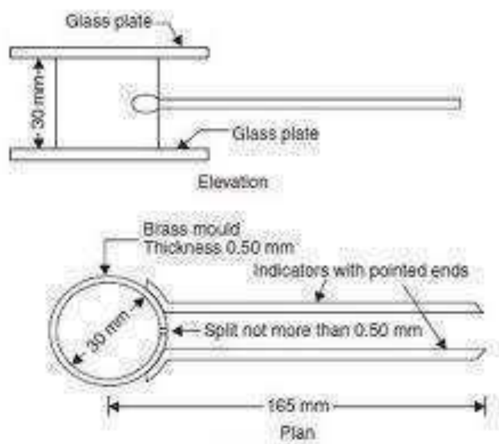


Figure 4: Le Chatelier apparatus

6) **Test for Soundness: If excess of lime is present during the manufacture of cement, it is liable to remain uncombined and over burnt in the kiln. Such over burnt lime particles slake at very slow rate and expand. If after setting of cement is completed, the over burnt lime expand, it will lead to the disruption of cement mass. The object of the soundness test is to detect the presence of over-burnt uncombined lime. The cement is tested by using Le Chatelier apparatus as shown in Figure 4.**
This apparatus consists of a small split cylinder of brass 0.5 mm thick. This forms a mould 30 mm internal diameter and 30 mm in height. On each side of the split an indicator is attached having pointed end. The distance between the centre of cylinder and the pointed end of each indicator is 165 mm. The mould is placed on a glass plate and is then filled with cement paste. The cement paste should be formed by gauging with 0.78 of the water required to give a paste of normal consistency. After filling the mould, another glass plate is placed on the top and is immediately submerged in water at a temperature of 27°C to 32°C for 24 hours. After this interval of time, the distance between the ends of the pointers is measured. Now the mould is again submerged and brought to boiling point in 25 to 30 minutes and boiled for duration of one hour. Then the mould is taken out of water and the distance between the ends of the pointers is measured. The difference between this measurement and the original measurement should not exceed 10 mm.

7) **Tensile strength: The tensile strength of cement is estimated by determining the tensile strength of cement sand mortar. For conducting the test briquettes of standard size are prepared. The briquettes are 2.54 cm thick and will have a minimum sectional area 2.54 cm x 2.54 cm. The cement mortar is made by mixing one part of cement to**

three parts of Leighton Buzzard sand. The percentage of water to be used for making the mix is 0.2Pa + 2.5 where Pa is the percentage of water for normal consistency of cement. At least 12 briquettes are to be made. After the mould is made a small heap of paste is placed on the top and is lightly beaten with the standard spatula until on the surface water appears. Now the same is repeated on the other face of the briquette. The briquettes are kept in a damp tank, the relative humidity in the tank being 90%. Now six briquettes are tested after 3 days and the other six after 7 days in a testing machine to destruction. The load must be increased at the rate of 3.5 N/mm^2 of section for each minute.

Stress at failure = Load at failure/Minimum sectional area of briquette.

The following are the requirements for good cement.

Sl. No.	Type of cement	Tensile strength in N/mm^2.	
1	Portland cement	3 days Not less than 2.0	7 days Not less than 2.5
2	Rapid hardening cement	1 days Not less than 2.0	3 days Not less than 3.0

8) Compressive strength: This is a test to study the quality of cement about compressive strength. The compressive strength is studied by determining the compressive strength of cement sand mortar.

180 grams of cement should be mixed with 3 times its weight of standard Leighton Buzzard sand for one minute and then mixed with water whose percentage is given by

$P = (Pa/4) + 3.5$

where Pa is the percentage of water for normal consistency. The mixing should be done for 3 minutes. And in this duration the mixture must reach a uniform color. The mould shall be of 7.06 cm side. The mortar is filled in the mould and the compaction is done by using a standard vibration machine for 2 minutes. After this the cubes are kept at a temperature for about 27°C in a chamber for 24 hours in which the relative humidity is 90%. After this the cubes are removed from the moulds and are kept under fresh water till they are tested.

3 cubes are tested at the end of three days and 3 more may be tested at the end of 7 days. The strength requirements are given below.

After 3 days: 11.5 N/mm^2 for ordinary cement.

21.0 N/mm^2 for Rapid hardening cement.

After 7 days: 17.5 N/mm^2 for ordinary cement.

