MATERIALS FOR MAKING CONCRETE
CEMENT

CEMENT

Presentations by

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CEMENT

- Adhesive and Cohesive materials, which are capable of bonding together particles of Solid matter into compact durable mass
- For Civil Engg, they are restricted to Calcareous Cements containing compounds of Lime as their chief constituent, its primary function being to bind the fine and coarse aggregate particles together

Brief History

- Egyptians. Pyramids. Lime and Gypsum as cementing material
- Romans. Pantheon. Concrete dome of 43.43m span.
  - Lime stone burnt in Kilns
  - Mixture of Lime and Puzzolanic mtrls (volcanic ash, tuff)
- Portland Cement, 1824. Formed by heating of Lime stone and finely divided clay in a furnace to a temperature high enough to drive off the carbonic acid gas

Portland Cement

- A product obtained by finely pulverizing 'Clinker' produced by calcining to incipient fusion, a intimate and properly proportioned mixture of 'Argillaceous and Calcareous' material.
- Argillaceous material. 'Silicates of Al2O3' in the form of
  - Clay
  - Shale
  - Slate
  - Blast Furnace Slag
- Calcareous material.
  - Cement Rock
  - Lime Stone
  - Marine Shell
  - Chalc

Portland Cement: Physical Requirements

Physical Requirement	*Method of testing*	*Grade*		
		33	*43*	*53*
1. Fineness (Sp. surface in m2/kg)	Blaine's air permissibility	225	225	225
2. Soundness	Le Chatelier apparatus	10mm	10mm	10mm
	Autoclave	0.8%	0.8%	0.8%
3. Setting time	Vicat apparatus			
Initial (min)		30	30	30
Final (max)		600	600	600
4. Compressive strength (MPa) not less than				
• 72 ± 1 hr		16	23	27
• 168 ± 2 hr		22	33	37
• 672 ± 4 hr		33	43	53

Chemical composn of Portland Cement

Ser No	Oxide	Function	Composition (Percent)
1	Ca O	Str and Soundness. Defi reduces Str and Setting time	60- 65
2	Si O2	Str. Excess causes slow setting	17 - 25
3	Al2 O3	Quick setting. If in excess, lowers the strength	3 - 8
4	Fe 2 O3	Color, Fusion of different ingradients	0.5- 6
5	Mg O	Color and Hardness. If in excess, Cracks in Mortar and Concrete and Unsoundness	0.5 - 4
6	Na2 O + K2 O, Ti O2, P2 O5	Residues, if in excess, efflorescence and cracking	0.1 – 0.2
7	SO3	Makes Cement Sound	1 - 2

Composn of Cement Clinker

The principal mineral compounds in Portland cement	*Formula*	*Name*	*Symbol*
1. Tricalcium silicate	3CaOSiO2	Alite	C3S
2. Dicalcium silicate	2CaOSiO2	Belite	C2S
3. Tricalcium aluminate	3CaOAl2O3	Celite	C3A
4. Tetracalcium alumino ferrite	4CaOAl2O3Fe2O3	Felite	C4AF

ALITE, C3S

1. Alite, C3S

- **Best cementing material** and is well burnt cement**.**
- 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.
- Heat of hydration is **500 J/g**.

BELITE, C2S

2. *Belite, C2S*

- 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
  - 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***.

CELITE, C3A

3. ***Celite, C3A***

- 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.
- C3A responsible for the ***initial set***, high heat of hydration and has greater tendency to volume changes causing cracking.
- Raising the C3A content
  - reduces the setting time
  - weakens resistance to sulphate attack
  - lowers the ultimate strength, heat of hydration and contraction during air hardening.
- The heat of hydration of ***865 J/g***

FELITE, C4AF

4. Felite, C4AF

- 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 C4AF content reduces the strength slightly.
- Heat of hydration is ***420 J/g***.

COMPUTING COMPOUND COMPOSN

- From PDF File pp 148

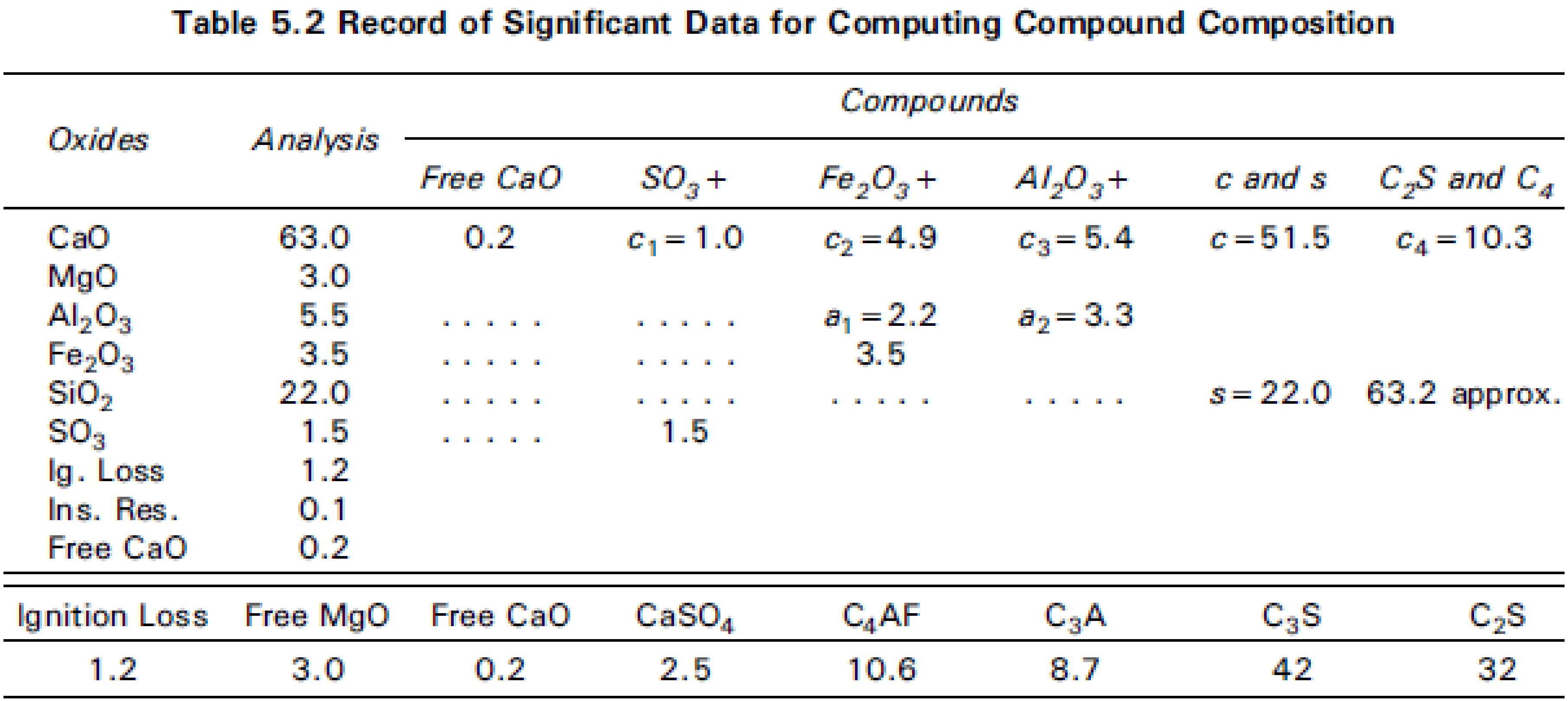

Table 5.2 Record of Significant Data for Computing Compound Composition

Oxides	*Analysis*	*Compounds*					
		Free CaO	*SO_3 +*	*Fe_2O_3 +*	*Al_2O_3 +*	*c and s*	*C_2S and C_4*
CaO	63.0	0.2	$c_1 = 1.0$	$c_2 = 4.9$	$c_3 = 5.4$	$c = 51.5$	$c_4 = 10.3$
MgO	3.0						
Al_2O_3	5.5	. . . . . .	. . . . . .	$a_1 = 2.2$	$a_2 = 3.3$		
Fe_2O_3	3.5	. . . . . .	. . . . . .	3.5			
SiO_2	22.0	. . . . . .	. . . . . .	. . . . . .	. . . . . .	$s = 22.0$	63.2 approx.
SO_3	1.5	. . . . . .	1.5				
Ig. Loss	1.2						
Ins. Res.	0.1						
Free CaO	0.2						

Ignition Loss	Free MgO	Free CaO	$CaSO_4$	C_4AF	C_3A	C_3S	C_2S
1.2	3.0	0.2	2.5	10.6	8.7	42	32

HYDRATION OF CEMENT

- The chemical reaction between cement and water is known as *hydration of cement.*
- *The **reaction*** takes place between the active components of cement (C4AF, C3A, C3S and C2S) and water.
- The **factors** responsible for the physical properties of concrete are
  - the extent of ***hydration*** of cement and
  - the ***resultant microstructure*** of the hydrated cement.

HYDRATION OF CEMENT

- When the cement comes in contact with water,
  - the hydration products start depositing on the outer periphery of the nucleus of hydrated cement. This reaction proceeds slowly for 2-5 hours and is called *induction or dormant period.*
  - *As hydration proceeds, the deposit of* hydration products on the original cement grain makes the diffusion of water to unhydrated nucleus more and more difficult, consequently ***reducing the rate of hydration with time***.
  - At any stage of hydration, the cement paste consists of gel (a fine-grained product of hydration having large surface area collectively), the unreacted cement, calcium hydroxide, water and some minor compounds.

HYDRATION OF CEMENT

- The crystals of the various resulting compounds gradually fill the space originally occupied by water, resulting in the stiffening of the mass and subsequent development of the strength.
- The reactions of the compounds and their products are as follows:
  - C3S + H2O ------→ C–S–H* + Ca (OH)2
  - C2S + H2O ------→ C–S–H + Ca (OH)2
  - C3A + H2O ------→ C3AH6
  - C3A + H2O + CaSO4 ----------→ CA C S* H12 .... Calcium sulpho-aluminate
  - C4AF + H2O ---------→ C3AH6 + CFH

H* is H2O
S* is SO3

HYDRATION OF CEMENT

- The product C–S–H gel represents the ‘Calcium Silicate Hydrate’ also known as *tobermorite gel* which is the gel structure.
- The hydrated crystals are extremely small, fibrous, platey or tubular in shape varying from less than 2 mm to 10 mm or more.
- The C–S–H phase makes up 50–60% of the volume of solids in a completely hydrated Portland cement paste and is, therefore, the most important in determining the properties of the paste.
- The ***surface area*** for C–S–H is of the order of 100–700 m2/g; and the solid to solid distance is about 18 Å.

HYDRATION OF CEMENT

- The $Ca(OH)_2$ liberated during the silicate phase crystallizes in the available free space. The calcium hydroxide crystals also known as ‘portlandite’ consists of 20-25% volume of the solids in the hydrated paste. These have lower surface area, and, their strength contributing potential is limited.
- The ‘Gel’ must be ‘saturated with water’, if hydration is to continue.
- The ‘calcium hydroxide’ crystals formed in the process dissolve in water providing hydroxyl (OH–) ions, which are important for the protection of reinforcement in concrete.
- As ‘Hydration’ proceeds, the two crystal types become more heavily interlocked increasing the strength, though the main cementing action is provided by the ‘Gel’ which occupies two-thirds of the total mass of hydrate

RATE OF HYDRATION

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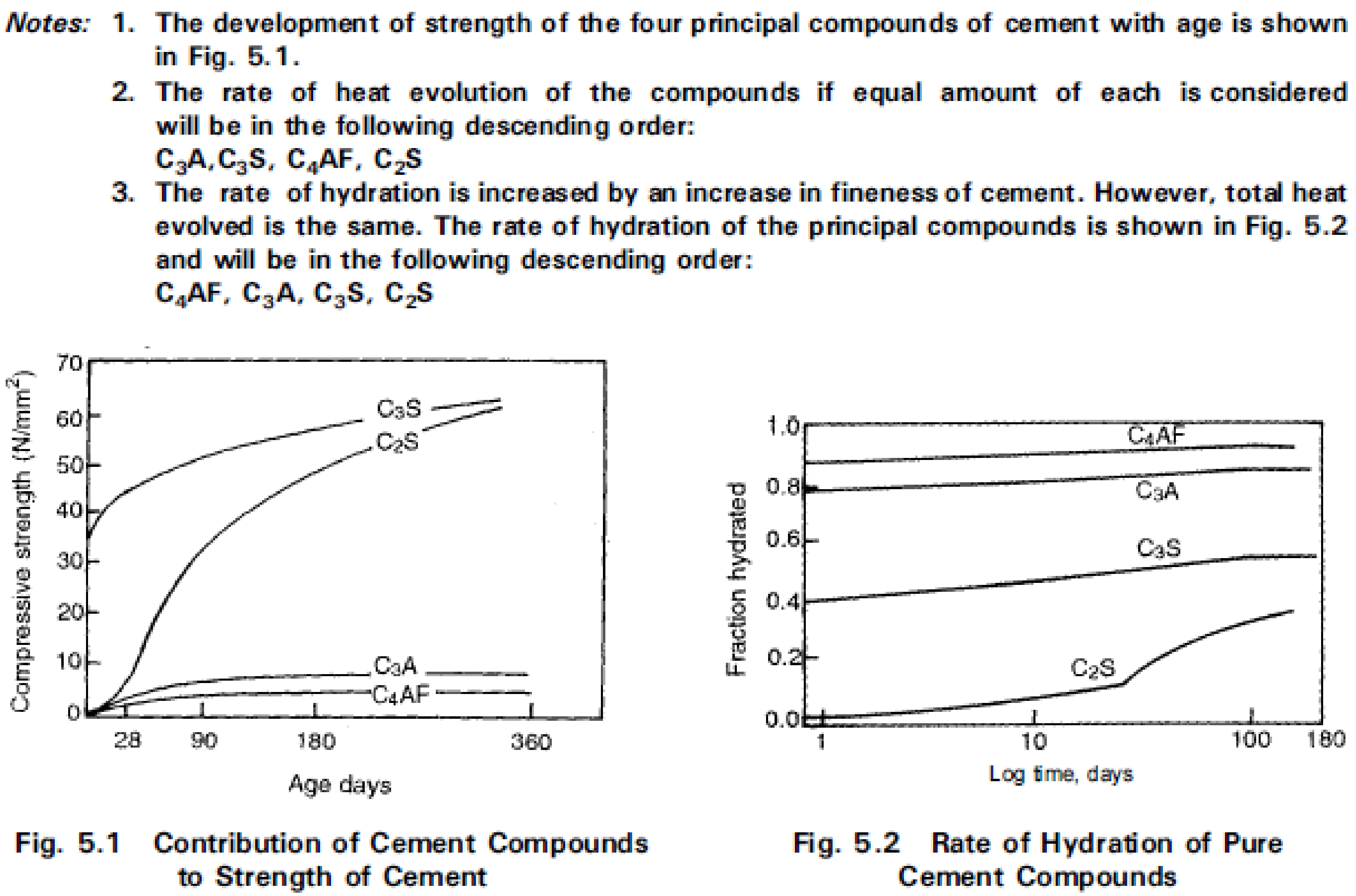

Notes:

1. The development of strength of the four principal compounds of cement with age is shown in Fig. 5.1.
2. The rate of heat evolution of the compounds if equal amount of each is considered will be in the following descending order:
   C_3A, C_3S, C_4AF, C_2S
3. The rate of hydration is increased by an increase in fineness of cement. However, total heat evolved is the same. The rate of hydration of the principal compounds is shown in Fig. 5.2 and will be in the following descending order:
   C_4AF, C_3A, C_3S, C_2S

Fig. 5.1 Contribution of Cement Compounds to Strength of Cement

Fig. 5.2 Rate of Hydration of Pure Cement Compounds

WATER REQMT FOR HYDRATION

- **BOUND WATER**. About an average ***23*** per cent (24 per cent C3S, 21 per cent C2S) of water by weight of cement is required for complete hydration of Portland cement. This water combines chemically with the cement compounds and is known as ***bound water***.
- **GEL WATER**. *Some quantity of water, about* **15** *per cent* by weight of cement, is required to fill the cement gel pores and is known as ***gel water***.
- Therefore, a ***total of 38*** per cent of water by weight of cement is required to complete the chemical reaction.
- The general belief that a water/cement ratio less than 0.38 should not be used in concrete because for the process of hydration, the gel pores should saturated – is not valid. This is because as even if excess water is present, complete hydration of cement never takes place due to deposition of hydration products.
- As a matter of fact w/c ratio less than 0.38 is very common for high strength concretes. If excess water is present, it will lead to capillary cavities.

MANUFACTURING OF CEMENT

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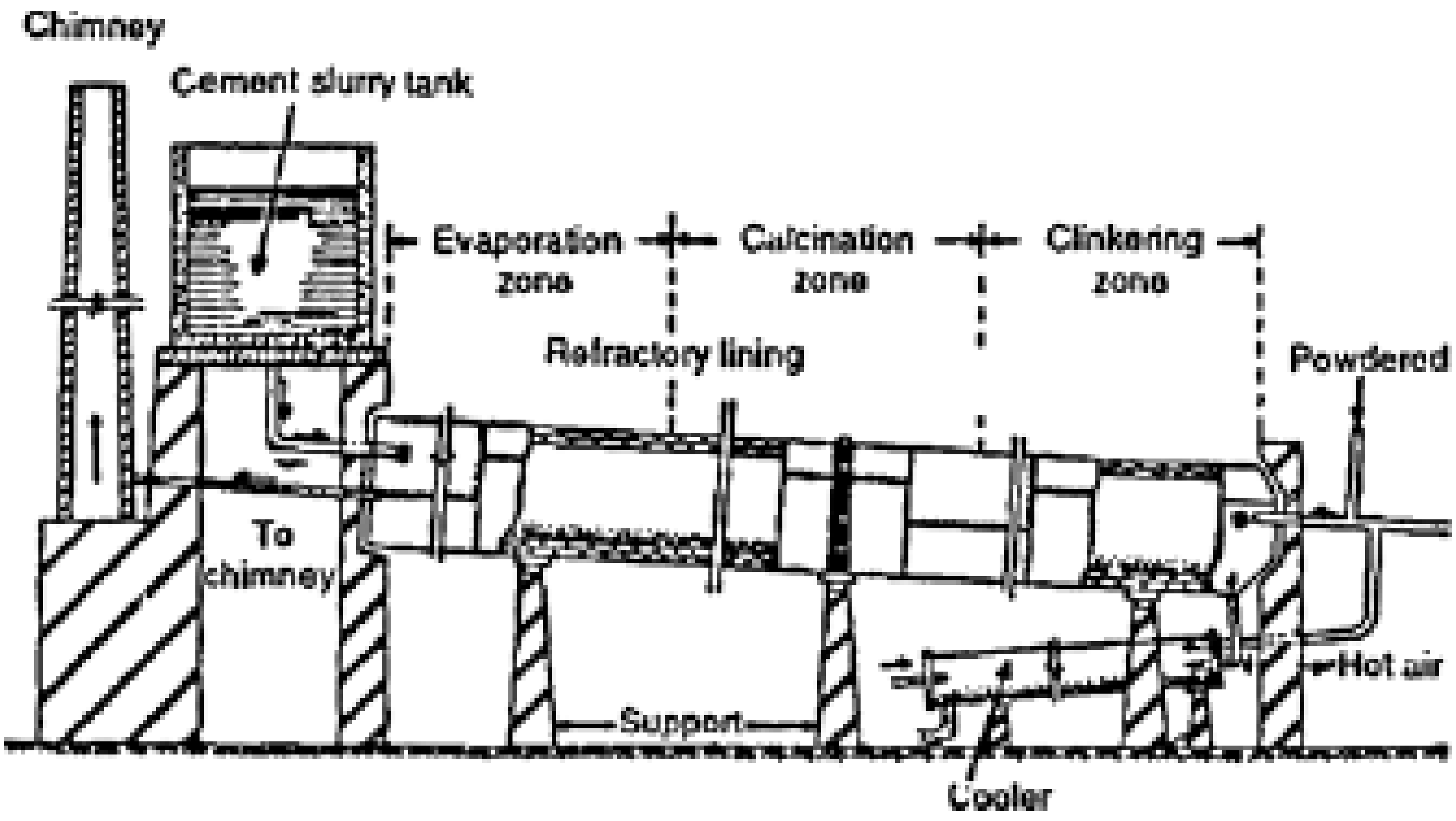


Fig. 5.3 Rotary Kiln

TUBE MILL

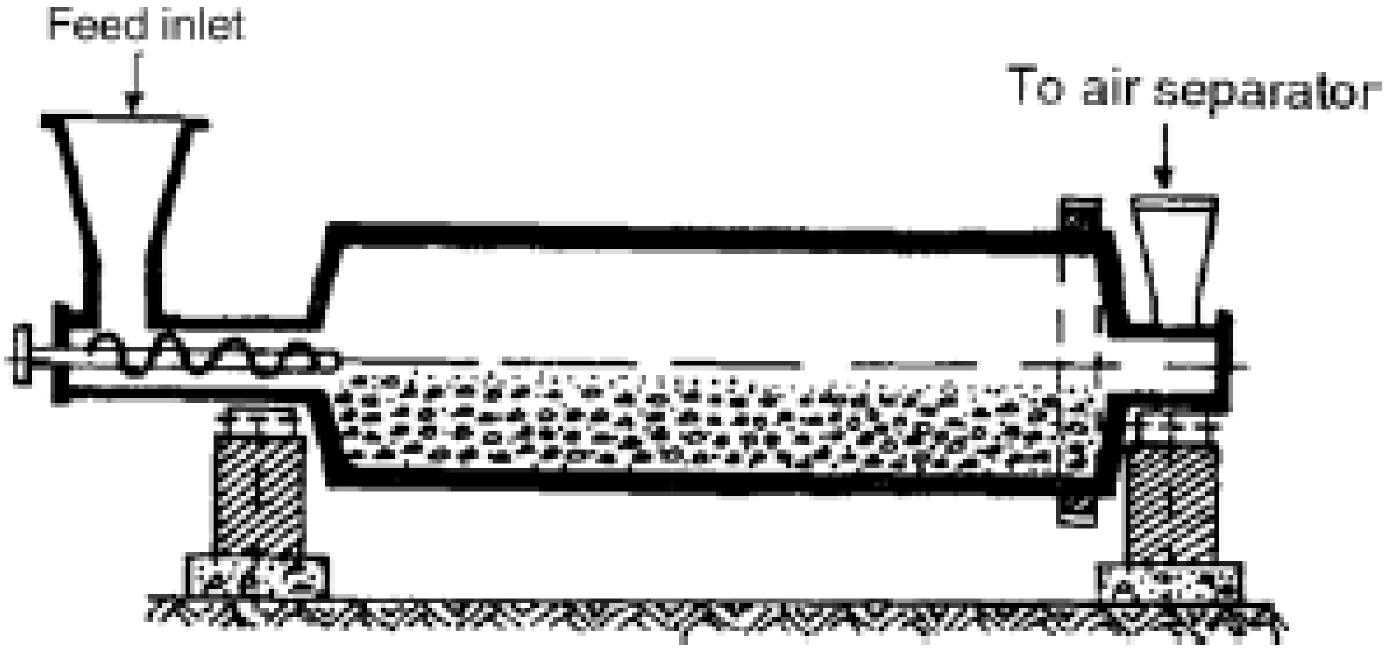


Fig. 5.4

DRY PROCESS

- Dry process is adopted when the raw materials are quite hard.
- The process is slow and the product is costly.

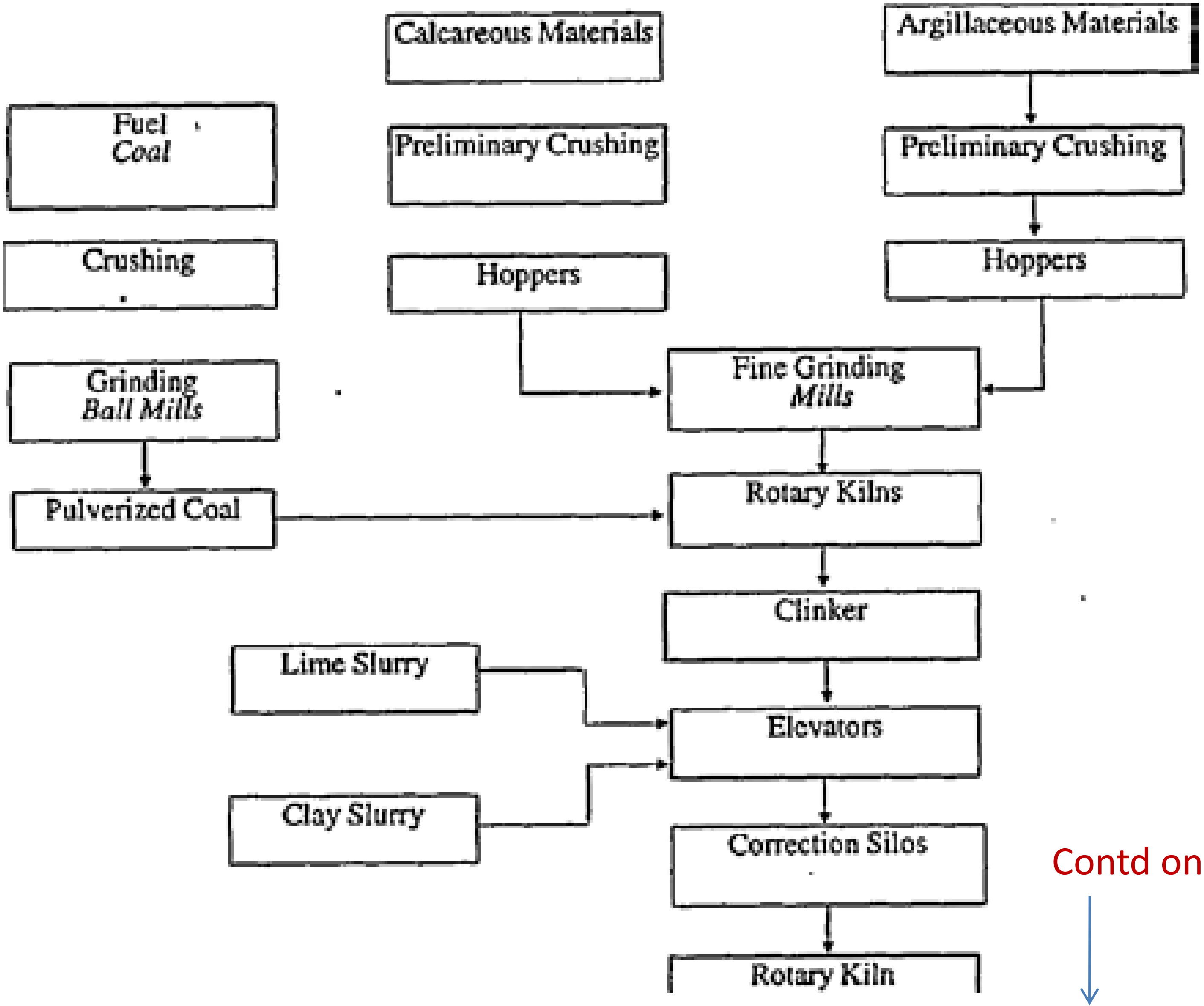
PROCESS

- Limestone and clay are ground to fine powder separately and are mixed. Water is added to make a thick paste. The cakes of this paste, which contain about 14 per cent of moisture, are dried and are charged into rotary kiln (Fig. 5.3 pp 152). The product obtained after calcination in rotary kiln is called *clinker.*
- *The clinker is obtained as a* result of incipient fusion and sintering at a temperature of about 1400°-1500°C. Because ferric oxide has lower melting point than the other oxides, it acts as a flux.
- The clinker is cooled rapidly to preserve the meta-stable compounds and their solid solutions, made as the clinker is heated. Clinker is cooled and ground in tube mills (Fig. 5.4, pp 152), where 2-3% of gypsum is added.

DRY PROCESS

- Aeration of cement clinker, which is commonly practiced to slake free lime, also causes an absorption of some moisture and carbon dioxide
- Absorption of moisture tends to decrease the setting where as that of carbon dioxide accelerates setting.
- Generally, cement is stored in bags of 50 kg. A flow diagram of dry process is shown in Fig. 5.5 pp 153.
- The purpose of adding Gypsum is to coat the cement particles by interfering with the process of hydration of the cement particles. This retards the setting of cement

Flow Chart – Dry Process Part 1



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Flow Chart – Dry Process Part 2

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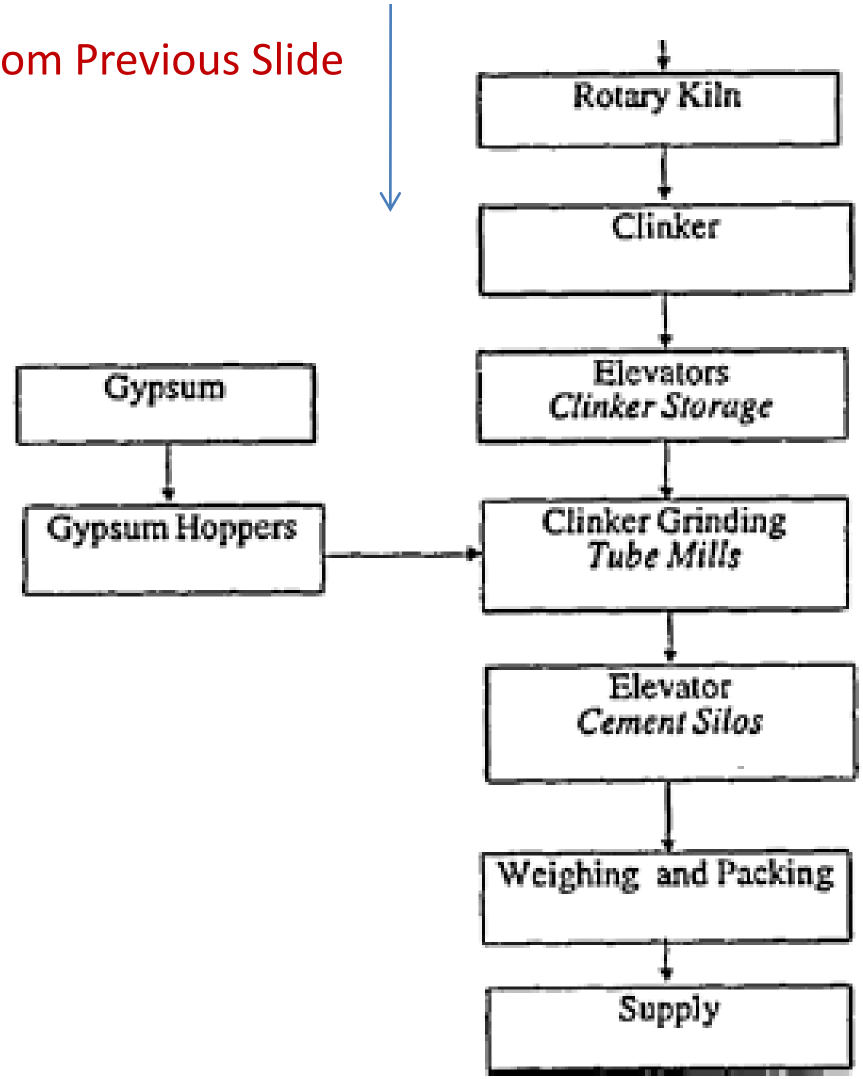


Rotary Kiln

Clinker

Elevators
Clinker Storage

Gypsum

Gypsum Hoppers

Clinker Grinding
Tube Mills

Elevator
Cement Silos

Weighing and Packing

Supply

Fig. 5.5 Flow Diagram of Cement Manufacture—Dry Process

WET PROCESS

- The operations in the wet process of cement manufacture are
  - Mixing
  - burning and
  - grinding.

MIXING

- The crushed raw materials are fed into ball mill (Fig. 5.6 pp 154) and a little water is added. On operating the ball mill, the steel balls in it pulverize the raw materials which form a slurry with water.
- This slurry is passed to silos (storage tanks), where the proportioning of the compounds is adjusted to ensure desired chemical composition.

WET PROCESS

BURNING

- The corrected slurry having about 40 per cent moisture content, is then fed into rotary kiln (Fig. 5.4 pp 152) where it loses moisture and forms into lumps or nodules. These are finally burned at 1500-1600°C. The nodules change to clinker at this temperature.

GRINDING

- Clinker is cooled and then ground in tube mills.
- While grinding the clinker, about 3 per cent gypsum is added. The cement is then stored in silos from where it is supplied. A flow diagram of manufacturing cement by wet process is shown in Fig. 5.7 pp 155.

BALL MILL

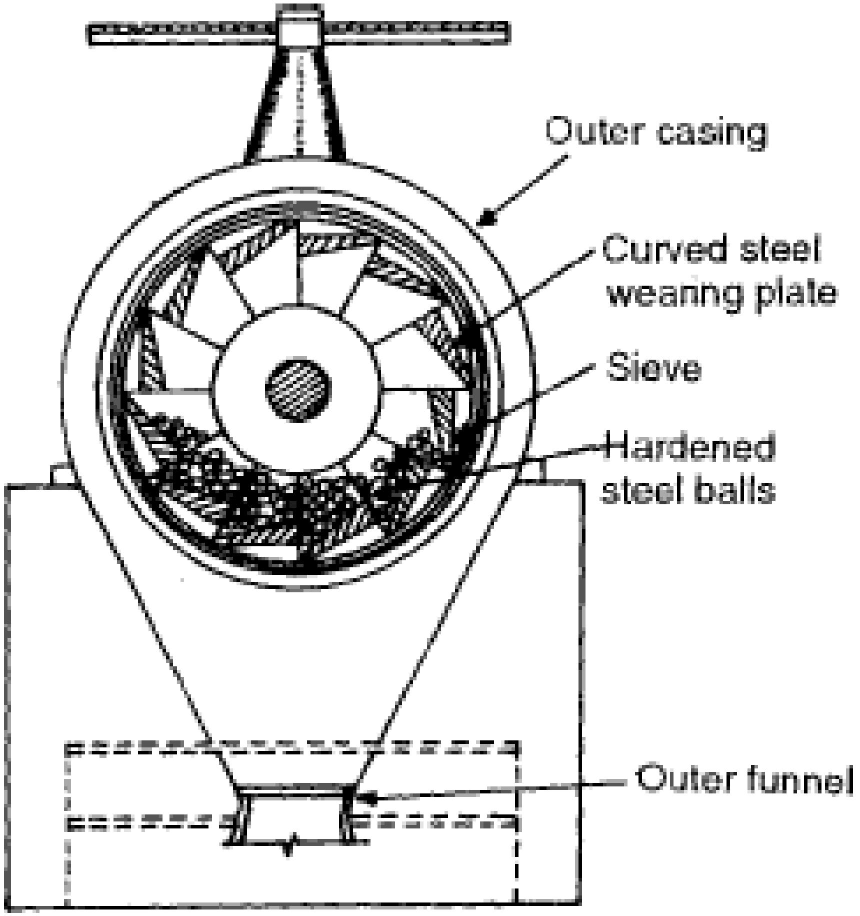
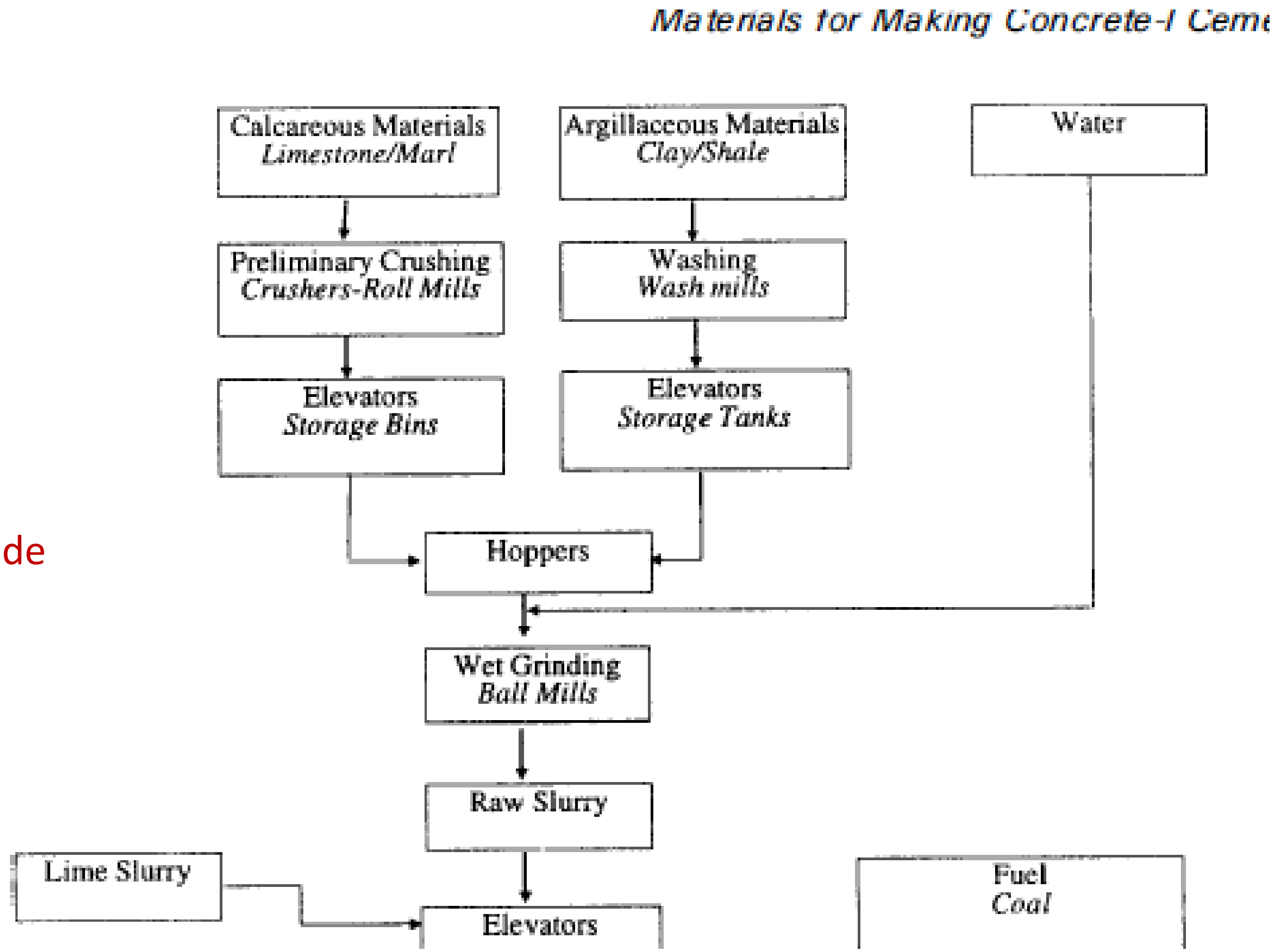


Fig. 5.6 Ball Mill

FLOW CHART WET PROCESS Part 1



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FLOW CHART WET PROCESS Part 2

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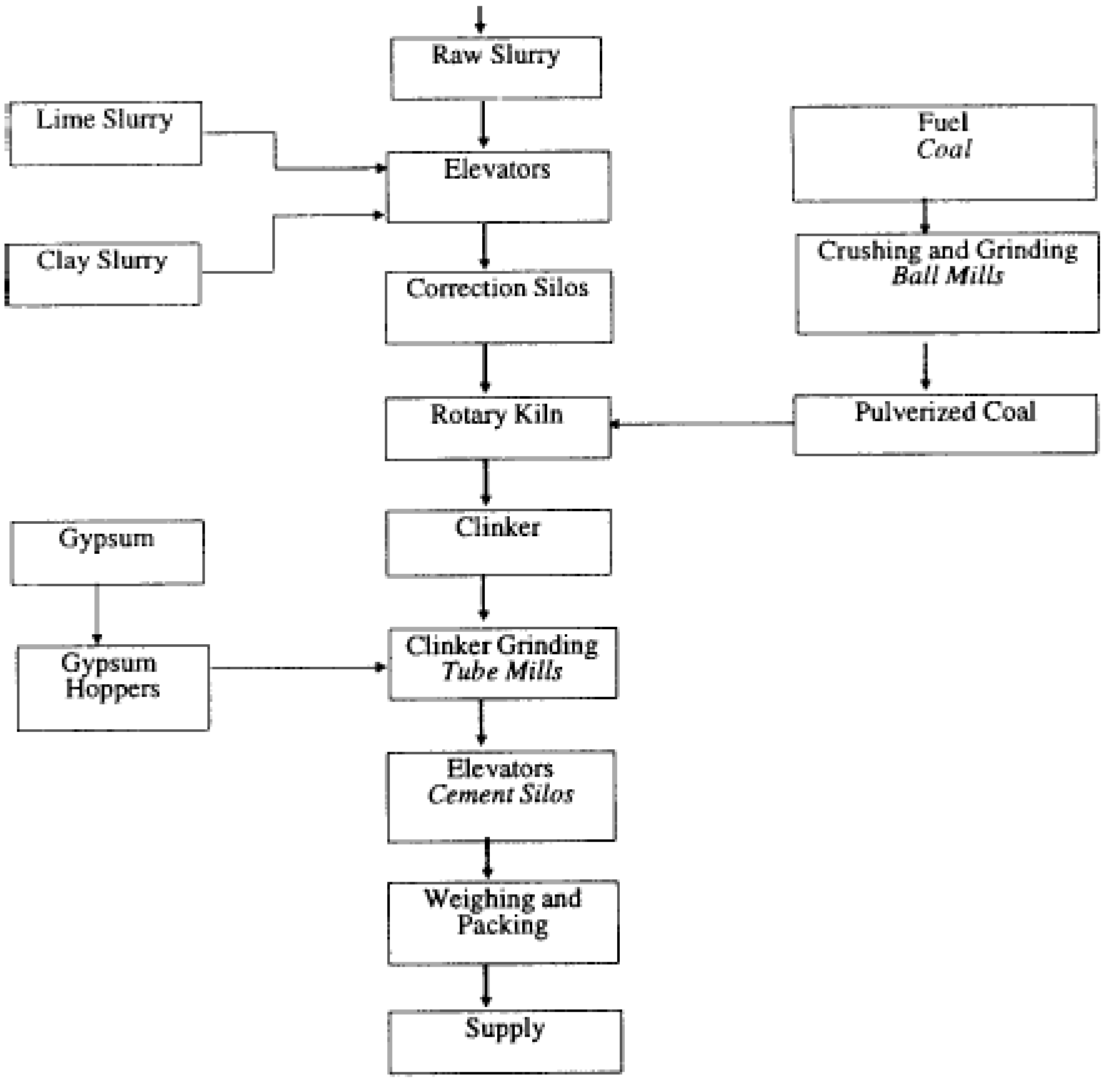

Fig. 5.7 Flow Diagram of Cement Manufacture—Wet Process

COMPARISON OF DRY AND WET PROCESSES

- Advantages of Wet process are
  - low cost of excavating and grinding raw materials
  - accurate control of composition and homogeneity of the slurry
  - economical utilization of fuel, through the elimination of separated drying operations.
- Disadvantages of Wet Process.
  - longer kilns cost more
  - less responsive to a variable clinker demand than the short kilns which can be used in the dry process.

TESTING OF CEMENT

- Main qualifications demanded of Cement
  - Permanency of Structure
  - Str
  - Rate of Setting suitable to the demands of wk
- Imp Physical Tests
  - Soundness or Constancy of Vol
  - Str
  - Time of Set of Activity
  - Fineness

FINENESS TEST

- The degree of ‘fineness’ of cement is the measure of the ‘***mean size***’ of the grains in it.
- Three methods for testing fineness:
  - Sieve method—using 90 micron (9 No.) sieve,
  - Air permeability method— Nurse and Blains method
  - Sedimentation method— Wagner Turbid meter method.
- The ‘last two methods’ measure the ***surface area***, whereas the ‘first’ measures mm ***grain size***.
- Since cement grains are finer than 90 micron, the sieve analysis method does not represent true mean size of cement grains. Also, the tiny cement grains tend to conglomerate into lumps resulting in distortion in the final grain size distribution curves.
- Considering these demerits, fineness is generally expressed in terms of ***‘specific area’***, which is the total surface area of the particles in unit weight of material.

FINENESS TEST: Conditions affecting

- The chemical *'composition'* and the degree of *'calcinations'* influence the hardness of the clinker and consequently the fineness.
- Clinker, high in ***iron or silica***, or, ***Hard-burned*** is hard and difficult to grind.
- ***Time*** of grinding
- Character of the pulverizing ***machinery***.
- Cement becomes finer with age, provided it does not absorb too much moisture.

FINENESS TEST: Importance

- ‘***Finer***’ the cement, more is the *‘strength’* since ‘surface area’ for hydration will be large.
- With increase in fineness, the ‘***early development of strength’*** is enhanced but the ultimate strength is not affected.
- An *increase in the fineness* of the cement increases the cohesiveness of the concrete mix, and thus, *reduces* the amount of water which separates to the top of a lift (‘*bleeding*’), particularly while compacting with vibrators.
- However, if the cement is ground beyond a certain limit, its cementative properties are affected due to the pre-hydration by atmospheric moisture.
- ***‘Finer cement’*** reacts more strongly in *‘alkali reactive aggregate’.*
- Water requirement and Workability will be more, leading to *‘higher Drying Shrinkage’* and *‘Cracking’*.

FINENESS TEST: SIEVE METHOD

- ***100 g*** of cement sample is placed on a ***90 micron*** sieve and continuously sieved for ***15 minutes***. The residue should not exceed the limits specified below:

Type of cement	**Percentage of residue by weight**	**Specific surface (m2/kg) not less than**
1. Ordinary Portland Cement (OPC)	10	225
2. Rapid Hardening Cement (RHC)	5	325
3. Portland Puzzolana Cement (PPC)	5	300

FINENESS TEST: AIR PERMEABILITY METHOD

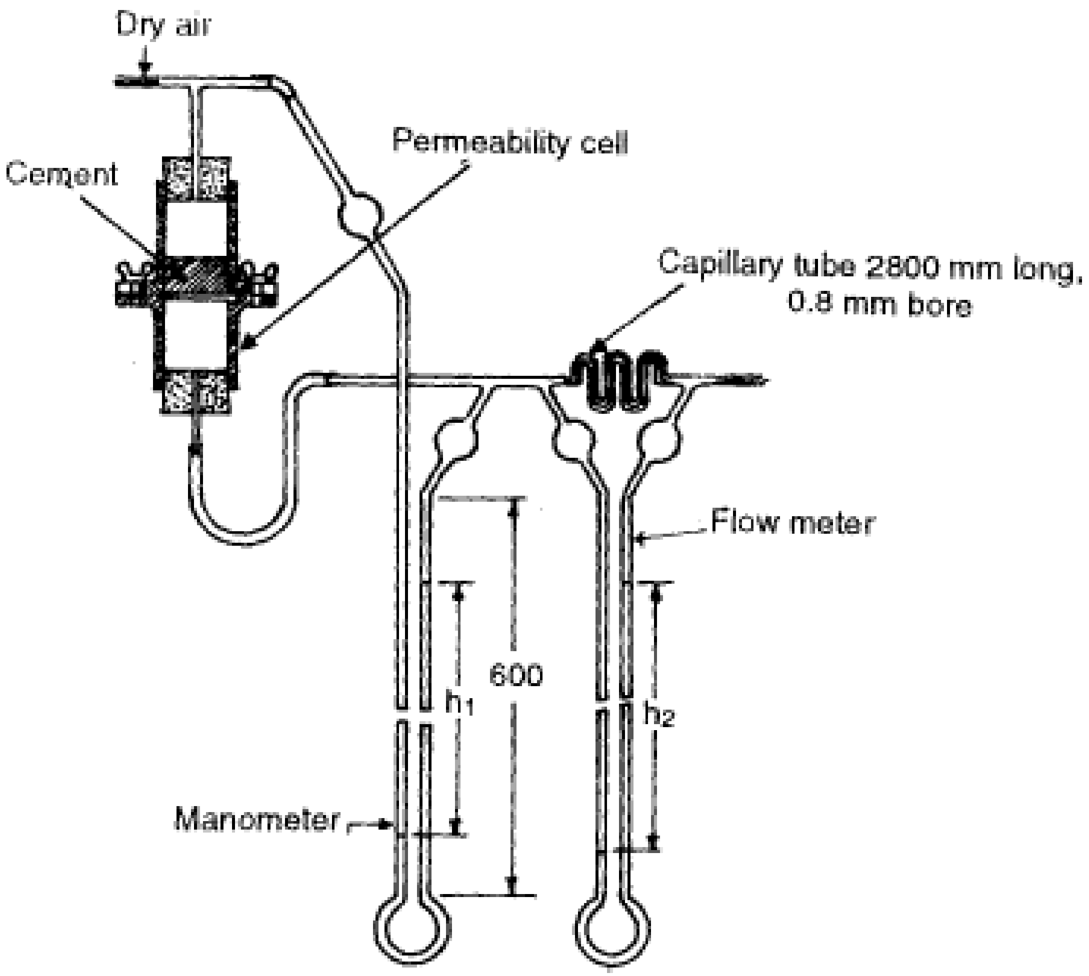

Fig. 5.8 Permeability Apparatus

WAGNER TURBIDIMETER METHOD

- To estimate the *'surface area'* of one gram of cement.
- Cement is dispersed uniformly in a '***rectangular glass tank***' filled with '*Kerosene*'. Then, parallel light rays are passed through the solution which strike the sensitivity plate of a '*Photoelectric Cell*'.
- The turbidity of the solution at a given instant is measured by taking readings of the *'current'* generated by the 'Cell'.
- By recording the readings at regular intervals while the particles are falling in the solution, it is possible to secure information regarding the *'grading in surface area'* and in *'size of particle'*.
- Readings are expressed in *sq. cm per gram*.

CONSISTENCY TEST

- TEST.
  - To estimate the quantity of mixing *water* to form a paste of '*normal consistency*'
  - *NORMAL CONSISTENCY* is defined as that percentage ***water*** requirement of the cement paste, the viscosity of which will be such that the ***Vicat's plunger (Fig 5.9, pp 159)*** penetrates up to a point ***5 to 7 mm*** from the bottom of the Vicat's mould.
- *IMPORTANCE.*
  - *The* ***water requirement*** for various tests of cement depends *on the '****normal consistency'*** of the cement, which itself depends upon the compound ***composition*** and ***fineness*** of the cement.

CONSISTENCY TEST

- *TEST PROCEDURE*.
  - ***300 g of cement*** *is mixed with* ***25*** *per cent water.*
  - *The paste is filled in the* ***mould of Vicat's apparatus*** (Fig. 5.9, pp 159) and the surface of the filled paste is smoothened and levelled.
  - A ***square needle 10 mm x 10 mm*** attached to the ***plunger*** is then lowered gently over the cement paste surface and is released quickly. The plunger pierces the cement paste. The reading on the attached scale is recorded.
  - When the reading is ***5-7 mm*** from the bottom of the mould, the amount of water added is considered to be the correct percentage of water for 'normal consistency'.

INITIAL AND FINAL SETTING TIMES

- When water is added to cement, the resulting paste starts to stiffen and gain strength and lose the consistency simultaneously.
- ‘***setting***’ implies solidification of the plastic cement paste. ‘Initial and final setting times’ may be regarded as the ‘two stiffening states’ of the cement.
- ***‘Initial Set’,***
  - The ***beginning of solidification***, marks the point in time when the paste has become unworkable.
  - The initial setting time may be defined as the time taken by the paste to stiffen to such an extent that the ***Vicat’s needle (Fig 5.9, pp159)*** is not permitted to move down through the paste to within ***5 ± 0.5 mm*** measured from the bottom of the mould.

INITIAL AND FINAL SETTING TIMES

- ***'Final Set',***
  - The time taken to *solidify completely*.
  - It should ***not be too long***, in order to resume construction activity within a reasonable time after the placement of concrete.
  - ***Vicat's apparatus (Fig 5.9, pp 159)*** is used for the purpose.
  - The *'final setting time'* is the time after which the paste becomes so hard that the angular attachment to the needle, under standard weight, fails to leave any mark on the hardened concrete.

VICAT'S APPARATUS

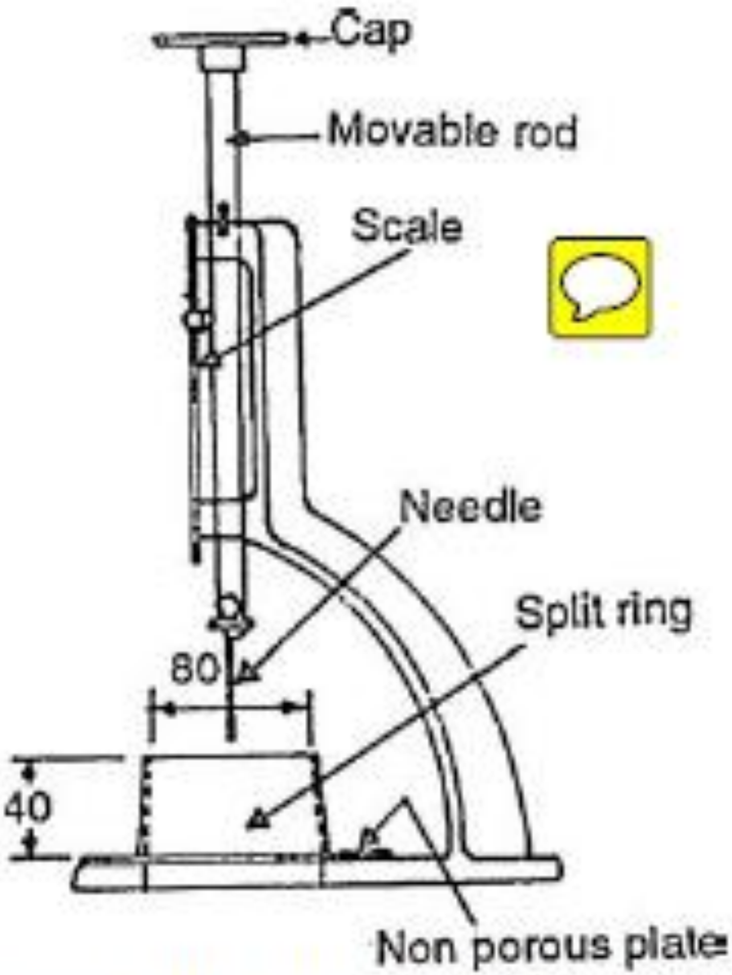

Fig. 5.9 Vicat's Apparatus

INITIAL AND FINAL SETTING TIMES (Contd)

IMPORTANCE

- It is important to know the '*initial* setting time', because of ***loss of useful properties*** of cement if the cement mortar or concrete is placed in moulds after this time.
- The importance of '*final* setting time' lies in the fact that the moulds can be removed after this time.
- *Initial* Setting Time defines the ***limit of handling.***
- *Final* Setting Time defines the beginning of development of ***mechanical strength.***

SETTING TIMES : FACTORS AFFECTING

- *The* ***factors*** *influencing the setting properties of cement* are its
  - Composition
  - Percentage of Retardant
  - Degree of Calcinations
  - Fineness of grinding
  - Aeration subsequent to grinding clinker
  - Percentage of water used to make cement paste
  - Temperature of the mixing water, Cement and the atmosphere where the cement paste is placed
  - The amount of manipulation the paste receives.

FACTORS AFFECTING SETTING TIMES

- The *effect of gypsum* is to ***increase the setting time*** of freshly ground cement. i.e. *delays setting*. It is usually mixed with the clinker before final grinding, or just after the clinker has received preliminary grinding.
- The addition of gypsum *before calcination* causes it to decompose into lime and sulphur trioxide. Since the latter is liberated in the kiln, there is resulting effect on the setting time.

FACTORS AFFECTING SETTING TIMES

- Often, an 'under limed cement' becomes 'quick setting' *after seasoning*. This can be avoided by adding to the cement 1 or 2 per cent of ***hydrated lime*** or the fraction of a per cent of ***Plaster of Paris***.
- Setting time of cement is 'rapid' with the increase in the 'fineness' of cement.
- When the 'mixing water' used in testing cement paste is increased by 1 per cent above that required for normal consistency, an increase of about 30 minutes or more is observed in the initial or final set.
- Cements stored in '*warm rooms*' will, in general, be 'quick setting' than those stored in cold places.

FACTORS AFFECTING SETTING TIMES

- ‘Cold mixing water ***retards set***’, while warm water ***accelerates*** it.
- Cement ‘exposed to thoroughly saturated atmosphere’ will set much more ‘slowly’ than those exposed to a dry atmosphere.
- If, however, a considerable proportion of ‘moist CO2 is present in the air’, the setting time is found to ‘reduce’ greatly.
- MANIPULATION. By lengthening the ‘time of mixing’ and by prolonged troweling of the surface mortars, it is also possible to considerably ‘delay the setting time’.

SOUNDNESS TEST

- It is essential that the cement concrete does not undergo ***large change in volume after setting***. This is ensured by limiting the quantities of *free lime and magnesia* which slake slowly causing change in volume of cement (known as unsound).
- Soundness of cement may be tested by ***Le-Chatelier method (Fig 5.10, pp 161), or, by autoclave method.***
- For OPC, RHC, LHC and PPC soundness is limited to ***10*** mm,
- For HAC and SSC it should not exceed ***5*** mm.
- IMPORTANCE. It is a very important test to assure the quality of cement since an unsound cement produces ***cracks, distortion and disintegration***, ultimately leading to ***failure.***

Le-chatelier Apparatus

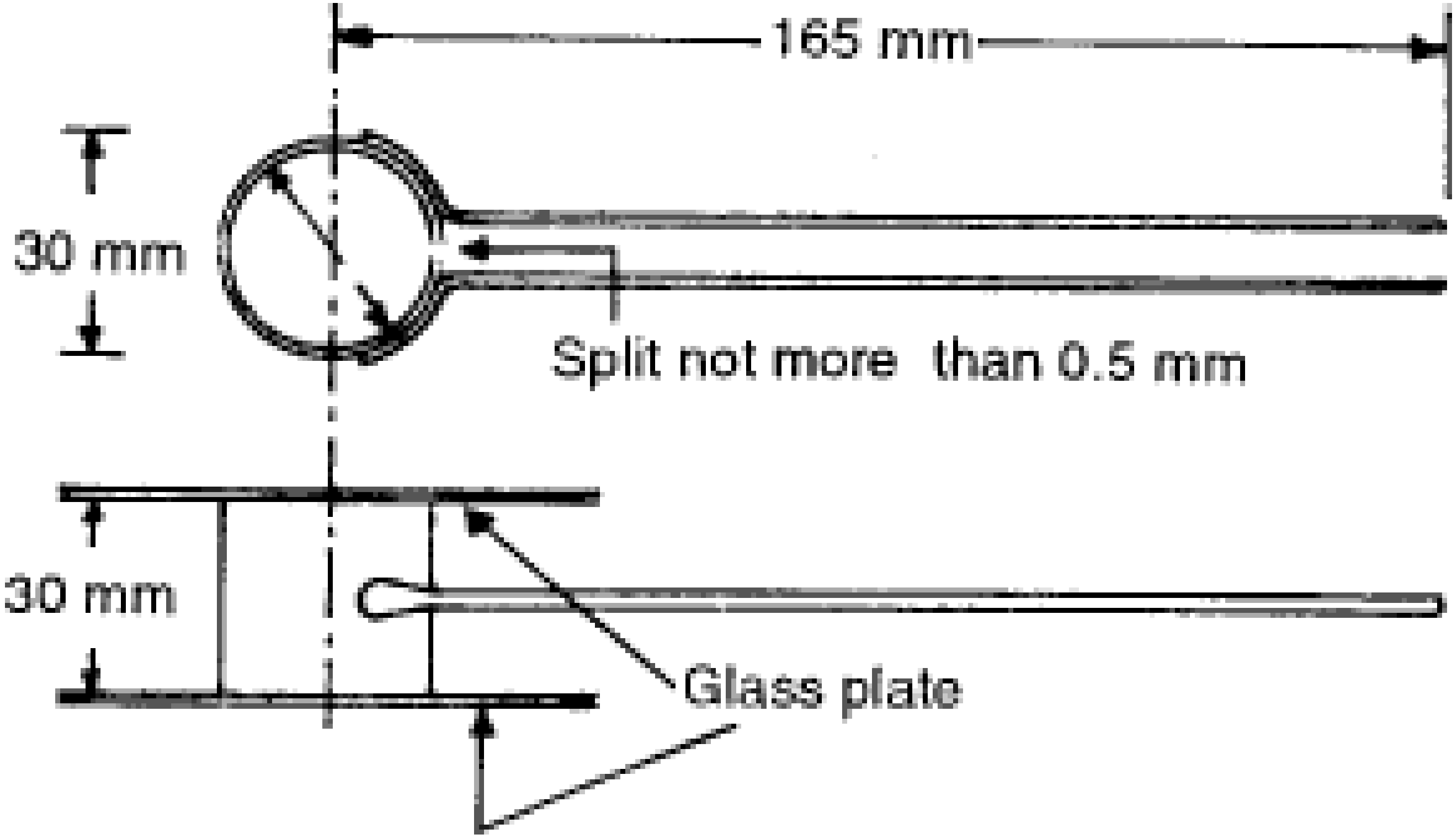

Fig. 5.10 Le-chatelier Apparatus

CONIDITIONS AFFECTING SOUNDNESS

- *The **main cause** for unsoundness in Portland cement is the hydration* of the *uncombined lime* encased within the cement particles.
- The uncombined lime in cement is a result of either *under burning* the clinker or of *excess lime* in the raw materials.
- **AERATION**. Freshly ground cement is often unsound due to the presence of uncombined lime. Cement is thus allowed to ***aerate*** for two to three weeks, allowing the *lime to hydrate*, to overcome unsoundness.
- ***Fine grinding*** of the raw material and clinker help to produce a sound cement. By grinding fine the raw materials, it is possible to produce a homogeneous mixture before burning where the lime is uniformly distributed.
- The coarse grains of cement may imprison minute particles of uncombined lime which do not hydrate. These lime particles on ‘***hydration’*** produce disintegration

LE-CHATELIER METHOD

- The apparatus is shown in Fig. 5.10 (ref PDF File pp 161).
- STEP 1. The mould is placed on a glass sheet and is filled with neat ***cement paste*** formed by ***100 g*** cement with 0.78 times the water required to give a paste of '***standard consistency'***. The mould is covered with a glass sheet and a small weight is placed on the covering glass sheet.
- STEP 2. The mould is then *submerged in the water* at temperature of 27°-32°C. After 24 hours, the mould is taken out and the distance separating the indicator points is measured.
- STEP 3. The mould is ***again submerged in water*** and *boiled for 3 hours*. The mould is cooled down and the distance between the indicator points is measured again. The difference between the two measurements represents the '***unsoundness***'.

AUTOCLAVE TEST

- **STEP 1**. The ***25 × 25 × 250 mm*** specimen with neat cement paste, kept in moist environ.
- ***STEP 2.*** *After 24 hours* the molded specimen is removed from the moist atmosphere, *measured for length*, and placed in an autoclave, exposed to saturated steam.
- **STEP 3.** The *temperature* of the autoclave is raised such that the '*gauge pressure of the steam*' rises to 2.1 N/mm2 in 1 - 1 ¼ hours. The *pressure* is maintained for 3 hours.
- ***STEP 4.*** *Heat supply is shut off*, autoclave is cooled at such a rate that the pressure is less than 0.1N/mm2, at the end of the hour.
- ***STEP 5.*** *Autoclave is opened*, test specimens are placed in water at temperature of 90°C. Temperature is brought down to 27±2°C in 15 minutes. Specimens are maintained at this temperature for 15 minutes and are then taken out.
- **STEP 6.** The length of the specimen is measured again. The *difference* in the two measurements gives the unsoundness of the cement.

CONDITIONS AFFECTING STRENGTH

- *High Lime or Alumina* content…. Cement is very strong at early ages.
- *Gypsum and Plaster of Paris* in small percentages increase the strength slightly, but when present in quantities larger than 3 per cent, these substances provide variable effects.
- The effect of the *clinker compounds* on strength already discussed in Sec 5.4.
- *In addition* to the effect of composition, strength of cement is influenced by
  - degree of burning
  - fineness of grinding
  - aeration it receives subsequent to final grinding.
- *Under burnt cement* is likely to be deficient in strength.

COMPRESSIVE STR

- Compressive strength is the basic data required for ***mix design***.
  - quality and the quantity of concrete can be controlled
  - degree of adulteration can be checked.
- The test specimens are 70.6 mm cubes having face area of about 5000 sq. mm.
- **STEP 1.** A mixture of *cement and sand 1:3* by weight is mixed until the mixture is of uniform color.
- **STEP 2.** Three specimen cubes are prepared.
  - The quantities of cement, standard sand and water are 185 g, 555 g and (P/4) + 3.5, respectively where P = percentage of water required to produce a paste of standard consistency.
  - The mould is filled completely with the cement paste. Vibrations are imparted for about 2 minutes at a speed of 12000±400 per minute.

COMPRESSIVE STR

- **STEP 3.** The cubes are then removed from the moulds and submerged in clean WATER.
- **STEP 4.** Compressive strength is taken to be the average of the results of the three cubes. The load is applied starting from zero at a rate of 35 N/sq mm/minute.
- **STEP 4.** The compressive strength is calculated from the crushing load divided by the average area over which the load is applied. The result is expressed in ***N/mm2***.

TENSILE STR

- *IMPORTANCE:*
  - Tensile strength of cement affords quicker indications of defects in the cement than any other test.
  - The test is ***more conveniently*** made.
  - Since the flexural strength is directly related to the tensile strength; this test is ideally fitted to give information both with regard to ***tensile and compressive*** strengths.

TENSILE STR

- BRIQUETTE METHOD.

  STEP 1. A mixture of Cement and Sand in1:3 ratio, by weight.

  Water = (P/5) + 2.5; where P = percentage of water required to produce a paste of standard consistency.

  STEP 2. The mix is filled in the moulds of the shape shown in Fig. 5.11 (pp 163).

  STEP 3. After filling the mould, an additional heap of mix is placed on the mould and is pushed down with the standard spatula, until the mixture is level with the top of the mould.

  STEP 4. This operation is repeated on the other side of the mould also.

  STEP 5. They are then kept for 24 hours at a temperature of 27° ± 2°C and in an atmosphere having 90 per cent humidity. The briquettes are then kept in clean fresh water.

  STEP 6. Six briquettes are tested and the average tensile strength is calculated.

  STEP 7. Load is applied steadily and uniformly, starting from Zero and increasing @ 0.7 N/sq mm of section in 12 seconds.

TENSILE STR (Contd)

- Dimensions of std ‘Briquette’ as per PDF File (Fig 5.11 pp 163)
- OPC should have tensile str
  - not less than 2.0 N/ mm2 after 3 days
  - not less than 2.5N/mm2 after 7 days

TENSILE STR- STD BRIQUETTER

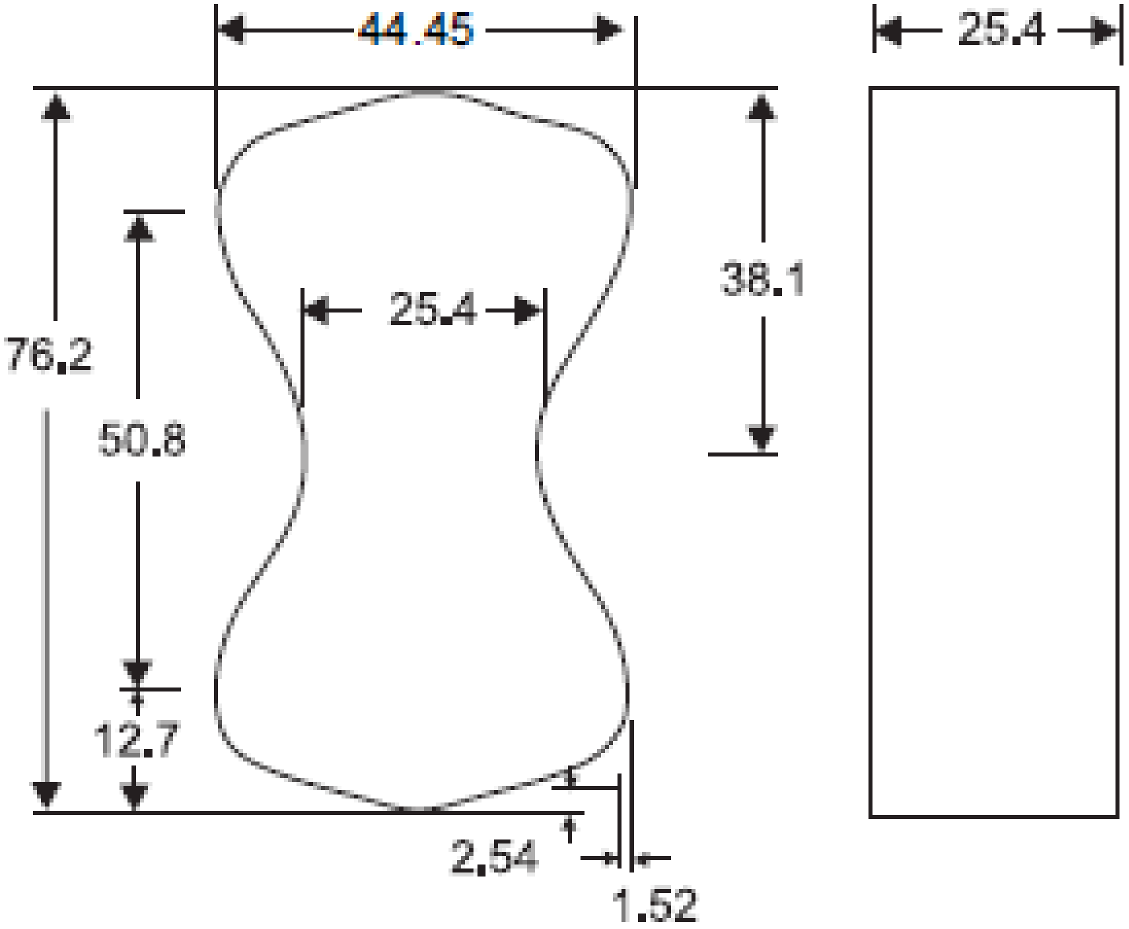

Fig. 5.11 Dimensions of Standard Briquette

HEAT OF HYDRATION

- *IMPORTANCE*
  - The evolution of heat causes an increase in temperature of the concrete, being greatest in mass concreting. Since the cooling of a mass of concrete can only occur from surfaces exposed to atmosphere, the temperature of the interior is higher than that at the surface and also there is a rapid increase in strength in the interior than at the surface.
  - ***Shrinkage cracks*** may result from stresses, induced by cooling of the surface while the interior of concrete is still at higher temperature.
- *TEST PROCEDURE*
- The apparatus is calorimeter and is shown in Fig. 5.12 (pp 164).

CALORIMETER

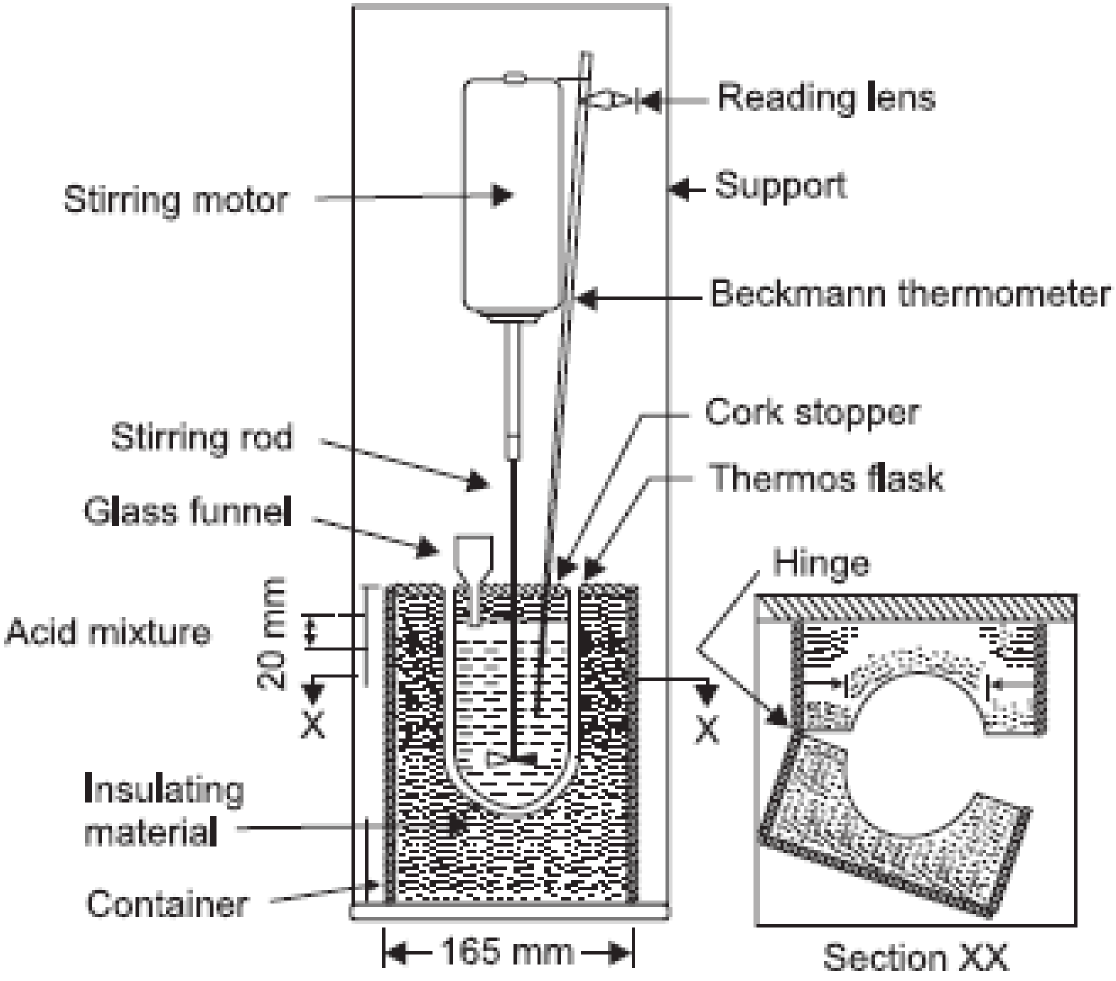

Fig. 5.12 Calorimeter

HEAT OF HYDRATION

STEP 1. ***60 g of cement*** and ***24 ml*** of ***distilled water*** are mixed for 4 minutes at temperature 15°–25°C. *Three specimen glass vials* 100 × 20 mm are filled with this mixture, corked and sealed with wax.

STEP 2. The ***vials*** are then stored with the mixture in a vertical position at 27°±2° C.

(The *heat of hydration* is obtained by subtracting the respective ‘***heats of solution of Un-hydrated and Hydrated cements***’.)

STEP 3. For determining the *heat of solution of un-hydrated cement*, weigh a sample of about 3 g. At the same time, weigh out 7.0 g of cement for the loss on ignition.

STEP 5. Balance procedure as per PDF File pp 164.

CALORIMETER - FORMULAE

The heat of solution of hydrated cement (Cal/g ignited weight)

$$= \frac{\text{Heat capacity} \times \text{corrected temperature rise}}{\text{Weight of sample corrected for ignition loss}} - 0.4(\varphi_0 - \varphi)$$

$$\text{Heat capcity (Cal/°C)} = \frac{\text{Weight of ZnO}}{\text{Corrected temperature rise}} \times [256.1 + 0.1\,(30.0 - \psi_0) + 0.1(\psi_0 - \psi)]$$

$$= \frac{\text{Weight of ZnO}\ \ (259.1 - 0.2\psi + 0.1\psi_0)}{\text{Corrected temperature rise}}$$

HEAT OF HYDRATION

HEAT OF SOLUTION OF THE HYDRATED CEMENT

- One of the glass vials is opened and the adherent wax is removed. The cement is ground rapidly, to avoid carbonation, to pass an 850 micron sieve. From this weigh out
  - 4.2 g of Cement Sample for heat of solution.
  - 7.0 g of Cement sample for loss on ignition.

- The heat of solution of hydrated cement (Cal/g ignited weight) = (Heat capacity × corrected temperature rise / Weight of sample corrected for ignition loss) - 0.4(X) (Ref to formula on pp 164)

IGNITION LOSS

- The ignition loss can be obtained by placing the sample in a cool furnace and raising the temperature of the furnace to 900°C over a period of 1 hour.
- The sample is kept at 900° ± 50°C for 3-4 hours and then cooled in a desiccator containing anhydrous calcium chloride.
- Weigh after half an hour.
- The difference in the two weighings give the loss on ignition.

HEAT OF HYDRATION

HEAT CAPACITY

STEP 1. Sufficient quantity of zinc oxide is ignited for one hour at 900° ± 50°C.

STEP 2. It is cooled in a Desiccator containing anhydrous calcium chloride and ground to pass 250 micron sieve.

STEP 3. About 7 g of this ignited oxide is reheated to 900° ± 50°C for 5 minutes and then cooled for about 2½ hours (not more than 5 hours).

STEP 4. The Calorimeter is assembled and temperature reading correct to 0.001°C is recorded to determine the initial heating or cooling correction.

STEP 5. The Zinc oxide is then introduced.

STEP 6. The Temperature readings are recorded at one minute intervals until the solution is complete.

HEAT OF HYDRATION

STEP 7. The recording of readings is continued for next 5 minutes to determine the final heating or cooling correction. The initial and final heating or cooling rates against the corresponding calorimeter temperature are plotted.

STEP 8. The two points thus obtained are joined by a straight line. From this graph the corrections are read off for each temperature reading during the solution period. Heat capacity is calculated from the expression.

STEP 9. Heat capacity is calculated as per eqn given on pp 165.

SP.GR. TEST

- *Le Chatelier Flask as per PDF File (Fig 5.13, pp 165)*
- *Conditions affecting Sp Gr*
  - **Long seasoning** *is the chief cause of a low specific* gravity in unadulterated cement. This is because the freshly ground cement when exposed to air, rapidly absorbs moisture and carbon dioxide.
  - Cements with high contents of ***iron oxide*** have a higher ***specific gravity***.
  - The effect of fineness of grinding upon specific gravity is slight. Very finely ground cements are likely to have lower specific gravities.

Le-Chatelier Flask

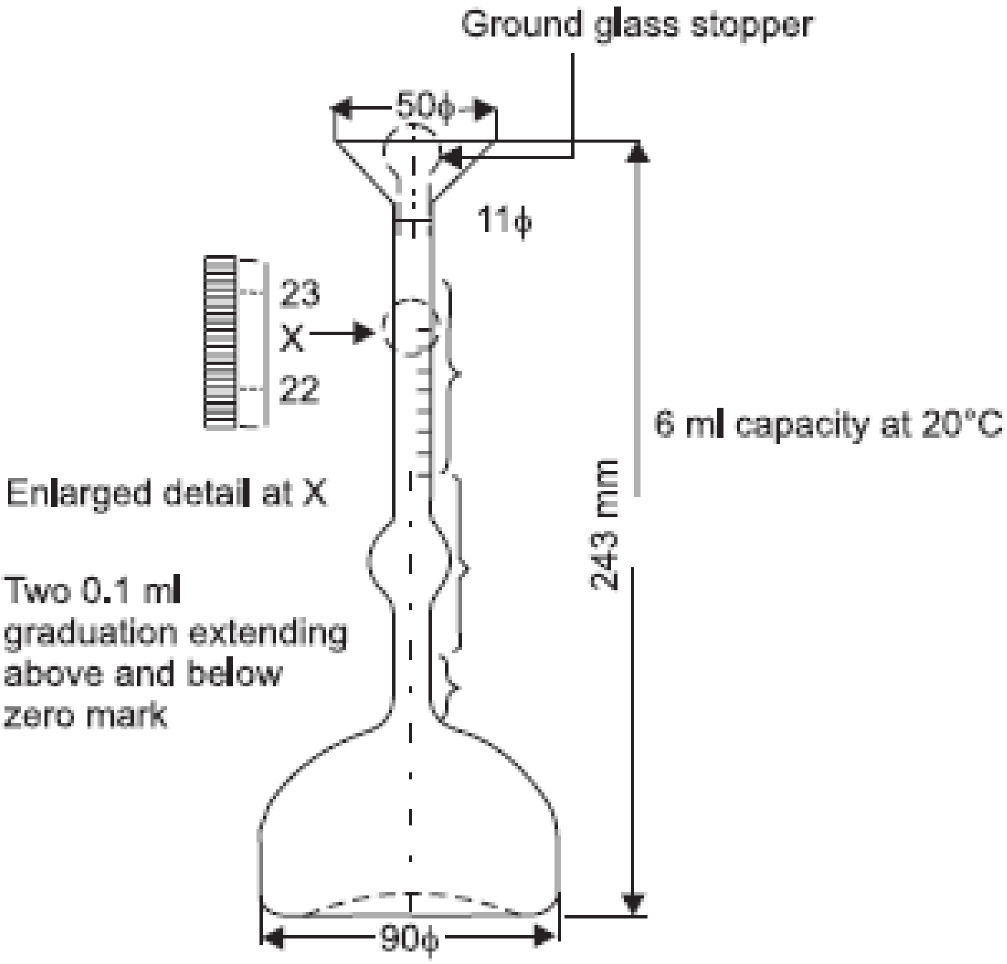

Fig. 5.13 Le-Chatelier Flask for Specific Gravity Test

SP.GR. TEST

- *TEST PROCEDURE*
  - *The flask is filled with either* **kerosene** *free of water, or* **naphtha** *having a* specific gravity not less than 0.7313 to a point on the stem between zero and 1-ml mark.
  - The flask is immersed in a constant temperature ***water bath*** and the reading is recorded.
  - A weighed quantity of cement (about 64 g of Portland cement) is then introduced in small amounts at the same temperature as that of the liquid. The flask is again immersed in the water-bath and the final reading is recorded.
  - The difference between the first and the final reading represents the volume of ***liquid displaced*** by the weight of the cement used in the test.
- Specific gravity = Weight of cement / Displaced volume of liquid in ml

CHEMICAL TESTS

LOSS ON IGNITION

- 1.00 g of the sample is heated for 15 minutes, in a weighed and covered platinum crucible, by placing it in a muffle furnace, between 900° and 1000°C.
- It is then cooled and weighed.
- Thereafter, the loss in weight is checked by a second heating for 5 minutes and reweighing.
- The loss in the weight is recorded as the loss on ignition and the percentage of loss on ignition calculated
- The percentage loss on ignition should not exceed 4 per cent.

SILICA

- 0.5 g of the sample is kept in an evaporating dish, moistened with 10 ml of distilled water at room temperature. To this 5 to 10 ml of hydrochloric acid is added, and digested with the aid of gentle heat and agitation until solution is complete.
- The solution is evaporated to dryness on a steam bath. It is treated with 5 to 10 ml of hydrochloric acid and then with an equal amount of water. The dish is covered and digested for 10 minutes on a water bath.
- The solution is diluted and is immediately filtered through an ashless filter paper, and the separated silica (SiO2) is washed thoroughly with hot water and the residue is reserved.
- The filtrate is again evaporated to dryness, baking the residue in an oven for one hour at 105°C to 110°C. Then the residue is added with 10 to 15 ml of hydrochloric acid (1:1) and is heated on a water bath. This solution is then diluted with hot water and the small amount of silica it contains is filtered and washed on another filter paper. The filtrate and washings are reserved for the determination of combined alumina and the ferric oxide.

SILICA

- The papers containing the residues are transferred to a weighed platinum crucible. The papers are dried and ignited, first at a low heat until the carbon of the filter papers is completely consumed without inflaming, and finally at 1100°C to 1200°C until the weight remains constant (say W1).
- The ignited residue thus obtained, which will contain small amounts of impurities is treated in the crucible with a few drops of distilled water, about 10 ml of hydrofluoric acid and one drop of sulphuric acid and evaporated cautiously to dryness. Finally, the small residue is heated at 1050°C to 1100°C for a minute or two: cooled and weighed (say W2).
- The difference between this weight and the weight of the ignited residue represents the amount of silica (W).
- Silica (%) = 200 (W1 – W2)

COMBINED FERRIC OXIDE AND ALUMINA

- 200 ml of the sample from the filtrate reserved in silica test is heated to a boil. A few drops of bromine water or concentrated nitric acid is added during boiling in order to oxidize any ferrous ion to the ferric condition.
- It is then treated with ammonium hydroxide (1:1), drop by drop, until the solution smells of ammonia. The solution containing the precipitates of aluminum and ferric hydroxides is boiled for one minute.
- The precipitate is allowed to settle, filtered through an ash less filter paper and washed with two per cent hot ammonium nitrate solution. The filtrate and washings are set aside.
- The precipitate and the filter paper is transferred to the same beaker in which the first precipitation was effected. The precipitate is then dissolved in hydrochloric acid (1:3). The solution is diluted to about 100 ml and the hydroxides are re precipitated. The solution is filtered and precipitated with two 10 ml portions of hot ammonium nitrate solution.
- The filtrate and washings are then combined with the filtrate set aside and is reserved for the determination of calcium oxide.

COMBINED FERRIC OXIDE AND ALUMINA

- The precipitate is placed in a weighed platinum crucible, heated slowly until the papers are charred, and finally ignited to constant weight at 1050°C to 1100°C with care to prevent reduction, and weighed (W1) as combined alumina and ferric oxide.
- If silica is suspected to be carried into the filtrate used for this estimation, the residue in the crucible is treated with a drop of water, about 5 ml of hydrofluoric acid and a drop of sulphuric acid and is evaporated cautiously to dryness. Finally, the crucible is heated at 1050°C to 1100°C for one or two minutes; cooled and weighed (W2).
- The difference between this weight and the weight (W1), represents the amount of residue silica.
- This amount is subtracted from the weight of ferric oxide and alumina found as W1 and the same amount is added to the amount of silica (W). The ratio of percentages of alumina to iron oxide should not exceed 0.66.
- Combined ferric oxide and alumina (%) = weight of residue × 200

FERRIC OXIDE

- 40 ml of cold water is added to 1 g of the sample and while the mixture is stirred vigorously, 50 ml of hydrochloric acid is added.
- The solution is heated to a boil and is treated with stannous chloride solution added drop by drop while stirring, until the solution is dicolourized.
- A few drops of stannous chloride solution is added in excess and the solution is cooled to room temperature.
- Then, 15 ml of a saturated solution of mercuric Chloride and 25 ml of manganese sulphate solution are added and titrated with standard solution of potassium permanganate until the permanent pink colour is obtained. Iron as ferric oxide is calculated.

ALUMINA

- The calculated weight of ferric oxide and the small amount of silica is subtracted from the total weight of oxides (WI).
- The remainder is the weight of alumina and of small amounts of other oxides reported as alumina.

CALCIUM OXIDE

- The combined filtrate reserved in the combined ferric oxide and alumina test is acidified with hydrochloric acid and evaporated to a volume of about 100 ml.
- 40 ml of saturated bromine water is added to the hot solution and ammonium hydroxide is added until the solution is distinctly alkaline.
- The solution is boiled for 5 minutes or more, making certain that the solution is at all times distinctly alkaline.
- Then the precipitate is allowed to settle, filtered and washed with hot water. The beaker and filter is washed once with nitric acid (1:33) and finally with hot water. Any precipitate (of manganese dioxide) that may be left on the Funnel is discarded.

CALCIUM OXIDE

- The filtrate is mixed with hydrochloric acid and boiled until all the bromine is expelled.
- 25 ml of boiling ammonium oxalate solution is added to the boiling solution.
- The solution is made alkaline with ammonium hydroxide and brought to boiling, the boiling being continued until the precipitated calcium oxalate assumes a well-defined, granular form.
- The precipitate is allowed to stand for about 20 minutes or until it has settled, filtered and washed moderately with ammonium oxalate solution (one gram per litre).
- The filtrate and washings (W3) are set aside for estimating magnesia.
- The precipitated lime after ignition and heating at 1100°C-1200°C is weighed.
- The percentage of CaO = weight of residue × 200.
- Also, see PDF File pp 168

MAGNESIA

- The filtrate (W3) is acidified with hydrochloric acid and is concentrated to about l50 ml.
- To this solution, about 10 ml of ammonium hydrogen phosphate solution (250 g per litre) is added and the solution is cooled.
- After cooling, ammonium hydroxide is added drop by drop, while stirring constantly, until the crystalline magnesium ammonium phosphate begins to form
- The solution is set aside for at least 16 hours in a cool atmosphere and then filtered. The precipitate is washed with ammonium nitrate wash solution. It is then charred slowly and the resulting carbon is burnt carefully. The precipitate is ignited at 1100°C to 1200°C to constant weight.
- From the weight of the magnesium pyrophosphate obtained, the magnesia content of the material taken for the test is calculated.
- The percentage of MgO = weight of residue × 72.4.
- Free magnesia in cement should be less than 4 per cent.

SULPHURIC ANHYDRIDE

- To one gram of the sample, 25 ml of cold water is added and while the mixture is stirred vigorously 5 ml of hydrochloric acid is added.
- The residue is filtered and washed thoroughly with hot water. The filter paper with the residue (W4) is set aside.
- The filtrate is diluted to 250 ml and heated to boiling. 10 ml of hot barium chloride (100 g per litre) solution is added drop by drop and the boiling is continued until the precipitate is well formed. The solution is digested on steam bath for 4 hours or preferably overnight.
- The precipitate is filtered and the precipitate is washed thoroughly. The filter paper and the contents are placed in a weighed platinum or porcelain crucible and slowly the paper is incinerated without inflaming. Then it is ignited at 800°C to 900°C, cooled in a desiccator and the barium sulphate is weighed.
- From the weight of the barium sulphate obtained, the sulphuric anhydride content of the material taken for the test is calculated.
- The percentage of SO_3 = weight of residue × 34.3.
- Sulphur should be less than 2.5 per cent.

TYPES OF CEMENTS

(i) RAPID HARDENING CEMENT (RHC)
(ii) HIGH ALUMINA CEMENT (HAC)
(iii) SUPER SUPLPHATED CEMENT (SSC)
(iv) SULPHATE RESISTING PORTLAND CEMENT (SRPC)
(v) PORTLAND SLAG CEMENT.(PSC)
(vi) LOW HEAT PORTLAND CEMENT (LHPC)
(vii) PORTLAND PAZZOLANA CEMENT
(viii) QUICK SETTING PORTLAND CEMENT
(ix) MASONRY CEMENT
(x) WHITE AND COLORED PORTLAND CEMENT
(xi) AIR ENTRAINING CEMENT
(xii) CALCIUM CHLORIDE CEMENT
(xiii) WATER REPELLENT CEMENT
(xiv) WATER PROOF CEMENT

*(i) RHC

- ★ Suitable for repair of Roads and Bridges, and, when load is applied in a Short Period of time.
- ★ Can be safely exposed to Frost, since it matures more quickly
- ★ Has high Lime content and can be obtained by
  - increasing the C_3S content
  - from OPC Clinker by finer grinding (450 m^2/kg).
- Basis of Application. Of RHC is hardening properties and heat emission, rather than setting rate.
- ★ Gypsum added during manufacture, to control rate of setting.
- RHC attains same strength in 1 day; which OPC may attain in 3 days.

(i) RHC

- Shrinkage. More
- Water requirement for workability. More.
- Cost. 10% more than OPC.
- *Setting Times*
  - *Initial setting time 30 min (min)*
  - Final setting time l0 hrs (max)
- Compr str
  - 1 day. 16.0 N/mm2
  - 3 day. 27.5 N/mm2

*(ii) High Alumina Cement

- ★ Alumina > 32%.
- ★ Good sulphate resistance, since C3A is not present
- ★ Rapid gain of Strength, since the rate of consolidation and crystallisation is high
- ★ CA. Main cement ingredient is ‘Mono Calcium Aluminate’ CA, which interacts with Water and forms ‘Di Calcium Octa Hydrate Hydro Aluminate’ & ‘Aluminium Hydroxide’.
- 2(CaO.AL2O3.10H2O) + H2O --------→ 2CaO.Al2O3.8H2O + 2Al(OH)2
- The ‘Di Calcium Hydro Aluminate Gel’ consolidates and the hydration products crystallise.

(ii) High Alumina Cement

- Manufactured by fusing
  - 40 per cent Bauxite
  - 40 per cent Lime
  - 15 per cent Iron Oxide
  - A little of ferric oxide and silica, magnesia, etc. at a very high temperature. (Ref Table 5.5 pp 169)
- This is not a type of Portland cement

(ii) High Alumina Cement

PROPERTIES

- Not quick setting:
  - initial setting time (minimum) is 30 minutes, even up to 2 hours.
  - The final setting time should not exceed 600 minutes.
  - Attains strength in 24 hours,
- ★ High
  - ‘Early Strength’
  - ‘Heat of Hydration’
  - Resistance to Chemical Attack.
- Compressive strength

– After one day .	30.0 N/mm2
– After 3 days.	35.0 N/mm2.

(ii) High Alumina Cement

PROPERTIES

- After setting and hardening, there is no free hydrated lime as in the case of OPC.
- Fineness. Min 225 m2/kg.
- Expansion. Not more than 5 mm.
- Resistant to the action of fire, sea water, acidic water and sulphates and is used as refractory concrete, in industries and is used widely for pre-casting.
- Not used in places where temperature > 18°C.

High Alumina Cement _ Composition

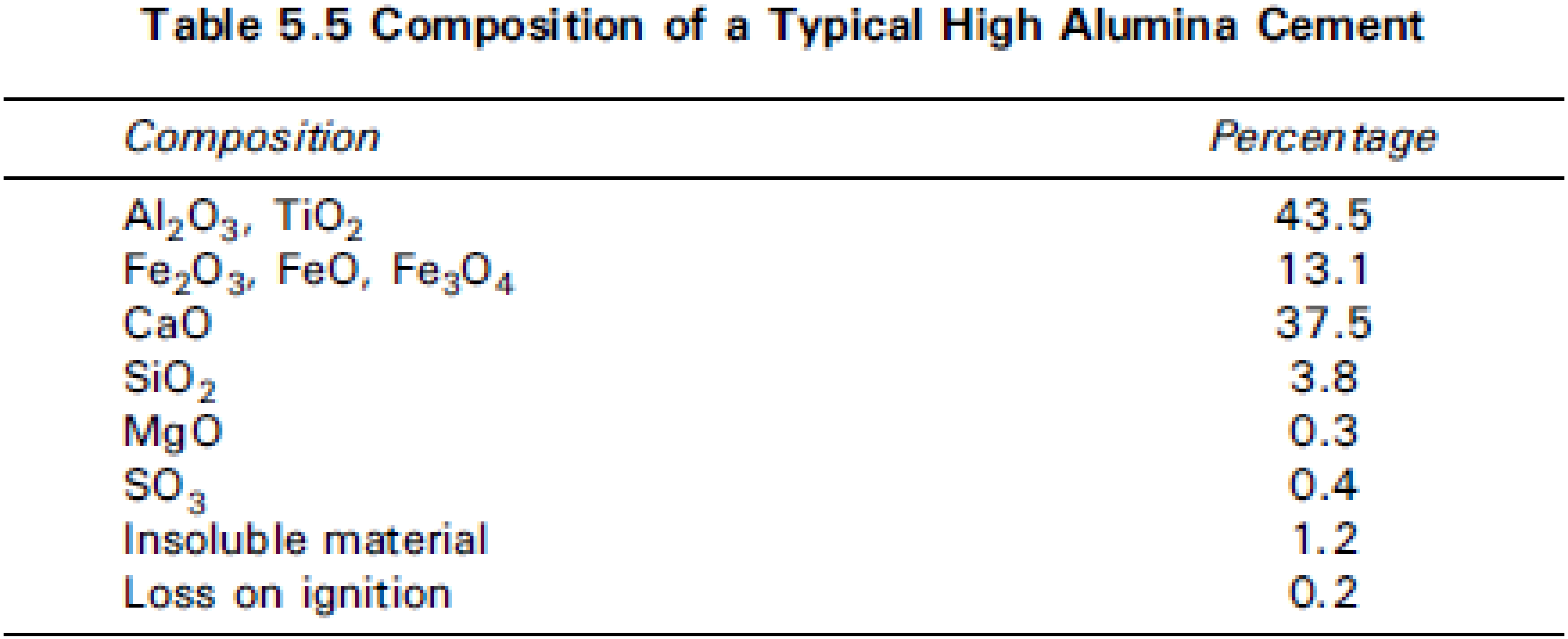

Table 5.5 Composition of a Typical High Alumina Cement

Composition	*Percentage*
Al_2O_3, TiO_2	43.5
Fe_2O_3, FeO, Fe_3O_4	13.1
CaO	37.5
SiO_2	3.8
MgO	0.3
SO_3	0.4
Insoluble material	1.2
Loss on ignition	0.2

*(iii) SUPER SULPHATED CEMENT

- Used when temp is < 40°C.
- Water resistance is higher than OPC, because of the absence of free 'Calcium Oxide Hydrate'.
- SSPC has satisfactory 'Frost and Air resistances'; but it is less resistant than concrete from OPC
- C3A is limited to less than 3.5 per cent. (C3A is susceptible to sulphates)

(iii) SUPER SULPHATED CEMENT

- Manufactured by intergrinding or intimately blending a mixture of
  - granulated blast furnace slag (not less than 70 per cent)
  - calcium sulphate
  - small quantity of 33 grade Portland cement.
- May also be produced by the addition of extra Iron Oxide before firing; this combines with Alumina, forming C4AF which is not affected by sulphates……… If extra Iron Oxide is not added; C3A is formed, instead of C4AF. C3A is susceptible to Sulphates.

(iii) SUPER SULPHATED CEMENT

PROPERTIES

- Low ‘Heat of Hydration’
- Resistant to Chemical Attacks and in particular to Sulphates.
- Compr Str:
  - 72 ± 1 hour > 15 N/mm2
  - 168 ± 2 hours > 22 N/mm2
  - 672 ± 4 hours > 30 N/mm2
- Fineness. 400 m2/kg.
- Expansion . Limited to 5 mm.
- SETTING TIMINGS
  - Initial setting time of the cement > 30 minutes
  - Final setting time < 600 minutes.

(iii) SUPER SULPHATED CEMENT

USES

- Higher water-resisting property, preferred in hydraulic engineering installations and in constructions intended for service in moist media.
- Places of Use
  - RCC pipes in ground water
  - Concrete structures in sulphate bearing soils
  - Sewers carrying industrial effluents
  - Concrete exposed to concentrated sulphates of weak mineral acids are some of the examples of this cement
- Not used in constructions exposed to
  - frequent freezing-and-thawing
  - moistening-and-drying conditions.

*(iv) SULPHATE RESISTING PORTLAND CEMENT

- Alternative to order Portland cement or PPC or Portland slag cement under normal conditions. Use is restricted where temperature < 40°C.
- ★ Particularly beneficial in cases of
  - Sulphate attack
  - Concrete in sea water
  - Exposed directly to sea coast.
- ★ C3A < 5%
- Expansion . limited to 5 mm.
- Setting Times
  - initial. > 30 min
  - final < 600 min.

(iv) SULPHATE RESISTING PORTLAND CEMENT

- Manufactured by
  - Grinding and intimately mixing together calcareous and argillaceous and/ or other Silica, Alumina and Iron oxide bearing materials.
  - Materials burnt to clinkering temperature. The resultant clinker is ground to produce the cement.
  - No material is added after burning, except gypsum
  - Air-entraining agents . $<$ 1%.

(iv) SULPHATE RESISTING PORTLAND CEMENT

PROPERTIES

- *Expansion* of cement is limited to
  - 10 mm’ by Le-chatelier method
  - 0.8 per cent, by autoclave
- Setting times are same as for OPC
- Compressive strength of the cubes.
  - 72 ± 1 hour. > 10 N/mm2
  - 168 ± 2 hours. > 16 N/mm2
  - 672 ± 4 hours. > 33 N/mm2
- Fineness. 400 m2/kg.

*(v) PORTLAND SLAG CEMENT

- **SLAG** is a non-metallic product consisting essentially of Glass containing Silicates and Alumino Silicates of Lime and other bases.

  e.g., as in the case of blast-furnace slag, which is developed simultaneously with iron in blast furnace or electric pig iron furnace.
- **GRANULATED SLAG** is obtained by further processing the molten slag by rapid chilling or quenching it with water or steam and air.
- The slag constituent. 25 to 65 per cent.

USES

- In all places where OPC is used.
- Because of its low heat of hydration, it can also be used for mass concreting, e.g., dams, foundations, etc.

(v) PORTLAND SLAG CEMENT

- Manufactured by
  - intimately inter-grinding
    - a mixture of Portland cement clinker and
    - granulated slag
    - with addition of gypsum or calcium sulphate,
  - by an intimate and uniform blending of Portland cement and finely ground granulated slag.

PROPERTIES

- Chemical requirements are same as that of 33 grade Portland cement.
- The specific surface > 225 m2/kg.
- The expansion of the cement

  < 10 mm, by Le Chatelier method

  < 0.8 per cent, by Autoclave test
- The initial and final setting times and compressive strength requirements. As per 33 grade OPC.

*(vi) LOW HEAT PORTLAND CEMENT

- *Most suitable for large mass concrete works such as dams, large raft foundations, etc.*
- C3A is minimized
- C2A and C4AF increased
- Heat of hydration
  - End of 7 days < 272 J/gm
  - End of 7 days < 314 J/gm
- Development of strength is slow, but the ultimate strength is same as that of OPC. This is achieved by increasing specific surface of cement to about 3200 cm2/g.

(vi) LOW HEAT PORTLAND CEMENT

PROPERTIES

- *Less heat is evolved during setting*
- *Expansion.*
  - *< 10mm, by Le* Chatelier method.
  - *< 0.8%, by* Autoclave test.
- Setting Time
  - Initial. > 60 mins
  - Final < 600 mins
- Compressive strength should be as follows.
  - 72 ± 1 hour > 10 N/mm2
  - 168 ± 2 hours > 16 N/mm2
  - 672 ± 4 hours > 35 N/mm2

*(vii) PPC

- Low heat evolution. Used in mass concrete , and in places of high temperature.
- Puzzolana (burnt clay, shale, or fly ash) has NO cementing value itself, but has the property of combining with lime to produce a stable lime-puzzolana compound which has definite cementitious properties.
- No Free lime. Hence, the resistance to chemical attack increases, making it suitable for marine wks. Greater water-resisting property than OPC.

(vii) PPC

- The hardening of PPC consists in
  - hydration of Portland cement clinker compounds and then
  - interaction of the Puzzolana with Calcium Hydroxide released during the hardening of clinker.
- At the same time, calcium hydroxide is bound into a water-soluble calcium hydro silicate according to the reaction

$$Ca(OH)_2 + SiO_2 + (n - 1)\ H_2O \text{ -------}\rightarrow CaO.SiO_2.nH_2O$$

- Manufactured
  - by grinding Portland Cement Clinker and Puzzolana (usually fly ash 10-25% by mass of PPC)
  - by intimately and uniformly blending OPC and fine Puzzolana.

(vii) PPC

PROPERTIES

- Lower rate of development of strength, but ultimate strength is as OPC.
- Compressive Strength

– 72 ± 1 hr.	16.0 N/mm2
– 168 ± 2 hrs.	22.0 N/mm2
– 672 ± 4 hrs.	33.0 N/mm2

- SETTING TIMES

– Initial.	30 minutes (min)
– Final.	600 minutes (max)

• Drying shrinkage	< 0.15%
• Fineness	> 300 m2/kg.

*(viii) QUICK SETTING PORTLAND CEMENT

- ★ *Concreting under water, or, in running water.*
- ★ Gypsum is reduced. Small percentage of Aluminium Sulphate is added.
- ★ Ground much finer than OPC.
- SETTING TIMES
  - *Initial. 5 minutes*
  - Final. 30 minutes

*(ix) MASONRY CEMENT

- The OPC clinker is ground and mixed intimately with
  - Pozzolanic material (flyash or calcined clay), or Non-Pozzolanic (inert) materials (limestone, conglomrates, dolomite, granulated slag)
  - Waste materials (carbonated sludge, mine tailings)
  - Gypsum
  - Air Entraining Plasticizer.

(ix) MASONRY CEMENT

Physical Requirements

1. Fineness: Residue on 45-micron IS Sieve, *Max, Percent (by wet sieving)* *15*
2. Setting Time (by Vicat Apparatus):
   - (a) Initial, *Min .* *90 min*
   - (b) Final, *Max .* *24 h*
3. Soundness:
   - (a) Le-Chatelier expansion, *Max.* *10 mm*
   - (b) Autoclave expansion, *Max.* *1 per cent*
4. Compressive Strength: *Min*
   - – 7 days. 2.5 MPa
   - – 28 days. 5 MPa
5. Air Content: Air content of 1:3 CM, *Min.* 6 per cent
6. Water Retention: Flow after suction of 1:3 CM by volume, *Min.* 60 per cent of *original flow*

*(x) WHITE AND COLORED PORTLAND CEMENT

Uses

- *For making*
  - *terrazzo flooring*
  - *face plaster of walls (stucco)*
  - ornamental works
  - casting stones.
- Iron oxide < 1 %
- Colored cements are made by adding 5 to 10 per cent colouring pigments before grinding.
- Sodium alumino fluoride is added during burning which acts as a catalyst in place of iron.
- It is manufactured from pure white chalk and clay free from iron oxide.

Properties

- *Loss on ignition of white cement. NIL*
- *The compressive and transverse strength* of this cement is 90 per cent of that of 33 grade OPC.

*(xi) AIR ENTRAINING CEMENTS

- OPC is ground with
  - Vinsol resin or
  - Vegetable fats and oils and fatty acids.
- These materials have the property to entrain air in the form of fine tiny air bubbles in concrete.

PROPERTIES

- Minute voids are formed while setting of cement
- These voids increase resistance against freezing and scaling action of salts.
- Air entrainment
  - improves workability
  - Reduces water/cement ratio , which in turn reduces shrinkage, etc.

USES

- *Same as OPC.*

*(xii) CALCIUM CHLORIDE CEMENT

- It is also known as extra rapid hardening cement
- Made by adding 2 per cent of calcium chloride.
- Since it is deliquescent, it is stored under dry conditions and should be consumed within a month of its dispatch from the factory.

PROPERTIES

- The rate of strength development is accelerated
- A higher percentage of calcium chloride causes excessive shrinkage.
- Strength gained
  - After 1 day. 25 per cent more than OPC
  - After 7 days. 20 per cent more than OPC

USES

- *It is very suitable for cold weather*

*(xiii) WATER REPELLENT CEMENT

- It is most suitable for Basements and for making Water Tight Concrete.
- Hydrophobic cement also features greater Water Resistance and Water Impermeability.
- When concrete is being prepared, hydrophobic admixtures
  - plasticize the mix and contribute to the formation of uniformly distributed fine pores in concrete as it hardens and
  - thus enhance its frost resistance.

(xiii) WATER REPELLENT CEMENT

- It is also called *Hydrophobic Cement.*
  - *During grinding of Clinker of OPC, A small amount of following* hydrophobic surfactants added, in amounts of 0.1 to 0.5% :
    - Stearic acid
    - Boric acid
    - Oleic acid.
  - These acids form a thin (monomolecular) film around the cement particles which prevent the entry of atmospheric moisture.
  - The film breaks down when the concrete is mixed, and the normal hydration takes place.

(xiii) WATER REPELLENT CEMENT

- Specific Surface > 350 m2/ kg.
- Compressive strength not less than
  - 72 ± 1 hour . 15.69 N/mm2
  - 168 ± 2 hours. 21.57 N/mm2
  - 672 ± 4 hours. 30.40 N/mm2
- ★ **Weak point** is. **small strength gain** during the **initial period** because of the hydrophobic films on cement grains which prevent the interaction with water
- 28-day strength is equal to that of OPC.

*(xiv) WATER PROOF CEMENT

- *Resistant to penetration of water.*
- *Water retaining structures like*
  - *tanks,*
  - *reservoirs,*
  - *retaining walls,*
  - *swimming pools,*
  - bridge piers, etc.
- It is manufactured by adding following at the time of grinding:
  - Strearates of Ca and Al
  - Gypsum treated with tannic acid