

BUILDING MATERIAL CHAPTER-1 CEMENT

SYLLABUS (ESE)

Stone, Lime, Glass, Plastics, Steel, FRP, Ceramics, Aluminum, Fly Ash, Basic Admixtures, Timber, Bricks and Aggregates: Classification, properties and selection criteria;

Cement: Types, Composition, Properties, Uses, Specifications and various Tests; Lime & Cement Mortars and Concrete: Properties and various Tests; Design of Concrete Mixes: Proportioning of aggregates and methods of mix design.

SYLLABUS (GATE)

Construction Materials and Management: Construction Materials: Structural Steel – Composition, material properties and behaviour; Concrete - Constituents, mix design, short-term and long-term properties.

INTRODUCTION

Cement is an artificial building material which has cohesive and adhesive property and which is able to bind together particles of solid matter and form a compact and durable mass.

Cement acquires adhesive property when it is mixed with water.



Bag of cement



Loose cement.

HISTORICAL DEVELOPMENT

First introduction of cement : In 1824, Joseph Aspdin was first to introduce Portland cement formed by heating a mixture of limestone and finely divided clay in furnace.

Prototype of Modern Portland cement : The prototype of modern cement in plant was formed by Isaac Johnson in 1845 who burnt a mixture of clay and chalk until clinkering.

GENERAL PROPERTIES OF CEMENT (ORDINARY PORTLAND CEMENT)

* Fineness of cement ↑ then
SP. gravity will be same
(-1 एत बिन्दु पर एत बिन्दु)

Solid form
(Cement) SP. 3150 kg/m³

CEMENT
50 kg

Property	Description
Weight of 1 bag of cement	50 kg
Density of cement	1440 kg/m ³
Volume of 1 bag of cement	0.0347 m ³ = 35 liter
Specific gravity of cement	3.15
Color	Gray

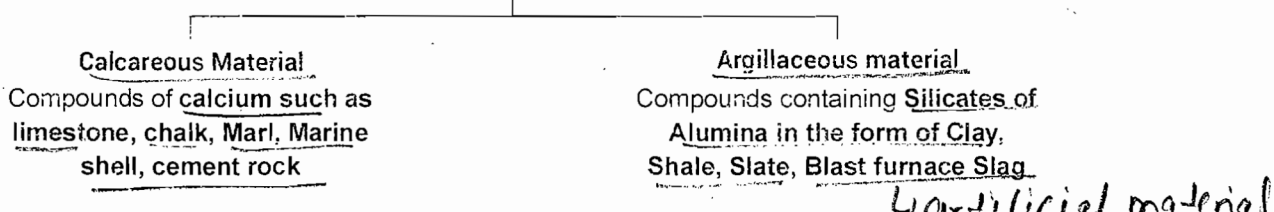
50
1940

$$G = \frac{W_s}{V_w}$$

MANUFACTURING OF CEMENT

Raw materials required for manufacture of Portland cement are calcareous and argillaceous material.

Raw materials for cement



Cement → Hydraulic Cement (react with water) ex diam, retaining
 → non H.C [non react with water] ex (POP) water resistance not resist

[2] BUILDING MATERIAL

CEMENT

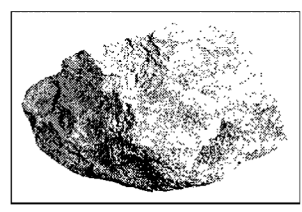
CALCAREOUS MATERIALS



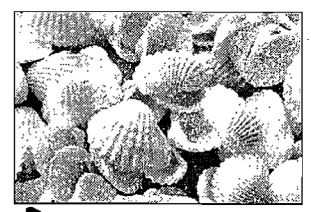
limestone



chalk

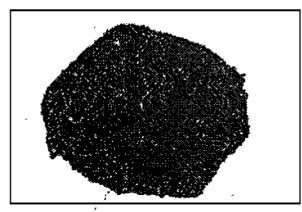


Marl stone

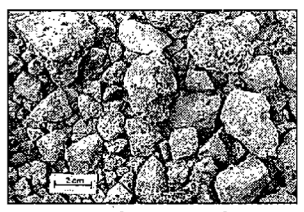


Marine shell

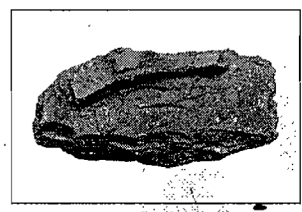
ARGILLACEOUS MATERIALS



Clay



Blast furnace slag



Shale



Slate

under water - gne.
 quick S.C. (strongest)
 RMC

CHEMICAL COMPOSITION OF RAW MATERIALS

calcium → sand

Three basic constituents of hydraulic cements are lime, silica and alumina.

Relative proportions of these oxide compositions are responsible for influencing the various properties of cement.

The approximate limits of chemical composition in Ordinary Portland cement and their effects are :

Ingredient	Composition (%)	Average (%)	Function	Excess/Deficiency causes
Lime (CaO)	60 to 65	62	It controls strength and soundness	Its deficiency reduces strength and setting time. Presence of unburnt lime (free lime) causes unsoundness
Silica (SiO ₂)	17 to 25	22	It imparts strength	Excess of it increases the strength but setting action is prolonged (Setting time ↑)
Alumina (Al ₂ O ₃)	3 to 8	5	Responsible for quick setting	If Alumina is in excess strength of cement decreases * Helps in reducing the clinkering temperature
Iron oxide (Fe ₂ O ₃)	0.5 to 6	3.3	Gives strength, hardness and color (gray) and helps in fusion of different ingredients.	Excess amount produces hard clinker dif?cult to grind.
Magnesia (MgO)	0.5 to 4	2.4	It imparts color (yellowish) and hardness (rigidity of paste).	Excess amount makes the cement <u>unsound</u> .
Sulphur trioxide (SO ₃)	1 to 2	1.5	Makes cement sound	Excess of it makes cement <u>unsound</u> .
Alkalies [Soda (Na ₂ O) and Potash (K ₂ O)]	0.5 to 1.3	0.9	These are residue Accelerate setting of cement paste	Excess of it cause efflorescence and Cracking due to alkali aggregate reaction.

Strength gain

Setting → Loading plasticity
 → Hardening occur after setting

Al₂O₃ setting time ↓

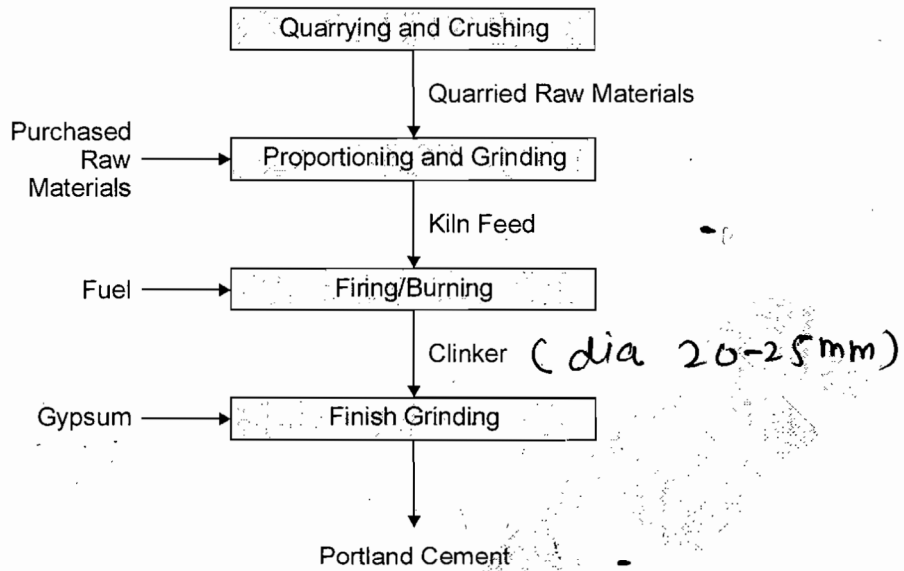
efflorescence

Cement + Agg → Alkali silica gel
 alkali ↓ silica

→ deficiency of lime ↑ the setting action (T/F)

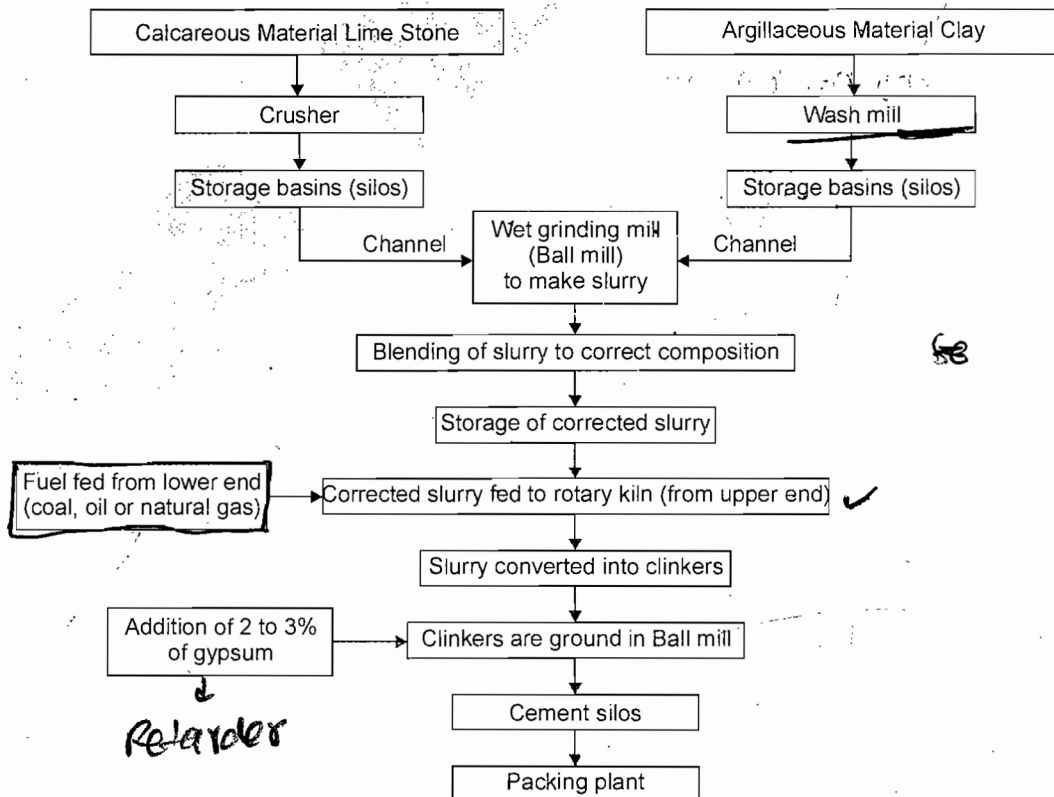
Setting time ↑

MANUFACTURING OF CEMENT



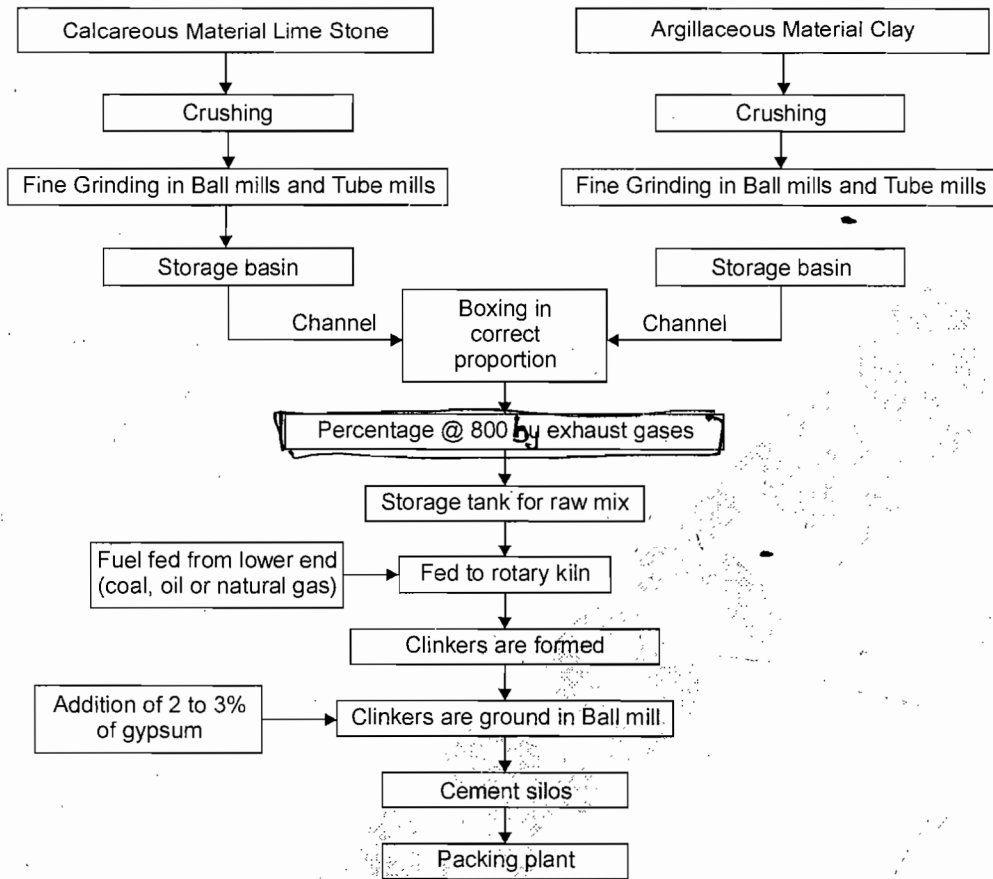
- ↳ Process consists of crushing the raw materials, mixing them in certain proportions depending upon their purity and composition and burning them in a kiln at 1300 to 1500°C.
- ↳ At this temperature, material sinters and fuses to form what is called as clinker.
- ↳ Clinker is cooled & grounded to fine powder, addition of Gypsum (3- 5%) in order to prevent flash-setting of the cement, this results in formation of Ordinary Portland cement.
- ↳ Two process i.e. wet and dry process.

WET PROCESS



Retarder

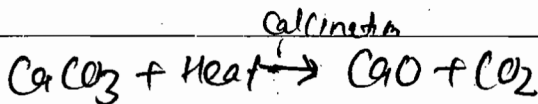
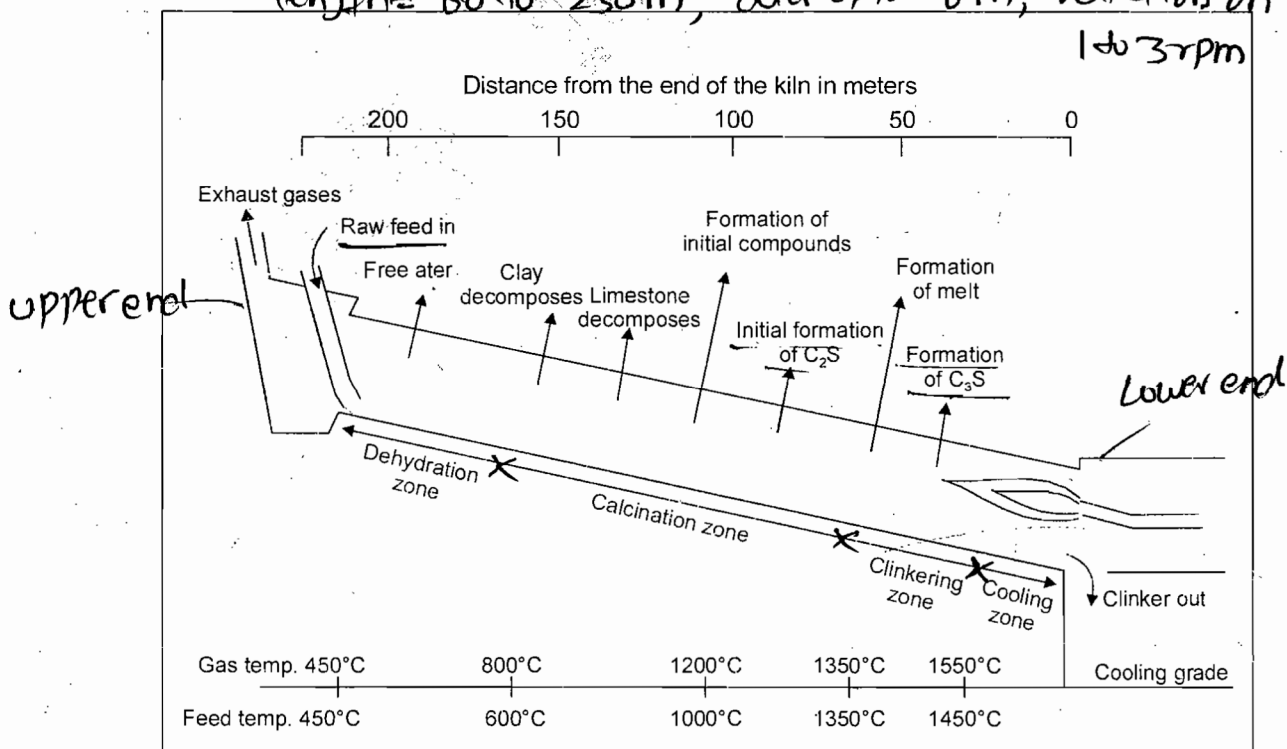
DRY PROCESS :



KILN :

length = 80 to 230 m, dia upto 8m, rotation on

1 to 3 rpm



1. C₃S is formed at 1450°C, C₂S at 1350°C, C₄S at 1200°C

• moderate cooling is good for higher strength

SUMMARY

↳ Advantages of wet process:

- Low cost of excavating and grinding raw materials as opposed to the harder materials used in dry process.
- Accurate control of composition and homogeneity of the slurry.
- X • Economical utilization of fuel through the elimination of separated drying operations

↳ Disadvantages of wet process:

- Longer kilns, less responsive to variable clinker demands than the shorter kilns used in dry process.

↳ Advantages of Dry process:

- The equipment used in the dry process kiln is comparatively smaller.
- The process is quite economical.
- The total consumption of coal in this method is only about 100 kg when compared to the requirement of about 350 kg for producing a ton of cement in the wet process.

Note:

- ✓ Previously wet process was used because control in the mixing of raw materials in powder form was not available then.
- ✓ Today dry process is used because technique of dry mixing of powdered materials is available and it is more energy efficient.

INFLUENCE OF RATE OF COOLING ON QUALITY OF CLINKER

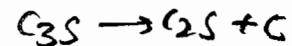
↳ Cooling rate of clinker affects Strength properties of cement, because rate of cooling affects degree of crystallization i.e. size of crystals and amount of amorphous material.

Property of amorphous material of same chemical composition will be different from crystalline material.

↳ SLOW COOLING

Produces large crystals of each phase. Slows down the reactivity of C₃A. Results in decomposition of Alite into free lime and Belite. Produces free MgO (Periclase) which causes "UN SOUNDNESS".

COO RAPID COOLING → C₂S



Produces small crystals of each phase which are more reactive and more easier to grind.

- Allows MgO to be absorbed into the solid solution of C₄AF and C₃A and hence, higher MgO in the raw meal can be tolerated.

Type of cement	Cooling condition	Compressive Strength MPa		
		3 Days	7 Days	28 Days
Normal Cement	Quick	9.9	15.3	26
	Moderate	9.7	21.0	27
	Slow	9.7	19.3	24
	Very Slow	8.7	18.7	23
High Early Strength Cement	Quick	10.2	18.8	29
	Moderate	14.2	26.7	33
	Slow	10.2	21.0	29
	Very Slow	9.1	18.1	28

COMPOSITION OF CEMENT CLINKER(BOGUE'S COMPOUNDS)

Raw materials subjected to high clinkering temperature combine with each other to form complex compounds known as Bogue's compounds.

Repair road → used RMC used

I → water → Thawing

W → Ice → Freezing

[6] BUILDING MATERIAL

CEMENT

Following Bogue's compounds are formed during clinkering process

Bogue's Compound	Formula	Name	Symbol	Composition
Tri-calcium Silicate	$3CaO \cdot SiO_2$	Alite	C_3S	25%-50%
Di-Calcium Silicate	$2CaO \cdot SiO_2$	Belite	C_2S	25%-40%
Tri-Calcium Aluminate	$3CaO \cdot Al_2O_3$	Celite	C_3A	8%-12%
Tetra-Calcium Alumina Ferrite	$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$	Felite	C_4AF	6%-10%

Silicate
↓ responsible for
Strength

Aluminate
↓ responsible for
setting action

Notations : C=CaO , S=SiO₂ , A=Al₂O₃ , F=Fe₂O₃

Difference in the various types of Portland cement arises due to variation in the relative proportion of these compounds

TRI CALCIUM SILICATE (C₃S)-(25-50%) (NORMALLY 40%)

- Best cementing material among all four Bogue's Compounds. ✓
- It Helps clinker easy to grind.
- It increases resistance to freezing and thawing and is solely responsible for gain of strength up to 28 days
- It hydrates rapidly generating high heat and develops an early hardness and strength (mainly 7 Days)
- Raising of C₃S content beyond the specified limits, increases heat of hydration and solubility of cement in water, but free lime will be more and cement will be unsound.

hardens → rate of strength

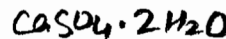
DI CALCIUM SILICATE (C₂S) (25-40%) (NORMALLY 32%)

- ↳ It hydrates and hardens slowly (>1 year or more) hence responsible for ultimate strength.
- ↳ It imparts resistance to chemical attack.
- ↳ At early ages (<1 month), C₂S has little influence on strength & hardness, But after 1 year, it is almost equal to C₃S.
- ↳ Raising of C₂S content results in harder to grind clinker, reduce early strength, decrease resistance to freezing & thawing at early ages and decreases heat of hydration.

C₂S ↑ CALOR ↓

TRI CALCIUM ALUMINATE (C₃A) (8-12%) (NORMALLY 10%)

- ↳ It rapidly reacts with water and responsible for flash set (stiffening without strength development).
- ↳ Unless the rapid hydration of C₃A is not slowed down, Portland cement can not be used for most construction purposes.
- ↳ Rapidity of action is controlled by the addition of 2-3% of gypsum (calcium sulphate) at the time of grinding of cement.
- ↳ It is responsible for the initial setting, high heat of hydration and has greater tendency to volume change causing cracking.
- ↳ Raising of C₃A contents reduces the setting time, resistance to sulphate attack decreases and lowers the ultimate strength.

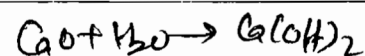


TETRA CALCIUM ALUMINA FERRITE (C₄AF) (6-10%) (NORMALLY 8%)

C₃A → Sulfate prone to sulfate attack
C₄AF

- ↳ It is also responsible for flash set but generates less heat.
- ↳ It has poorest cementing value because hydrated product due to C₄AF does not contribute anything to the strength.
- ↳ If C₄AF is increased, it slightly reduces the strength.
- ↳ Resistance to sulphate attack decreases. However it is less prone to sulphur attack compared to C₃A due to presence of Fe in it.

C₃S



ET PHA ↓ RISE

STRENGTH DEVELOPMENT OF BOGUE'S COMPOUNDS WITH AGE

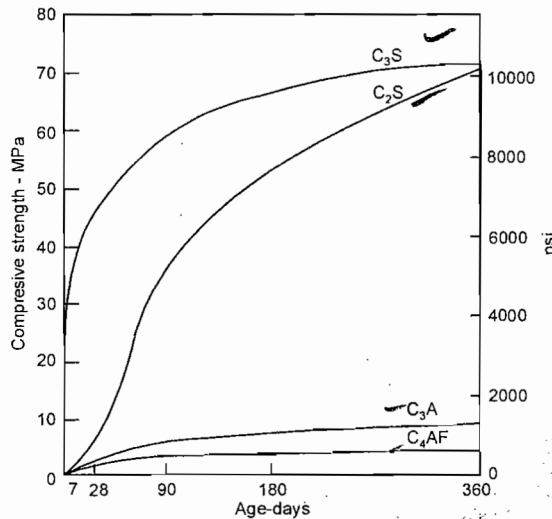
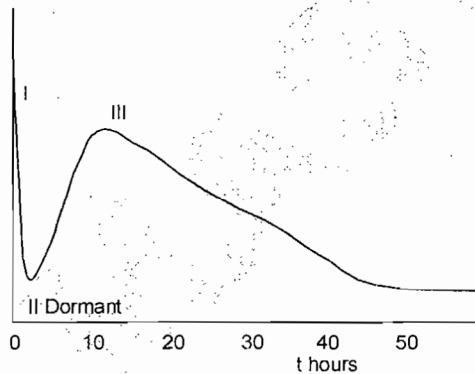


Fig. Development of strength of pure compounds

Strength Contribution
 $C_3S > C_2S > C_3A > C_4AF$

HYDRATION OF CEMENT

gypsum \rightarrow dihydrate
 gypsum \rightarrow monohydrate



C-S-A - Cal. Sulpho-
 aluminate is called
 ettringite

Chemical reaction between cement and water is known as Hydration of cement.

It is an exothermic reaction and the amount of heat liberated is called "Heat of Hydration".

Almost immediately on adding water some of the clinker sulphates and gypsum dissolve producing an alkaline, sulfate-rich solution

- The C₃A reacts with the water to form an aluminate-rich gel. The gel reacts with sulfate in solution to form small rod-like crystals of ettringite.
- C₃A reaction with water is strongly exothermic but does not last long, typically only a few minutes, and is followed by a period of a few hours of relatively low heat evolution. This is called the dormant, or induction period.

HYDRATION OF CEMENT

As the dormant period progresses, the paste becomes too stiff to be workable.

At the end of the dormant period, the alite and belite in the cement start to react, with the formation of calcium silicate hydrate and calcium hydroxide.

- This corresponds to the main period of hydration, during which time concrete strengths increase.
- The individual grains react from the surface inwards, and the anhydrous particles become smaller. C₃A hydration also continues, as fresh crystals become accessible to water.

Ferrite reaction also starts quickly as water is added, but then slows down, probably because a layer of iron hydroxide gel forms, coating the ferrite and acting as a barrier, preventing further reaction.

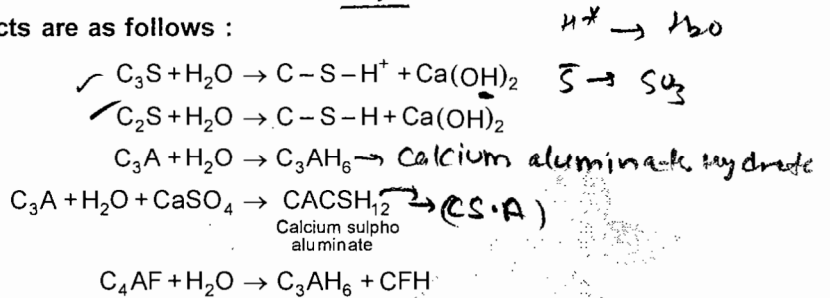
At any stage of hydration, cement paste consists of gel (a fine grained product of hydration having large surface area), unreacted cement, calcium hydroxide, water and some minor compounds.

dry cement

The crystals of various resulting compounds form an interlocking and gradually filling the space occupied by water, resulting in the stiffening of the mass and subsequent development of strength.

✓ **The setting (the change of cement paste from plastic to stiff solid state) and hardening (gain of strength with hydration) is a chemical reaction**, wherein water plays an important role, and is not just a matter of drying out, in fact setting and hardening stop as soon as the concrete becomes dry.

Reactions of compounds and their products are as follows :



- ✓ C—S—H gel (calcium silicate hydrate) also known as 'Tobermorite gel'.
- ✓ C₃S produces lesser C—S—H and more Ca(OH)₂ compared to C₂S
- ✓ Ca(OH)₂ is not a desirable product in the concrete as it is soluble in water and gets leached out making the concrete porous
- ✓ Particularly in hydraulic structure, cement with small % of C₃S and more C₂S is recommended

Alternative way to overcome this difficulty is to grind some pozzolanic material with cement.

Pozzolana is a siliceous material which reacts with lime in presence of moisture to give a relatively strength producing calcium silicates.

Ca(OH)₂ reacts with sulphate present in soil or water to form CaSO₄ that further reacts with C₃A to form ettringite (227% of C₃A volume) resulting in cracks and disintegration of concrete

The only advantage of Ca(OH)₂ is that being alkaline in nature it maintains pH of 13 in concrete which resists the corrosion of reinforcement.



HEAT OF HYDRATION

Heat of Hydration of the Bogue's compounds will be in following descending order.

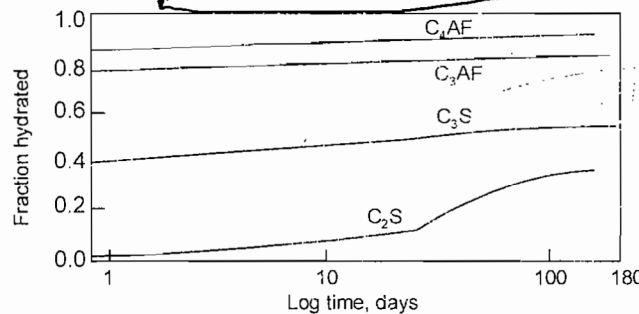
$$C_3A > C_3S > C_4AF > C_2S$$

Bogue's Compound	Heat of hydration
Tri calcium Silicate(C ₃ S)	500 J/g ✓
Di Calcium Silicate(C ₂ S)	260 J/g ✓
Tri Calcium Aluminate(C ₃ A)	865 J/g ✓
Tetra Calcium Alumina Ferrite(C ₄ AF)	420 J/g ✓

RATE OF HYDRATION

Rate of hydration of the Bogue's compounds is in following descending order:

$$C_4AF > C_3A > C_3S > C_2S$$



although rate of hydration of C₄AF is higher than that of