PROPERTIES OF STRUCURAL MATERALS

(SE-503)

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Course Learing Outcome (CLO's)

Sr. No.	Objective
1	Understand the general behavior of concrete
2	Strength and durability issues in concrete
3	Repair and strengthening of concrete structures using innovative materials
4	Destructive and Non destructive testing of concrete

Significance of proper material selection

- Structural engineering depends on the knowledge of materials and their properties, in order to understand how different materials support and resist loads.

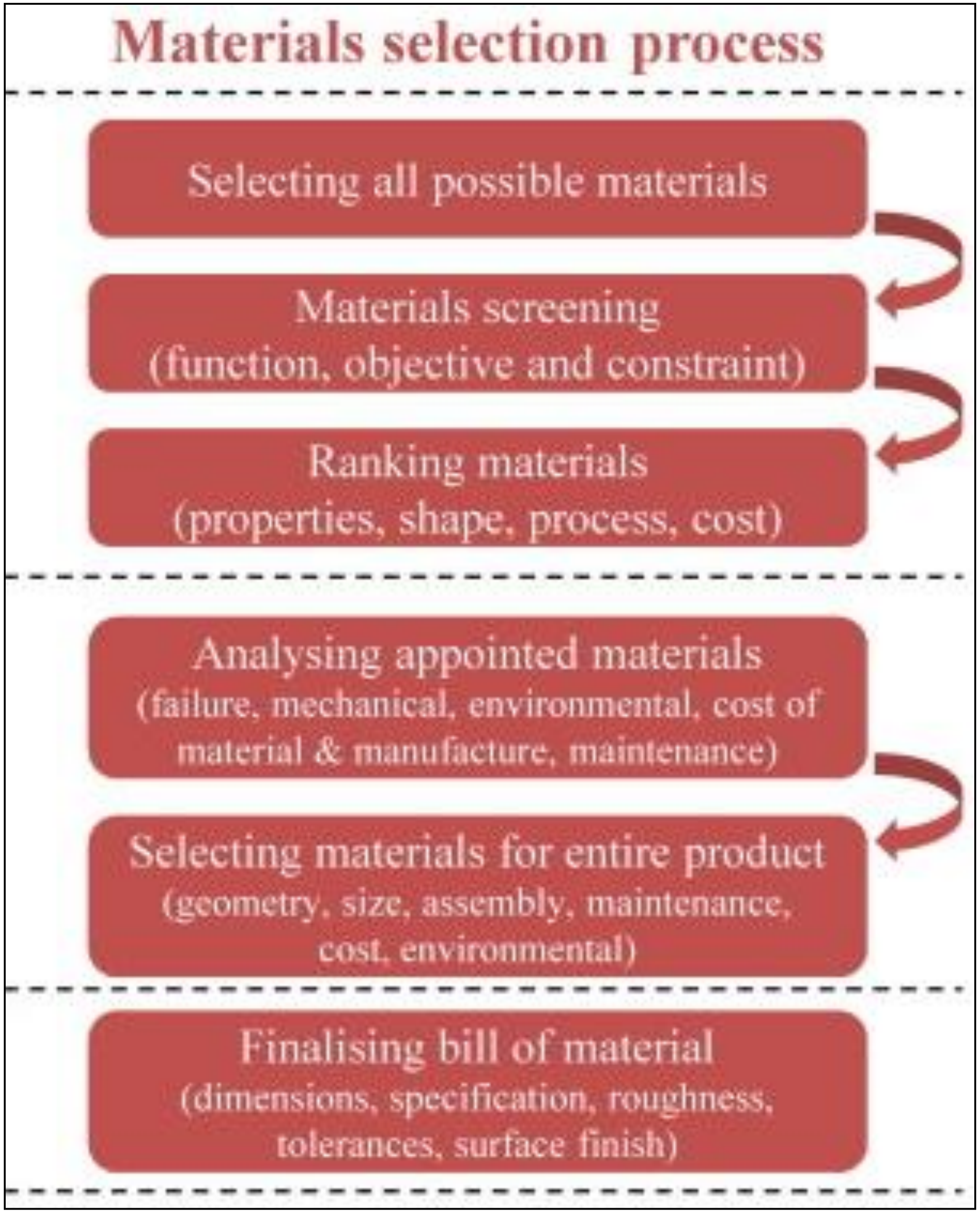
Selection criteria:

  - Component function,
  - Objective and
  - Constraints

- Due to the large variety of materials, selection of materials for a given job may be a challenging task.
- If the selection process is not rigorous, the designer may opt for an inappropriate material or overlook an attractive alternative material.
- Utilising systematic materials selection processes is therefore essential.

Significance of proper material selection

- The two key steps in materials selection are screening and ranking. The former enables to quickly narrow the field of possible materials to a manageable few while the latter narrows the choices further and then evaluates and ranks the choices to identify the optimal material(s).



Factors Determining the Choice of Proper Material for a Structure

- Strength, rigidity & Durability Requirements
  - Permanent loading → Creep Strength
  - Repeated loading → Fatique Strength
  - Impact loading → Toughness & Resilience
  - Surface loading → Hardness & Resistance to abrasion
- Environmental Requirements
  - Temperature change → coefficient of thermal conductivity
  - Moisture movement → permeability
  - Chemical effects → chemical composition

Factors Determining the Choice of Proper Material for a Structure

- Economy.
- Choose the cheaper & available materials considering;
  - Initial cost
  - Useful life
  - Frequency of maintenance
  - Cost of maintenance
  - Salvage value (damaged value)
    prevention from damage
  - Comfortability

General Properties of Civil Engineering Materials

- Physical **
- Mechanical **
- Chemical
- Other
  - Thermal, Acoustical, Optical, Electrical

    Related to Sound

** Most CE Applications Focus on Physical & Mechanical Properties

Physical Properties

- Properties of physical structure
  - density
  - specific gravity
  - porosity
  - permeability
  - surface energy
  - texture (micro, macro)
  - other (color, thermal expansion, shape)

Mechanical Properties

- Resistance to applied loads (stress) initially & over time
  - stiffness
  - strength
  - fracture / yielding (brittle / ductile)
  - tension
  - compression
  - flexure (bending)
  - torsion
  - direct shear
  - multiaxial

Chemical Properties

- Chemical composition, potential reaction with environment
  - oxide content
  - carbonate content
  - acidity, alkalinity
  - resistance to corrosion

Determining the Properties of Civil Engineering Materials

- Properties of materials are determined by
  - Laboratory testing
  - Field testing.

- To avoid inconsistencies in test results **STANDARDS** are devised which describe the test apparatus and the procedure.

Items usually standardized in a test are:

- Obtaining test specimens and number of specimens
- Size and shape of the specimen
- Preparation of specimens for testing
- Temperature & moisture during preparation & testing
- Type of machinery
- Rate of loading
- Interpretation of test results
- Writing a report

An Introduction to

C O N C R E T E, IT'S INGREDIENTS & PROPERTIES

Dr. Muhammad Yousaf

International Context

- Population growth and need for new infrastructure
- Decaying existing infrastructure
- Transportation congestion
- Climate change and more frequent natural disasters inflicting damage to infrastructure
- World population growth
- RC structure continue to deteriorate prematurely

International Context

INTRODUCTION

Concrete - composite construction material

Cement + Coarse Aggregate + Fine Aggregate + Water + Chemical Admixtures

In its simplest form, concrete is a mixture of paste and aggregates.

The word concrete comes from the Latin word "concretus" (meaning compact or condensed).

Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration.

The water reacts with the cement, which bonds the other components together, eventually creating a robust stone-like material.

Concrete is used more than any other man-made material in the world. As of 2006, about 7.5 cubic kms of concrete are made each year—more than one cubic meter for every person on Earth.

Advantages of Concrete: Concrete is the second most consumed material after water and it shapes the built environment. An estimated 25 billion tonnes of concrete are manufactured every year. Concrete has many environmental advantages, including durability, longevity, heat storage capability, and chemical inertness.

Long-living

- Ability to be Cast
- Fire resistant
- On-site fabrication
- Aesthetic properties.
- The raw materials used in cement production are widely available in great quantities.
- Needs little or no finish or final treatments.

Advantages of Concrete

- Chemically inert concrete doesn't require paint to achieve a given colour; natural -mineral pigments and colouring agents can be added at the mixing to provide a rainbow of options.
- Low maintenance.
- Can be reused or recycled.
- Concrete can be reused with bituminous asphalt as road base materials, can be recycled and reused by crushing into aggregates for new concrete or as fill material for road beds or site works.

Limitations of Concrete

- Low tensile strength
- Low ductility
- Volume instability
- Low strength-to-weight ratio

Progress in Concrete Technology

- Lightweight Concrete
- High-Strength Concrete
- High Workability or Flowing Concrete
- Shrinkage Compensating Concrete
- Fiber-Reinforced Concrete
- Concrete Containing polymers
- Heavyweight Concrete
- High density concrete etc

Investigation of concrete structures

➢ Utility of the investigation:

Concrete is generally investigated at different sub-division levels. when we want to numerically model the concrete then micro, meso or macro level models can be considered depending upon the purpose of modeling to investigate which aspect of its properties to be considered as relevant properties are to be given / incorporated to the model program.

3-levels of investigation:

- Micro level:

Here we take in to account the micro-structure of the cement paste and the interaction between the cement particles and water and / or admixtures. It may consist of (i) Unhydrated cement particles (ii) C-S-H Gel (iii) CH and (iv) Gel pores. Actually the micro-structure is heterogeneous (diversity in the type, size, amount, and distribution of phases present in solid constituent) so, this can't be modeled easily but its knowledge and relationship b/w individual components is necessary to control the properties of concrete.

Investigation of concrete structures

The term **microstructure** is used for the microscopically magnified portion of a macrostructure.

- Progress in the field of materials has resulted primarily from recognition of the principle that the properties of a material originate from its internal structure.
- The properties can be modified by making suitable changes in the structure of a material.
- The gross elements of the structure of a material can readily be seen, whereas the finer elements are usually resolved with the help of a microscope.

Investigation of concrete structures

➢ Meso level:

Here concrete cracks, coarse and fine aggregate particles, other inclusions like powder, Cement matrix and ***ITZ*** (Zone / layer / boundary b/w the matrix and coarse aggregates)etc. are considered.

- Importance of ITZ is realized w.r.t tensile strength, compressive and bond strength. ITZ is the weakest zone and is looser than that of the binder paste mass and its strength is lower. Under the action of external force, *fracture* commonly initiates from inside of this zone.

Investigation level

➢ Macro level:

- Concrete is treated as a continuum and is taken as homogeneous entity.
- The term **macrostructure** is generally used for the gross structure, visible to the human eye.
- The limit of resolution of the unaided human eye is approximately one-fifth of a millimiter (200 µm).

“Laws of Fives”

- $1 spent on design and construction
- equivalent to $5 spent as damage initiates and before it propagates
- $25 once deterioration has begun to propagate
- and $125 after extensive damage has occurred
- This course: Focus on the $1 to $5 situation, so as not to face the $25 or $125 situation
- Caution: poorly designed and/or executed repairs can worsen situation

Classification of Concrete

Based on unit weight

- Ultra light concrete <1,200 kg/m3
- Lightweight concrete 1200- 1,800 kg/m3
- Normal-weight concrete ~ 2,400 kg/m3
- Heavyweight concrete > 3,200 kg/m3

Based on strength (of cylindrical sample)

- Low-strength concrete < 20 MPa compressive strength
- Moderate-strength concrete 20 -50 MPa compressive strength
- High-strength concrete 50 - 200 MPa compressive strength
- Ultra high-strength concrete > 200 MPa compressive strength

Based on additives:

- Normal concrete
- Fiber reinforced concrete
- Shrinkage-compensating concrete
- Polymer concrete

States of concrete

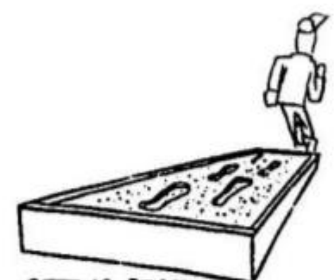
Concrete has three different states:

- PLASTIC : Plastic concrete in a relatively fluid state can be readily molded by hand like a clump of modeling clay.

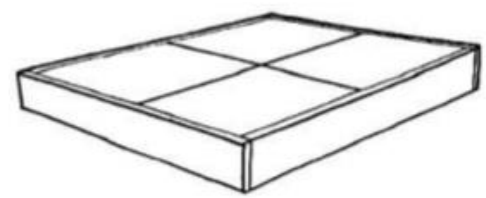
- SETTING: The stiffening of concrete, when it is no longer soft

- HARDENING: This is the end product of any concrete design.

PLASTIC STATE



SETTING STATE



Material Properties of Concrete

The Properties of Concrete are its characteristics or basic qualities :

- Workability
- Uniformity
- Non-segregation

} Plastic concrete

- Strength
- Durability
- Watertightness

} Hardened concrete

AGGREGATES

Aggregates, which account for **60 to 75 percent of the total volume of concrete**, are divided into two distinct categories.

Coarse Aggregate

- Aggregate size more than 4.75mm
- Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder

Fine Aggregate

- Aggregate size less than 4.75mm
- Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a sieve.

Aggregate processing consists of **crushing, screening, and washing the aggregate** to obtain proper cleanliness and gradation.

Once processed, the aggregates are **handled and stored** in a way that **minimizes segregation and degradation and prevents contamination.**

Aggregates strongly influence concrete's freshly mixed and hardened properties, mixture proportions, and economy.

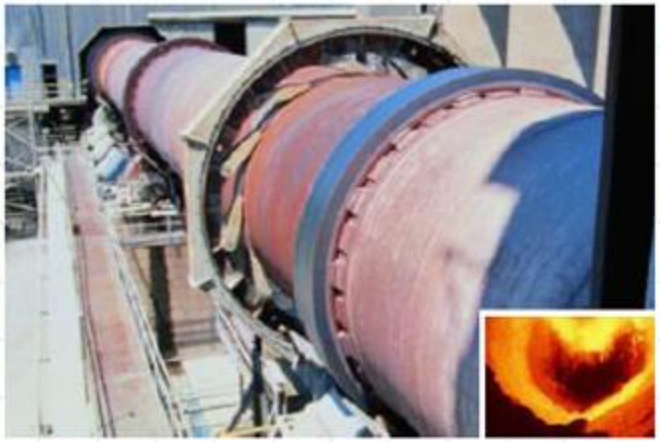
SUITABILITY REQUIREMENTS FOR AGGREGATES

Some of the important characters of the aggregates are:

- Strength
- Size
- Particle shape
- Surface texture
- Grading
- Impermeability
- Cleanliness
- Chemical inertness
- Physical and Chemical Stability at high temperatures
- Co-efficient of thermal expansion
- Cost

To summarize, the aggregate should be composed of inert mineral matter, should have high resistance to attrition, should be clean, free from any adhering coating, dense, durable and sufficiently strong to enable the full strength of the cement matrix to be developed.

(Attrition: A reduction or decrease in size or strength)

Introduction: Cement

World Production of Cement

- World production around 500 million tonnes.
- Percentage of use varies between 3 and 57% (of total production).
- Percentage of use in concrete is 7 to 96% (of total used depending on location).
- In North America, 12 to 15% (of total production) is used in concrete, in Europe about 10%.

Cement

- Most commonly used cement is called Portland Cement patented in 1824 in England, when mixed with water, hardens, hence hydraulic cement .
- Basic raw materials used in the manufacture of cement are calcium carbonate found in lime Stone or chalk, and silica, alumina and iron oxide found in clay or shale.

History of Cementing Material

- Oldest cementing material: mud mixed with straw to bind un-burnt bricks (ancient Egypt). No resistance to water. Works only in very dry climates.
- Ancient Egyptians used gypsum in the construction of the pyramid of Cheops (3000 BC). Setting will not take place in water (non-hydraulic binder, gypsum is soluble in water).
- Lime mortars (by calcinating limestone) were used in Egypt in the Roman period and earlier in Crete, Cypris and Greece.

(A **Greek** island in the Mediterranean)

History of Cementing Material

This bridge, over the river Gard, is 275 meters (900 feet) long and 49 meters (160 feet) high. It was part of an aqueduct nearly 50 kilometers (30 miles) long which supplied Nimes with water

A city of southern France

Hydraulic lime is a general term for varieties of lime (calcium oxide), or slaked lime (calcium hydroxide), used to make lime mortar which set through hydration: thus they are called *hydraulic*.

Hydraulic Lime

Calcining: To reduce, oxidize, or desiccate by roasting or exposing to strong heat.

- Greek and Romans produced hydraulic limes by calcinating limestone containing clayey impurities
- They also knew that some volcanic deposits when ground and mixed with lime produce mortars which are not only stronger, but also resistant to water.
- Best variety was found near village of Pozzuoli in Italy, the origin of the name pozzolana

Hydraulic Mortars

The Romans used hydraulic mortars to make a form of concrete. The Pantheon, the best preserved building of the ancient world (2nd century AD) was largely built using concrete.

A **building** in Rome, Italy,

Dome is 141 ft 6 in in diameter

Evolution of Cement

STAGE 1 : materials used before invention of cement:

Clay (calcium silicate)

Calcined Gypsum mortar (calcium sulphated-hidrate)

Mixture of lime (CaCo3) sand and water

STAGE 2 : Invention of Pozzolanic-cement

Romans were the 1st ones who developed a cement by mixing of slaked lime with Pozzolan, a volcanic ash from Mount Vesuvius. This cement was called as 'Pozzolanic cement' and was capable of hardening underwater.

STAGE 3 : Invention of Portland cement

Joseph Aspdin, a mason produced a material by firing finely ground clay and limestone until the clay was calcined. He named it as' Portland cement in1824

Evolution of Cement

STAGE 4 : Development of Portland cement

In1845 ,Isaac Johnson made the first modern Portland cement by firing a mixture of chalk and clay at much higher temperatures

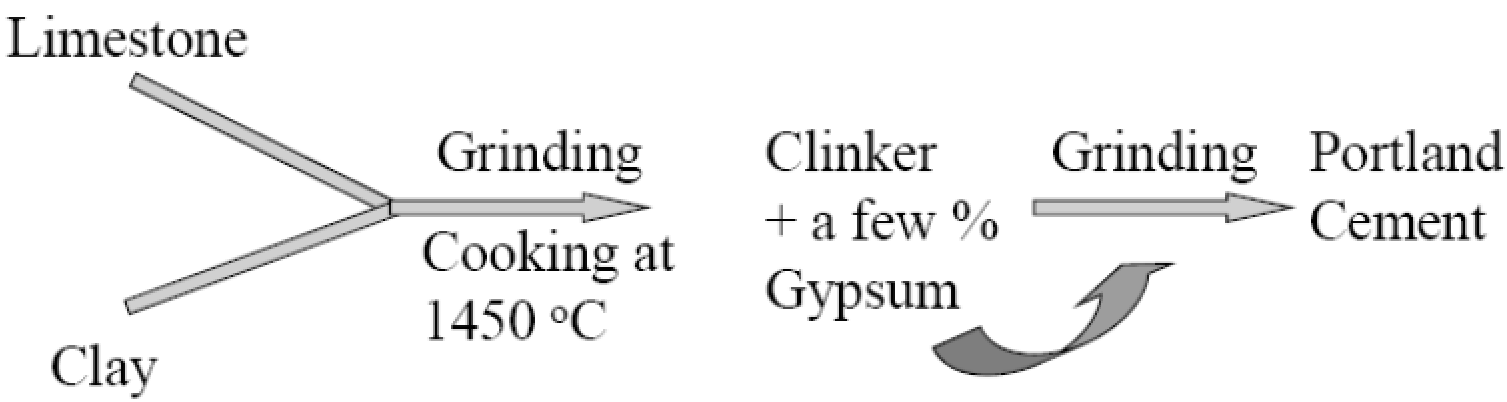
STAGE 5 : Invention of different types of Cement

As cement industry went on developing, many different types of cements with different chemical properties were started to be manufactured for variety of uses.

PRODUCTION STEPS

1) Raw materials are crushed, screened & stockpiled.
2) Raw materials are mixed with definite proportions to obtain "raw mix". They are mixed either dry (dry mixing) or by water (wet mixing).
3) Prepared raw mix is fed into the rotary kiln.
4) As the materials pass through the kiln their temperature is raised upto 1300-1600 °C. The process of heating is named as "burning". The output is known as "clinker" which is 0.15-5 cm in diameter.
5) Clinker is cooled & stored.
6) Clinker is ground with gypsum (3-6%) to adjust setting time.
7) Packing & marketting.

Cement Manufacturing



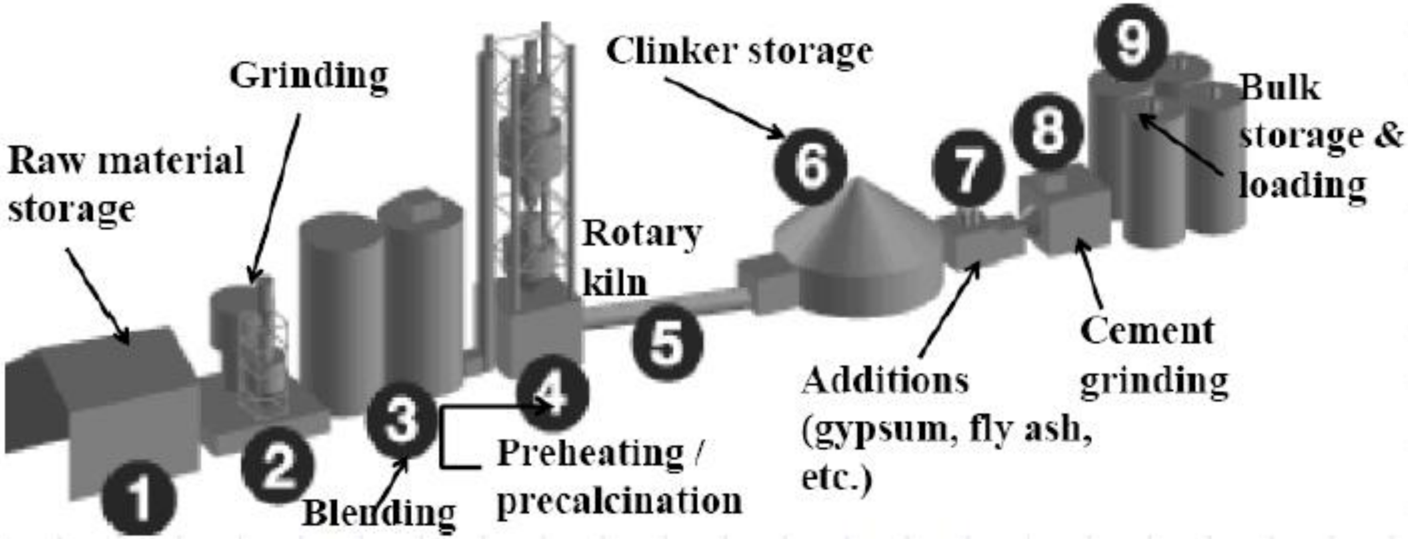
Lime = CaO,

Iron = Fe_2O_3

Silica = SiO_2,

Alumina = Al_2O_3

Development of Portland Cement

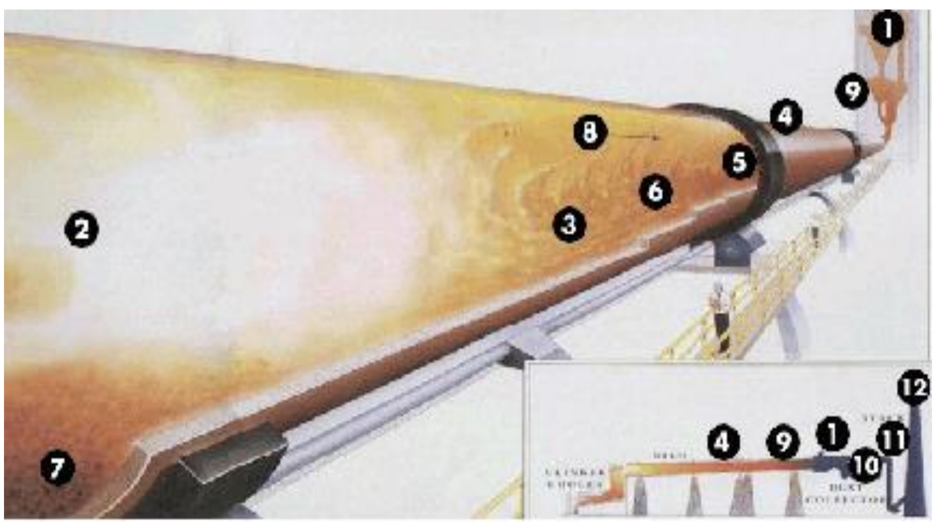


Development of Portland Cement

After cooking in a kiln at about 1500 °C

The raw material becomes cement clinker

KILN



CEMENT SILOS

Development of Portland Cement

Clinker is ground with small proportions of gypsum to give portland cement

Clinker

Gypsum

Raw Materials for Cement Manufacturing

- Lime (CaO): limestone, marble, calcite, seashells, etc.
- Silica (SiO_2): clay, sand, calcium silicate, etc.
- Alumina (Al_2O_3): clay, shale, bauxite, etc.
- Iron Oxide (Fe_2O_3): iron ore, blast furnace dust, etc.

Impurities

- Other impurities exist in clinker: free lime, MgO, alkalis (Na_20 and K_2O), sulfates, etc.
- They lower the melting temperature & improve combination of lime.
- Their incorporation in silicates improves strength.

Cement Ingredients

The main features of these Cement ingredients along with their functions and usefulness or harmfulness are given below:

Function of Lime: Lime is calcium oxide or calcium hydroxide.

Presence of lime in a sufficient quantity is required to form silicates and aluminates of calcium.

Deficiency in lime reduces the strength of cement.

Deficiency in lime causes cement to set quickly.

Excess lime make cement unsound.

Excessive presence of lime cause cement to expand and disintegrate.

Silica: Silicon Di-oxide is known as Silica, chemical formula SiO_2.

Sufficient quantity of silica should be present in cement to dicalcium and tricalcium silicate.

Silica imparts strength to cement.

Silica usually present to the extent of about 30 percent cement.

Alumina: Alumina is Alumina oxide Chemical formula is Al_2O_3.

Alumina imparts quick setting property to the cement.

Clinkering temperature is lowered by the presence of requisite quantity of alumina.

Excess alumina weaken the cement.

Magnesia: Magnesium Oxide. Chemical formula is MgO.

Magnesia should not be present more than 2% in cement.

Excess magnesia will reduce the strength of the cement.

Iron oxide: Chemical formula is Fe_2O_3.

Iron oxide imparts color to cement.

It acts as a flux. Bonding with impurities in molten state to remove them.

At a very high temperature it imparts into chemical reaction with calcium and aluminum to form tricalcium aluminoferrite.

Tricalcium aluminoferrite imparts Hardness and strength to cement.

Calcium Sulfate: Chemical formula is $CaSO_4$

.

This is present in cement in the form of gypsum($CaSO_4.2H_2O$)

It slows down or retards the setting action of cement.

Sulfur Trioxide: Chemical formula is SO_3

.

Should not be present more than 2%.

Excess Sulfur Trioxide causes cement to unsound.

Alkaline:

Should not be present more than 1%.

Excess Alkaline matter causes efflorescence.

Typical Oxide Composition in Cement

CaO	63%	C	SO_3	2
SiO_2	20	S	K_2O and Na_2O	1
Al_2O_3	6	A	Others	1
Fe_2O_3	3	F	Loss on ignition	2
MgO	1		Insoluble residue	½

Cement Chemist Notation

Major Constituents of Cement

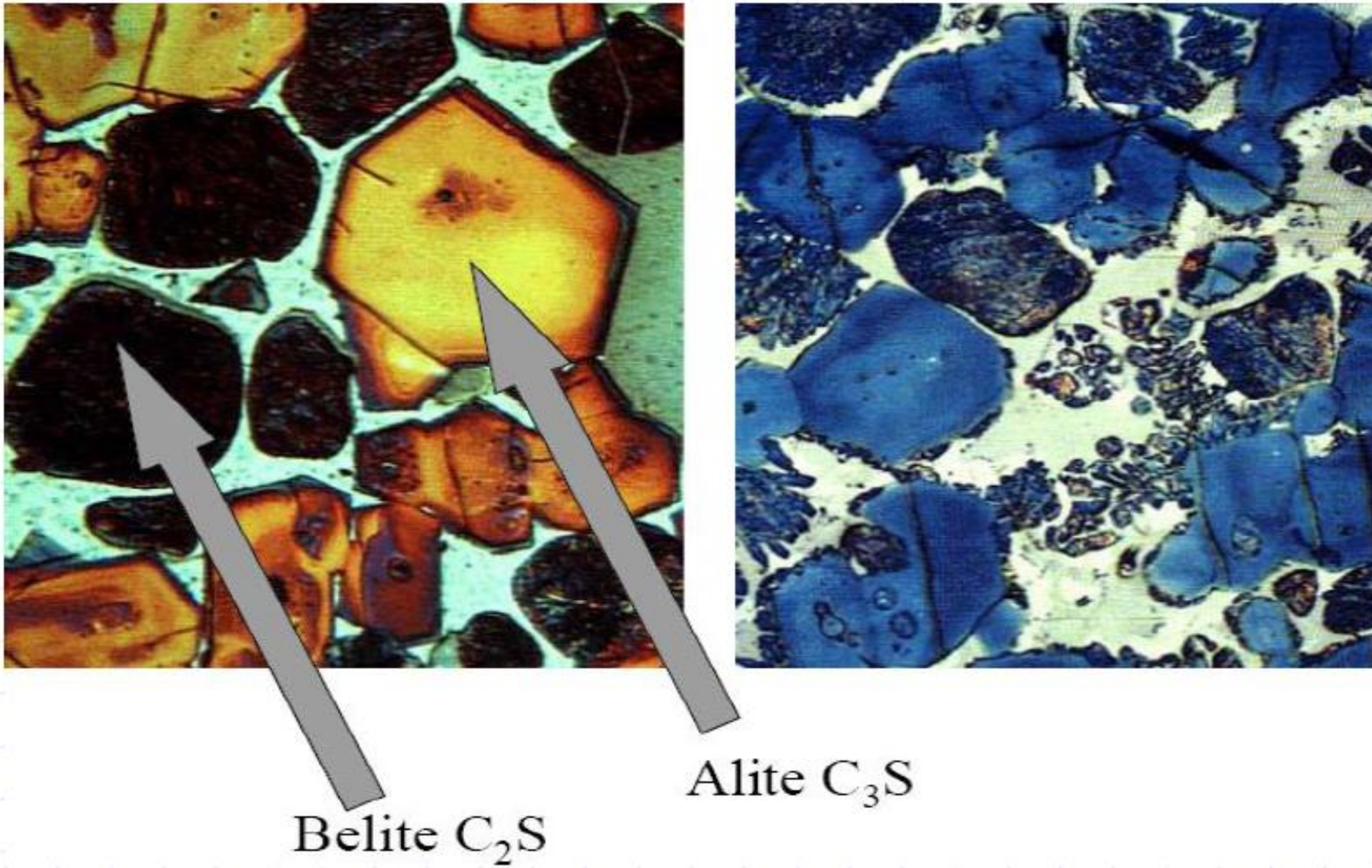
These oxides interact in the kiln to form more complex products. Upon cooling, crystallization takes place.

The four major constituents (about 90%) of cement are:

Name of compound	Oxide composition	Notation
Tricalcium silicate	$3CaO.SiO_2$	C_3S
Dicalcium silicate	$2CaO.SiO_2$	C_2S
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A
Tetracalcium aluminoferrite	$4CaO.Al_2O_3.\ Fe_2O_3$	C_4AF

Cement Chemist Notation

Major Constituents of Cement



Major Constituents of Cement

(Characteristics)

1) C_3S Tri-Calcium Silicate

- $3CaO \cdot SiO_2$ -"C_3S - Alite"
- Provides Early strength development
- 70% reacts by 28 days
- Usually present at 40-70%

2) C_2S Di-Calcium Silicate

- $2CaO \cdot SiO_2$ -"C_2S - Belite"
- Provides late strength development
- 30% reacts by 28 days
- Present at 20-40%

Major Constituents of Cement

3) C_3A Tri-Calcium Aluminate

- $3CaO \cdot Al_2O_3$ -“calcium aluminate”
- Generates heat in early hydration
- High C_3A not as resistant to sulfate attack
- Little contribution to strength
- Early hydration controlled by adding gypsum (no gypsum = flash set, too much gypsum = false set)

Major Constituents of Cement

4) C_4AF Tetra-Calcium Alumino Ferrite

- $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$ -“calcium alumino-ferrite”
- Governs the color of the cement
- Present at 1-10%
- Iron facilitates formation of other compounds-acts as a flux
- Little contribution to strength

Percentage of Main Components of Cement

Percentages of main components are calculated using Bogue's equation. Terms between brackets represent the percentage of the given oxide in the total mass of cement.

$C_3S = 4.071(CaO) - 7.600(SiO_2) - 6.718(Al_2O_3) - 1.430(Fe_2O_3) - 2.852(SO_3)$

$C_2S = 2.867\ (SiO_2) - 0.754\ C_3S$

$C_3A = 2.650(Al_2O_3) - 1.692\ (Fe_2O_3)$

$C_4AF = 3.043\ (Fe_2O_3)$

This is a simple method provided in ASTM C150 but there are more advanced methods.

Clinker analysis										
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	LOI	IR	Total
21.5	5.2	2.8	66.6	1.0	0.6	0.2	1.0	1.5	0.5	98.9
Free lime = 1.0% CaO										

Chemical reactions with water
(Hydration of Cement)

- As water comes in contact with cement particles, hydration reactions immediately starts at the surface of the particles to form new compounds that are the infrastructure of the hardened cement paste in concrete. The rate of hydration is controlled by fineness of cement. For a rapid rate of hydration a higher fineness is necessary.
- Although simple hydrates such as C-H are formed but actually the process of hydration is a complex one and results in re-organization of the constituents of original compounds to form new hydrated compounds.

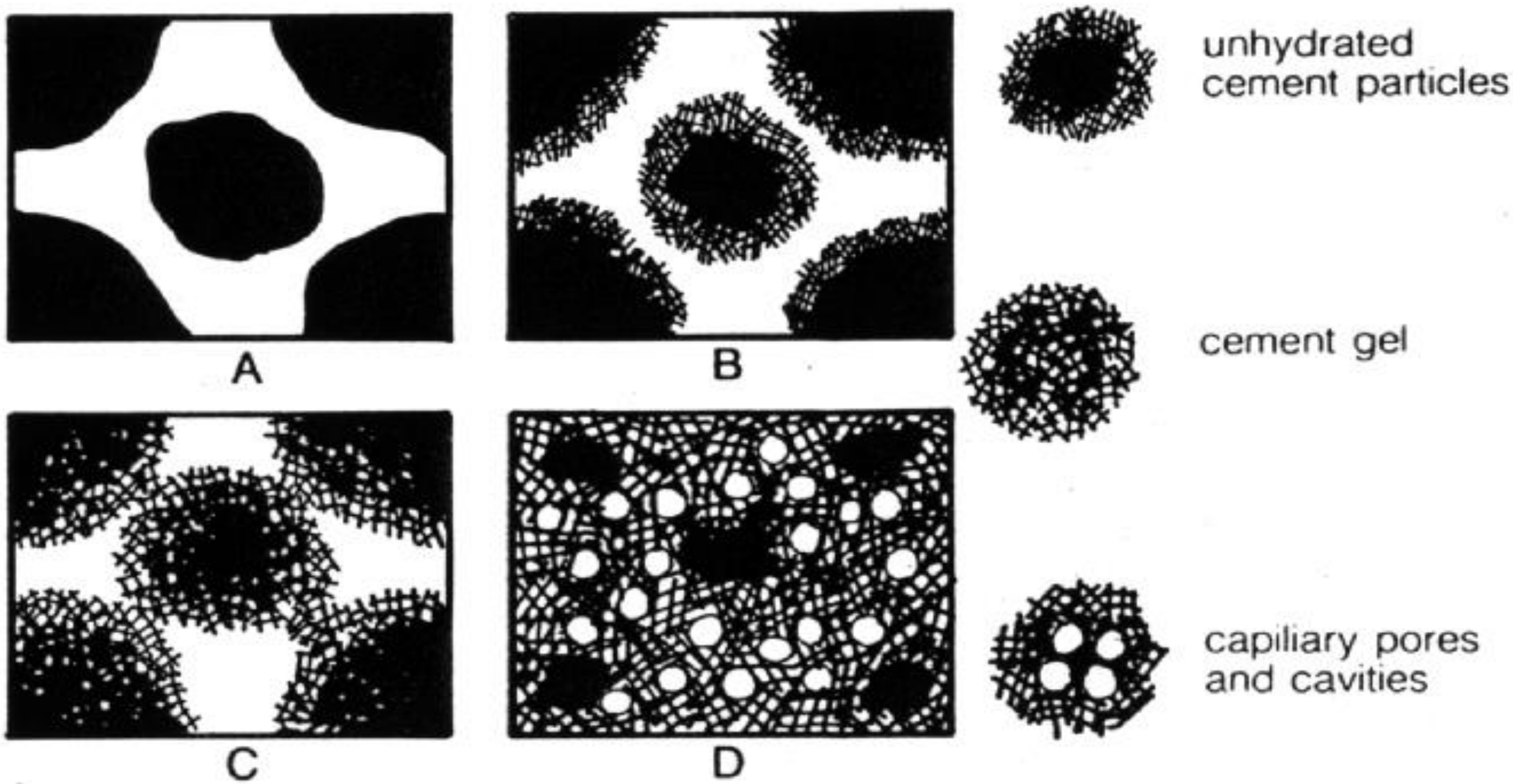
Hydration of Cement

- Both C_3S and C_2S hydrate to form calcium hydroxide and calcium silicate hydrate (CSH). Hydrated cement paste contains 15% to 25% Calcium hydroxide and about 50% calcium silicate hydrate by mass. The strength and other properties of hydrated cement are due primarily to calcium silicate hydrate.

- C_3A reacts with water and calcium hydroxide to form tetracalcium aluminate hydrate.

- C_4AF reacts with water and calcium hydroxide to form calcium aluminoferrite hydrate.

Cement mixing with water



A) Immediately after mixing

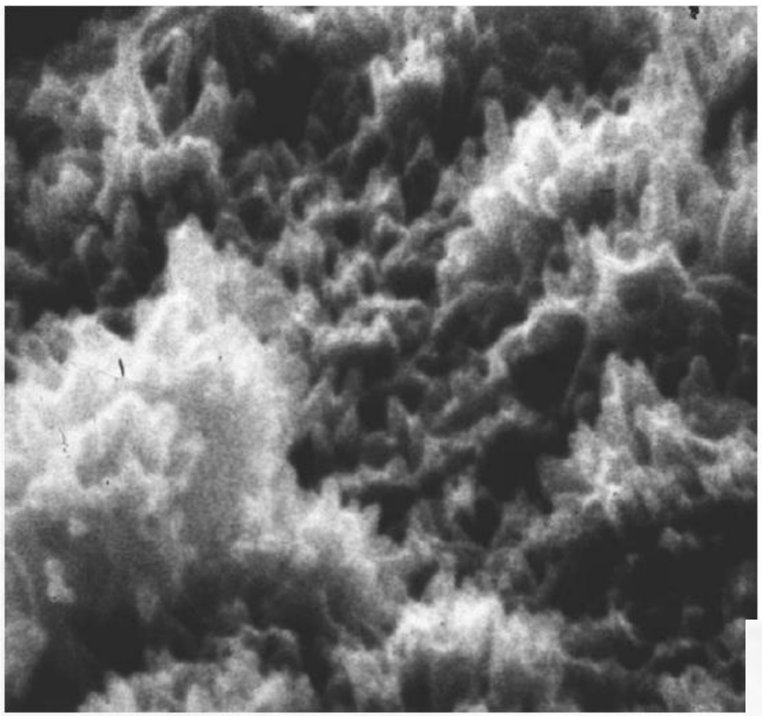
B) Reaction around particles – early stiffening

C) Formation of skeletal structure – first hardening

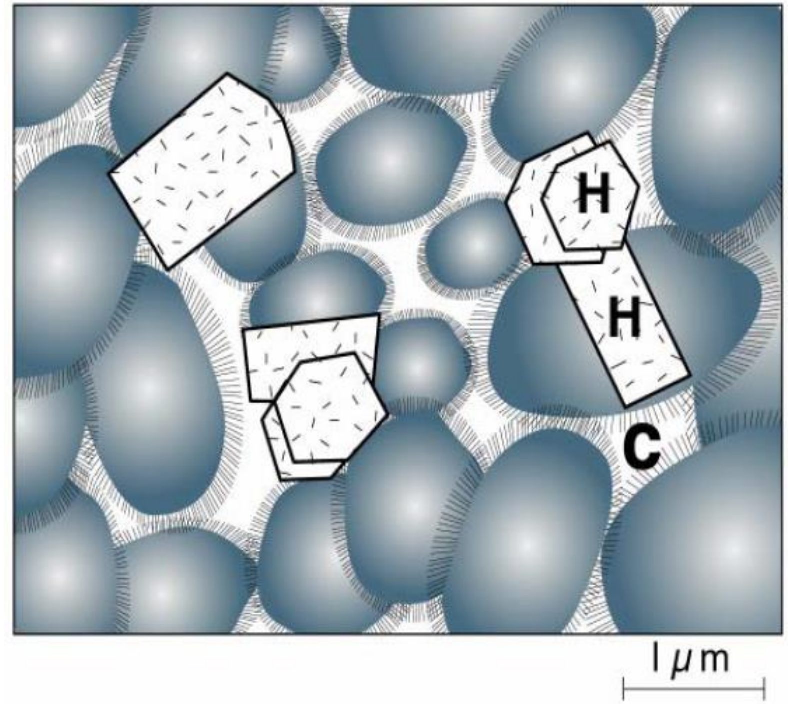
D) Gel infilling – later hardening

Cement mixing with water

Hydrated Paste



C-S-H



Notation: C-S-H
C/S Ratio: 1.5 to 2.0
Main Characteristics: High Surface (100 to 700 m2/ g) ----> High *Van der Walls* Force -----> Strength.
Volume % : 50 a 60

Hydration process stages

Stage 1: Heat of wetting or initial hydrolysis, C_3A and C_3S Hydration. 7 min after mixing.

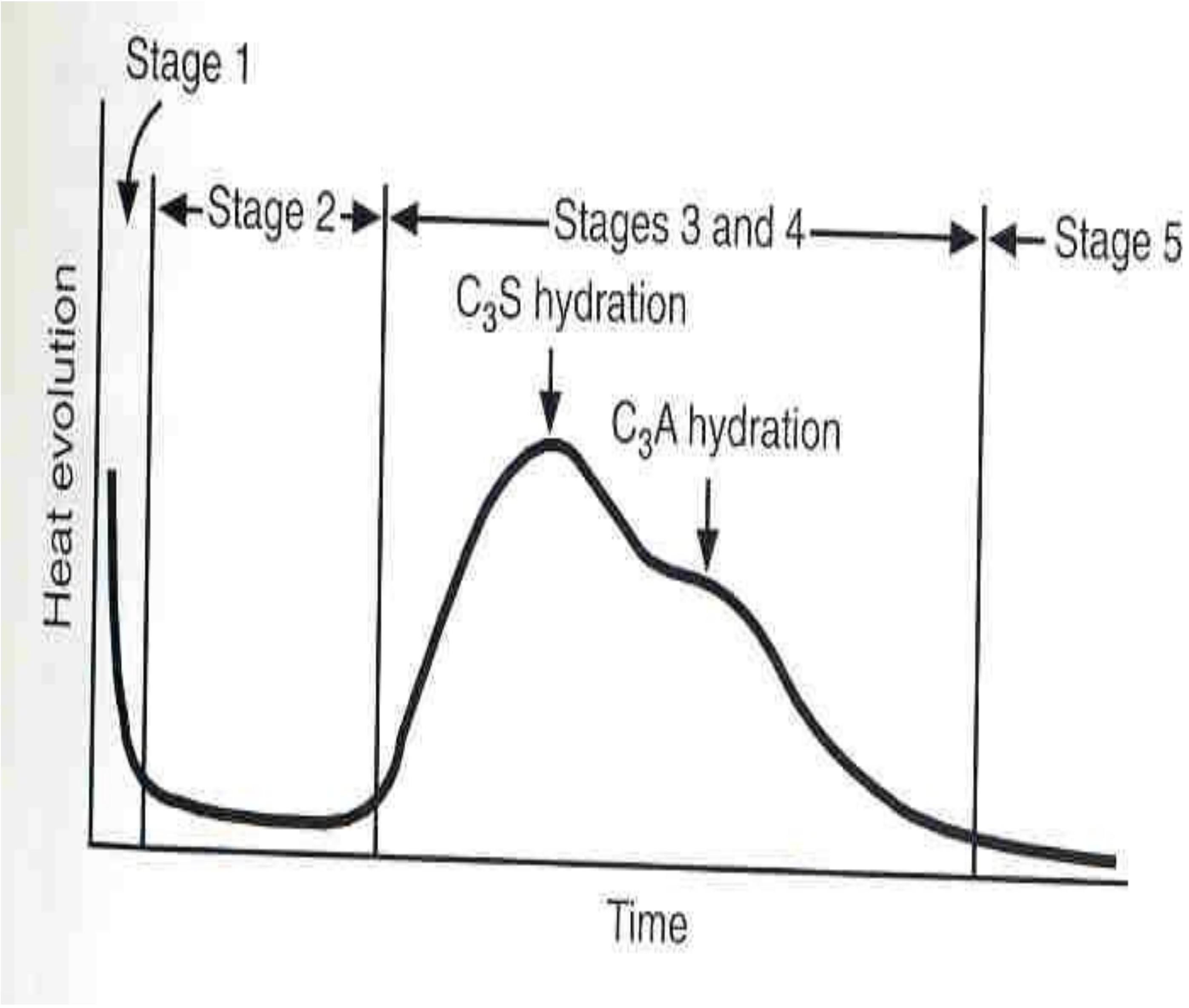
Stage 2: Dormant period related to initial set.

Stage 3. Accelerated reaction of the hydration products. That determine the rate of hardening and final set.

Stage 4: Decelerates formation of hydration products and determines the rate of early strength gain.

Stage 5: is a slow, steady formation of hydration products.

Heat of Hydration of opc



Main Components of PC

Main Components of PC

	amount	notes
C3S	50%	very reactive compound, high heat of hydration, high early strength
C2S	25%	low heat of hydration, slow reaction
C3A	10%	problems with sulfate attack, high heat of hydration
C4AF	10%	
gypsum	5%	used to control the set of cement

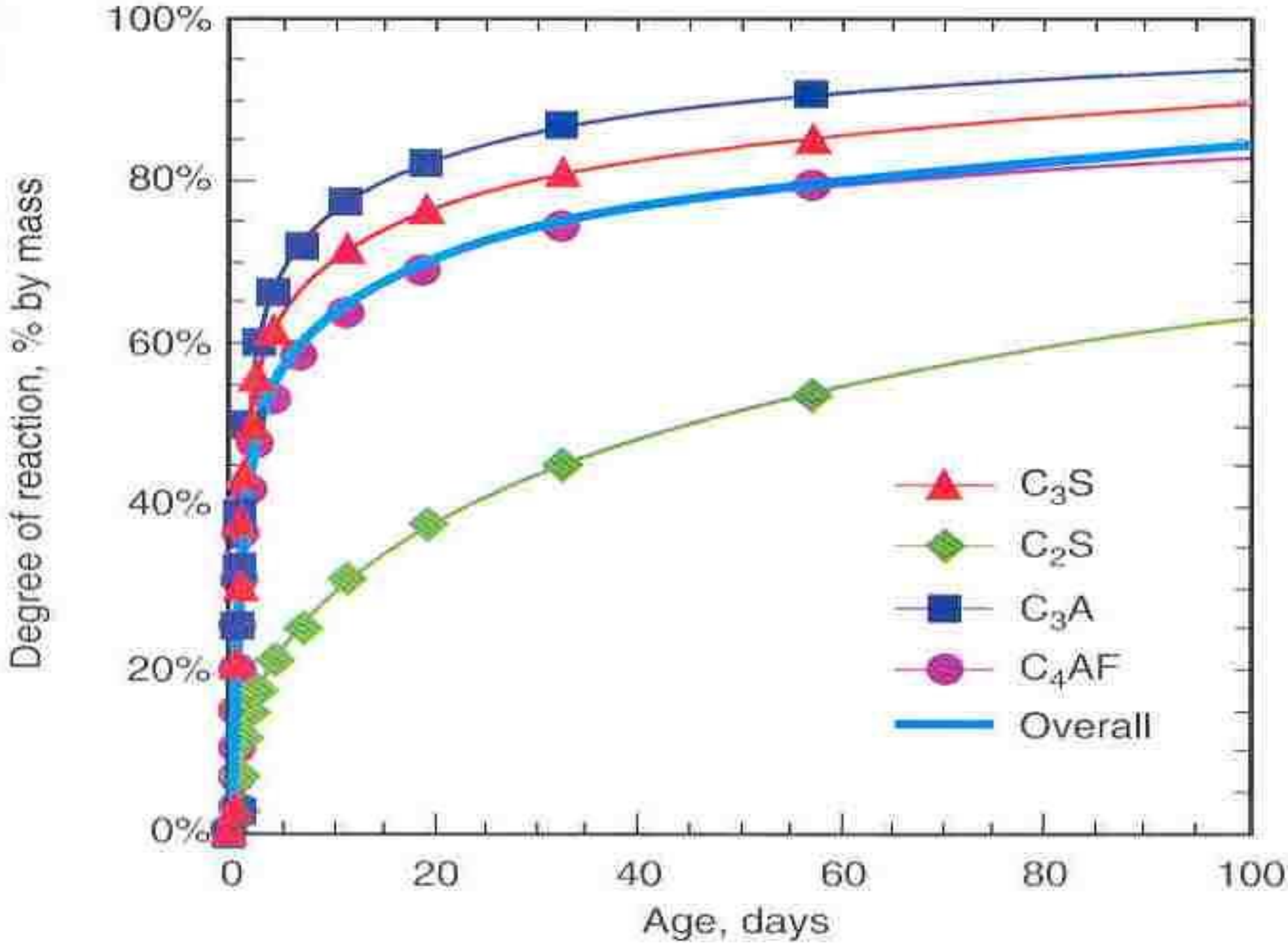
Hydration Reactions

Table 2-5. Portland Cement Compound Hydration Reactions (Oxide Notation)

2 ($3CaO \cdot SiO_2$) Tricalcium silicate	+ 11 H_2O Water	= $3CaO \cdot 2SiO_2 \cdot 8H_2O$ Calcium silicate hydrate (C-S-H)	+ 3 ($CaO \cdot H_2O$) Calcium hydroxide
2 ($2CaO \cdot SiO_2$) Dicalcium silicate	+ 9 H_2O Water	= $3CaO \cdot 2SiO_2 \cdot 8H_2O$ Calcium silicate hydrate (C-S-H)	+ $CaO \cdot H_2O$ Calcium hydroxide
$3CaO \cdot Al_2O_3$ Tricalcium aluminate	+ 3 ($CaO \cdot SO_3 \cdot 2H_2O$) Gypsum	+ 26 H_2O Water	= $6CaO \cdot Al_2O_3 \cdot 3SO_3 \cdot 32H_2O$ Ettringite
2 ($3CaO \cdot Al_2O_3$) Tricalcium aluminate	+ $6CaO \cdot Al_2O_3 \cdot 3SO_3 \cdot 32H_2O$ Ettringite	+ 4 H_2O Water	= 3 ($4CaO \cdot Al_2O_3 \cdot SO_3 \cdot 12H_2O$) Calcium monosulfoaluminate
$3CaO \cdot Al_2O_3$ Tricalcium aluminate	+ $CaO \cdot H_2O$ Calcium hydroxide	+ 12 H_2O Water	= $4CaO \cdot Al_2O_3 \cdot 13H_2O$ Tetracalcium aluminate hydrate
$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$ Tetracalcium aluminoferrite	+ 10 H_2O Water	+ 2 ($CaO \cdot H_2O$) Calcium hydroxide	= $6CaO \cdot Al_2O_3 \cdot Fe_2O_3 \cdot 12H_2O$ Calcium aluminoferrite hydrate

Note: This table illustrates only primary transformations and not several minor transformations. The composition of calcium silicate hydrate (C-S-H) is not stoichiometric (Tennis and Jennings 2000).

Relative Reactivity of Cement compounds



Heat of Hydration

Type	Name	Heat of hydration (kj/kg)
I	Normal	100%(349)
II	Moderate	80-85% (263)
III	High early strength	up to 150% (370)
IV	Low heat of hydration	40-60% (233)
V	Sulfate resistant	60-75% (310)

Standard Specification for Portland Cement

ASTM C150 (AASHTO 185)

I	Normal
IA	Normal, air-entraining
II	Moderate sulfate resistance
IIA	Moderate sulfate resistance, air-entraining
III	High early strength
IIIA	High early strength, air-entraining
IV	Low heat of hydration
V	High sulfate resistance

Why Five Types of Cement

What makes them different

- Different uses require different performance
- All types manufactured from similar raw materials:
  - Vary the chemical composition (proportions)
  - Vary the physical characteristics

ASTM C50: Type I (General Purpose)

- General uses
- Ready-mix is biggest customer
- IA (air-entrained)
- Most common-more than 90% of cement used is Type I or II

ASTM C50: Type II (Moderate Sulphate Resistant)

- Similar to Type I, some cements marketed as Type I/II
- Moderate sulfate resistance
- Low heat of hydration option
- IIA (air-entrained)

Type III (High Early Strength)

- Early strength means faster setting
  - Precast
  - Cold weather
  - Roadway applications
  - Repair
- IIIA (air-entrained)

Type IV (Low Heat of Hydration)

- Delayed reaction, low heat generated
- No longer common
- Other options are available for heat considerations

Niagara Hydroelectric Dam

Type V (High Sulphate Resistant)

- High sulfate resistance
  - Seawater exposures
  - Pipes
  - Industrial exposures
  - Sulfate soils
- Also has slightly lower heat of hydration

Effect of cement type on concrete compressive strength

Sr. No.	Type of Portland cement	Compressive strength-percent of strength of OPC			
		1 Day	7Days	28 Days	3 Months
1	Normal	100	100	100	100
2	Moderate	75	85	90	100
3	High Early strength	190	120	110	100
4	Low-heat	55	55	75	100
5	Sulfate resistant	65	75	85	100

Other types of cement

Blended Cement

a hydraulic cement consisting of two or more inorganic constituents, which contribute to the strength gaining properties of cement.

ASTM C595

Blended cement (center) surrounded by (right and clockwise) clinker, gypsum, portland cement, fly ash, slag, silica fume, and calcined clay.

Blended Cement

ASTM C595

Type IS	Portland blast-furnace slag cement
Type IP	Portland-pozzolan cement
Type P	Portland-pozzolan cement for use when higher strengths at early ages are not required
Type I(PM)	Pozzolan-modified portland cement
Type S	Slag cement for use in combination with portland cement in making concrete and in combination with hydrated lime in making masonry mortar.
Type I(SM)	Slag-modified portland cement

Benefits of Blended Cement

- Require less energy to manufacture
- Less CO_2 emissions
- Beneficial use of by-products
- Reduce solid waste
- Improved concrete performance

Special Cement

Special Cements

- White--primarily architectural and decorative concretes

Quality Tests on Cement

- Quality control
  - Chemical aspects
  - Physical aspects
- Factors that affect performance of cement/concrete
  - Fresh properties influence placing and workability
  - Hardened properties influence strength and durability

QUALITY TESTS OF CEMENT:

(1) Fineness Test,
(2) Consistency test
(3) Setting Time Test
(4) Compressive strength test

QUALITY TESTS: FINENESS OF CEMENT

- As hydration takes place at the surface of the cement particles, it is the surface area of cement particles which provide the material available for hydration. The rate of hydration is controlled by fineness of cement. For a rapid rate of hydration a higher fineness is necessary.
- 95% of cement particles are smaller than 45 micrometer, with the average particle around 15 micrometer.
- Fineness of cement affects heat released and the rate of hydration. More is the fineness of cement more will be the rate of hydration. Thus the fineness accelerates strength development principally during the first seven days.

QUALITY TESTS: FINENESS OF CEMENT

- Fineness of cement is determined by air permeability methods. For example, in the Blaine air permeability method a known volume of air is passed through cement. The time is recorded and the specific surface is calculated by a formula.

- Fineness tests indirectly measures the surface area of the cement particles per unit mass :
  - Sieving using No. 325sieve (45 µm) (ASTM C 430)

Soundness of cement

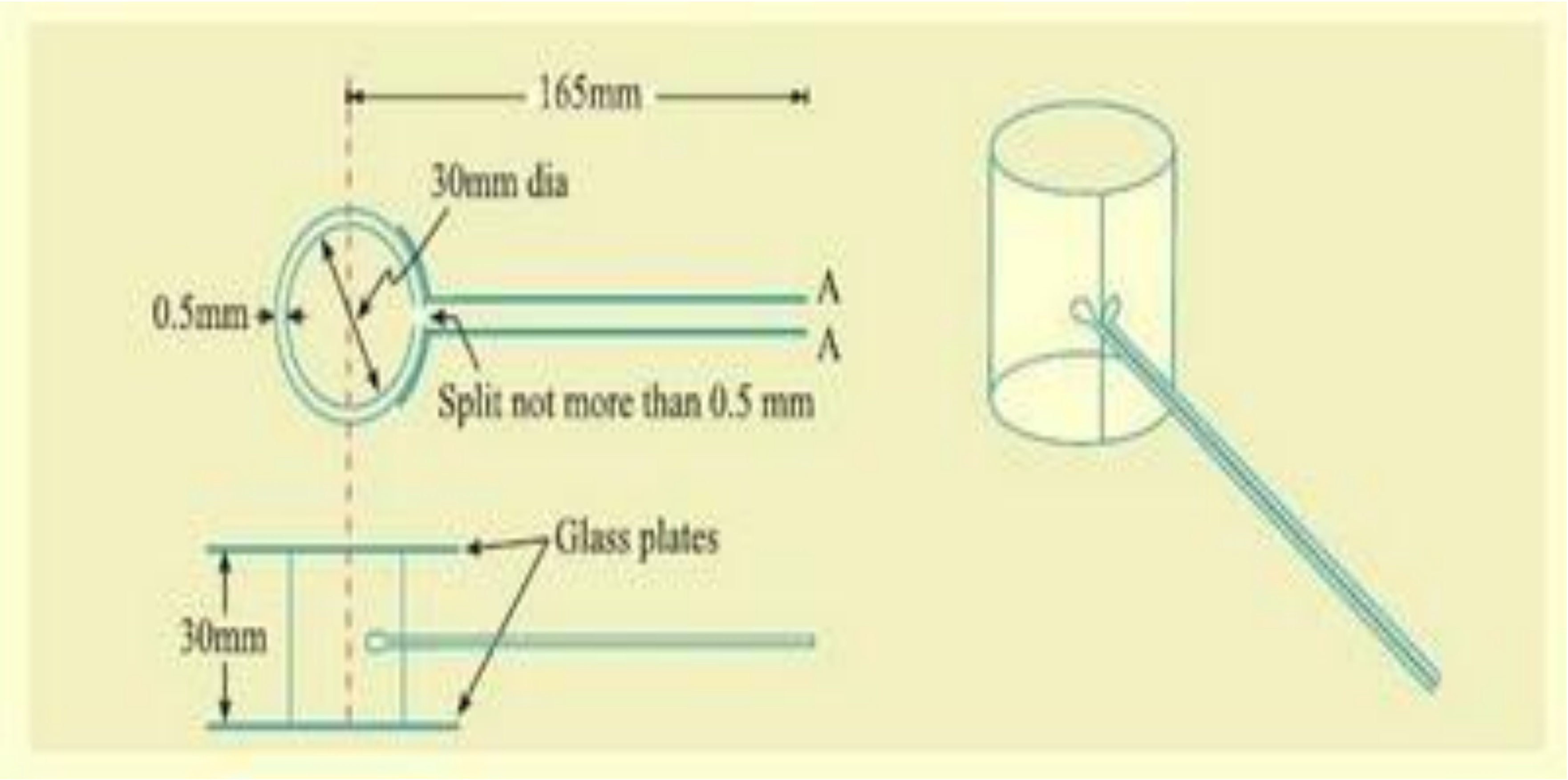
- Soundness is defined as the volume stability of cement paste.
- The cement paste should not undergo large changes in volume after it has set. Free CaO&MgO may result in unsound cement. Upon hydration C&M will form CH&MH with volume increase thus cracking.
- Since unsoundness is not apparent until several months or years, it is necessary to provide an accelerated method for its determination.

1) Lechatelier Method: Only free CaO can be determined.
2) Autoclave Method: Both free CaO&MgO can be determined.

QUALITY TESTS: *SOUDNESS TEST*

- It consists of a small split cylinder of spring brass.
- It is 30mm diameter & 30mm high. Cement is filled into the mould & kept on a glass plate & covered with another glass plate.
- This is immersed in water at a temperature 27^0c-32^0c for 24 hours. Measure the distance between indicators.
- Heat the water & bring to boiling point of about 25-30min.
- Remove the mould from the water after 3 hours.
- Measure the distance between the indicators.
- This must not exceed 10mm for ordinary, rapid hardening, low heat Portland cements.
- If this expansion is more than 10mm the cement is said to be unsound.

QUALITY TESTS: *SOUDNESS TEST*



Consistency Test :

- Consistency refers to the relative mobility of a freshly mixed cement paste or mortar or its ability to flow.
- The water content has a marked effect on the time of setting. In acceptance tests for cement, the water content is regulated by bringing the paste to a standard condition of wetness. This is called "***normal consistency***"**.**Normal or Standard consistency of cement is determined using the Vicat's Apparatus. It is defined as that percentage of water added to form the paste which allows a penetration of 10 ± 1 mm of the Vicat plunger.

➢ Normal consistency of O.P.C. Ranges from 20-30% by weight of cement.

Consistency Test /Setting Time Test :

- Setting refers to a change from liquid state to solid state. Although, during setting cement paste acquires some strength, setting is different from hardening.
- The water content has a marked effect on the time of setting. In acceptance tests for cement, the water content is regulated by bringing the paste to a standard condition of wetness. This is called "***normal consistency***".
- Normal consistency of O.P.C. Ranges from 20-30% by weight of cement.
- Setting can be obtained by using the vicat apparatus.

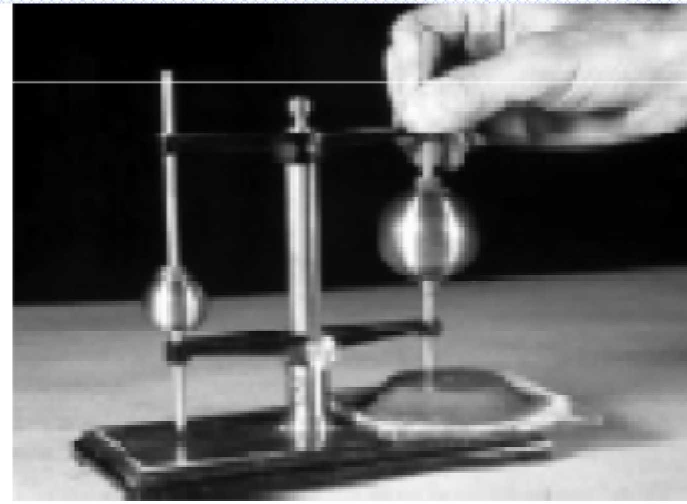
ASTM C150-- Initial setting time>45min

Final setting time<375min (about 10hrs)

Setting of cement

- Vicat apparatus is used to determine normal consistency. Normal consistency is that condition for which the penetration of a standard weighed plunger into the paste is 10mm in 30sec. By trial & error determine the w/c ratio.
- In practice, the terms initial set&final set are used to describe arbitrary chosen time of setting. Initial set indicates the beginning of a noticeable stiffening & final set may be regarded as the start of hardening (or complete loss of plasticity).

Setting Behaviour of Cement Tests



Vicat, ASTM C 191, time

300g needle with 1 mm diameter

Initial set: 25-mm penetration

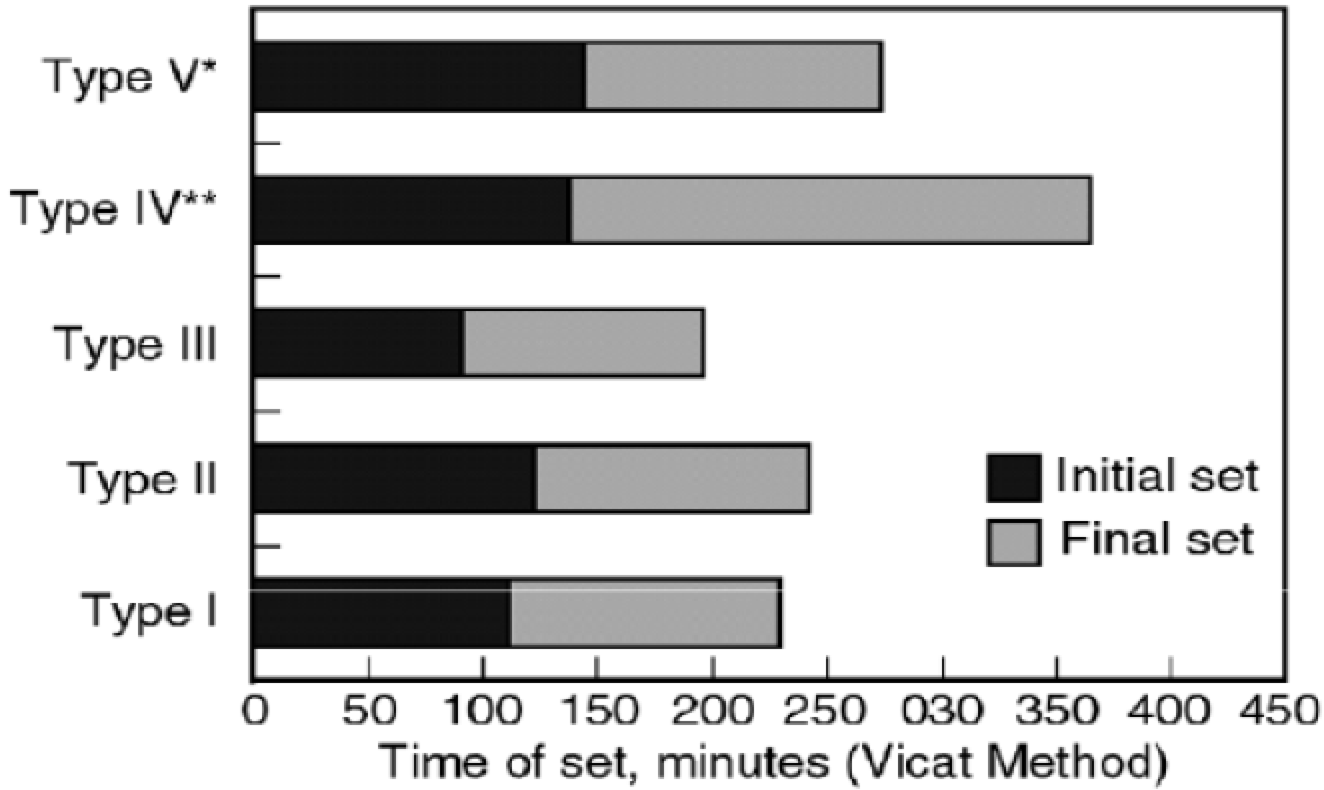
Final set: zero penetration

Gillmore, ASTM C 266,

Initial set: 2 mm diameter needle, 113 g

Final set: 1 mm needle, 454 g

Setting Time for Portland Cement



*Average of two values for final set
**Average of two values for initial set; one value for final set

Setting Behaviour of Cement

- Initial Set - From 1 to 4 hours
- Final Set - From 3 to 6 hours
- False Set - Rapid setting without much heat liberation, can be remixed (too much gypsum)
- Flash Set – Very rapid setting with significant heat liberation, can't be remixed (not enough gypsum)

Factors affecting setting time

- Temperature & Humidity
- Amount of Water
- Chemical Composition of Cement
- Fineness of Cement (finer cement, faster setting)

Flash-set

➢ Abnormal Settings

False-set

Setting of cement

Flash-Set: is the immediate stiffening of cement paste in a few minutes after mixing with water. It is accompanied by large amount of heat generation upon reaction of C3A with water.

- Gypsum is placed in cement to prevent flash-set. The rigidity can not be overcome & plasticity may not be regained without addition of water.

- Amount of gypsum must be such that it will be used upto almost hardening. Because expansion caused by ettringite can be distributed to the paste before hardening. More gypsum will cause undesirable expansion after hardening.

Setting of cement

False-Set: is a rapid development of rigidity of cement paste without generation of much heat. This rigidity can be overcome & plasticity can be regained by further mixing without addition of water. In this way cement paste restores its plasticity & sets in a normal manner without any loss of strength.

- Probable Causes of False-Set:

1) When gypsum is ground by too hot of a clinker, gypsum may be dehydrated into hemihydrate ($CaSO_4.1/2H_2O$) or anhydrate ($CaSO_4$). These materials when react with water gypsum is formed, which results in stiffening of the paste.

Setting of cement

- Alkali oxides in cement may carbonate during storage. Upon mixing such a cement with water, these alkali carbonates will react with $Ca(OH_2)$ (CH-Calcium Hydroxide) liberated by hydrolysis of C_3S resulting in $CaCO_3$. $CaCO_3$ precipates in the mix & results in false-set.

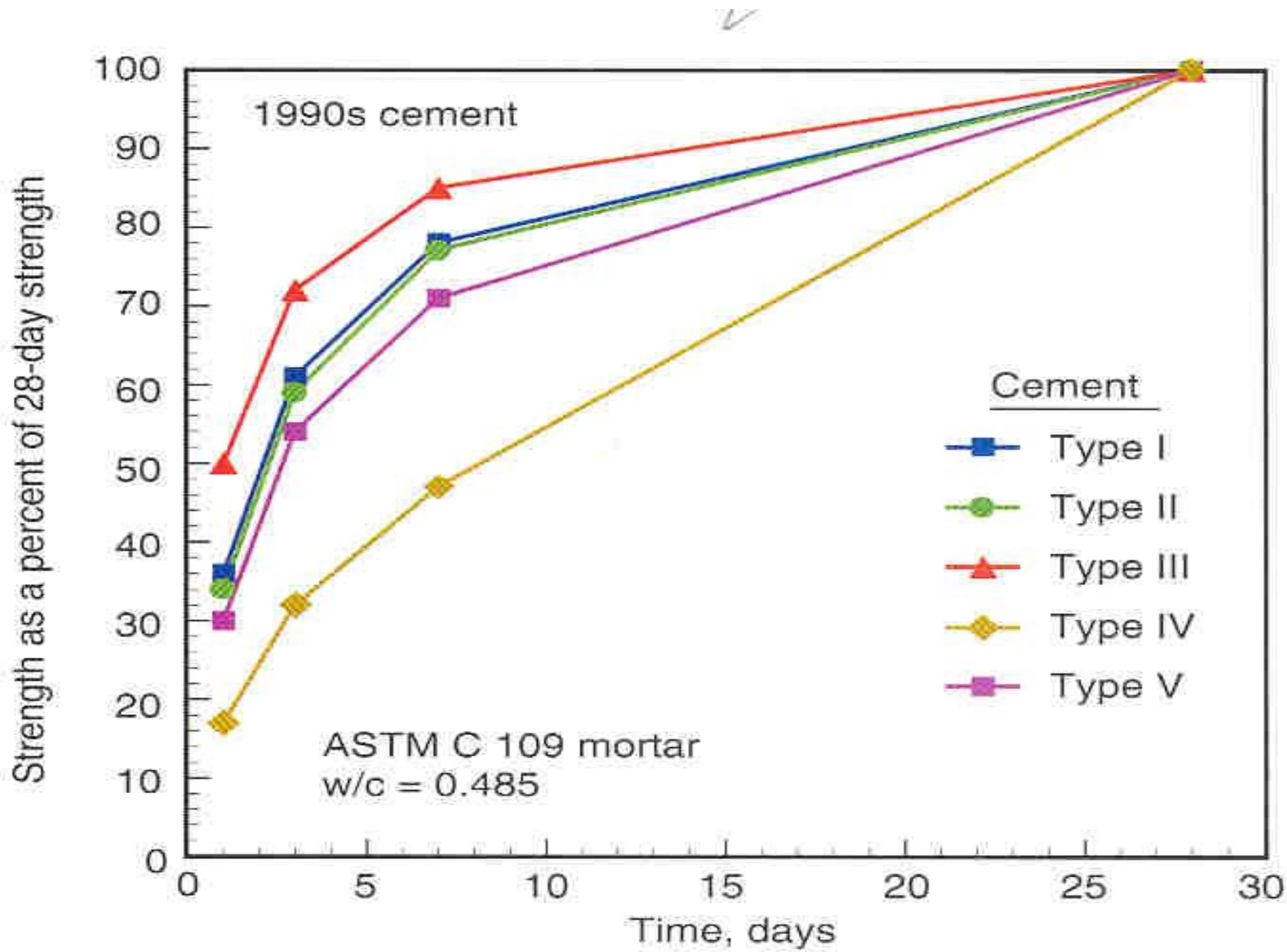
STRENGTH OF CEMENT

- Strength tests are carried out on fresh cement pastes, due to cohesive property of cement.Compressive strength of cement is the most important property.
- It is determined by conducting compression tests on standard 50 mm mortar cubes in accordance with ASTM C 109.
- In general, cement strength (based on mortar-cube tests) can not be used to predict concrete compressive strength with great degree of accuracy because of many variables in aggregate characteristics, concrete mixtures, construction procedures, and environmental conditions in the field.

Strength Tests

- ASTM C 109
  - 50-mm (2-in.) mortar cubes
  - Made from 1 part cement, 2.75 parts sand
  - In molds for 1 day, lime water till testing
  - Results in MPa/psi

Strength Development of Cement mortar cubes



Chemical Tests on Cement

- ASTM C 114
  - Chemical analysis to determine oxides
  - Use this to calculate potential compound composition
    - C_3S
    - C_2S
    - C_3A
    - C_4AF

Cement Fineness

- 300 m^2/kg (Blaine) - 1950's Type I
- 370 m^2/kg (Blaine) - Today's cements
- Finer = faster hydration, more heat generation, higher early-age strength less long-term gains

Typical compound composition and fineness of OPCs (using Wagner tubidimeter test)

Sr. No.	Type of Portland cement	Compound composition, %				Fineness, Cm^2/gm
		C3S	C2S	C3A	C4AF	
1	**Normal**	50	24	11	8	1800
2	**Moderate**	42	33	5	13	1800
3	**High Early strength**	60	13	9	8	2600
4	**Low-heat**	26	50	5	12	1900
5	**Sulfate resistant**	40	40	4	9	1900