

CEMENT

Chapter 3

Introduction

- Cement is a natural rock that has been turned to powder and it will solidify again when reacting with water
- It is a binder, a substance that sets and hardens independently, and can bind other materials together.



Raw Materials of Portland Cement

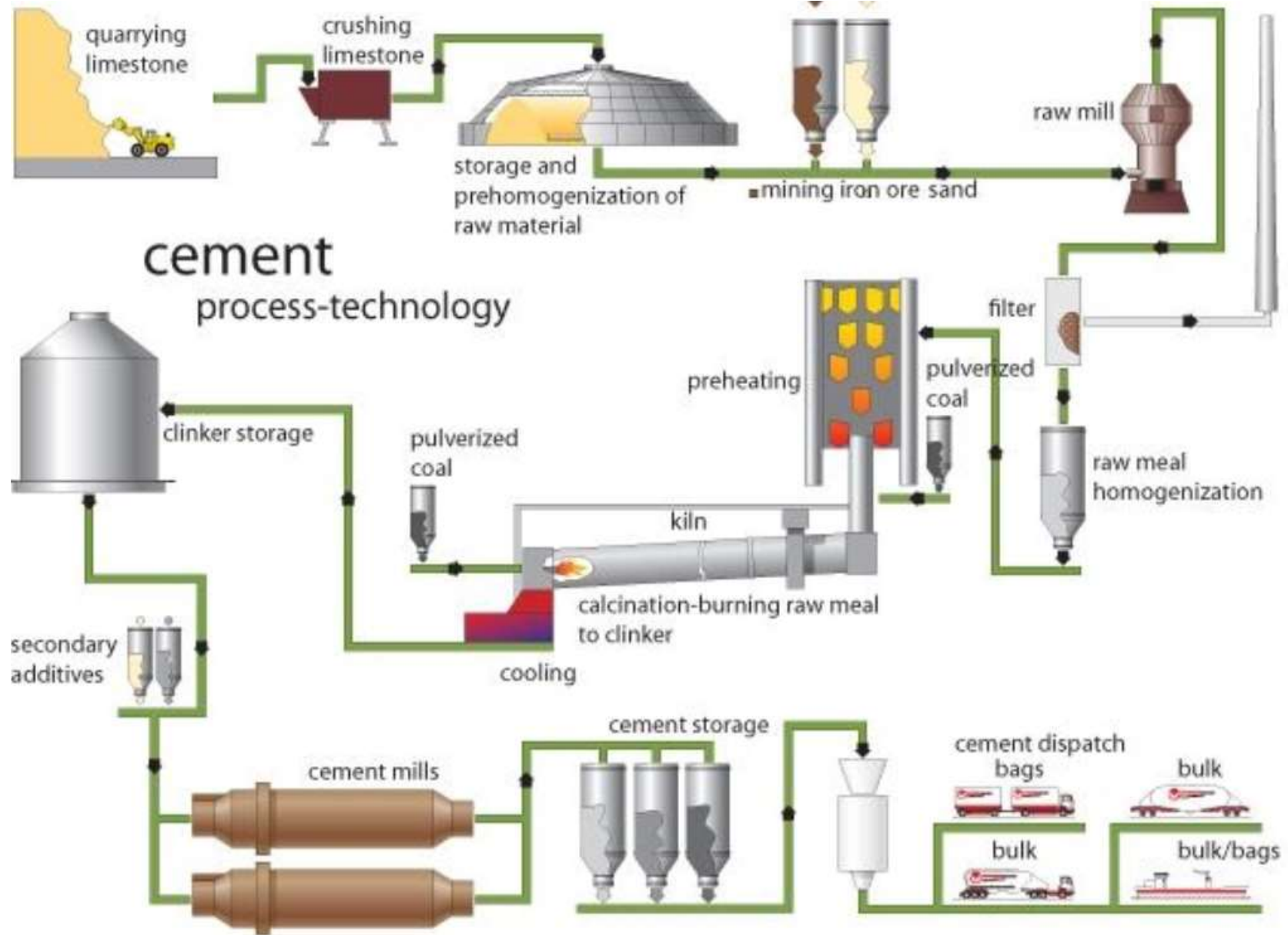
- I. Calcareous rocks (contain $\text{CaCO}_3 > 75\%$) such as limestone, marl, chalk as the main source of calcium oxides.
- II. Argillaceous rocks (contain $\text{CaCO}_3 < 40\%$) such as clay and shale, as main source of silica
- III. Or any other silica-, Alumina-, and iron oxide-bearing materials.

<u>Calcium</u>	<u>Iron</u>	<u>Silica</u>	<u>Alumina</u>	<u>Sulfate</u>
Alkali waste	Blast-furnace flue dust	Calcium silicate	Aluminum-ore refuse*	Anhydrite
Aragonite*	Clay*	Cement rock	Bauxite	Calcium sulfate
Calcite*	Iron ore*	Clay*	Cement rock	Gypsum*
Cement-kiln dust	Mill scale*	Fly ash	Clay*	
Cement rock	Ore washings	Fuller's earth	Copper slag	
Chalk	Pyrite cinders	Limestone	Fly ash*	
Clay	Shale	Loess	Fuller's earth	
Fuller's earth		Marl*	Granodiorite	
Limestone*		Ore washings	Limestone	
Marble		Quartzite	Loess	
Marl*		Rice-hull ash	Ore washings	
Seashells		Sand*	Shale*	
Shale*		Sandstone	Slag	
Slag		Shale*	Staurolite	
		Slag		
		Traprock		

Note: Many industrial byproducts have potential as raw materials for the manufacture of portland cement.

*Most common sources.

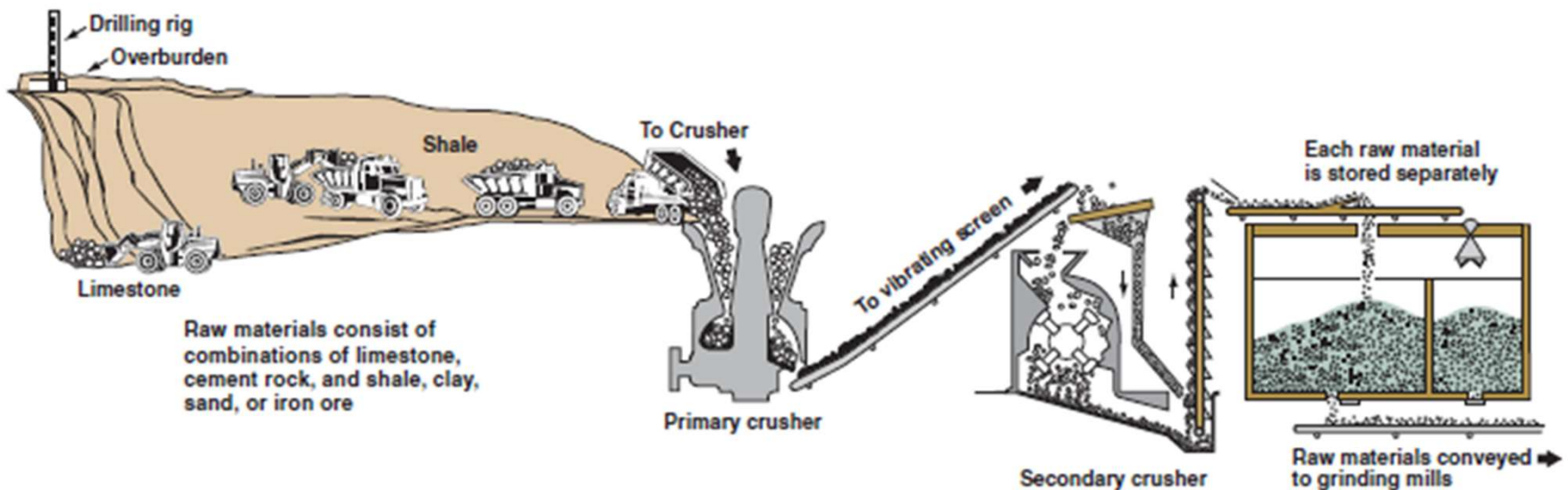
Manufacturing Process



Manufacturing Process

▪ Stage 1: Preparation of selected raw materials

Selected raw materials are transported from the quarry and crushed to the size of a typical gravel.

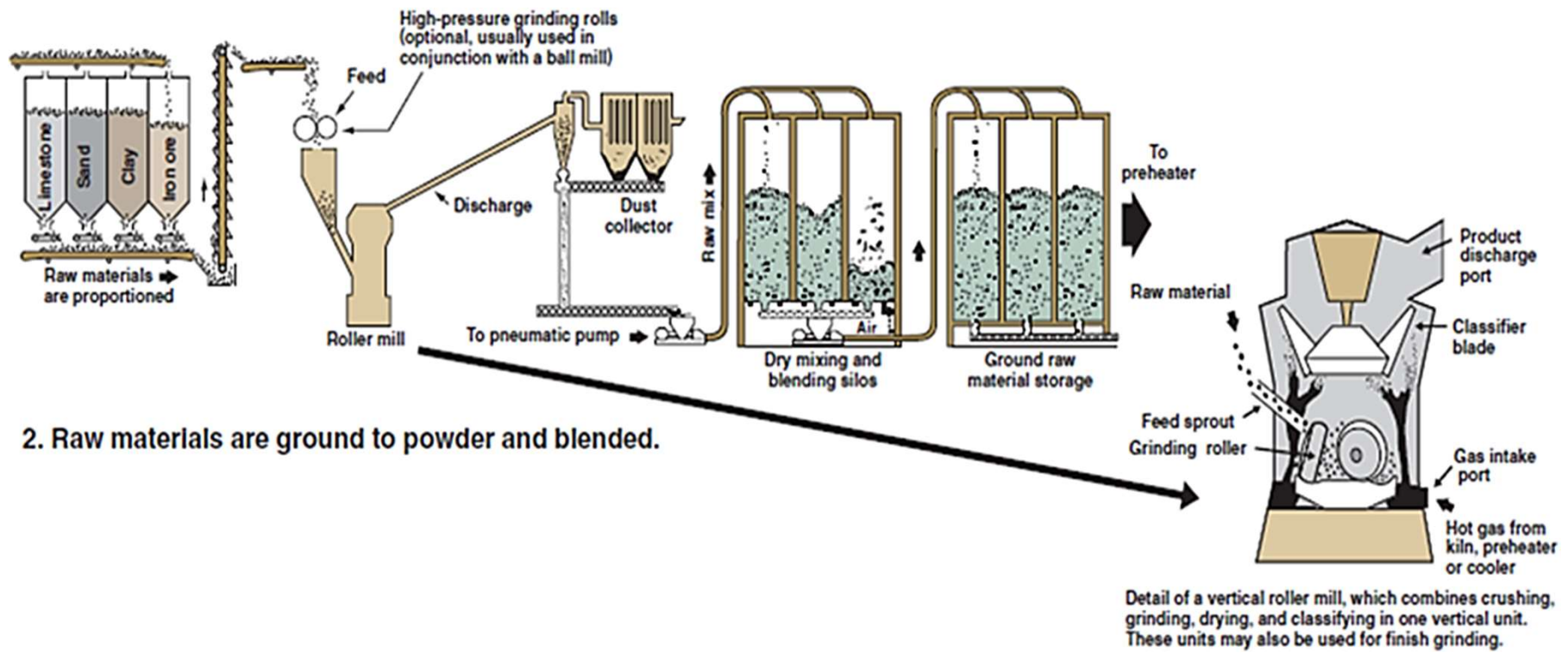


1. Stone is first reduced to 125 mm (5 in.) size, then to 20 mm ($\frac{3}{4}$ in.), and stored.

Manufacturing Process

■ Stage 2 : Proportion of raw material

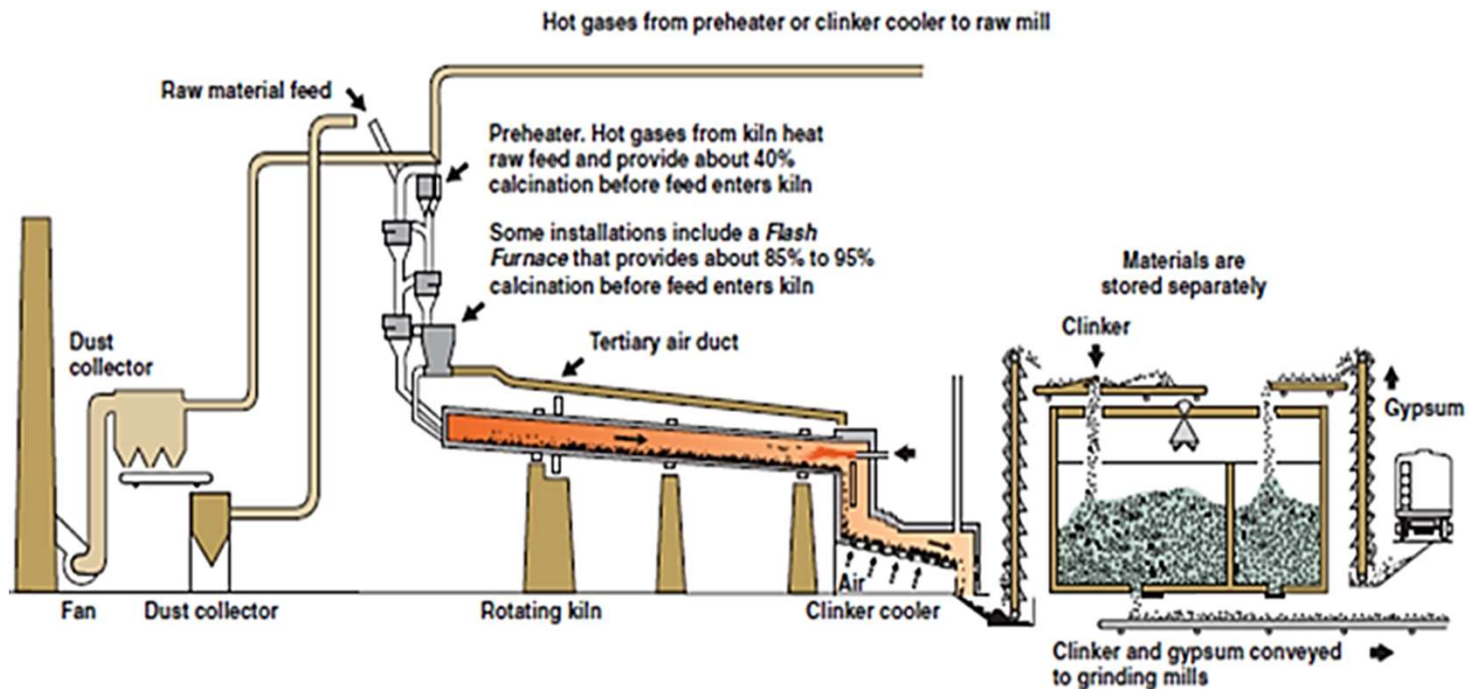
The stone is then milled and proportioned so that the resulting mixture has the desired chemical composition.



Manufacturing Process

■ Stage 3: Burning

After blending, the ground raw materials are fed into the upper end of a kiln.



3. Burning changes raw mix chemically into cement clinker. Note four-stage preheater, flash furnaces, and shorter kiln.



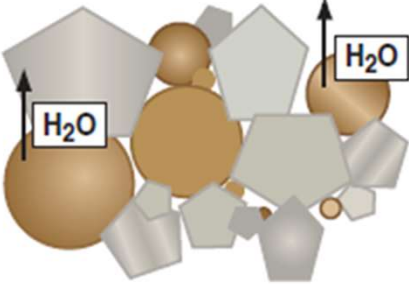
Cement Kiln

- The Kiln is Basically, a long cylinder (up to 200m long, 6m diameter) rotating about its axis once every minute or two. The axis is inclined at a slight angle (has a downward slope of 3-4%), the end with the burner being lower.
- Fuel is forced into the lower end of the kiln where it ignites and generates material temperatures of 1400 to 1550 degrees Celsius



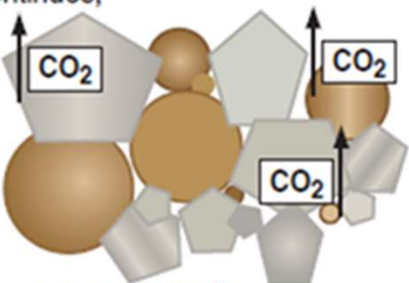


Kiln Reactions

1. Evaporation: free water is driven from the powder at about 700 degrees Celsius



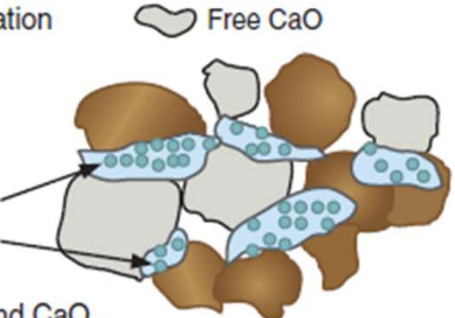

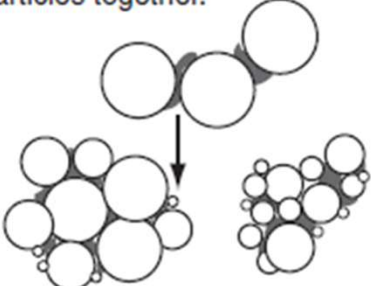
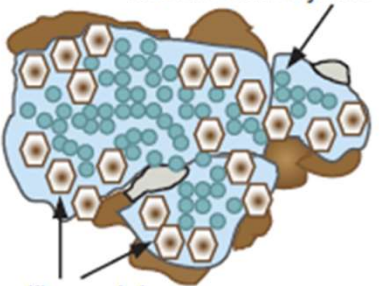
<p>To 700°C (1290°F) Raw materials are free-flowing powder</p> 	<p>Particles are solid. No reaction between particles.</p> 	<p>Water is lost. Dehydrated clay re- crystallizes</p>  <p>● Clay particle ◆ Limestone particle</p>
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2. Calcination: from 700 to 900 degrees Celsius the carbon dioxide in the limestone is driven off. At this stage, the first calcium silicates are nucleating to form C_2S , or belite

<p>700-900°C (1290-1650°F) Powder is still free-flowing</p> 	<p>Particles are still solid.</p> 	<p>As calcination continues, free lime increases Reactive silica combines with CaO to begin forming C_2S. Calcination maintains feed temperature at 850°C (1560°F).</p> 
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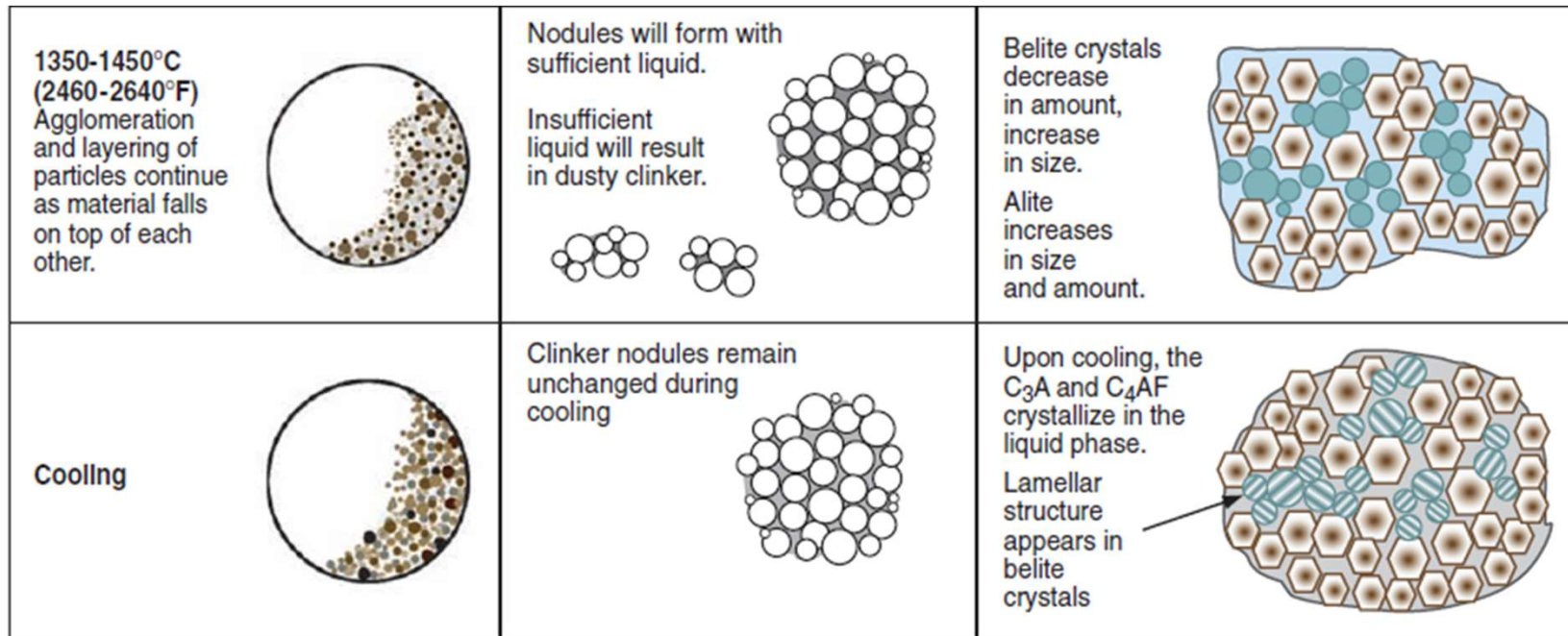
Kiln Reactions

- Between 1150 and 1200 degrees Celsius the material becomes 'sticky' and the temperature increases rapidly. Once the mixture reaches 1250 degrees Celsius, the liquid phase forms and the free calcium oxide and the expanding crystals of belite form C_3S , also called alite.

<p>1150-1200°C (2100-2190°F) Particles start to become "sticky"</p> 	<p>Reactions start happening between solid particles.</p> 	<p>When calcination is complete, temperature increases rapidly.</p> <p>Small belite crystals form from combination of silicates and CaO.</p> 
<p>1200-1350°C (2190-2460°F) As particles start to agglomerate, they are held together by the liquid.</p> <p>The rotation of the kiln initiates coalescing of agglomerates and layering of particles.</p> 	<p>Capillary forces of the liquid keep particles together.</p> 	<p>Above 1250°C (2280°F), liquid phase is formed.</p> <p>Liquid allows reaction between belite and free CaO to form alite.</p> <p>Round belite crystals</p> <p>Angular alite crystals</p> 

Kiln Reactions

3. Clinkering: At peak temperatures (between 1350 and 1450 degrees Celsius), the C_2S continues to react with the free lime to form more C_3S . Additionally, nodules form as the liquid agglomerates crystals together forming clinker.



4. Cooling: Upon cooling, tricalcium aluminate, C_3A , and tetracalcium aluminoferrite, C_4AF , form. The rate at which clinker cool can significantly alter cement reactivity.

Kiln Reactions

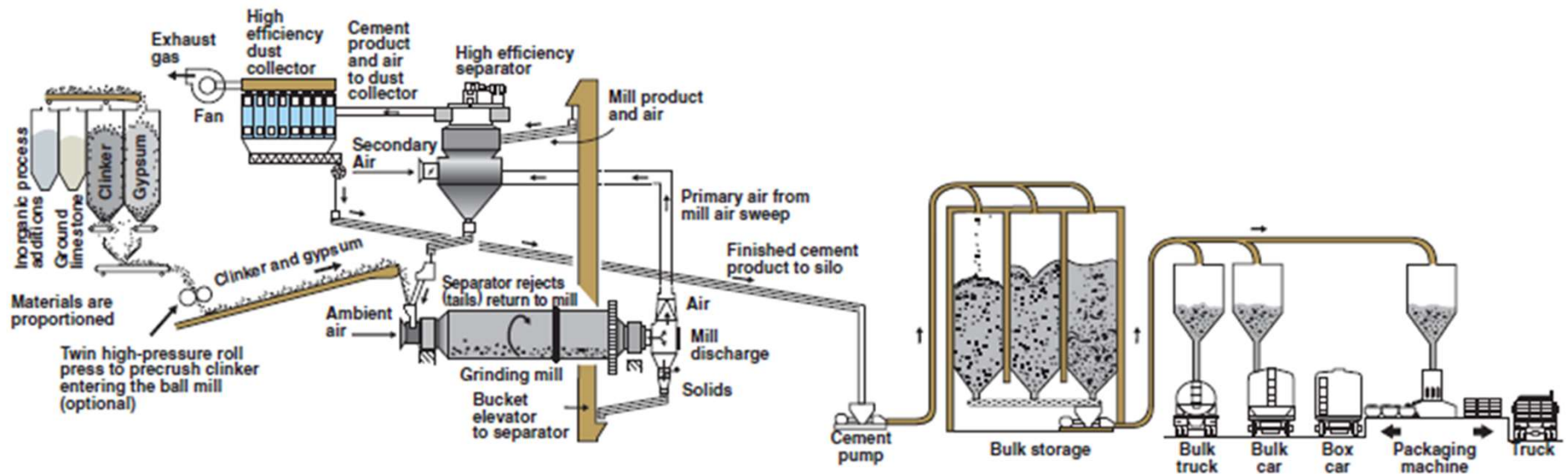
Clinker: The final product from the kiln



Manufacturing Process

▪ Stage 4: Mill Grinding

Clinker is rapidly cooled and then pulverized into a fine material. During this operation, small amounts of gypsum are added mostly to regulate the setting time of the cement. Limestone and inorganic processing additions may also be added, each in amounts up to 5% by mass.



4. Clinker with gypsum is ground into portland cement and shipped.

Basic Chemistry of Cement

1. Cement Compounds

- The major cement compounds are C_3S , C_2S , C_3A , C_4AF - Table 2.1.
- Cement also includes other compound such as added gypsum, in addition to Minor compounds, such as MgO, TiO₂, Mn₂O₃, K₂O, and Na₂O and CaO (free lime). However, the amount of these compounds is not more than a few per cent of the mass of cement.
- The chemical formulas of cement compounds are traditionally written by cement chemists using shortened notation for each cement oxide as shown in the tables.

1. Cement Compounds

Table 2.1: Main compounds in Portland cement

<u>Name of compound</u>	<u>Oxide composition</u>	<u>Abbreviation</u>
Tricalcium silicate	$3\text{CaO} \cdot \text{SiO}_2$	C_3S
Dicalcium silicate	$2\text{CaO} \cdot \text{SiO}_2$	C_2S
Tricalcium aluminate	$3\text{CaO} \cdot \text{Al}_2\text{O}_3$	C_3A
Tetracalcium aluminoferrite	$4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$	C_4AF

<i>Oxide</i>	<i>Shorthand Notation</i>	<i>Common Name</i>
CaO	C	lime
SiO ₂	S	silica
Al ₂ O ₃	A	alumina
Fe ₂ O ₃	F	ferric oxide
MgO	M	magnesia
K ₂ O	K } N }	alkalis
Na ₂ O		
SO ₃	$\bar{\text{S}}$	sulfur trioxide
CO ₂	$\bar{\text{C}}$	carbon dioxide
H ₂ O	H	water

1. Cement Compounds - Percentages

- The compounds percentages varies from sample to sample, however, in average, Alite (C_3S) constitutes 50% to 70% of the clinker, whereas belite (C_2S) accounts for only 10% to 25%. Aluminate compounds constitute up to about 10% of the clinker and ferrite compounds generally up to as much as 15%.
- The specific percentage of each cement compound in a particular sample of cement can be estimated from a chemical oxide analysis (ASTM C114) of the unhydrated cement using the **Bogue equations**, a form of which are provided in ASTM.
- The Knowledge of the percentage of each cement compound is a key to produce different type of cements.

2. Cement Hydration

- In the presence of water, Cement Compounds hydrate (chemically react with water) to form new solids that are the infrastructure of hardened cement paste in concrete. The main characteristic of this reaction in general are:
 - The reaction is exothermic (accompanied by the release of heat).
 - It takes time to complete and may not proceed to 100% completion (depend on W/C ratio <0.4).
 - The formation of the hydration products over time leads to Stiffening (loss of workability), Setting (solidification) and Hardening (strength gain) of the mix.

2. Cement Hydration

- **Each primary cement compound has its own hydration reaction** that differs from other compounds. Accordingly, the hydration reaction properties for a particular cement sample such as reaction rate, the heat of hydration, the rate of heat and strength development are directly related to the percentage of the primary cement compounds (phases) in this sample.

2. Cement Hydration

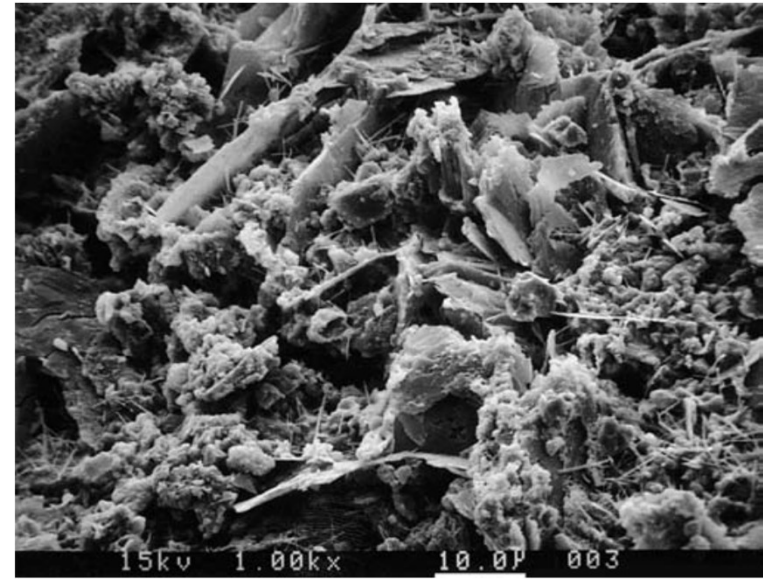
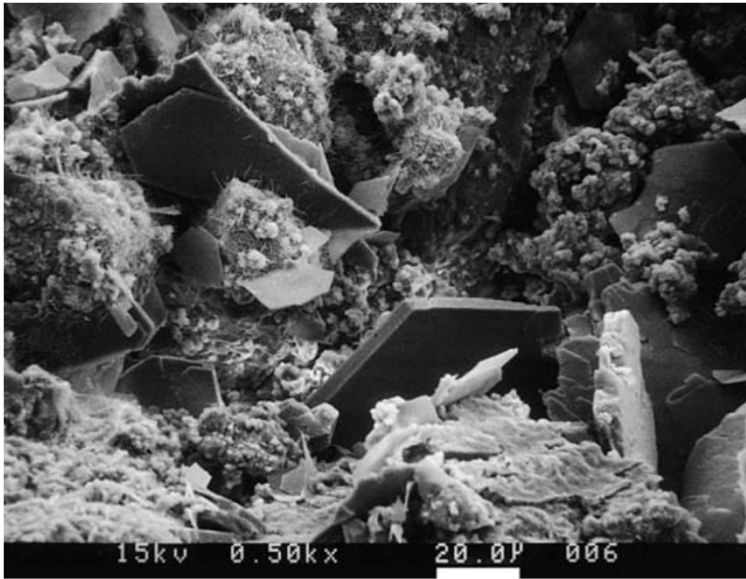
Typical Hydration Reactions of Primary Compounds

2 (3CaO • SiO ₂) Tricalcium silicate (C ₃ S)	+ 11 H ₂ O Water (H)	= 3CaO • 2SiO ₂ • 8H ₂ O Calcium silicate hydrate (C-S-H)	+ 3 (CaO • H ₂ O) Calcium hydroxide (CH)
2 (2CaO • SiO ₂) Dicalcium silicate (C ₂ S)	+ 9 H ₂ O Water (H)	= 3CaO • 2SiO ₂ • 8H ₂ O Calcium silicate hydrate (C-S-H)	+ CaO • H ₂ O Calcium hydroxide (CH)
3CaO • Al ₂ O ₃ Tricalcium aluminate (C ₃ A)	+ 3 (CaO • SO ₃ • 2H ₂ O) Gypsum (C \bar{S} H ₂)	+ 26 H ₂ O Water (H)	= 6CaO • Al ₂ O ₃ • 3SO ₃ • 32H ₂ O Ettringite (C ₆ A \bar{S} ₃ H ₃₂)
2 (3CaO • Al ₂ O ₃) Tricalcium aluminate (C ₃ A)	+ 6CaO • Al ₂ O ₃ • 3SO ₃ • 32H ₂ O Ettringite (C ₆ A \bar{S} ₃ H ₃₂)	+ 4 H ₂ O Water (H)	= 3 (4CaO • Al ₂ O ₃ • SO ₃ • 12H ₂ O) Calcium monosulfaluminate
3CaO • Al ₂ O ₃ Tricalcium aluminate (C ₃ A)	+ CaO • H ₂ O Calcium hydroxide (CH)	+ 12 H ₂ O Water (H)	= 4CaO • Al ₂ O ₃ • 13H ₂ O Tetracalcium aluminate hydrate
4CaO • Al ₂ O ₃ • Fe ₂ O ₃ (C ₄ AF) Tetracalcium aluminoferrite	+ 10 H ₂ O Water (H)	+ 2 (CaO • H ₂ O) Calcium hydroxide (CH)	= 6CaO • Al ₂ O ₃ • Fe ₂ O ₃ • 12H ₂ O Calcium aluminoferrite hydrate

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

Cement Paste (product of hydration)

scanning-electron micrographs of hardened cement paste at (left) 500x, and (right) 1000x.

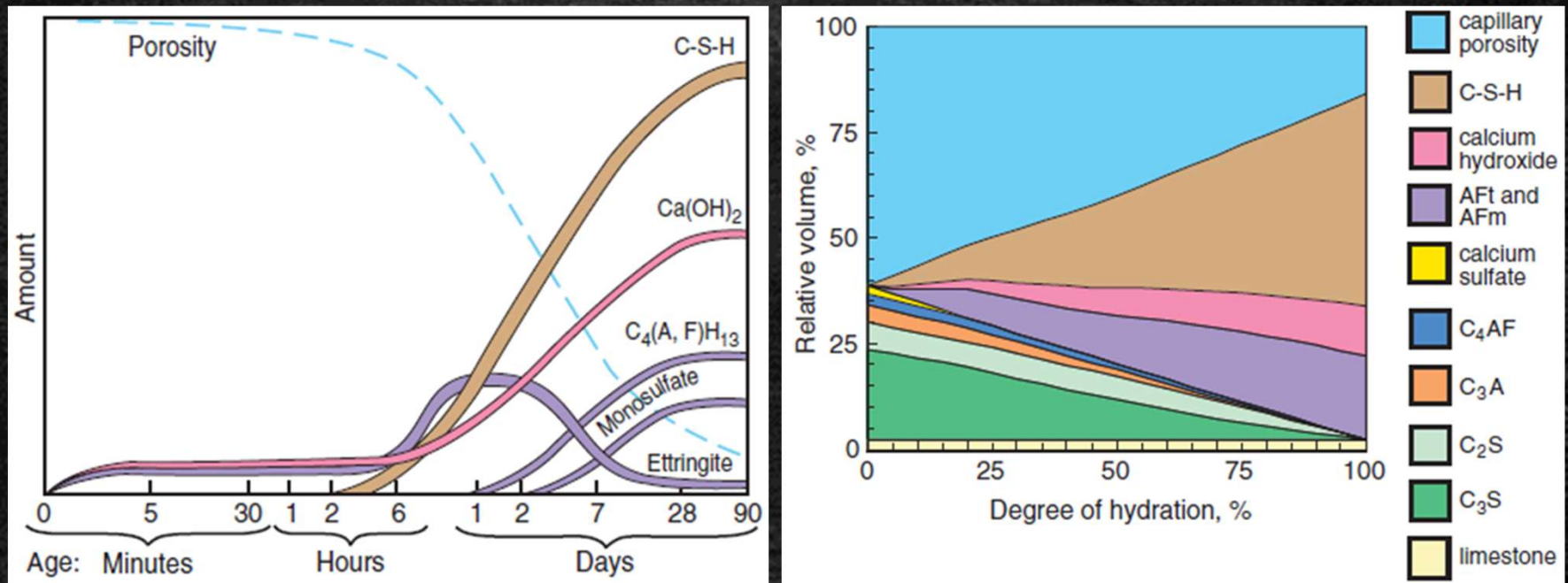


These images show scanning-electron micrographs of hardened cement paste. The plate-like material is made from crystallized calcium hydroxide. The remainder is primarily calcium-silicate-hydrate (CSH) with some ettringite needles showing in the image on the right. The calcium silicate hydrate is primarily responsible for the strength properties of the cement paste.

Basic Chemistry of Cement

2. Cement Hydration

Hydration Products



Relative volumes of the cement phases and hydration products in the microstructure of hydrating portland cement pastes (left) as a function of time and (right) as a function of the degree of hydration

Cement Main Compounds Characteristics and Importance

- **Tricalcium Silicate, C_3S** , hydrates and hardens rapidly and is largely responsible for initial set and early strength (see Figure 1). In general, the early strength of Portland cement concrete is higher with increased percentages of C_3S .
- **Dicalcium Silicate, C_2S** , hydrates and hardens slowly and contributes largely to strength increase at ages beyond one week.
- **Tricalcium Aluminate, C_3A** , liberates a large amount of heat during the first few days of hydration and hardening. It also contributes slightly to early strength development. Cements with low percentages of C_3A are more resistant to soils and waters containing sulfates.

Cement Main Compounds Characteristics and Importance

- **Tetracalcium Aluminoferrite, C_4AF** , is the product resulting from the use of iron and aluminum raw materials to reduce the clinkering temperature during cement manufacture. It contributes little to strength. Most color effects that give cement its characteristic gray color are due to the presence of C_4AF and its hydrates.
- **Calcium Sulfate, as gypsum** or any other similar material is added to cement during final grinding to provide sulfate to react with C_3A to form ettringite. This controls the hydration of C_3A . Without sulfate, cement would set much too rapidly. In addition to controlling setting and early strength gain, the sulfate also helps control drying shrinkage and can influence strength through 28 days.

Cement Main Compounds Characteristics and Importance

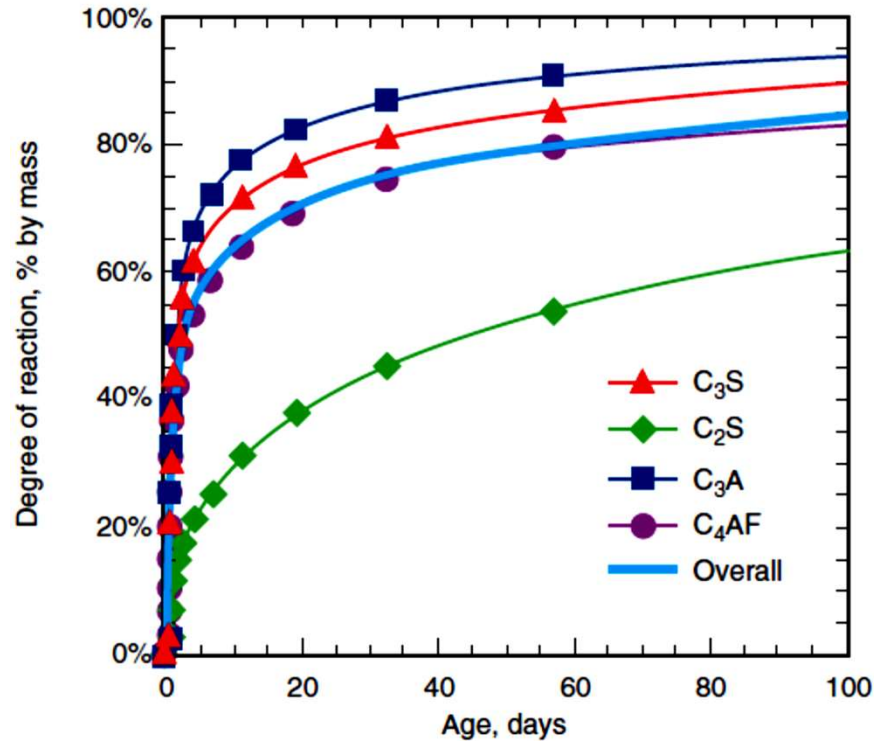


Figure 1 - Relative reactivity of cement compounds

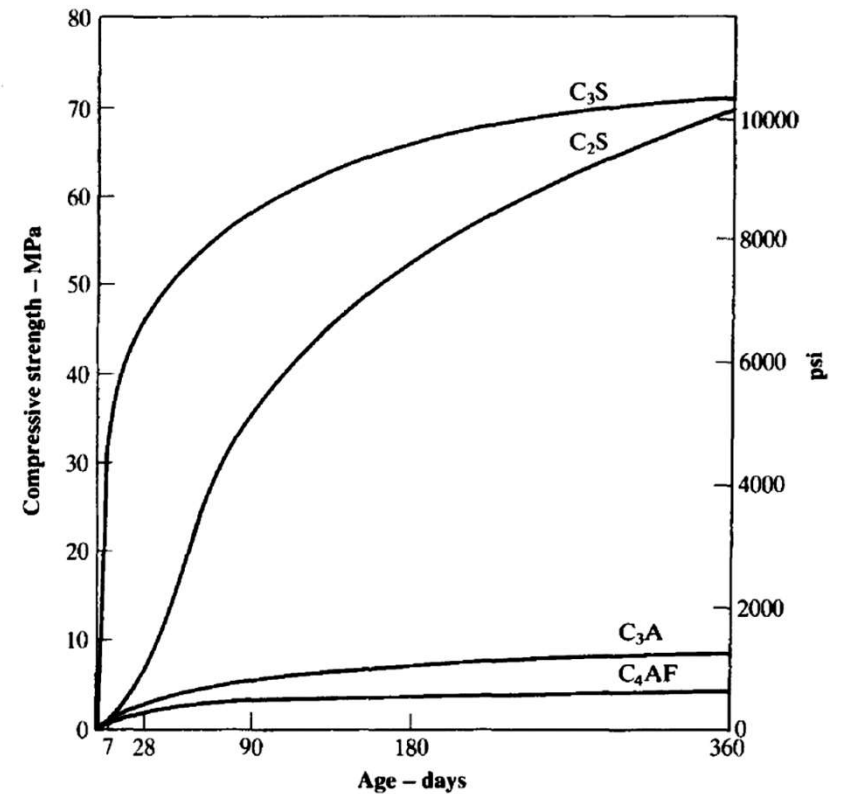


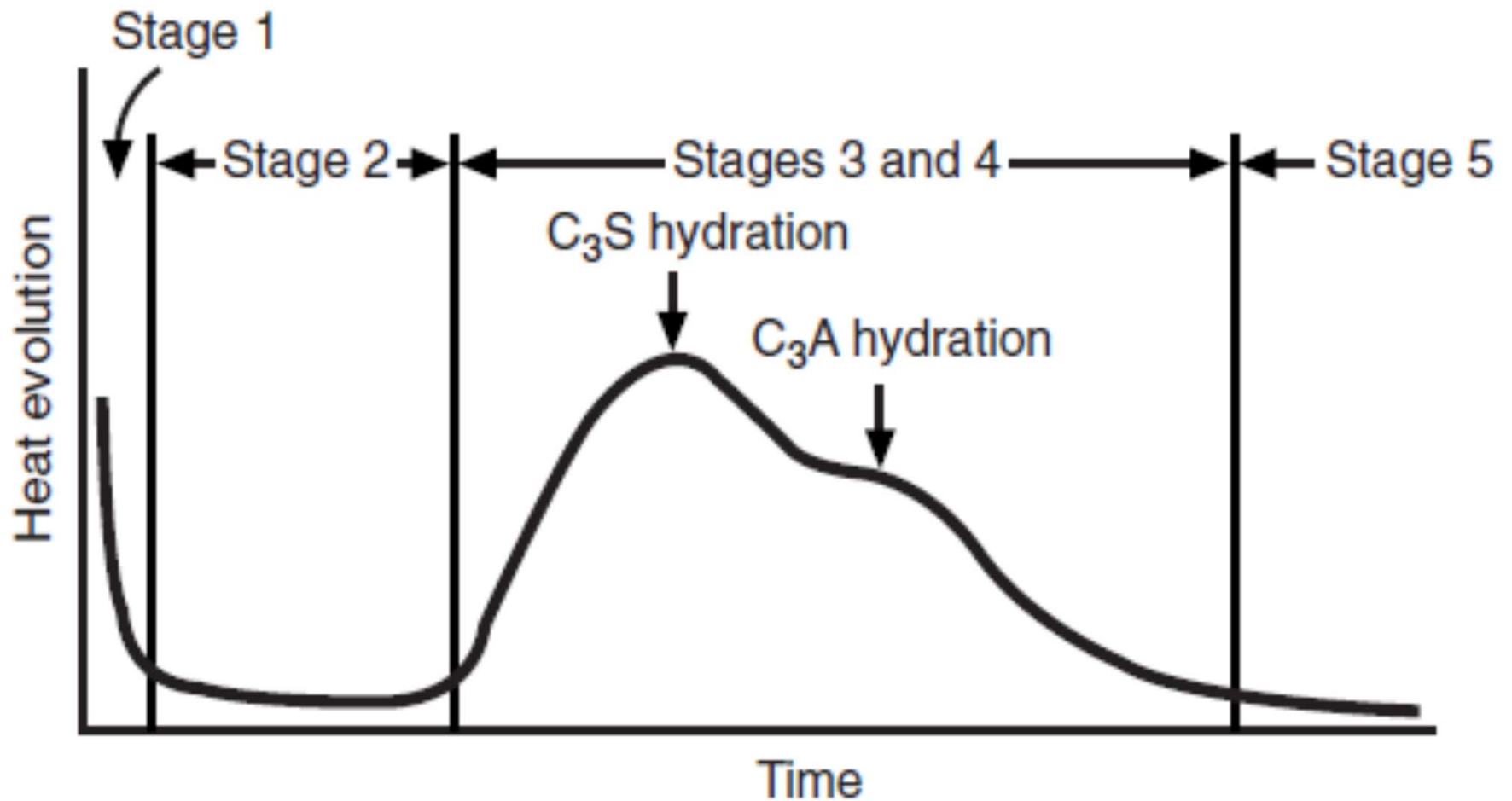
Figure 2 - Development of strength of pure compounds

3. HEAT OF HYDRATION

- **Heat of hydration** is the quantity of heat (in joules) per gram of unhydrated cement, evolved upon complete hydration at a given temperature. It is approximately equal to the sum of the heats of hydration of the individual pure compounds.
- **The rate of heat development** from the reaction is more important than the total heat produced. It depends on the following:
 - The temperature at which hydration occurs
 - Proportions of C_3A and C_3S , reducing the proportions of C_3A and C_3S , heat of hydration (and its rate) of cement can be reduced.
 - Fineness of cement
- **Significant:** The rate and amount of heat generated are critical and may be damaging in structures of considerable mass, greater than a meter thick. On the other hand it is beneficial during cold weather concreting.

3. HEAT OF HYDRATION

Heat evolution as a function of time for cement paste



3. HEAT OF HYDRATION

Heat evolution as a function of time for cement paste – refer to the figure in the previous slide

- The first peak shown in the heat profile is caused by heat generated from the initial hydration reactions of tricalcium aluminate C_3A (heat of wetting)
- This initial heat peak is followed by a period of slow thermal activity known as the induction period.
- After several hours, a broad second heat peak attributed to tricalcium silicate C_3S hydration emerges, signaling the onset of the paste hardening process.
- A third peak due to the renewed activity of tricalcium aluminate (C_3A) is experienced.
- Finally, stage 5 is a slow, steady formation of hydration products establishing the rate of later strength gain.

Types of Portland Cement

Introduction

- **Conceptually:** Major cement compounds have different properties, so suitable adjustment of compound composition, modify the properties of Portland cements and produce new cements with various desirable properties. However obtaining some special property of cement may lead to undesirable features in another respect.
- The division of the available cements in the markets into different types is no more than a broad classification and there may sometimes be wide differences between cements of nominally the same type. On the other hand There are often no sharp discontinuities in the properties of different types of cement, and some cements can be classified as more than one type.

Basic ASTM types of Ordinary Portland Cement

The ASTM has designated five types of Portland cement, they are:

- Ordinary cement (Type I)
- Modified cement (Type II)
- Rapid-hardening cement (Type III)
- Low-heat cement (Type IV)
- Sulfate-resisting cement (Type V)

Typical average values of compound composition of Portland cement of basic types

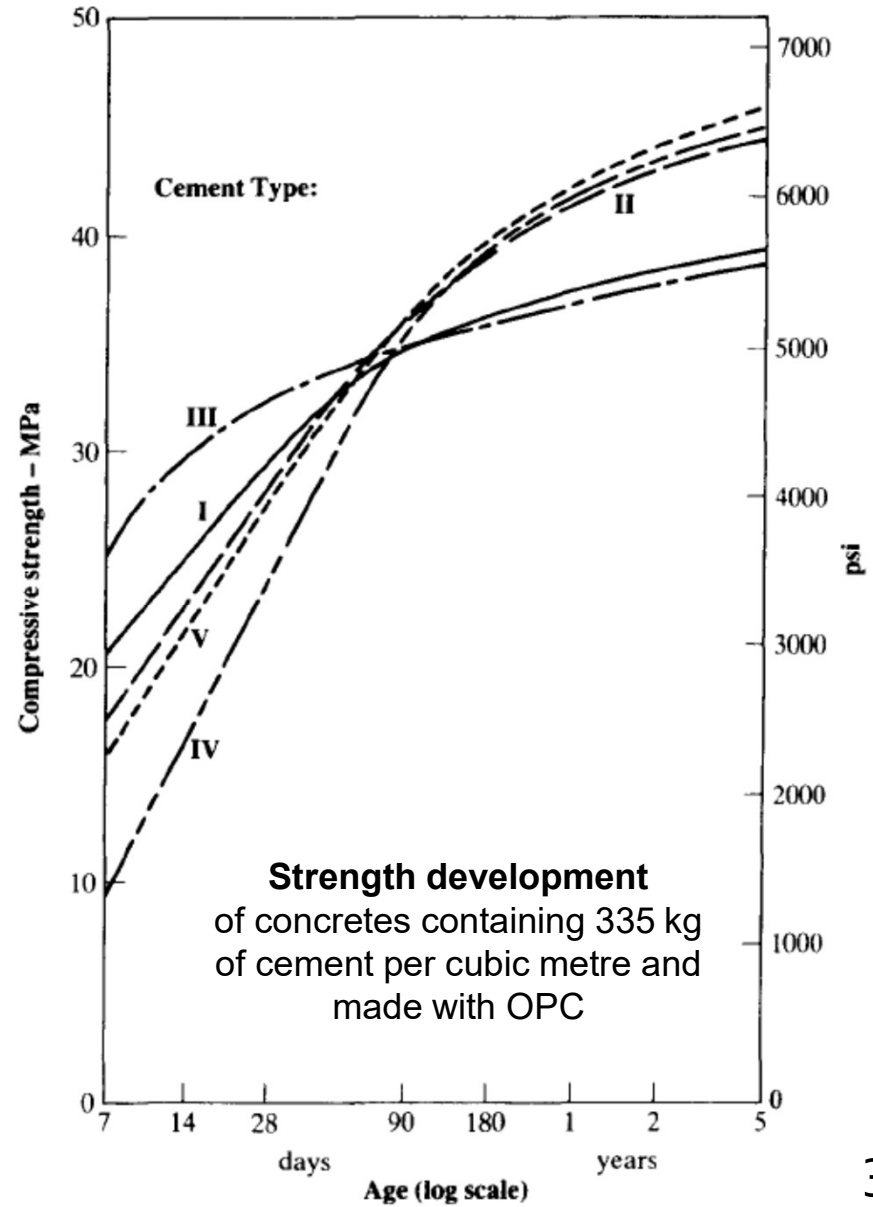
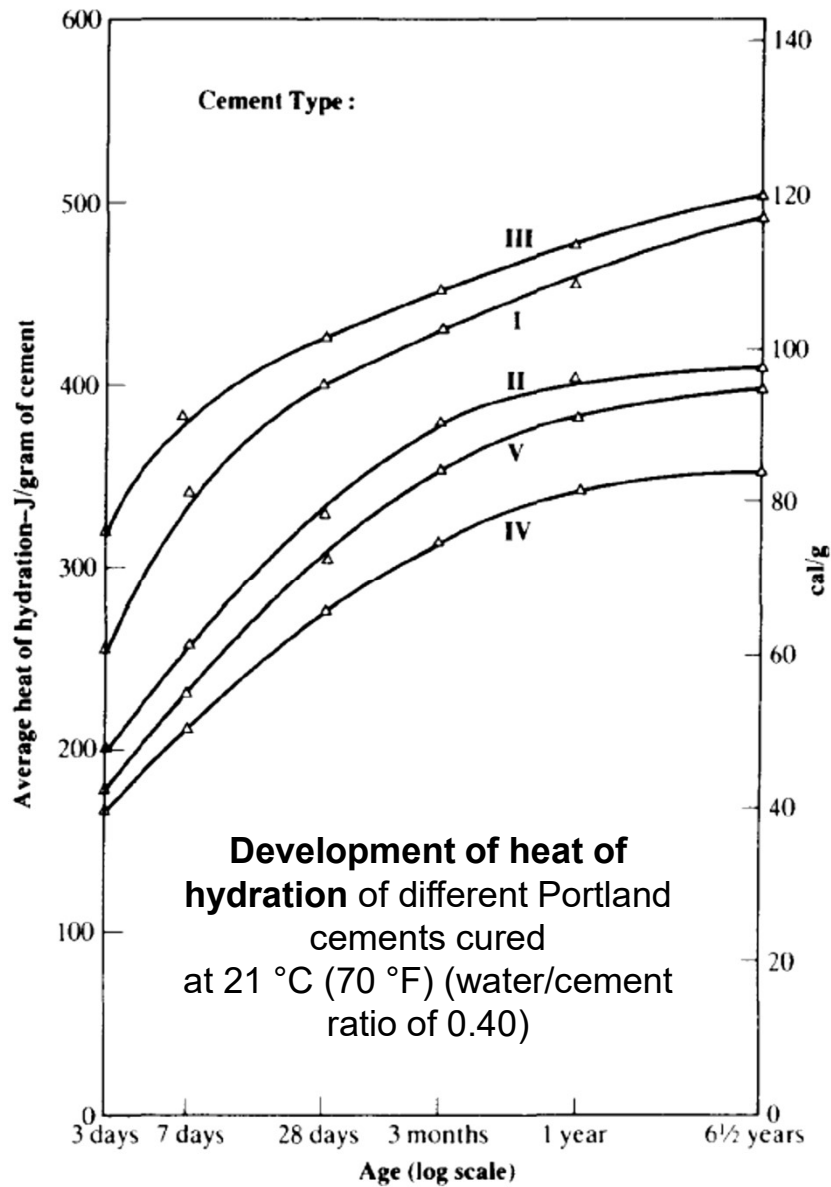
Cement type	Compound composition, per cent							
	C ₃ S	C ₂ S	C ₃ A	C ₄ AF	CaSO ₄	Free CaO	MgO	Loss on ignition
I	59	15	12	8	2.9	0.8	2.4	1.2
II	46	29	6	12	2.8	0.6	3.0	1.0
III	60	12	12	8	3.9	1.3	2.6	1.9
IV	30	46	5	13	2.9	0.3	2.7	1.0
V	43	36	4	12	2.7	0.4	1.6	1.0

Basic ASTM types of Ordinary Portland Cement

Comparison between different ASTM basic types (see table – previous page)

- Physically and chemically, these cement types differ primarily in their fineness and content of C_3A .
- In terms of performance, they differ primarily in the rate of early hydration and in their ability to resist sulfate attack. (see figure in the next page)
- All five types contain about 75% by weight calcium silicate minerals,
- properties of mature concretes made with all five are quite similar.

Basic ASTM types of Ordinary Portland Cement



Basic ASTM types of Ordinary Portland Cement

Ordinary Portland Cement (Type I)

- Type I Portland cement is a general-purpose cement suitable for all uses where the special properties of other cement types are not required. Typical uses for normal or general use cements include pavements, floors, bridges, and buildings.
- Specified to be made from 95-100 per cent of Portland cement clinker and 0-5 per cent of minor constituents,



Basic ASTM types of Ordinary Portland Cement

Modified Portland cement (Type II)

- There is actually little difference between Type I and Type II cement. It Was designed to be used where protection against moderate sulfate attack is necessary through reducing its content of C_3A .
- Type II cement is also recommended for structures where a moderately low heat generation is desirable.
- Typical use: slabs on ground, pipes



Basic ASTM types of Ordinary Portland Cement

Rapid-hardening Portland cement (Type III)

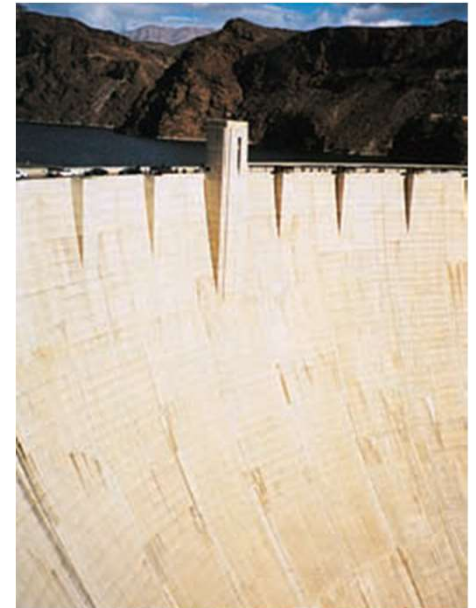
- Provides strength at an earlier period than normally expected due to a higher C_3S content and fineness (the major factor in early strength). So it is used where early concrete strength is needed, such as in cold weather concreting, fast track paving and rapid form removal for precast concrete.
- The downsides of rapid-reacting cements are a shorter period of workability, greater heat of hydration, and a slightly lower ultimate strength.



Basic ASTM types of Ordinary Portland Cement

Low-heat Portland cement (Type IV)

- Type IV cements are manufactured to generate heat at a slower rate than most other cements due to the lower content of C_3S and C_3A .
- It is used for massive structure and elements such as very thick bridge supports, and dams.
- Type IV cements are not commonly manufactured currently



Basic ASTM types of Ordinary Portland Cement

Sulfate-resisting cement(Type V)

- Type V Portland cement is used in concrete exposed to severe sulfate environments, principally where soils or groundwater have high sulfate content, such as in marine structures or sewage structures due to its low C_3A content.
- Sulfate-resisting cement is costly when compared with other types of cement due to the special composition of the raw materials. Thus, in practice, it shall be specified only when necessary.



Basic ASTM types of Ordinary Portland Cement

Summary of the general characteristics of the main types of Portland cement.

	Classification	Characteristics	Applications
Type I	General purpose	Fairly high C_3S content for good early strength development	General construction (most buildings, bridges, pavements, precast units, etc)
Type II	Moderate sulfate resistance	Low C_3A content (<8%)	Structures exposed to soil or water containing sulfate ions
Type III	High early strength	Ground more finely, may have slightly more C_3S	Rapid construction, cold weather concreting
Type IV	Low heat of hydration (slow reacting)	Low content of C_3S (<50%) and C_3A	Massive structures such as dams. Now rare.
Type V	High sulfate resistance	Very low C_3A content (<5%)	Structures exposed to high levels of sulfate ions

Blended Hydraulic Cements

Portland blast-furnace cement (Type IS)

- This type of cement is made by blending Portland cement clinker with ground granulated blast-furnace slag (GGBS), which is a waste product in the manufacture of pig iron that contains lime, silica and alumina.
- The amount of slag should be between 25 and 70 per cent of the mass of the mixture, according to ASTM C 595-05.
- Portland blast-furnace cement is similar to ordinary Portland (Type I) in regards fineness, setting times and soundness.
- Typical uses are in mass concrete because of a lower heat of hydration and in sea-water construction because of a better sulfate resistance (due to a lower C_3A content) than with ordinary Portland cement.

Pozzolans

- Pozzolans are a broad class of siliceous or siliceous and aluminous materials which is in finely divided form
- In the presence of moisture, chemically react with lime (liberated by hydrating Portland cement) at ordinary temperatures to form compounds possessing cementitious properties.
- Typical materials of this type are volcanic ash (the original pozzolan), pumicite (volcanic rock), and fly ash (PFA).



volcanic ash



pumicite



fly ash



calcined diatomaceous earth

Blended Hydraulic Cements

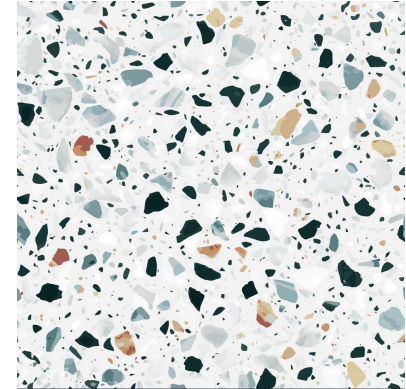
Portland-pozzolan cements (Type IP)

- These cements are made by intergrinding , blending or combination of both of Portland cement and pozzolan. Usually the pozzolan content of these cements is up to 40% by mass.
- Advantages
 - Chief advantage lies in slow hydration and therefore low rate of heat development.
 - The use of fly ash particularly improves sulfate resistance.
 - Pozzolans may often be cheaper than the Portland cement
- Uses: The typical uses of this cement are in roller compacted concrete, in concrete with low-heat characteristics, and in concrete requiring good chemical resistance.

Special Cements

White and colored Portland cements

- White cement is made from china clay, which contains little iron oxide and manganese oxide, together with chalk or limestone free from specified impurities. With special precautions during the grinding to avoid contamination. As a result, the cost of white cement is high (twice that of ordinary Portland cement)
- White cement can be colored by paint or by adding pigments to the mixer, provided there is no adverse effect on strength.
- Uses : For architectural purposes; It is also used because of its low content of soluble alkalis so that staining is avoided.



Special Cements

Expansive (or expanding) cements

- Expansive cements consist of a mixture of Portland cement, expanding agent and stabilizer.
- Expansive cements are used in special circumstances, such as prevention of water leakage and, generally, to minimize cracking caused by drying shrinkage in concrete slabs, pavements and structures.

Masonry and Mortar Cements

Portland cement mixed with limestone up to 35% as Inert filler

Used in the local market in mortar for masonry construction and for finishes and rehabilitation works only.

Special Cements

Special cements	Type	Application
White portland cements, ASTM C150	I, II, III, V	White or colored concrete, masonry, mortar, grout, plaster, and stucco
White masonry cements, ASTM C91	M, S, N	White mortar between masonry units
Masonry cements, ASTM C91	M, S, N	Mortar between masonry units*, plaster, and stucco**
Mortar cements, ASTM C1329	M, S, N	Mortar between masonry units*
Plastic cements, ASTM C1328	M, S	Plaster and stucco**
Expansive cements, ASTM C845	E-1(K), E-1(M), E-1(S)	Shrinkage compensating concrete
Oil-well cements, API-10A	A, B, C, D, E, F, G, H	Grouting wells
Water-repellent cements		Tile grout, paint, and stucco finish coats
Regulated-set cements		Early strength and repair***
Cements with functional additions, ASTM C595 (AASHTO M 240), ASTM C1157		General concrete construction needing special characteristics such as: water-reducing, retarding, air entraining, set control, and accelerating properties
Finely ground (ultrafine) cement		Geotechnical grouting***
Calcium aluminate cement		Repair, chemical resistance, high temperature exposures
Magnesium phosphate cement		Repair and chemical resistance
Geopolymer cement		General construction, repair, waste stabilization***
Ettringite cements		Waste stabilization***
Sulfur cements		Repair and chemical resistance
Rapid hardening hydraulic cement, ASTM C1600	URH, VRH, MRH, GRH	General paving where very rapid (about 4 hours) strength development is required
Natural cement, ASTM C10		Historic restoration of natural cement mortar, cement plaster, grout, whitewash, and concrete

* Portland cement Types I, II, and III and blended cement Types IS and IP are also used in making mortar.

** Portland cement Types I, II, and III and blended cement Types IP and IS(≤ 70) are also used in making plaster.

*** Portland and blended hydraulic cements are also used for these applications.

European Cement Specifications

- European cement standard, EN 197-1 covers 27 products in the family of common cements as given by Table. The products are grouped into five main cement types as follows:
 - CEM I Portland cement
 - CEM II Portland-composite cement
 - CEM III Blast furnace cement
 - CEM IV Pozzolanic cement
 - CEM V Composite cement
- EN 197 also includes strength classes and ranges (32.5, 42.5, and 52.5 MPa).
- EN 197 cement Types CEM I, II, III, IV, and V do not correspond to the cement types in ASTM,

European Cement Specifications

Main types	Notation of the 27 products (types of common cement)		Composition (% by mass)											
			Main constituents										Other constituents	
			Clinker	Blast-furnace slag	Silica fume	Pozzolana		Fly ash		Calcined (burnt) shale	Limestone			
						Natural	Natural calcined	Siliceous	Calcareous		L	LL		
K	S	D ^b	P	Q	V	W	T	L	LL					
CEM I	Portland cement	CEM I	95-100											0.5
CEM II	Portland-slag cement	CEM II/A-S	80-94	6-20										0.5
		CEM II/B-S	65-79	21-35										0.5
	Portland-silica fume cement	CEM II/A-D	90-94		6-10									0.5
	Portland-pozzolan cement	CEM II/A-P	80-94			6-20								0.5
		CEM II/B-P	65-79			21-35								0.5
		CEM II/A-Q	80-94				6-20							0.5
		CEM II/B-Q	65-79				21-35							0.5
	Portland-fly ash cement	CEM II/A-V	80-94					6-20						0.5
		CEM II/B-V	65-79					21-35						0.5
		CEM II/A-W	80-94						6-20					0.5
		CEM II/B-W	65-79						21-35					0.5
	Portland-burnt shale cement	CEM II/A-T	80-94							6-20				0.5
		CEM II/B-T	65-79							21-35				0.5
	Portland-limestone cement	CEM II/A-L	80-94								6-20			0.5
		CEM II/B-L	65-79								21-35			0.5
		CEM II/A-LL	80-94									6-20		0.5
CEM II/B-LL		65-79									21-35		0.5	
Portland-composite cement	CEM II/A-M	80-94						6-20					0.5	
	CEM II/B-M	65-79						21-35					0.5	
CEM III	Blastfurnace cement	CEM III/A	35-64	36-65									0.5	
		CEM III/B	20-34	66-80									0.5	
		CEM III/C	5-19	81-95									0.5	
CEM IV	Pozzolan cement	CEM IV/A	65-89				11-35				0.5			
		CEM IV/B	45-64				36-55				0.5			
CEM V	Composite cement	CEM V/A	40-64	18-30			18-30				0.5			
		CEM V/B	20-38	31-50			31-50				0.5			

Tests on Cement

Introduction

- Because the quality of cement is vital for the production of good concrete, the manufacture of cement requires strict control.
- A number of tests are performed to ensure that the cement is of the desired quality and that it conforms to the requirements of the relevant national standards
- The most important tests of cements include Fineness tests, setting times, soundness tests and strength tests.

Fineness of cement

- Fineness of cement can be measured through Specific surface which is expressed as the total surface area in square meters of all the cement particles in one kilogram of cement. The higher the specific surface is, the finer cement will be.
- Importance:
 - The rate of hydration depends on the fineness of cement particles,
 - The fineness of cement particles determine the development of strength of the paste. A high fineness means a rapid strength development.
 - Cement fineness can affect other properties, e.g. gypsum requirement, workability of fresh concrete and long-term Behavior.
- Methods of Measurement
 - Wagner turbidimeter method: Measurement of the particle size distribution by sedimentation or elutriation based on Stoke's law.
 - Air permeability method using Blaine Air-Permeability Apparatus.

Blaine Air-Permeability Method

- The air-permeability method of determining the specific surface (ASTM C 204) is based on the relationship between the surface area of the particles in a porous bed and the rate of fluid flow through the bed.
- A known volume of air passes at a prescribed average pressure, the rate of flow diminishing steadily; the time taken for the flow to take place is measured, and for a given apparatus and standard porosity, the specific surface can be calculated.



Typical Surface Areas

- For normal cement: about 350 m²/ kg
- For high early strength cement: about 500 m²/ kg

Consistence of standard paste

- It is a test to determine for any given cement the water content which will produce a paste of standard consistence.
- Consistence is determined by the Vicat apparatus, which measures the depth of penetration of a 10mm diameter, 300g needle under its own weight into fresh cement paste.
- A paste is said to have normal consistency when the plunger penetrates 10 ± 1 mm below the original surface in 30 s.

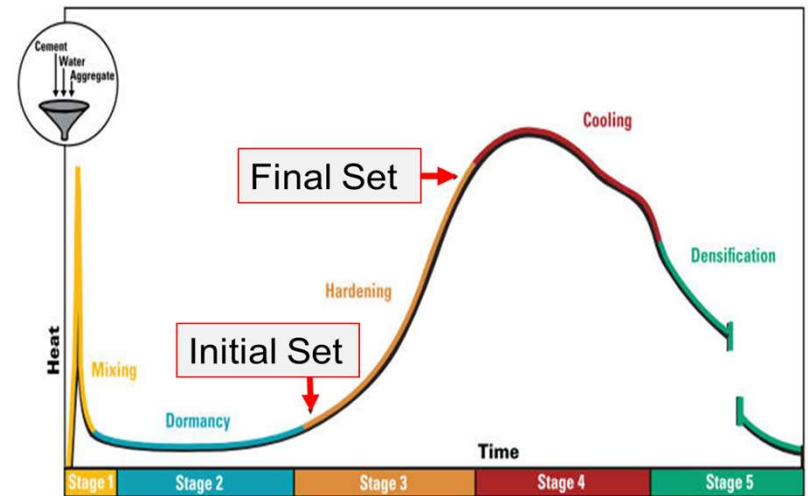


Consistence of standard paste

- The test identify the standard mix that shall be used for other tests such as the initial setting time, the final setting time, and for Le Chatelier soundness tests.
- The test is very sensitive to the conditions under which it is carried out, particularly temperature and the way the cement is compacted into the mold.

Setting Time Test

- Setting refers to a change from a fluid to a rigid state. Setting is mainly caused by a selective hydration of C_3A and C_3S and is accompanied by temperature rises in the cement paste.
- Initial set which indicates the time at which the paste is beginning to stiffen considerably and can no longer be molded.
- Final set which indicates the time at which the cement has hardened to the point at which it can sustain some load.

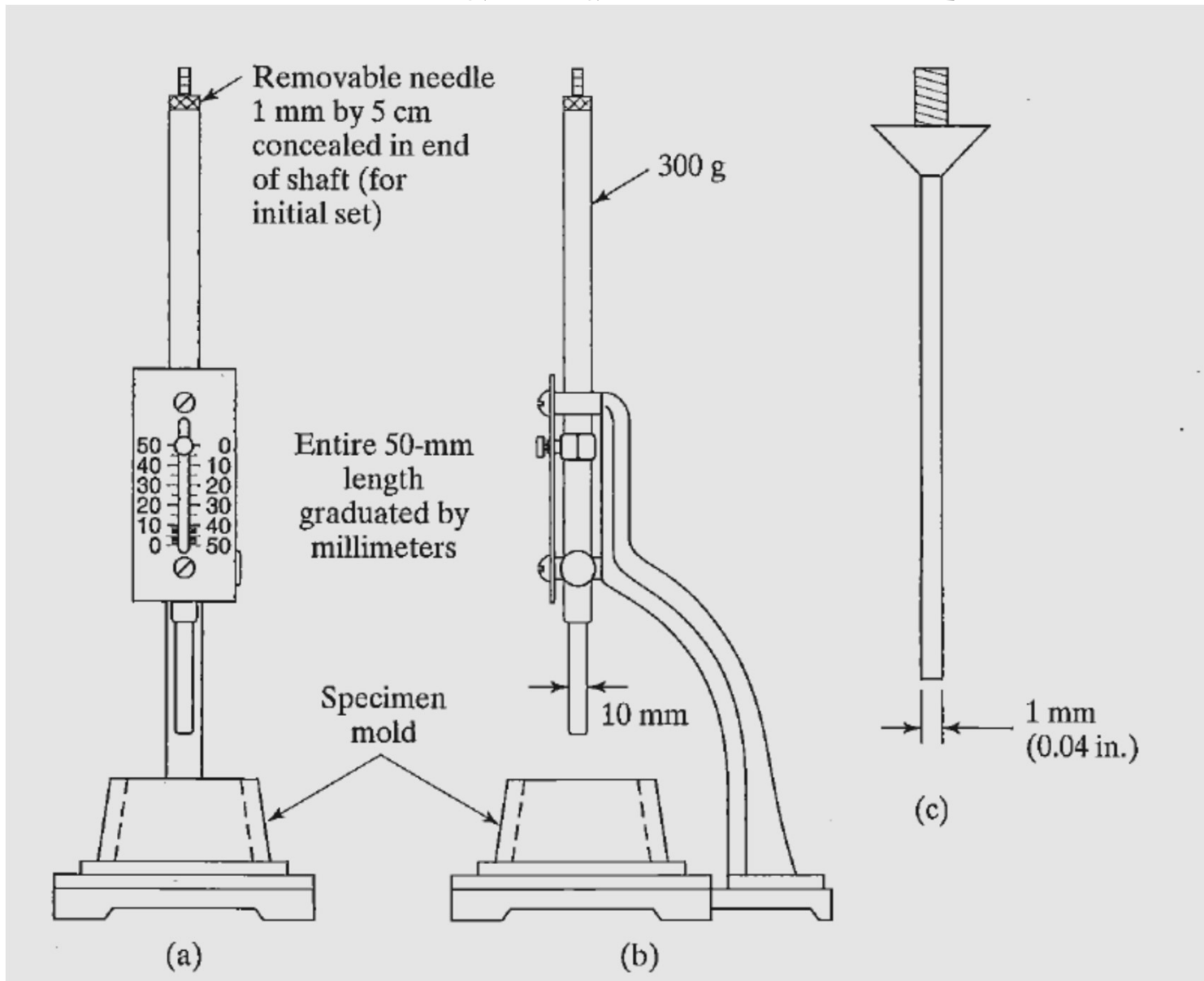


For Portland cements, ASTM prescribed:

- a minimum initial setting time of 60 min.
- a maximum final setting time of 10 hours

Generally, initial set occurs in 2 to 4h, and final set in 5 to 8h.

Time of setting by the Vicat needle



Soundness Test

- Unsoundness in cement paste results from excessive volume change after setting which can cause cracking and even failure under conditions of restraint.
- Unsoundness in cement is caused by the slow hydration of MgO, free lime, and by the reaction of Calcium sulfate that can form ettringite from excess gypsum that was not reacted with C_3A .
- These expansive reactions take place very slowly, and so unsoundness will only appear after many months, or even years.
- So the autoclave expansion test (ASTM C 151) is an accelerated test that can detect unsoundness due to both excess CaO and excess MgO.

Strength Tests

- Since cement is used primarily as a structural material, its strength properties are of prime importance
- Strength tests are required to be carried out on mortars (Sand + Cement).
- The factors that can influence the measurement of strength include the w/c ratio, cement/sand ratio, type and grading of sand, manner of mixing and molding specimens, curing conditions, size of specimen, shape of specimen, moisture content at time of test, loading conditions, and age.
- Strength can be measured in compression, tension, or flexure.
- The strengths of mortar as determined by strength tests cannot be related directly to the strengths of concrete made with the same cements. Thus, the strength tests on mortars serve primarily as quality-control tests.

Strength Tests

- The most common strength test, compressive strength, is carried out on a 50 mm (2-inch) cement mortar test specimen. The test specimen is subjected to a compressive load (usually from a hydraulic machine) until failure. This loading sequence must take no less than 20 seconds and no more than 80 seconds.

