بسم الله الرحمن الرحيم

Lecture # 2

Civil Engineering Material

Cement

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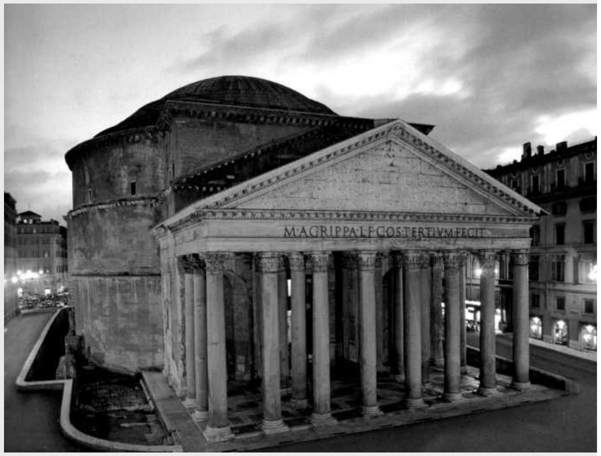
INTRODUCTION

Definition: "Cement is a crystalline compound of calcium silicates and other calcium compounds having hydraulic properties" (Macfadyen, 2006).

History

- Lime and clay have been used as cementing material on constructions through many centuries.



- Romans are commonly given the credit for the development of hydraulic cement, the most significant incorporation of the Roman's was the use of pozzolan-lime cement by mixing volcanic ash from the Mt. Vesuvius with lime. Best know surviving example is the Pantheon in Rome

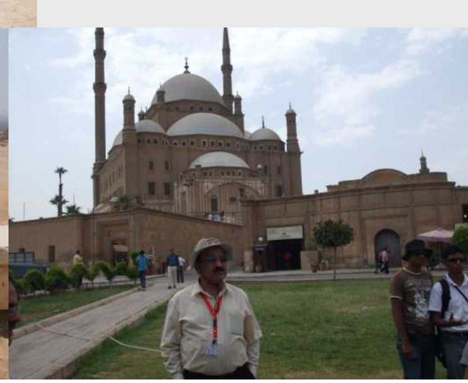
- In 1824 Joseph Aspdin from England invented the Portland cement

History of cement and concrete

- **The early days:**
  - **Setting stone blocks without cementing them**
  - **Mud mixed with straw is the oldest cementing material used to bind dried bricks together**
  - **Pyramid of Cheops.**

Cheops, Giza

- Stones were brought from Aswan and Tura using the Nile river
- Built around 2566 B.C.
- It would have taken over 2,300,000 blocks of stone with an average weight of 2.5 tons each
- Total weight of 6 million tons
- 30 years and 100,000 slaves to build it
- Has a height of 482 feet (140m)
- It is the largest and the oldest of the Pyramids of Giza
- Mortars made by calcining impure gypsum



History of cement and concrete

- **Non-hydraulic cements**
  - **Gypsum and lime**
  - **Cements based on compounds of lime (calcareous cements)**
- **Gypsum**
  - **Calcining impure gypsum at 130 ° C**
  - **Add water calcined gypsum and water recombine**
  - **Cannot harden under water because gypsum is quite soluble.**
  - **Pyramid of Cheops (3000 B.C.)**

History of cement and concrete

- **Lime**
  - Lime mortars used in Egypt in the Roman period
  - Made by calcining limestone at 1000 °C

$$CaCO_3 \xrightarrow{\text{Heat}} CaO + CO_2$$

  - Lime mortar hardens in air, due to evaporation of the mixing water and carbonation
  - Carbonation (secondary reaction)

$$CaO + H_2O \rightarrow Ca(OH)_2 \xrightarrow{CO_2} CaCO_3 + H_2O$$

  - These mortars contain < 25% silica and alumina
  - Thorough mixing leads to excellent performance of these mortars

Hydraulic Limes

- **Pont du Gard at Nimes, France**

- Built shortly before the Christian era by Roman emperor Claude to allow the aqueduct of Nîmes (which is almost 50 km long) to cross the Gard river.
- The bridge stands almost 50 m high and is on three levels, the longest measuring 275 m.

Hydraulic Limes

- **Hydraulic limes**
  - **Cements that are capable of hardening under water (hydraulic cements)**
  - **Mixture of calcareous (limestone) and argillaceous (clayey) materials**
  - **Calcine below sintering temperature**
  - **Volcanic deposits finely ground (pozzolanas) and mixed with limestone and sand = strong mortar resistant to water**
  - **Finely crushed brunt brick**
  - **Pantheon**

Hydraulic Limes

Pantheon, Rome

- Built between 118 and 126 A.D. with bearing masonry.
- Hemispherical dome unsupported on monolithic 4m (46 ft) high Egyptian marble columns.
- The dome has a span of 43.2 m (142 feet).
- The dome is constructed of stepped rings of solid concrete with low density aggregate (pumice), diminishing in thickness to about 1.2 m (4 feet) at the edge of the oculus.

Pantheon, Rome

- The dome rests on a cylinder of masonry walls 6 m (20 feet).
- Hidden voids and the interior recesses hollow out this construction, so that it works less as a solid mass and more like three continuous arcades which correspond to the three tiers of relieving arches visible on the building exterior.

History of Cement and Concrete

- **Natural cements**
  - Made by calcining naturally occurring mixture of calcareous and argillaceous materials with the right composition of lime and silica
  - Calcining is done at temperatures below the sintering temperature (only partial chemical combination occurs)
- **Portland cement**
  - Joseph Aspdin, 1824 England
    - Calcining finely ground limestone, mixing it with finely divided clay and calcining the mixture in a kiln until the CO_2 is driven off. The product was then finely ground.
  - Portland cement is a trade name and has no relationship to composition or properties
- **Portland cement manufacture**
  - Originally made in vertical kilns
  - First rotary kiln built 1886 in England
  - Gypsum first interground with clinker in the US to increase the setting time
- **Tests on concrete**
  - First systematic tests on tensile and compressive strength carried out in Germany in 1836
  - Tests standardized in 1900

- Concrete admixtures
  - Romans used animal fat, milk, and blood to improve concrete
  - Blood is a good air entraining agent
  - Calcium chloride used as an accelerator
  - Systematic study of admixtures began in the 1930´s

Types of Cement

- Cements are considered hydraulic because of their ability to set and harden under or with excess water through the hydration of the cement's chemical compounds or minerals.
- There are two types:

  Those that activate with the addition of water

  And pozzolanic that develop hydraulic properties when the interactwith hydrated lime $Ca(OH)_2$

Pozzolanic: any siliceous material that develops hydraulic cementitious properties when interacted with hydrated lime.

HYDRAULIC CEMENTS:

Hydraulic lime: Only used in specialized mortars. Made from calcination of clay-rich limestones.

Natural cements: Misleadingly called Roman. It is made from argillaceous limestones or interbedded limestone and clay or shale, with few raw materials. Because they were found to be inferior to Portland, most plants switched.

Portland cement: Artificial cement. Made by the mixing clinker with gypsum in a 95:5 ratio.

Portland-limestone cements: Large amounts (6% to 35%) of ground limestone have been added as a filler to a Portland cement base.

Blended cements: Mix of Portland cement with one or more SCM (supplementary cemetitious materials) like pozzolanic additives.

Pozzolan-lime cements: Original Roman cements. Only a small quantity is manufactured in the U.S. Mix of pozzolans with lime.

Masonry cements: Portland cement where other materials have been added primarily to impart plasticity.

Aluminous cements: Limestone and bauxite are the main raw materials. Used for refractory applications (such as cementing furnace bricks) and certain applications where rapid hardening is required. It is more expensive than Portland. There is only one producing facility in the U.S.

GEOLOGY (RAW MATERIALS)

The fundamental chemical compounds to produce cement clinker are:

- Lime (CaO)
- Silica (SiO_2)
- Alumina (Al_2O_3)
- Iron Oxide (Fe_2O_3)

Raw materials used in the production of clinker cement

Types of Raw Materials	
Sources of calcium carbonate	Limestone, marl, chalk
Sources of argillaceous materials	Clay, shale, sand, iron ore, mill scale, bauxite, diaspore, diatomite, staurolite, loess, silt, sandstone, volcanic ash
Waste material substitutes	Fly ash, bottom ash, foundry sand, metallurgical slags

Fly ash: by-product of burning finely grounded coal either for industrial application or in the production of electricity

Clinker compounds in Type I portland cement

Compound	Abbreviation	Common Abbreviation	Oxide Composition	Stoichiometric Composition	Approximate Content in Type I Portland Cement, %*
Tricalcium silicate (alite)	3CS	C_3S	$(CaO)_3SiO_2$	Ca_3SiO_5	45
Dicalcium silicate (belite)	2CS	C_2S	$(CaO)_2SiO_2$	Ca_2SiO_4	27
Tricalcium aluminate	3CA	C_3A	$(CaO)_3Al_2O_3$	$Ca_3Al_2O_6$	11
Tetracalcium-aluminoferrite†	4CAF	C_4AF	$(CaO)_4(Al_2O_3)(Fe_2O_3)$	$Ca_4Al_2Fe_2O_{10}$	8

Adapted from Clausen 1960.

* Commercial cements contain 4%–6% gypsum or anhydrite (for regulation of the "setting time" of the concrete), approximately 0.5% each of alkali oxides (Na_2O and K_2O) and uncombined CaO, plus a few percent impurities, largely MgO.

† This composition of the iron-containing phase is an approximation and may range from $(CaO)_2Fe_2O_3$ to $(CaO)_6(Al_2O_3)_2(Fe_2O_3)$.

(Macfadyen, 2006)

www.recycleworks.org/images/flyash_concrete.gif

SOURCES OF $CaCO_3$

- Sedimentary deposits of marine origin (limestone)
- Marble (metamorphosed limestone)
- Chalk
- Marl
- Coral
- Aragonite
- Oyster and clam shells
- Travertine
- Tuff

LIMESTONES
Originate from the biological deposition of shells and skeletons of plants and animals.

Massive beds accumulated over millions of years.

In the cement industry limestone includes calcium carbonate and magnesium carbonate. Most industrial quality limestones is of biological origin.

The ideal cement rock 77 to 78% CaCO3, 14% SiO2, 2.5% Al2O3, and 1.75% FeO3. Limestone with lower content of CaCO3 and higher content of alkalis and magnesia requires blending with high grade limestone

(Macfadyen, 2006)

(Kussmaul, 2003)

http://en.wikipedia.org/wiki/Image:Limestoneshale7342.jpg

SOURCES OF ARGILLACEOUS MINERALS

Argillaceous mineral resources:

- Clay and shale for alumina and silica
- Iron ore for iron

Other natural sources of silica are and alumina are:

Loess, silt, sandstone, volcanic ash, diaspore, diatomite, bauxite

Shales, mudstones, and sandstones are typically interbedded with the limestone and were deposited as the inland waters and oceans covered the land masses. Clays are typically younger surface deposits

(Macfadyen, 2006)

http://en.wikipedia.org/wiki/Image:ShaleUSGOV.jpg

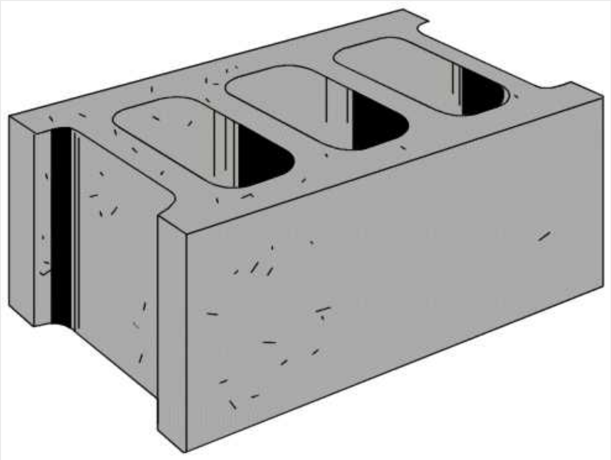
USES

Uses

Main use is in the fabrication of concrete and mortars

Modern uses

- Building (floors, beams, columns, roofing, piles, bricks, mortar, panels, plaster)
- Transport (roads, pathways, crossings, bridges, viaducts, tunnels, parking, etc.)
- Water (pipes, drains, canals, dams, tanks, pools, etc.)
- Civil (piers, docks, retaining walls, silos, warehousing, poles, pylons, fencing)
- Agriculture (buildings, processing, housing, irrigation)



Mortar holding weathered bricks

SUBSTITUTES

It competes in the construction industry with concrete substitutes:

- Alumina
- Asphalt
- Clay brick
- Fiberglass
- Glass
- Steel
- Stone Wood

Some materials like fly ash and ground granulated furnace slugs have good hydraulic properties and are being used as partial substitutes for Portland cement in some concrete applications

PRODUCTION

World Production and Capacity:

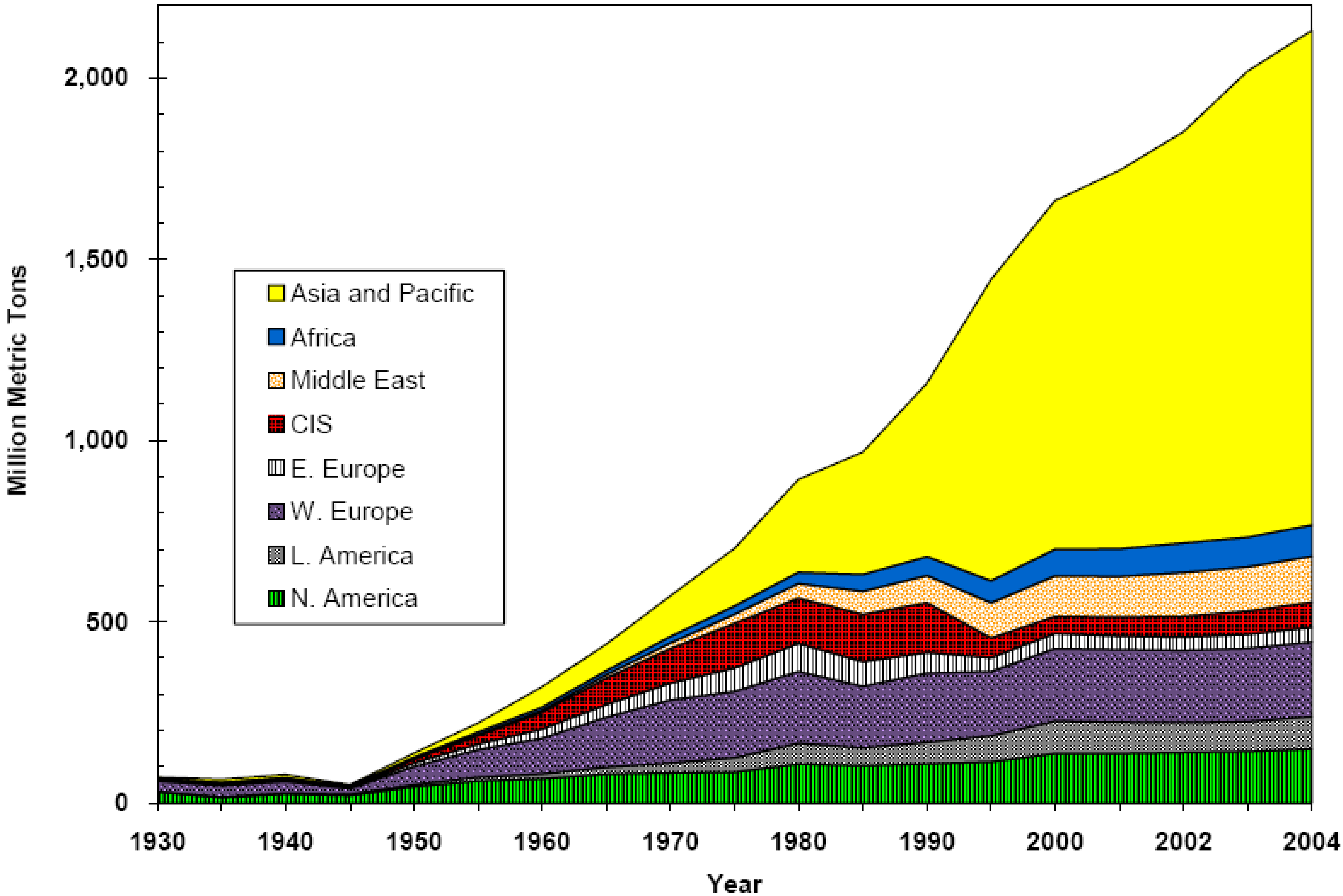
	Cement production		Yearend clinker capacity[e]	
	2004	**2005[e]**	**2004**	**2005**
United States (includes Puerto Rico)	99,000	99,100	105,000	106,000
Brazil	[e]38,000	39,000	45,000	45,000
China	934,000	1,000,000	850,000	850,000
Egypt	[e]28,000	27,000	35,000	35,000
France	21,000	20,000	22,000	22,000
Germany	32,000	32,000	31,000	31,000
India	[e]125,000	130,000	150,000	150,000
Indonesia	[e]36,000	37,000	42,000	42,000
Iran	[e]30,000	32,000	33,000	35,000
Italy	[e]38,000	38,000	46,000	46,000
Japan	67,400	66,000	76,000	74,000
Korea, Republic of	53,900	50,000	62,000	62,000
Mexico	35,000	36,000	40,000	40,000
Russia	[e]43,000	45,000	65,000	65,000
Saudi Arabia	23,200	24,000	24,000	24,000
Spain	46,800	48,000	40,000	40,000
Thailand	35,600	40,000	50,000	50,000
Turkey	38,000	38,000	35,000	35,000
Vietnam	25,300	27,000	20,000	22,000
Other countries (rounded)	381,000	392,000	330,000	346,000
World total (rounded)	2,130,000	2,220,000	2,100,000	2,120,000

Data in thousand metric tons

World Production and Capacity:

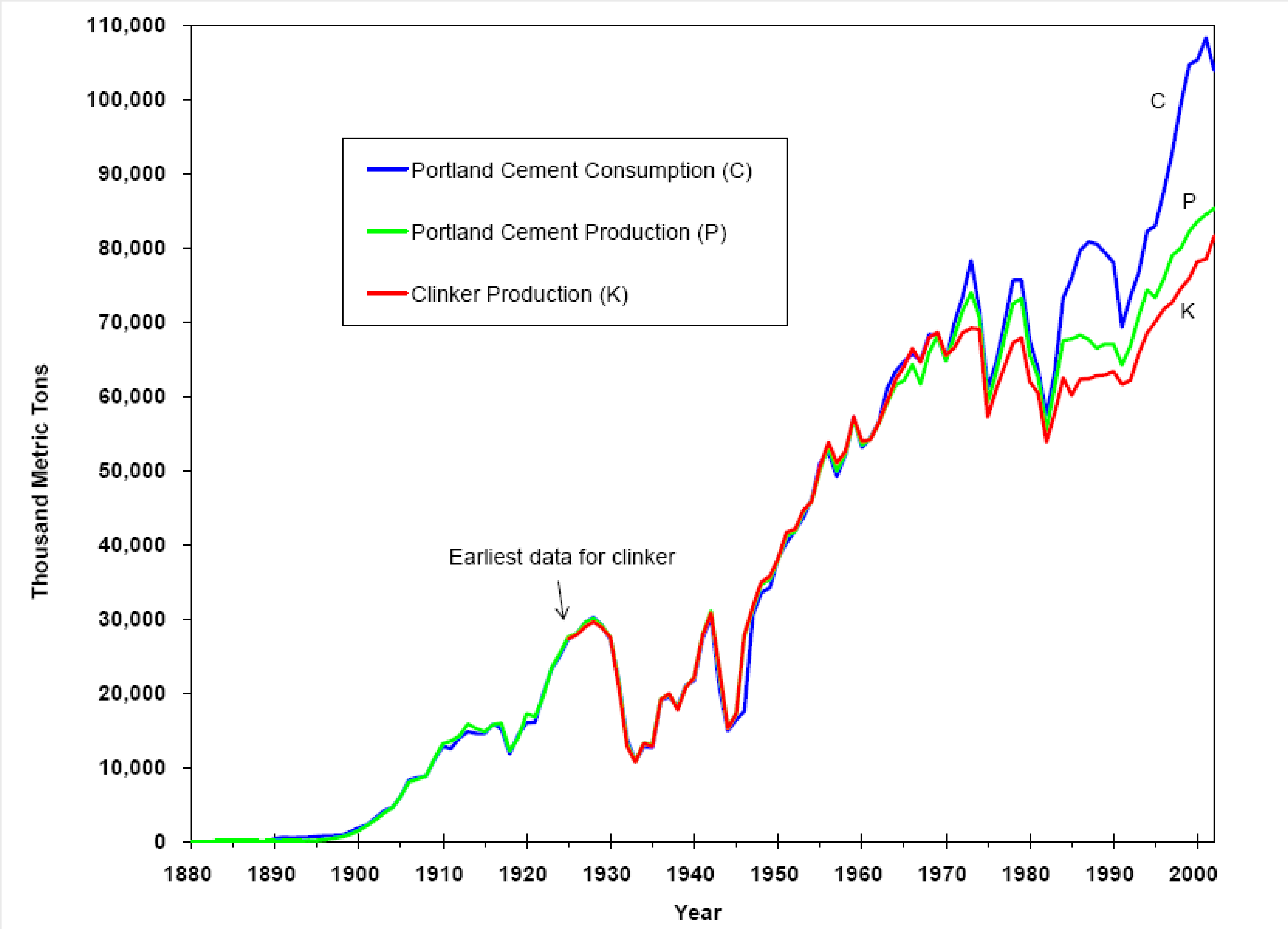
	Cement production		Yearend clinker capacity[e]	
	2005	**2006[e]**	**2005**	**2006**
United States (includes Puerto Rico)	101,000	101,000	104,000	104,000
Brazil	36,700	37,000	45,000	45,000
China	1,040,000	1,100,000	950,000	980,000
Egypt	[e]29,000	29,000	35,000	35,000
France	21,300	21,000	22,000	22,000
Germany	30,600	30,000	31,000	31,000
India	[e]145,000	155,000	150,000	150,000
Indonesia	[e]37,000	40,000	42,000	42,000
Iran	32,700	33,000	34,000	35,000
Italy	46,400	46,000	46,000	46,000
Japan	69,600	68,000	74,000	74,000
Korea, Republic of	51,400	52,000	62,000	62,000
Mexico	[e]36,000	40,000	40,000	40,000
Russia	48,700	54,000	65,000	65,000
Saudi Arabia	26,100	26,000	24,000	27,000
Spain	50,300	50,000	42,000	42,000
Thailand	37,900	40,000	50,000	50,000
Turkey	42,800	45,000	40,000	41,000
Vietnam	29,000	33,000	17,000	20,000
Other countries (rounded)	[e]400,000	500,000	327,000	389,000
World total (rounded)	2,310,000	2,500,000	2,200,000	2,300,000

http://minerals.usgs.gov/minerals/pubs/commodity/cement/cemenmcs07.pdf



World production of hydraulic cement by region

(http://pubs.usgs.gov/of/2005/1152/2005-1152.pdf).



U.S production and consumption of portland cement

(http://pubs.usgs.gov/of/2005/1152/2005-1152.pdf)

PORTLAND CEMENT

- ✓ Chemical composition of Portland Cement:

  a) Tricalcium Silicate (50%)

  b) Dicalcium Silicate (25%)

  c) Tricalcium Aluminate (10%)

  d) Tetracalcium Aluminoferrite (10%)

  e) Gypsum (5%)

FUNCTION :TRICALCIUM SILICATE

- ✓ Hardens rapidly and largely responsible for initial set & early strength
- ✓ The increase in percentage of this compound will cause the early strength of Portland Cement to be higher.
- ✓A bigger percentage of this compound will produces higher heat of hydration and accounts for faster gain in strength.

FUNCTION :DICALCIUM SILICATE

- ✓ Hardens slowly
- ✓ It effects on strength increases occurs at ages beyond one week .
- ✓ Responsible for long term strength

FUNCTION :TRICALCIUM ALUMINATE

- ✓ Contributes to strength development in the first few days because it is the first compound to hydrate .
- ✓ It turns out higher heat of hydration and contributes to faster gain in strength.
- ✓ But it results in poor sulfate resitance and increases the volumetric shrinkage upon drying.

- ✓ Cements with low Tricalcium Aluminate contents usually generate less heat, develop higher strengths and show greater resistance to sulfate attacks.
- ✓ It has high heat generation and reactive with soils and water containing moderate to high sulfate concentrations so it's least desirable.

FUNCTION : TETRACALCIUM ALUMINOFERRITE

- ✓ Assist in the manufacture of Portland Cement by allowing lower clinkering temperature.
- ✓ Also act as a filler
- ✓ Contributes very little strength of concrete eventhough it hydrates very rapidly.
- ✓ Also responsible for grey colour of Ordinary Portland Cement

Manufacture of Portland cement

- Manufacture of Portland cement
  - Raw materials
  - Preparation of materials
  - Burning
  - Final processing
  - Quality control

Raw materials

- Limestone (calcium carbonate) is a common source of calcium oxide.
- Iron-bearing aluminosilicates are the most common source of silica.
- Aluminum and iron oxides act as fluxing agents i.e. lower fusion temperature of part of the raw mix to a practical firing temperature

Preparation of Materials

- Crush the materials and store them
- Blend the materials and grind them
- Store them and do final blending
- Blending – assure constant composition and predictable properties.
- Wet, dry, and semi-dry processes
- Burn the materials
- Grind, blend, and store the materials

WET PROCESS

- ✓ Raw materials are homogenized by crushing, grinding and blending so that approximately 80% of the raw material pass a No.200 sieve.
- ✓ The mix will be turned into form of slurry by adding 30 - 40% of water.
- ✓ It is then heated to about 2750ºF (1510ºC) in horizontal revolving kilns (76-153m length and 3.6-4.8m in diameter.

- ✓ Natural gas, petroluem or coal are used for burning. High fuel requirement may make it uneconomical compared to dry process.

Wet process is obsolete

DRY PROCESS

- ✓ Raw materials are homogenized by crushing, grinding and blending so that approximately 80% of the raw material pass a No.200 sieve.
- ✓ Mixture is fed into kiln & burned in a dry state
- ✓ This process provides considerable savings in fuel consumption and water usage but the process is dustier compared to wet process that is more efficient than grinding.

DRY PROCES & WET PROCESS

- ✓ In the kiln, water from the raw material is driven off and limestone is decomposed into lime and Carbon Dioxide.

  limestone ⟶ lime + Carbon Dioxide

- ✓ In the burning zone, portion of the kiln, silica and alumina from the clay undergo a solid state chemical reaction with lime to produce calcium aluminate.

  silica & alumina + lime ⟶ calcium aluminate

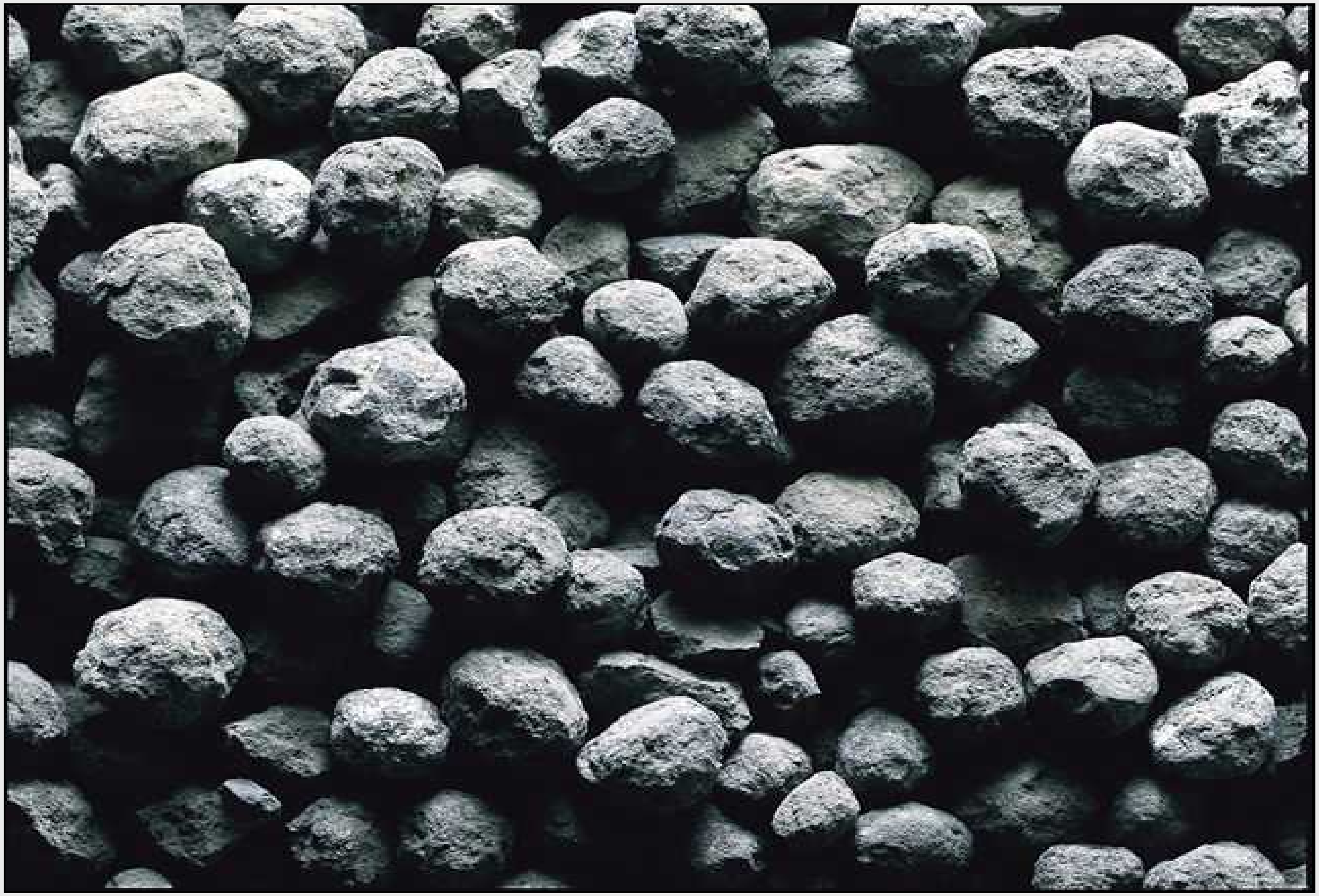
Burning process

- **Sintering (become a coherent mass with no melting)**
- **Fusion (complete melting)**
- **Clinkering – only about ¼ of the charge is in the liquid state**
- **Kiln**
  - **Long steel pipe**
  - **Lined with refractory brick**
  - **Inclined a few degrees**
  - **Rotated at 60 to 200 rev/h**
  - **Typically 6 m (20 ft) in diameter and 180 m (600 ft) long**
- **Time in the kiln from 2 h (wet process) to 1 h (dry process) or even (20 min) modern heat exchangers**
- **Four processes take place in the kiln**
- **Evaporation 240 to 450 ° C**

- **Calcination 600 to 1100 °C**
  - **Clay decomposes (600 °C)**
  - **Limestone decomposes (700 °C) – CO_2 driven off**
  - **Formation of initial compounds (1000 °C)**
  - **Initial formation of C_2S (1200 °C), formation of calcium aluminates and Ferrites**
  - **Formation of melt (flux compounds melt) (1350 °C)**
- **Clinkering – charge temperature is 1400 to 1600 °C**
  - **Formation of C_3S**
- **Cooling**
  - **Rate of cooling significantly affects the reactivity of the final cement**
- **Klinker**

- The rotation and shape of kiln allow the blend to flow down the kiln, submitting it to gradually increasing temperature.
- As the material moves through hotter regions in the kiln, calcium silicates are formed
- These products, that are black or greenish black in color are in the form of small pellets, called cement clinkers
- Cement clinkers are hard, irregular and ball shaped particles about 18mm in diameter.

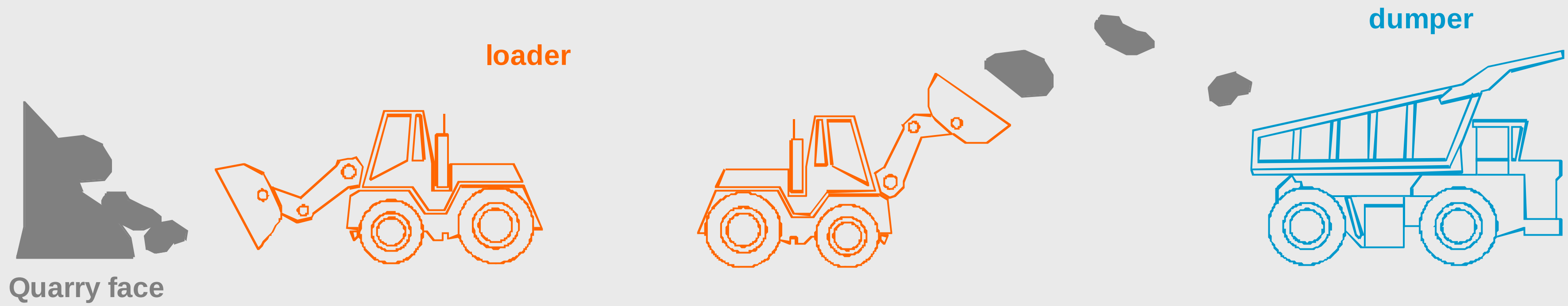
CEMENT CLINKERS



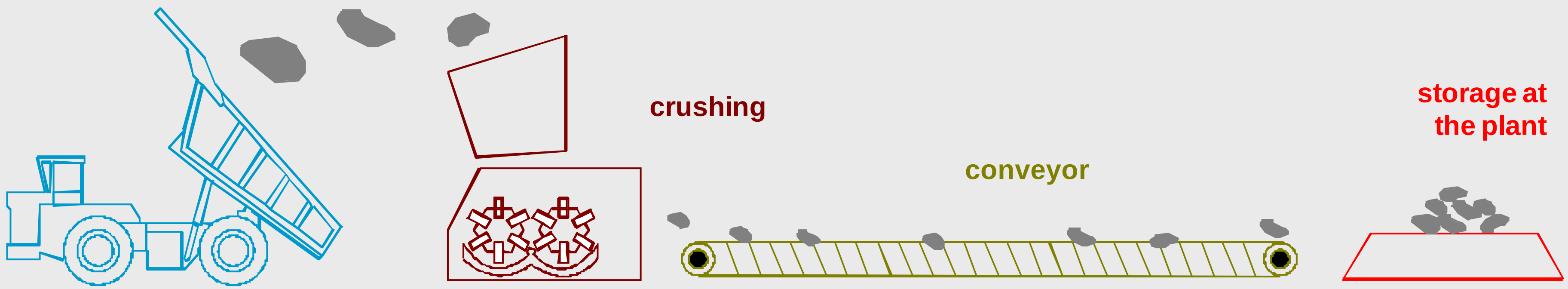
- ✓ The cement clinkers are cooled to about 150ºF (51ºC) and stored in clinker silos.
- ✓ When needed, clinker are mixed with 2-5% gypsum to retard the setting time of cement when it is mixed with water.
- ✓ Then, it is grounded to a fine powder and then the cement is stored in storage bins or cement silos or bagged.
- ✓ Cement bags should be stored on pallets in a dry place.

THE CEMENT MANUFACTURING PROCESS

quarry



1. BLASTING **2. TRANSPORT**



3. CRUSHING & TRANSPORTATION

1. BLASTING : The raw materials that are used to manufacture cement (mainly limestone and clay) are blasted from the quarry.

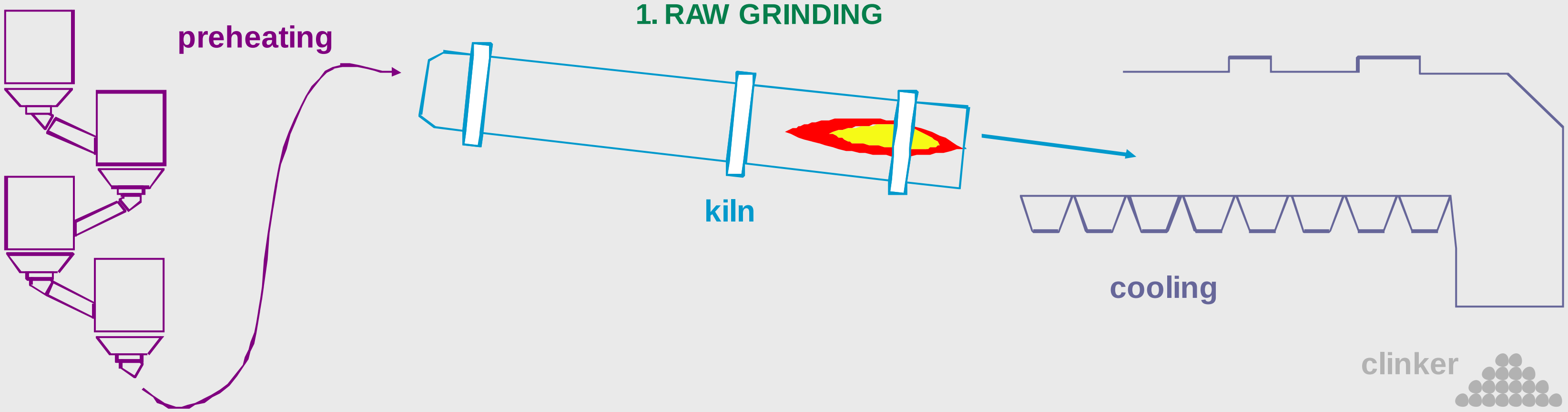
2. TRANSPORT : The raw materials are loaded into a dumper.

3. CRUSHING AND TRANSPORTATION : The raw materials, after crushing, are transported to the plant by conveyor. The plant stores the materials before they are homogenized.

THE CEMENT MANUFACTURING PROCESS

Raw grinding and burning

1. RAW GRINDING



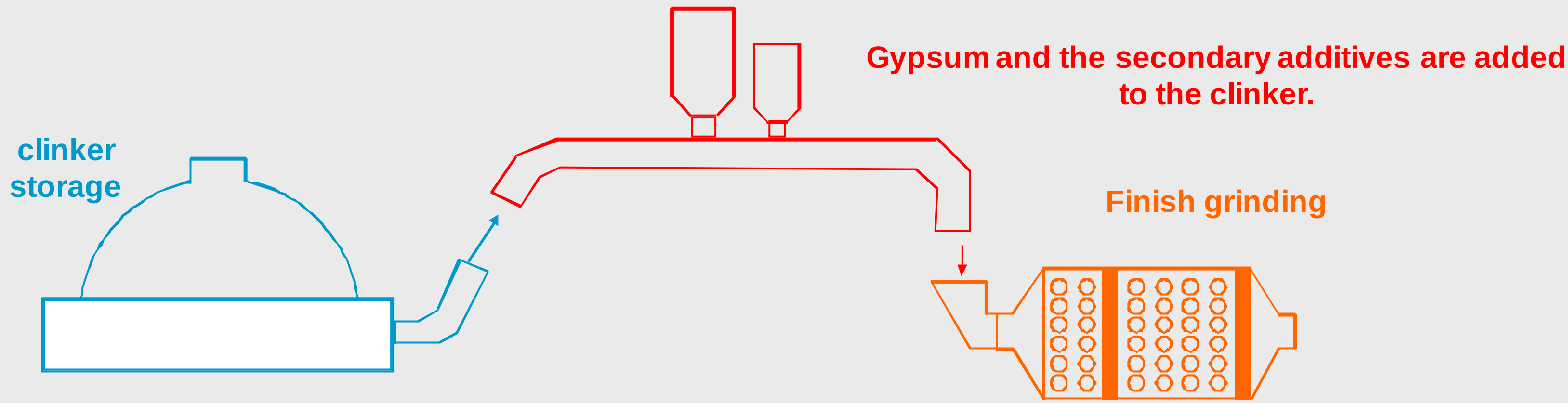
2. BURNING

1. RAW GRINDING : The raw materials are very finely ground in order to produce the raw mix.

2. BURNING : The raw mix is preheated before it goes into the kiln, which is heated by a flame that can be as hot as 2000 °C. The raw mix burns at 1500 °C producing clinker which, when it leaves the kiln, is rapidly cooled with air fans. So, the raw mix is burnt to produce clinker : the basic material needed to make cement.

THE CEMENT MANUFACTURING PROCESS

Grinding, storage, packing, dispatch



1. GRINDING

2. STORAGE, PACKING, DISPATCH

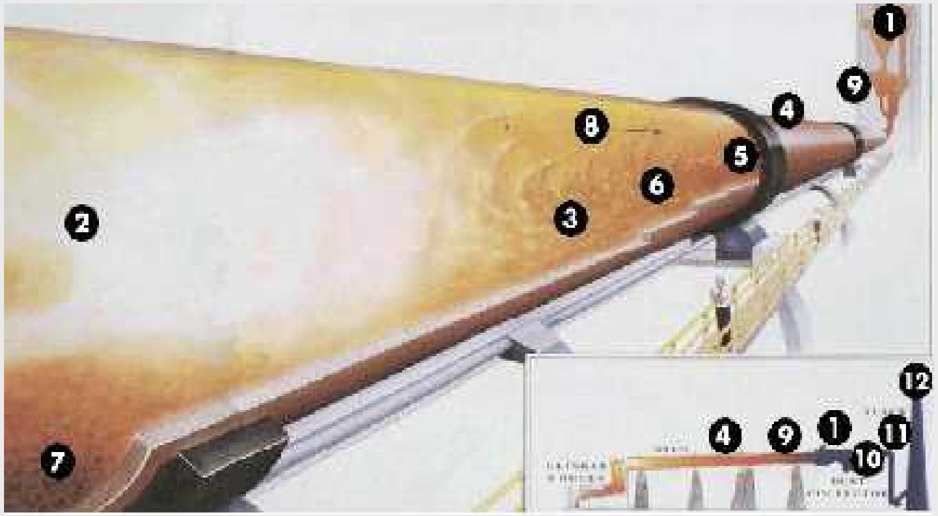
1.GRINDING : The clinker and the gypsum are very finely ground giving a "pure cement". Other secondary additives and cementitious materials can also be added to make a blended cement.

2. STORAGE, PACKING, DISPATCH : The cement is stored in silos before being dispatched either in bulk or in bags to its final destination.

Oxides composition of cement

Oxide	Shorthand notation	Common name	Weight percent
CaO	C	Lime	63
SiO_2	S	Silica	22
Al_2O_3	A	Alumina	6
Fe_2O_3	F	Ferric oxide	2.5
MgO	M	Magnesia	2.6
K_2O	K	Alkalis	0.6
Na_2O	N		0.3
SO_3	S	Sulfur trioxide	2
CO_2	C	Carbon dioxide	-
H_2O	H	Water	-

KILN



CEMENT SILO

Properties of cement and tests

- **<u>1. Fineness</u>**
- 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.

Continue on Fineness

- Fineness tests indirectly measures the surface area of the cement particles per unit mass :
  - Wagner turbidimeter test

    (ASTM C 115)
  - Blaine air-permeability test

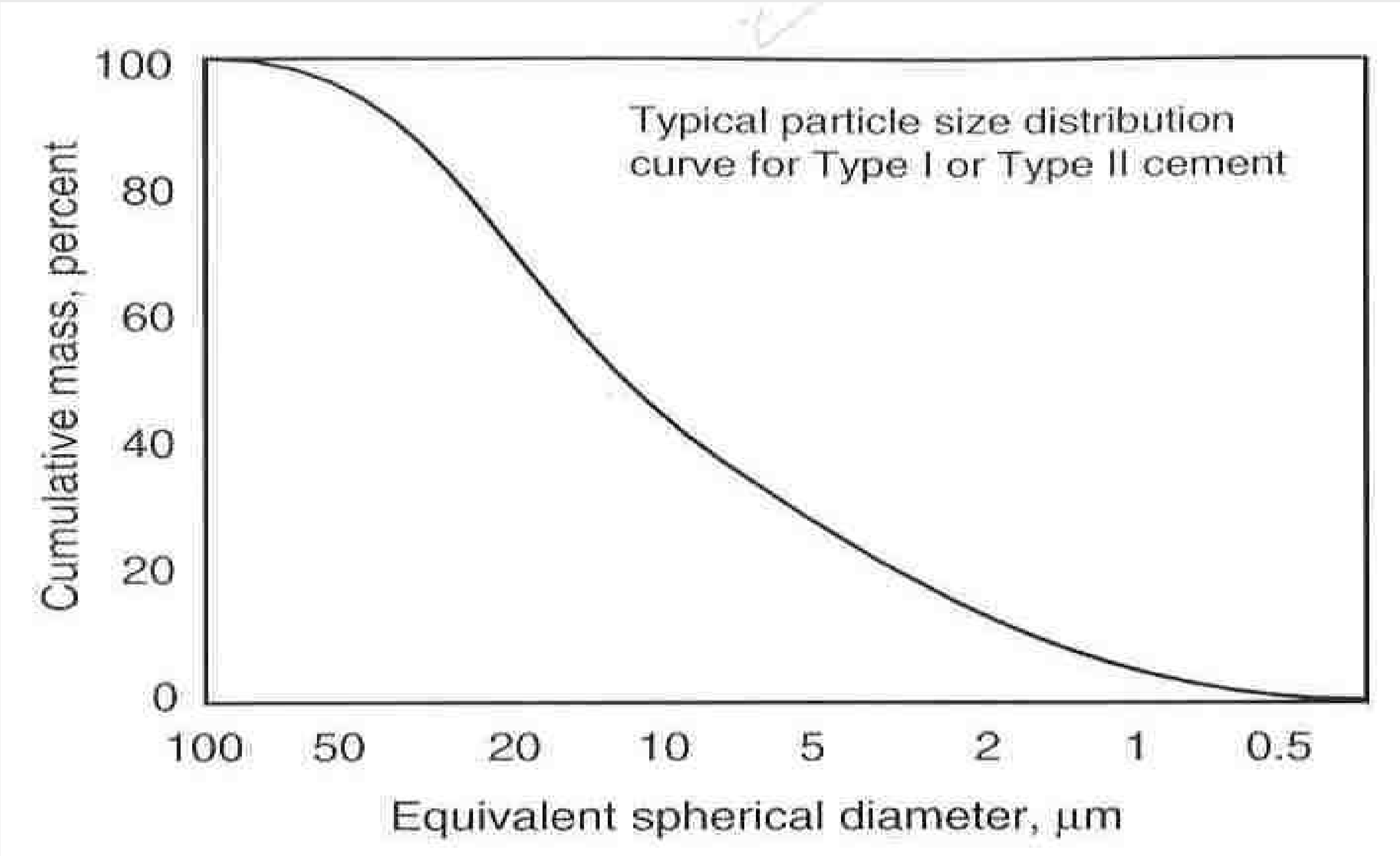
    (ASTM C 204)
  - Sieving using No. 325 (45 μm) sieve (ASTM C 430)

Fineness Testing

- On left, Blaine test apparatus.

- On right, agner turbidmeter

Particle size distribution of Portland Cement



2. Soundness

- Soundness is the ability of a hardened paste to retain its volume after setting.
- A cement is said to be unsound (i.e. having lack of soundness) if it is subjected to delayed destructive expansion.
- Unsoundness of cement is due to presence of excessive amount of hard-burned free lime or magnesia

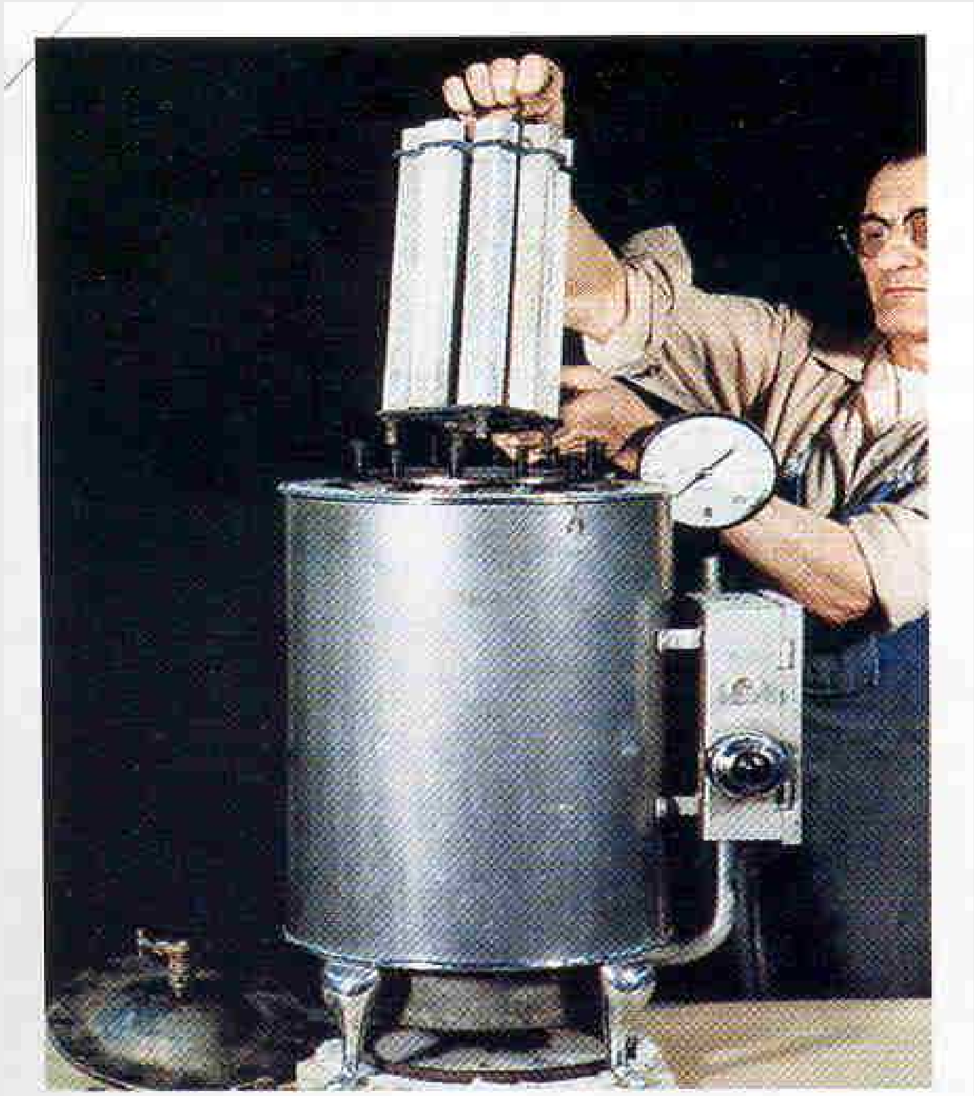
Cont. on Soundness

- Unsoundness of a cement is determined by the following tests:
  - Le-Chatelier accelerated test

    (BS 4550: Part 3)
  - Autoclave-expansion test

    (ASTM C 151)

Autoclave-expansion test
(ASTM C 151)

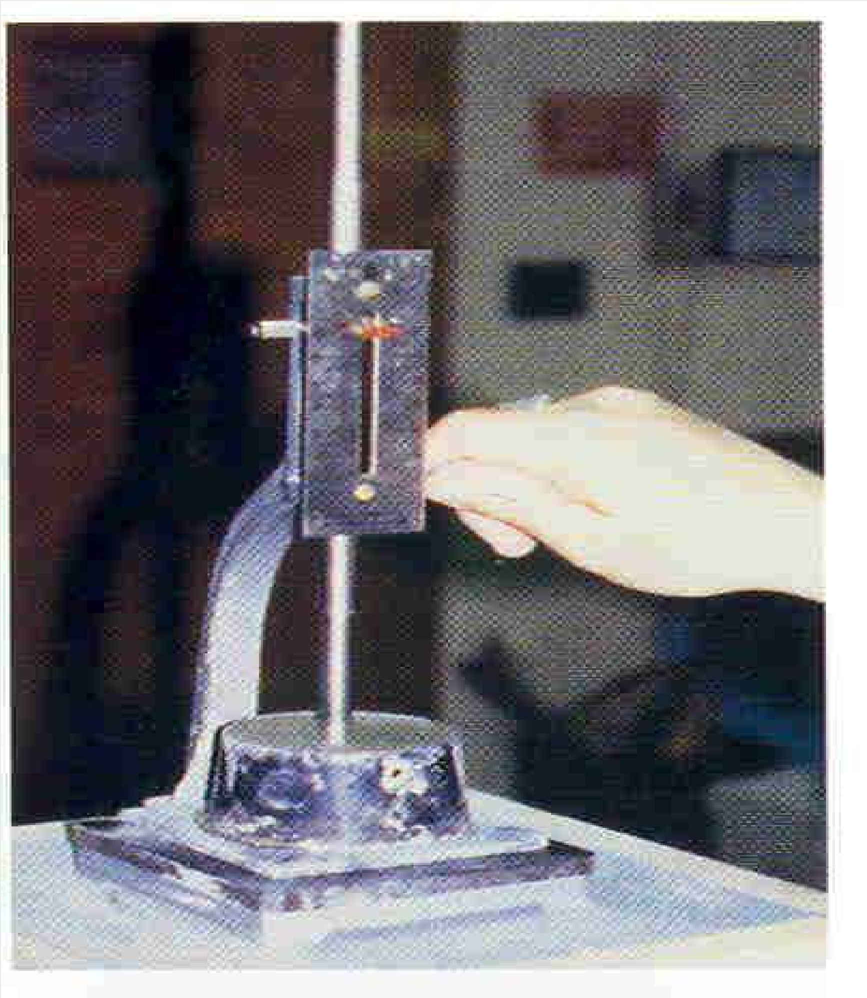


3. Consistency

- Consistency refers to the relative mobility of a freshly mixed cement paste or mortar or its ability to flow.

- 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.

Vicat Plunger Consistency Test



Consistency Test for mortar using the flow table

4. Setting Time

- This is the term used to describe the stiffening of the cement paste.
- Setting time is to determine if a cement sets according to the time limits specified in ASTM C 150.
- Setting time is determined using either the Vicat apparatus (ASTM C 191) or a Gillmore needle (ASTM C 266).
- “Initial setting time” is the time from the instant at which water is added to the cement until the paste ceases to be fluid and plastic which corresponds to the time at which the Vicat’s initial set needle penetrate to a point 5 mm from the bottom of a special mould.

Cont. on Setting Time

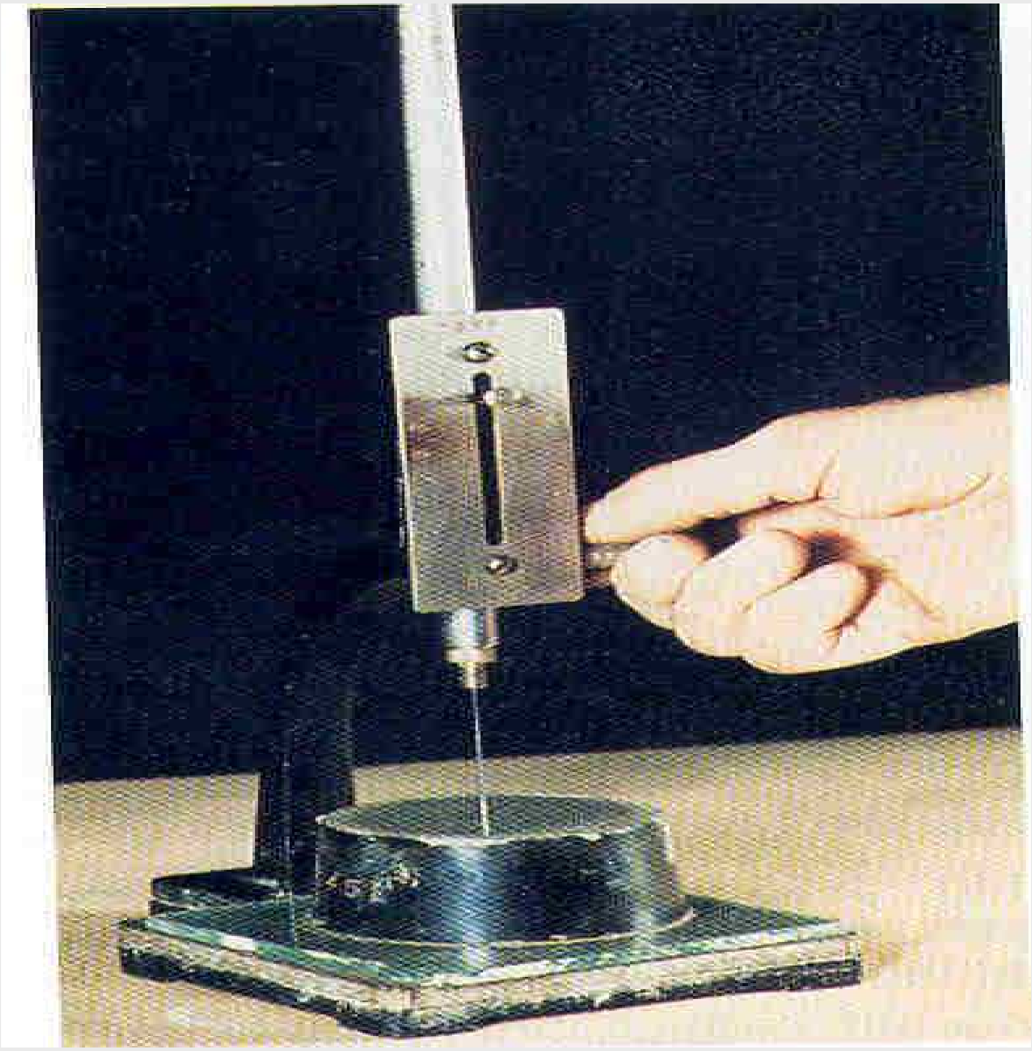
- ASTM C 150 prescribes a minimum initial setting time of 60 minutes for Portland cements.

- "Final setting time" the time required for the paste to acquire certain degree of hardness. This corresponds to the time at which the Viact's final set needle makes an impression on the paste surface but the cutting edge fails to do so.

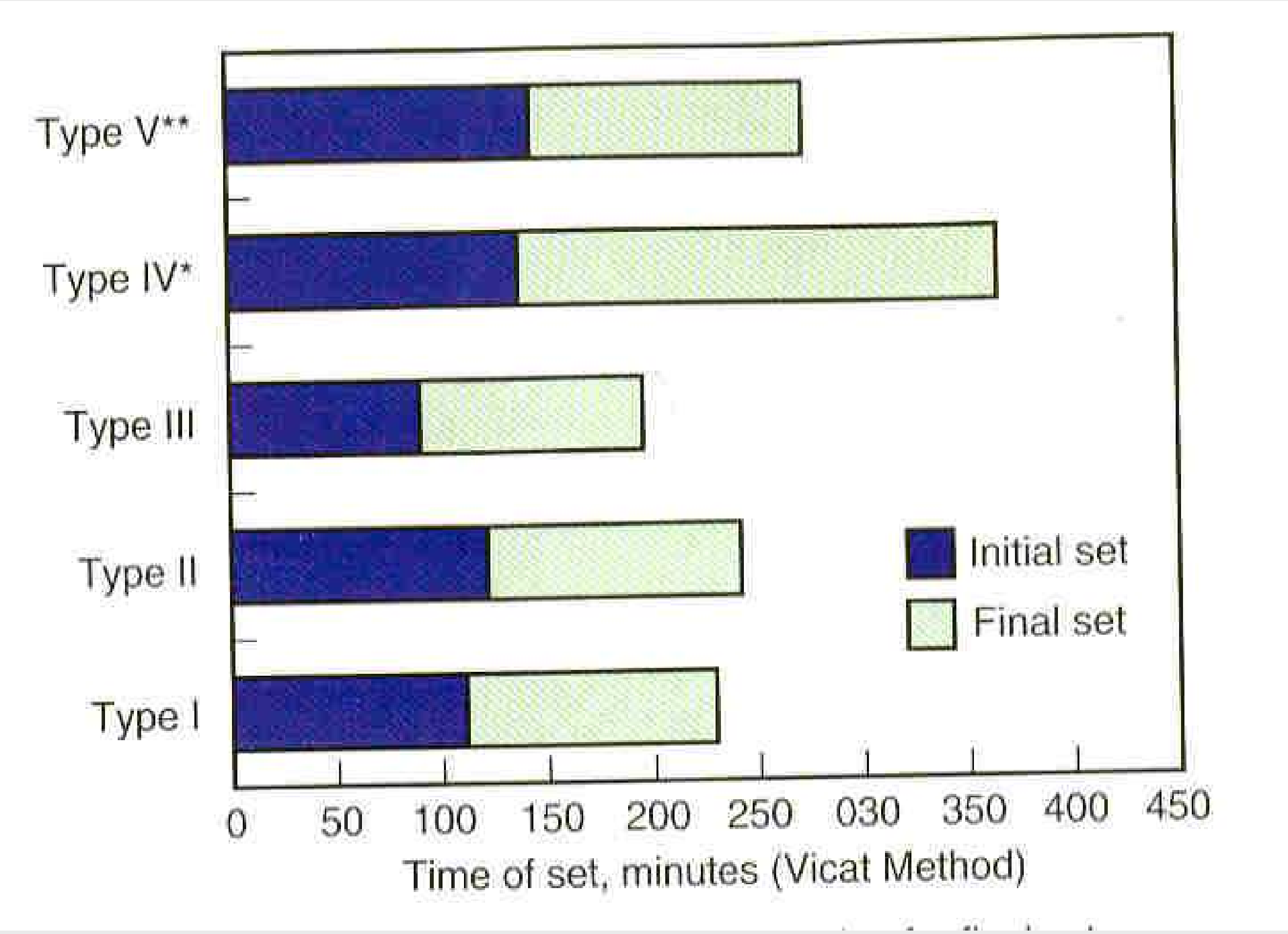
- ASTM C 150 prescribes a maximum final setting time of 10 hours for Portland cements.

- Gypsum in the cement regulates setting time. Setting time is also affected by cement fineness, w/c ratio, and admixtures.

Vicat Needle



Time of Set for Portland Cements



5. Early Stiffening (False Set and Flash Set)

- Early stiffening is the early development of stiffening in the working plasticity of cement paste, mortar or concrete. This includes both false set and flash set.

False Set

- False set is evidenced by a significant loss of plasticity, i.e. stiffening, without the evolution of much heat shortly after mixing.

- Stiffening caused by rapid crystallization of interlocking needle-like secondary gypsum.

- False set cause no difficulty in placing and handling of concrete if the concrete is mixed for a longer time than usual or if it is remixed without additional water before it is transported or placed.

Flash Set (quick set)

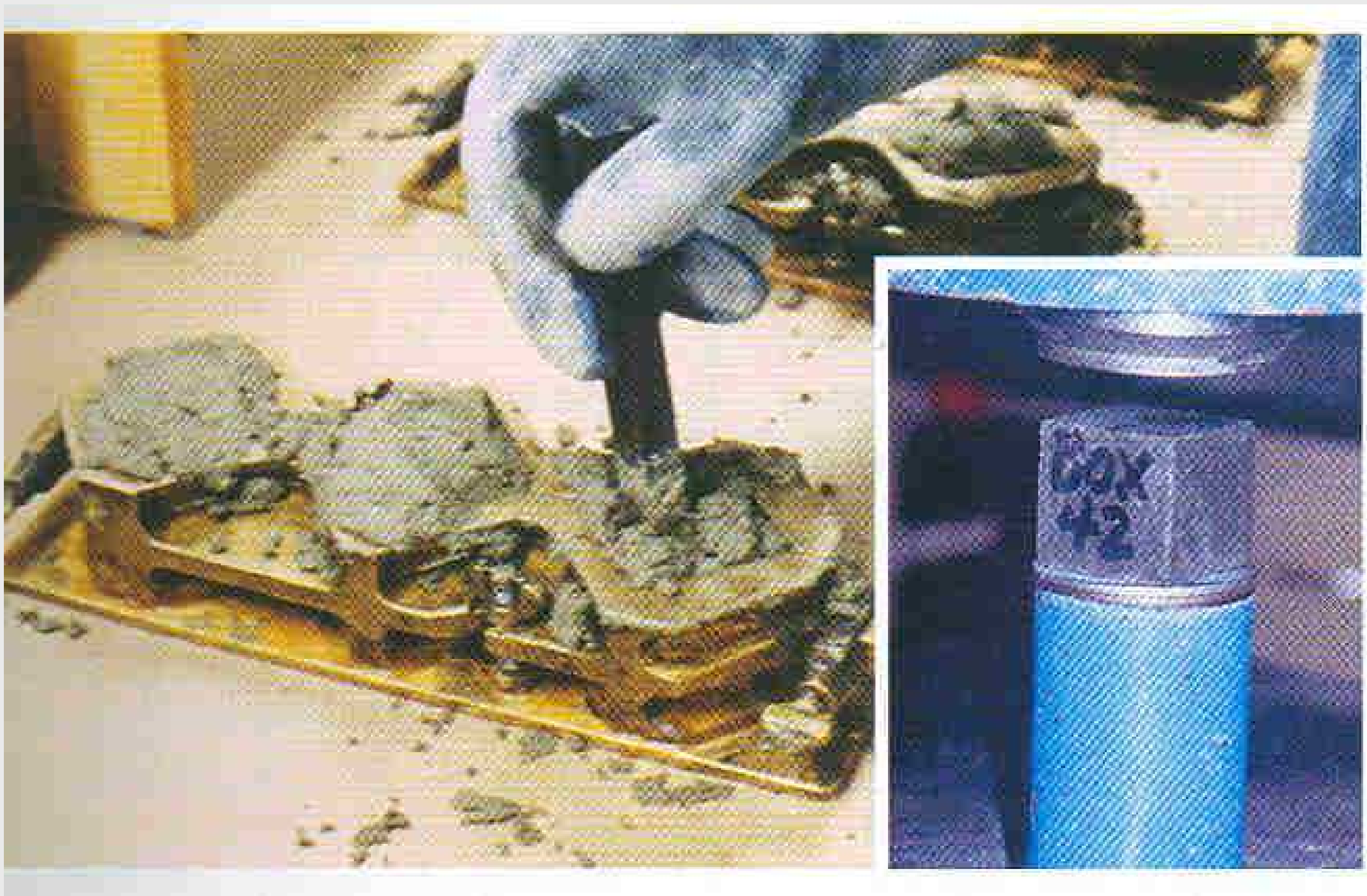
- Evidence by a quick and early loss of workability and it is usually accompanied by evolution of considerable heat from the hydration of aluminates.

- The workability can not be regained without the addition of water.

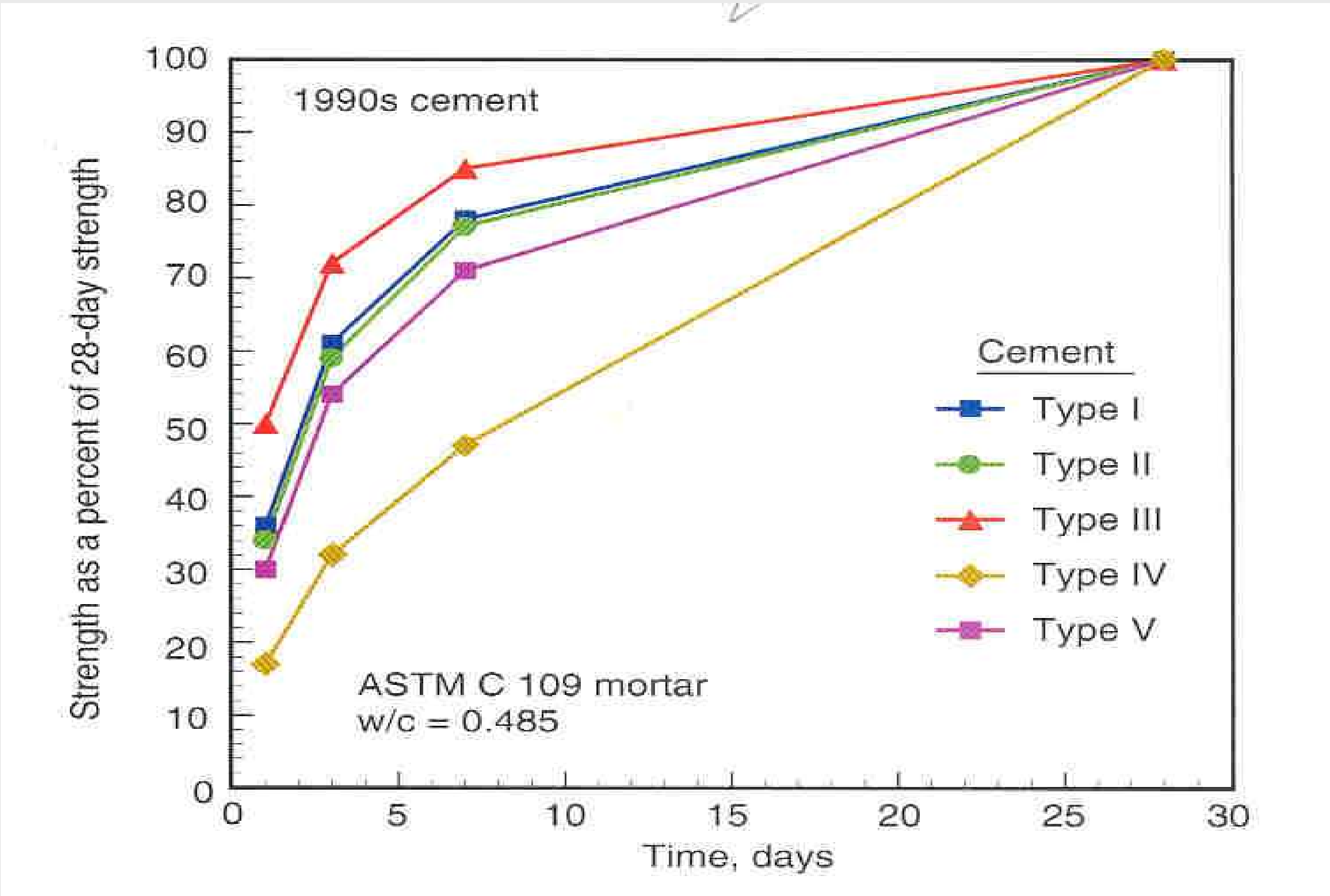
6. Compressive Strength

- Compressive strength of cement is the most important property.
- It is determined by ducting 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.
- Rates of compressive strength development for concrete, made with various types of cement, are shown in Fig. 2-42.

Compressive Strength Test



Strength Development of Portland Cement mortar cubes



7. Heat of Hydration

- **It is the quantity of heat (in joules) per gram of un-hydrated cement evolved upon complete hydration at a given temperature.**
- **The heat of hydration can be determined by ASTM C 186 or by a conduction calorimeter.**
- **The temperature at which hydration occurs greatly affects the rate of heat development.**
- **Fineness of cement also affects the rate of heat development but not the total amount of heat librated.**

Heat of Hydration determined by ASTM C 186 (left) or by a conduction calorimeter (right).

Cont. on Heat of Hydration

- The amount of heat generated depends upon the chemical composition of cement. Following are the heat of hydration generated on hydration of the four compounds of cement.

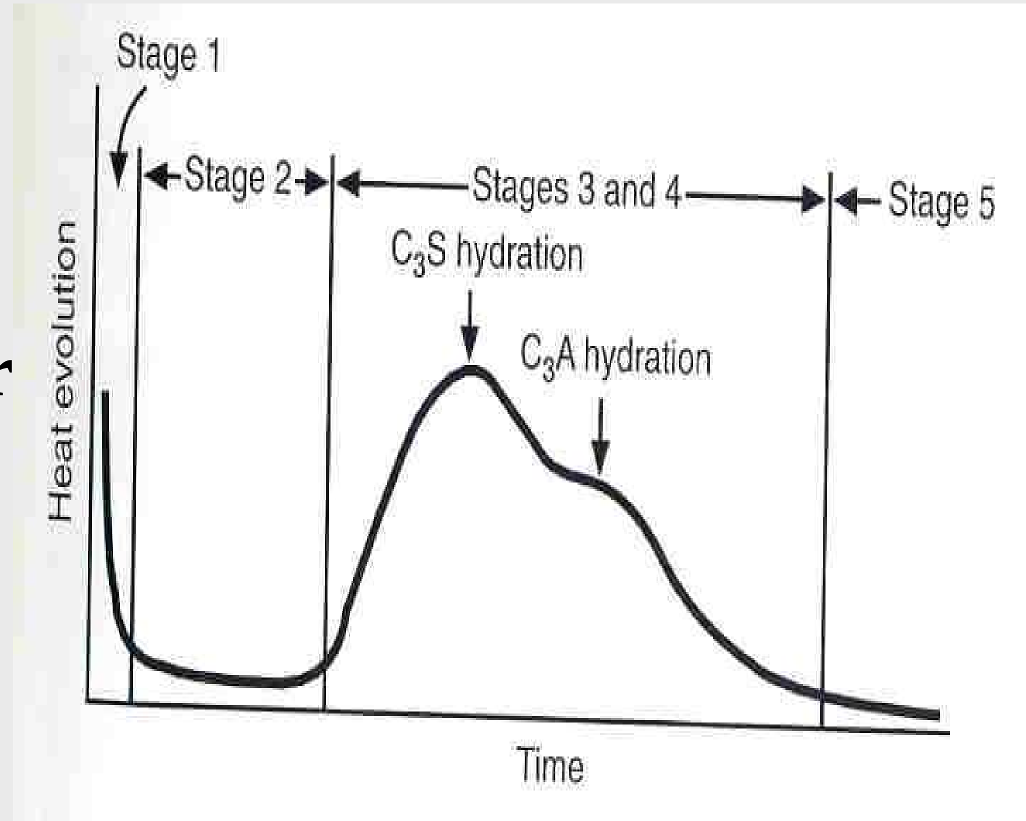
- Compound Heat of hydration Remarks C_3S 502 j/g--C_2S 260 j/gMinimumC_3A 867 j/g MaximumC_4AF 419 j/g--C_3S and C_3A are the compounds responsible for the high heat evolution.

- The approximate amount of heat generated using ASTM C 186, during the first 7 days (based on limited data) are as follows:

Type	Name	**Heat of hydration (kj/kg)**
I	**Normal**	**349**
II	**Moderate**	**263**
III	**High early strength**	**370**
IV	**Low heat of hydration**	**233**
V	**Sulfate resistant**	**310**

Cont. on Heat of Hydration

- **Cements do not generate heat at constant rate as illustrated in Figur 2-45 for a typical type I Portland cement**



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.

8. Loss on Ignition (LOI)

- The test for loss on ignition is performed in accordance with ASTM C 114.

- A high weight loss on ignition of a cement sample (between 900 to 1000ºC) is an indication of pre-hydration and carbonation, which may be caused by:
  - Improper and prolonged storage
  - Adulteration during transport and transfer
- Loss on ignition values range between 0 to 3%

Loss on Ignition Test of cement

9. Density and Specific Gravity (ASTM C 188)

- Density is the mass of a unit volume of the solids or particles, excluding air between particles. The particle density of Portland cement ranges from 3.10 to 3.25 Mg/m^3, averaging 3.15 Mg/ m^3.

- It is used in concrete mixture proportioning calculations.

- For mixture proportioning, it may be more useful to express the density as relative density (specific gravity). On an average the specific gravity of cement is 3.15.

Storage of Cement

- Cement is moisture-sensitive material; if kept dry it will retain its quality indefinitely.

- When exposed to moisture, cement will set more slowly and will have less strength compared to cement that kept dray.

- At the time of use cement should be free-flowing and free of lumps.

Storage of Cement