Manufacturing Process of Cement

PRESENTATION – OUTLINE

1) Introduction
2) History
3) Raw materials & process
4) Video to understand

CEMENT

- WHAT……??????

  "Cement is a crystalline compound of calcium silicates and other calcium compounds having hydraulic CEMENTITIOUS properties."

- WHY……..????

  A **cement** is a binder, a substance used in construction that sets and hardens and can bind other materials together.

From where did cement evolve???

2)

CEMENT – HISTORY

- In India, Portland cement was first manufactured in **1904** near Madras, by the **South India Industrial Ltd**. But this venture failed.
- Between 1912 and 1913, the **Indian Cement Co. Ltd**., was established at **Porbander** (Gujarat) and by **1914** this Company was able to deliver about**1000** tons of Portland cement.
- By **1918** three factories were established. Together they were able to produce about **85000** tons of cement per year.
- During the **First Five-Year Plan (1951-1956)** cement production in India rose from **2.69 million tons to 4.60 million tons**.
- By **1969** the total production of cement in India was **13.2 million tons** and India was then occupying the **9th place in the world**.

CEMENT – RAW MATERIAL

Raw Materials

- Calcareous Material (limestone or chalk)
- Argillaceous Material (shale or clay)

Waste Material Substitutes

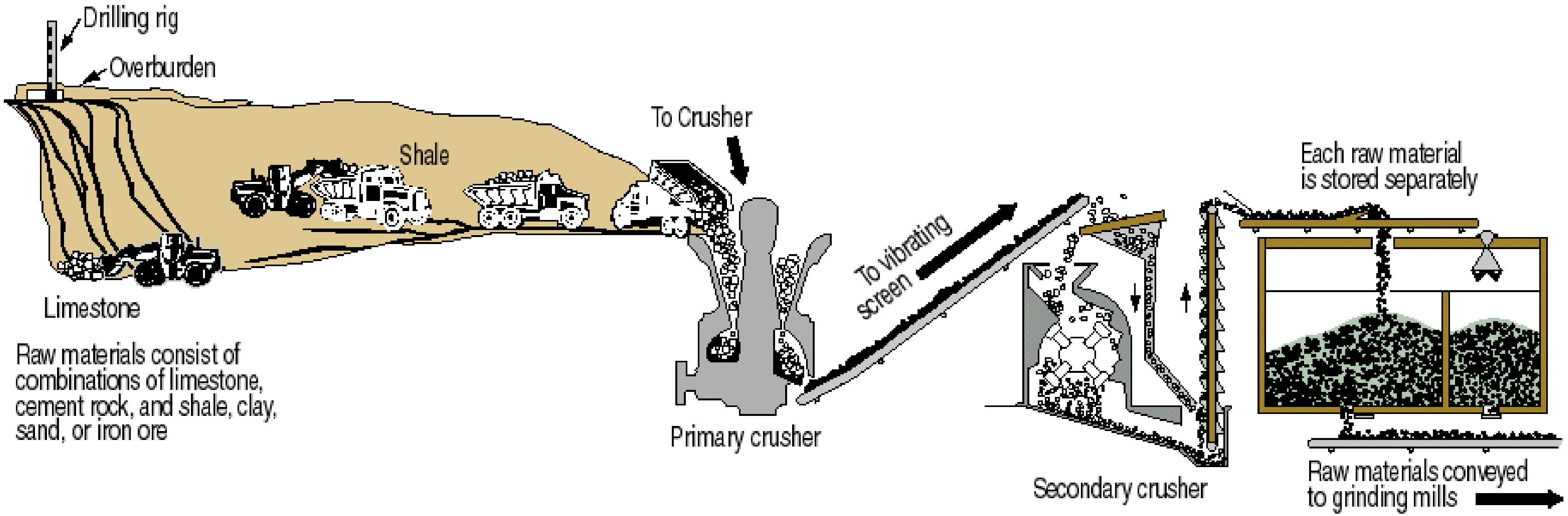
- Fly ash, foundry sand etc..

3)

CEMENT – MANUFACTURING PROCESS

- There are three processes by which cement is being manufactured:
  - A) WET Process
  - B) DRY Process

CEMENT – MANUFACTURING



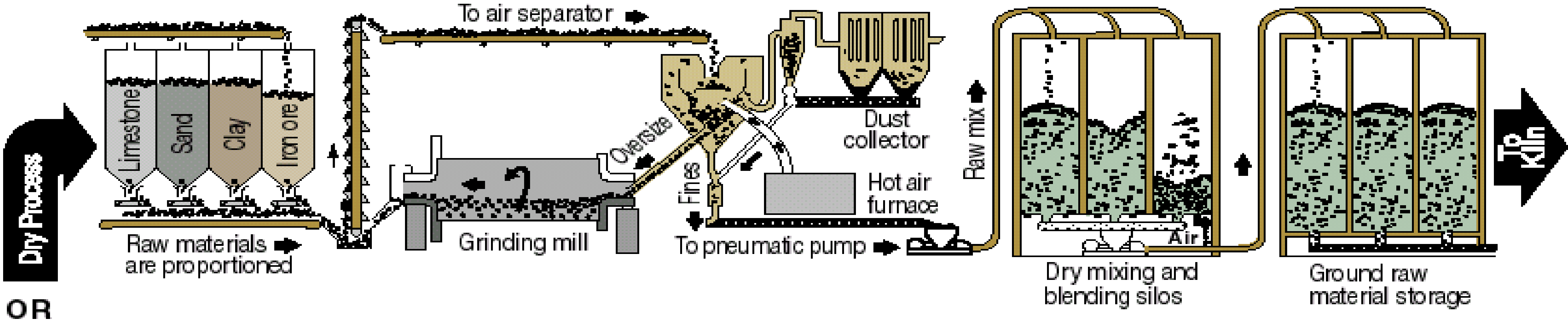
- STEP-1

  Stone is first reduced to 125 mm (5 in.) size, then to 20 mm (3/4 in.), and stored.

CEMENT – MANUFACTURING (DRY PROCESS)

- STEP-2

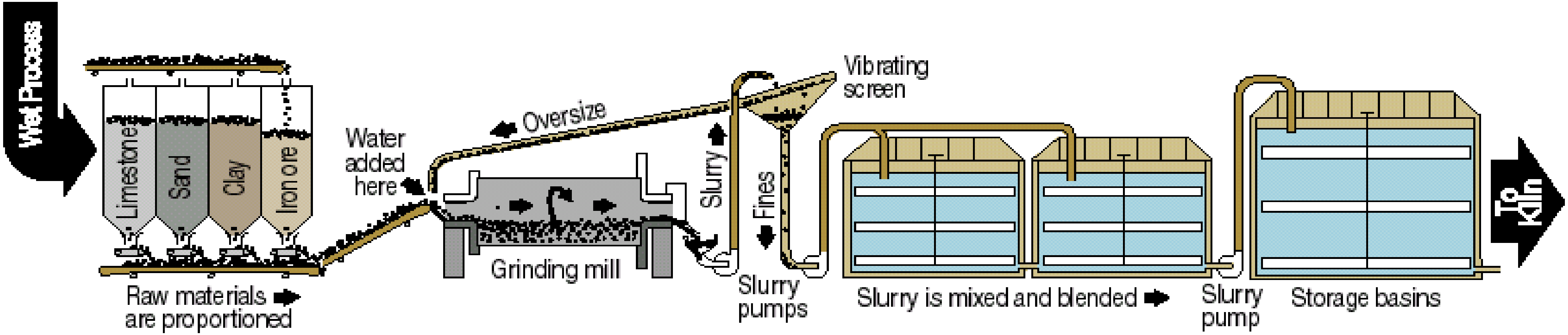
  Raw materials are grounded to powder and blended.



CEMENT – MANUFACTURING (WET PROCESS)

- STEP-2

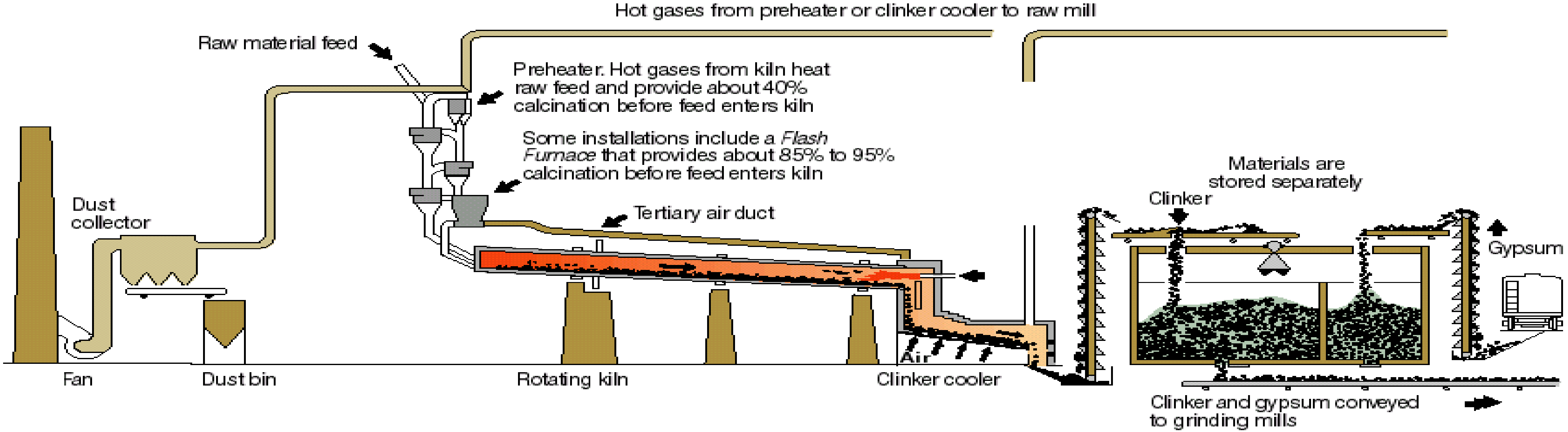
Raw materials are grounded mixed with water to form slurry and blended.



CEMENT – MANUFACTURING (DRY PROCESS)

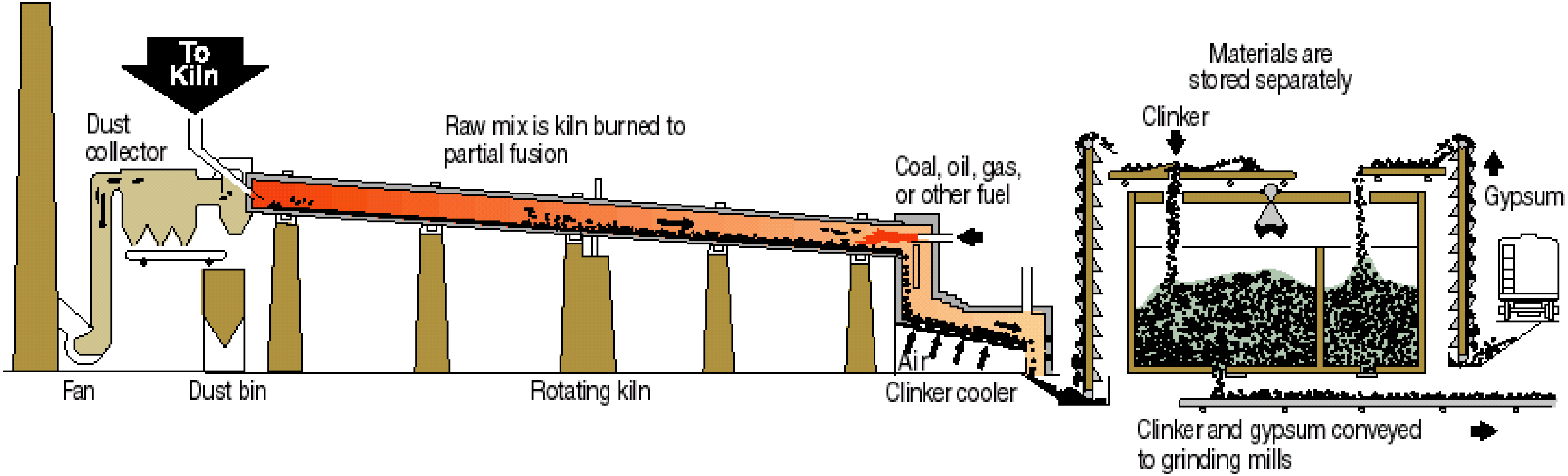
- STEP-3

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



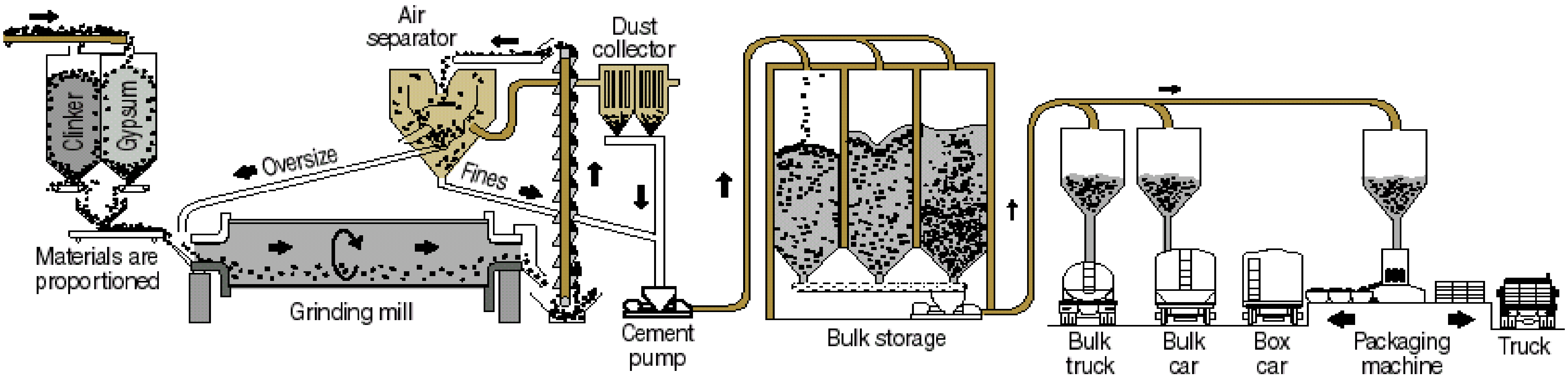
- STEP-3

  Burning changes raw mix chemically into cement clinker.



- STEP-4

Clinker is ground with gypsum into portland cement and shipped.



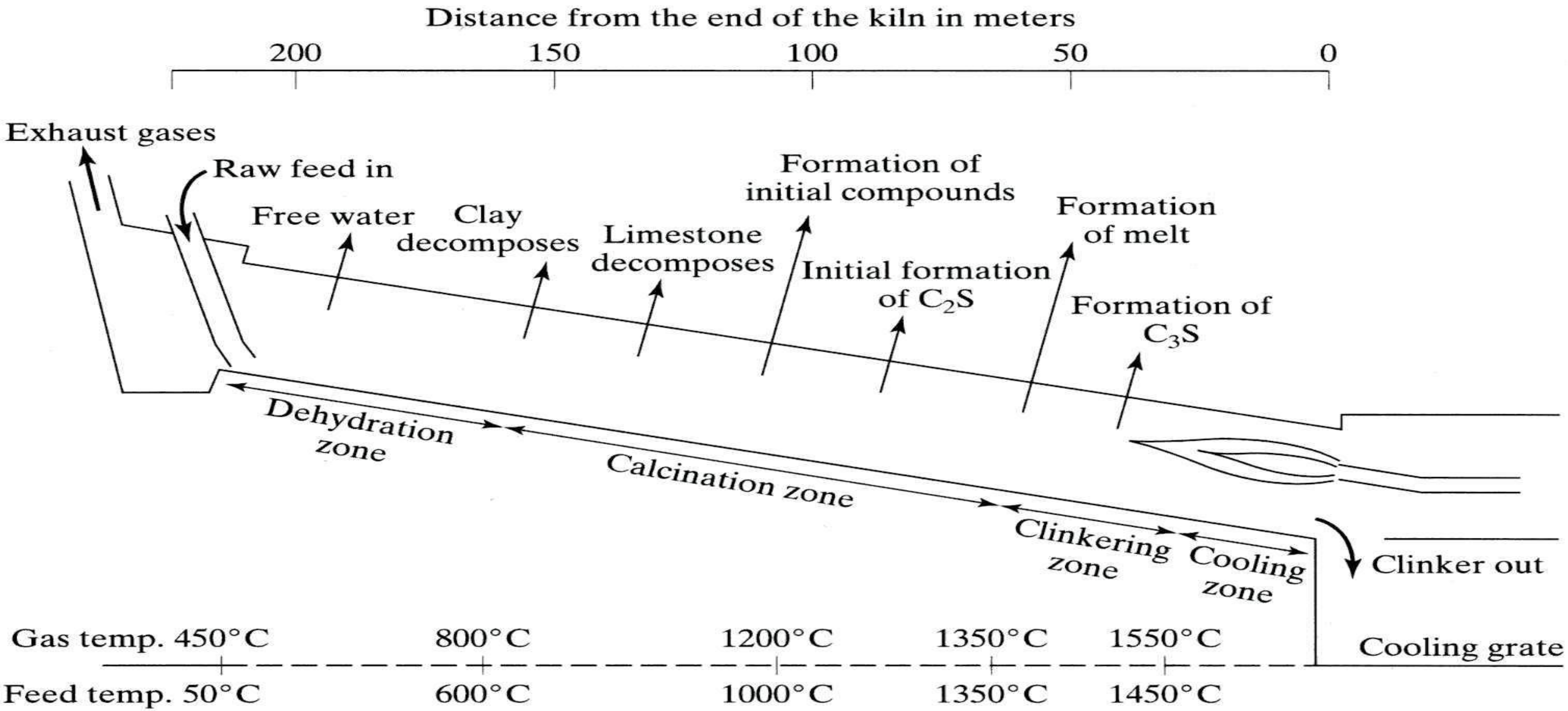


FIGURE 3.2

Schematic outline of conditions and reactions in a typical dry-process rotary kiln. When suspension preheaters are used, dehydration and initial calcination takes place outside the kiln in the preheater tower.

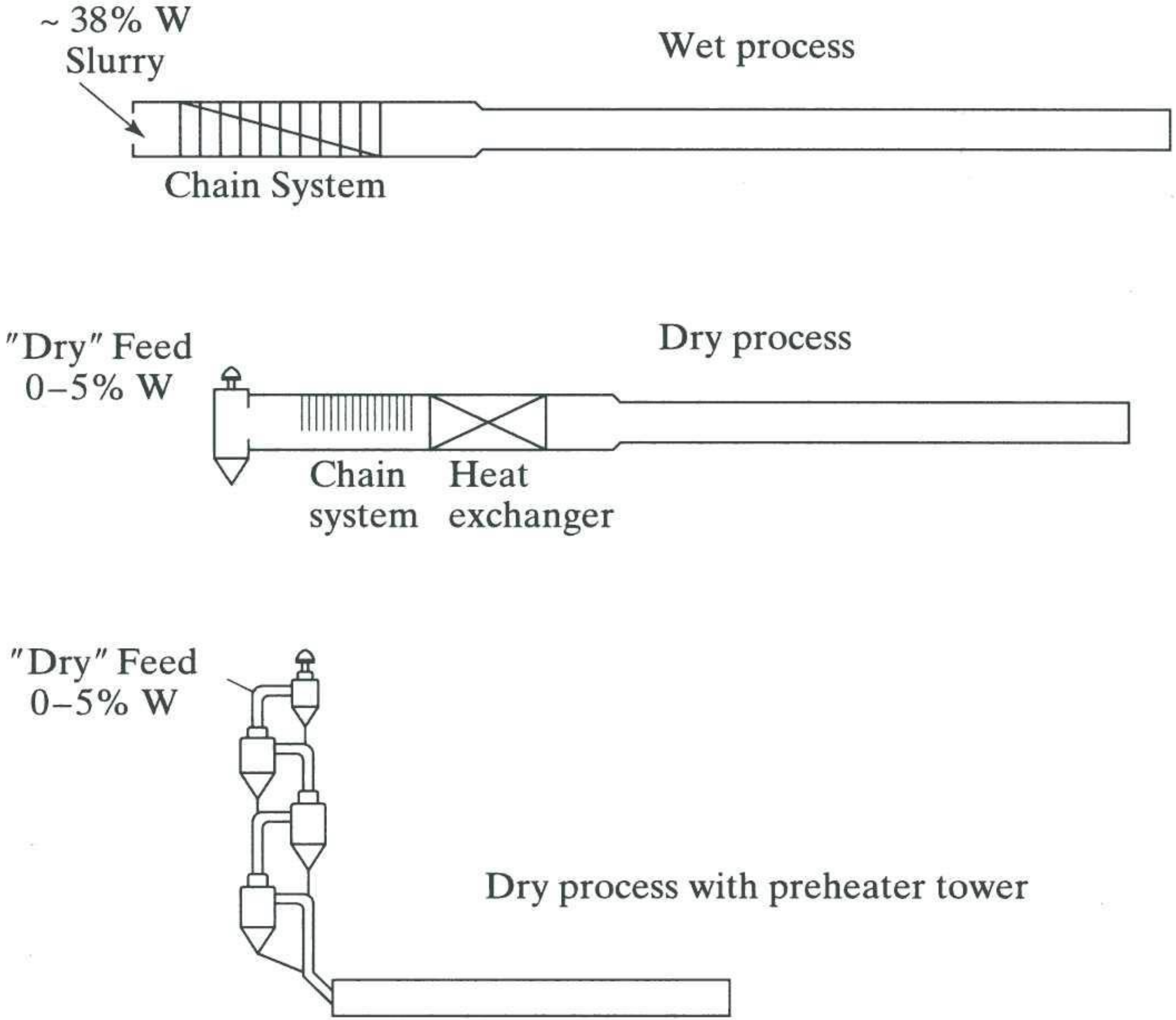
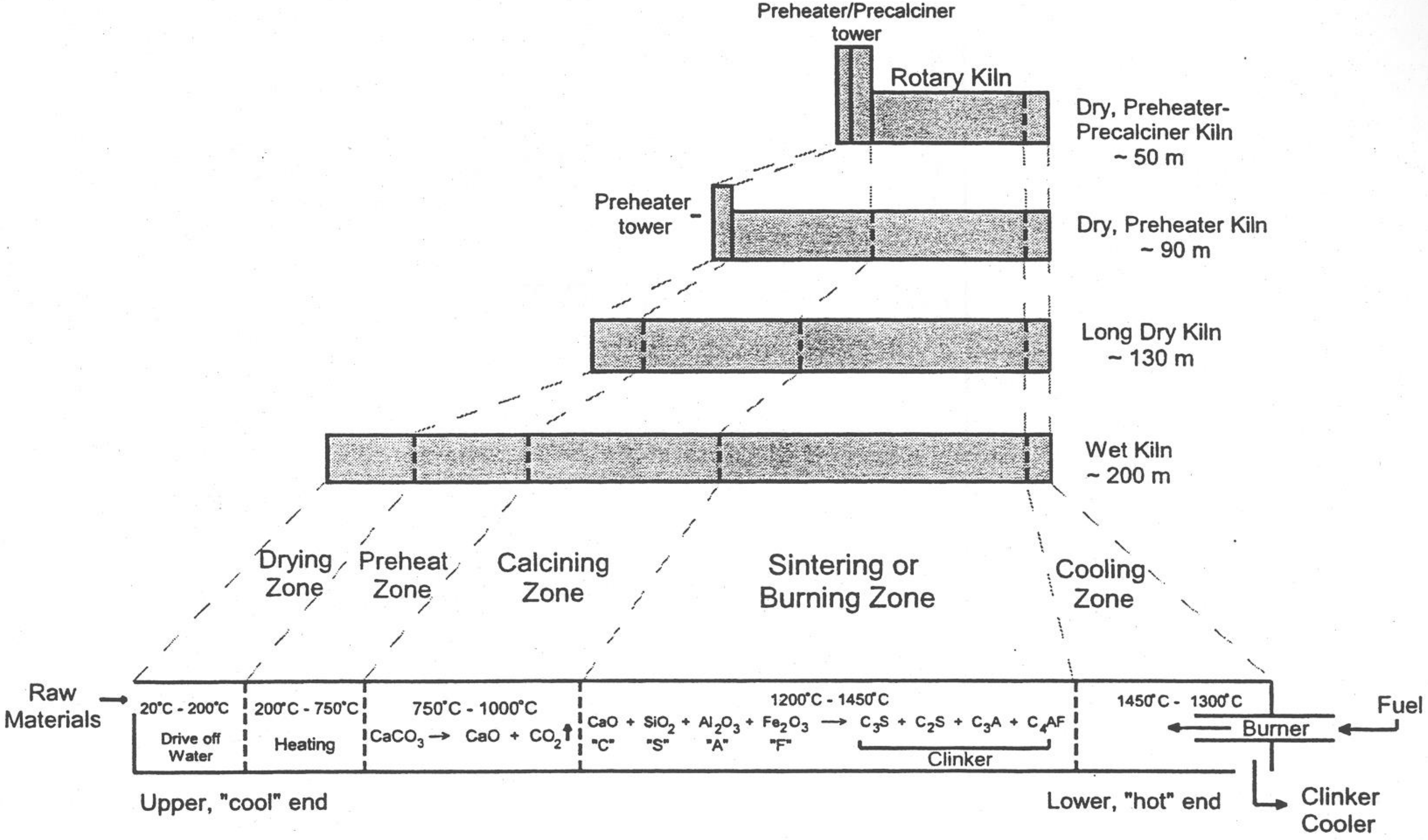
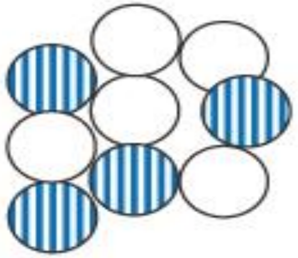
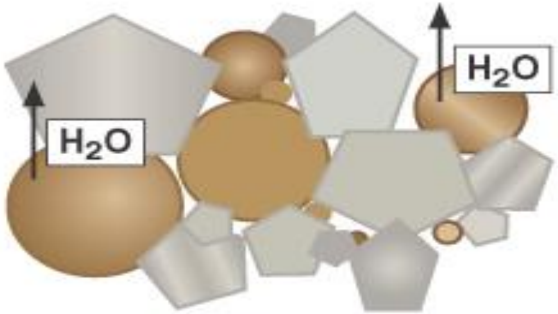
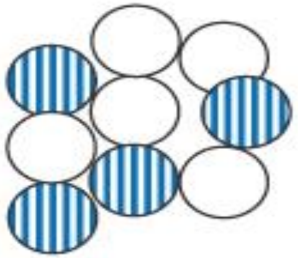
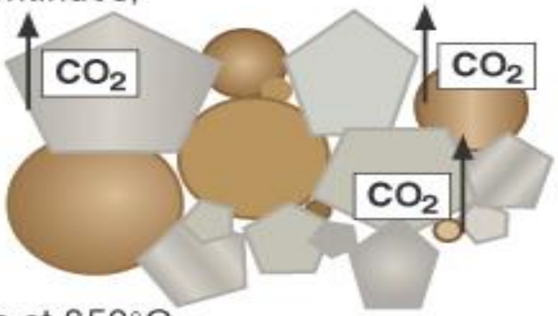


FIGURE 3.3

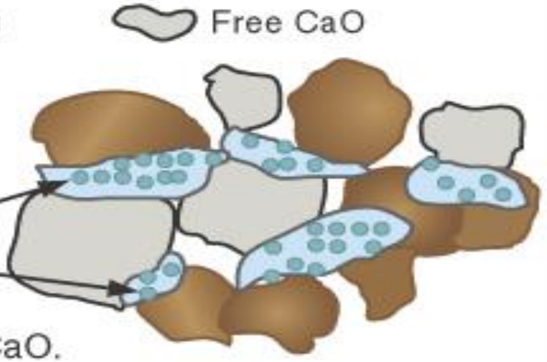
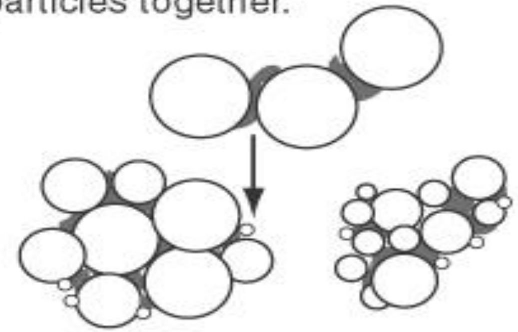
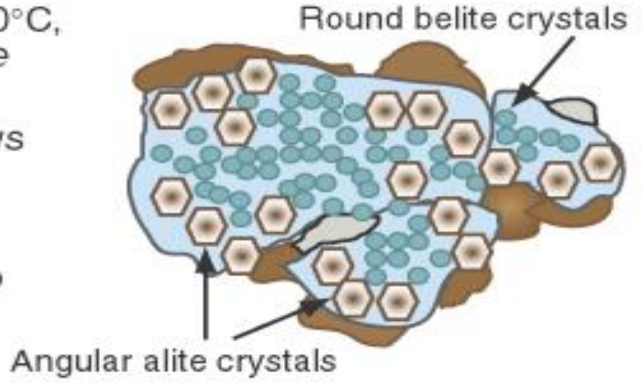
Comparison of kiln systems in older and modern cement plants. (W = water content of incoming feed.)


Preheater/Precalciner tower
Rotary Kiln
Dry, Preheater-Precalciner Kiln
~ 50 m
Preheater tower
Dry, Preheater Kiln
~ 90 m
Long Dry Kiln
~ 130 m
Wet Kiln
~ 200 m
Drying Zone
Preheat Zone
Calcining Zone
Sintering or Burning Zone
Cooling Zone
Raw Materials
20°C - 200°C
Drive off Water
200°C - 750°C
Heating
750°C - 1000°C
$CaCO_3 \rightarrow CaO + CO_2\uparrow$
1200°C - 1450°C
$CaO + SiO_2 + Al_2O_3 + Fe_2O_3 \rightarrow C_3S + C_2S + C_3A + C_4AF$
"C" "S" "A" "F"
Clinker
1450°C - 1300°C
Burner
Fuel
Upper, "cool" end
Lower, "hot" end
Clinker Cooler

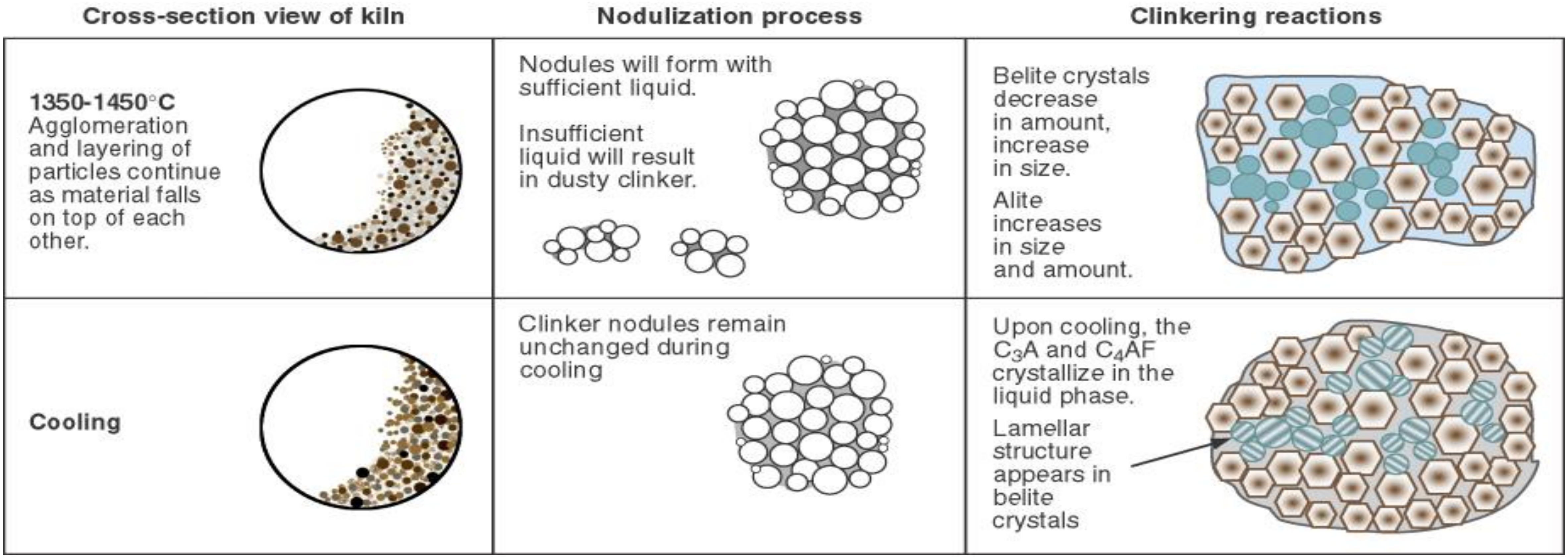
CEMENT – CLINKER PRODUCTION PROCESS

Cross-section view of kiln	Nodulization process	Clinkering reactions
To 700°C Raw materials are free-flowing powder 	Particles are solid. No reaction between particles. 	Water is lost. Dehydrated clay re-crystallizes  Clay particle; Limestone particle
700-900°C Powder is still free-flowing 	Particles are still solid. 	As calcination continues, free lime increases. Reactive silica combines with CaO to begin forming C_2S. Calcination maintains feed temperature at 850°C. 

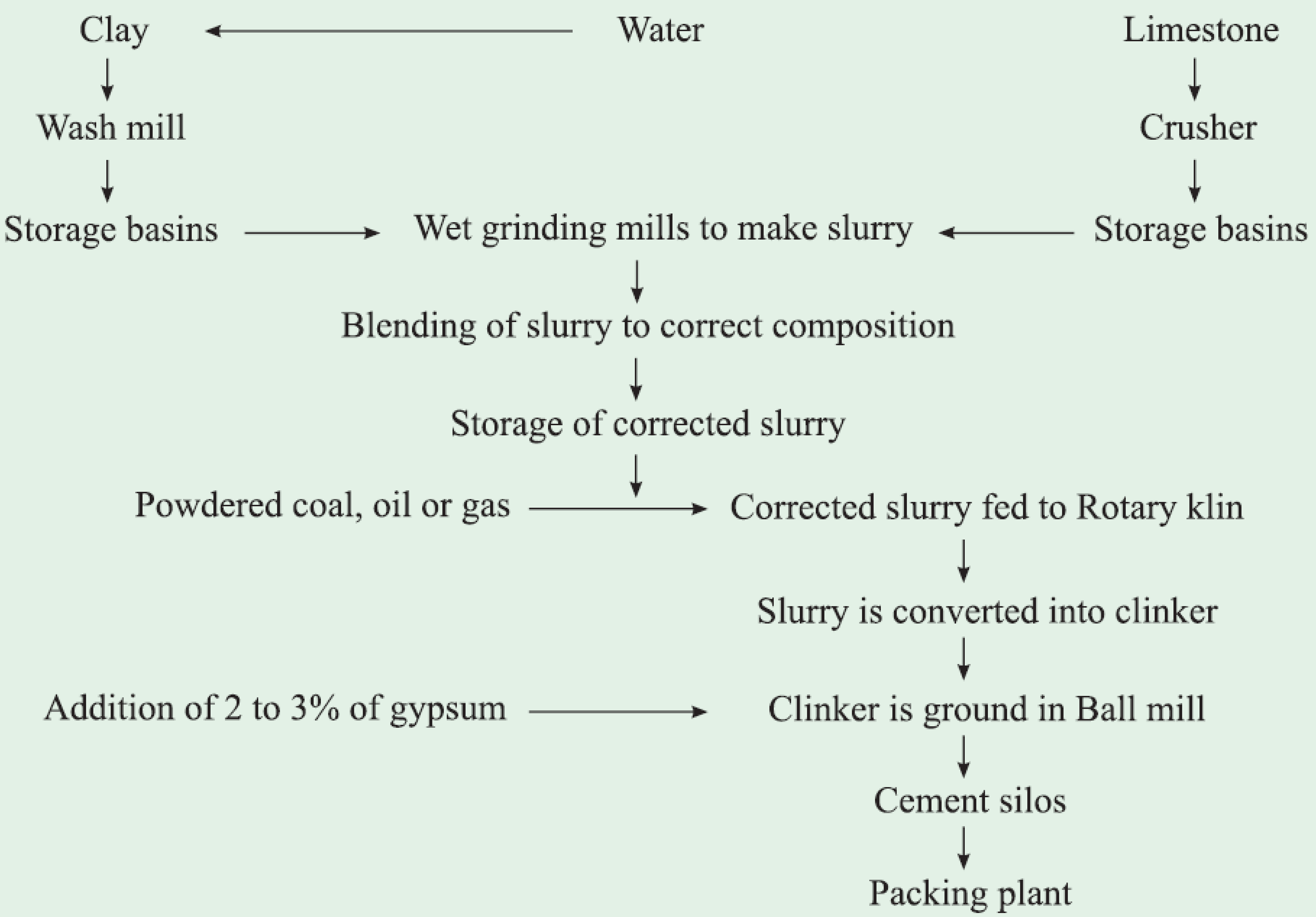
CEMENT – CLINKER PRODUCTION PROCESS

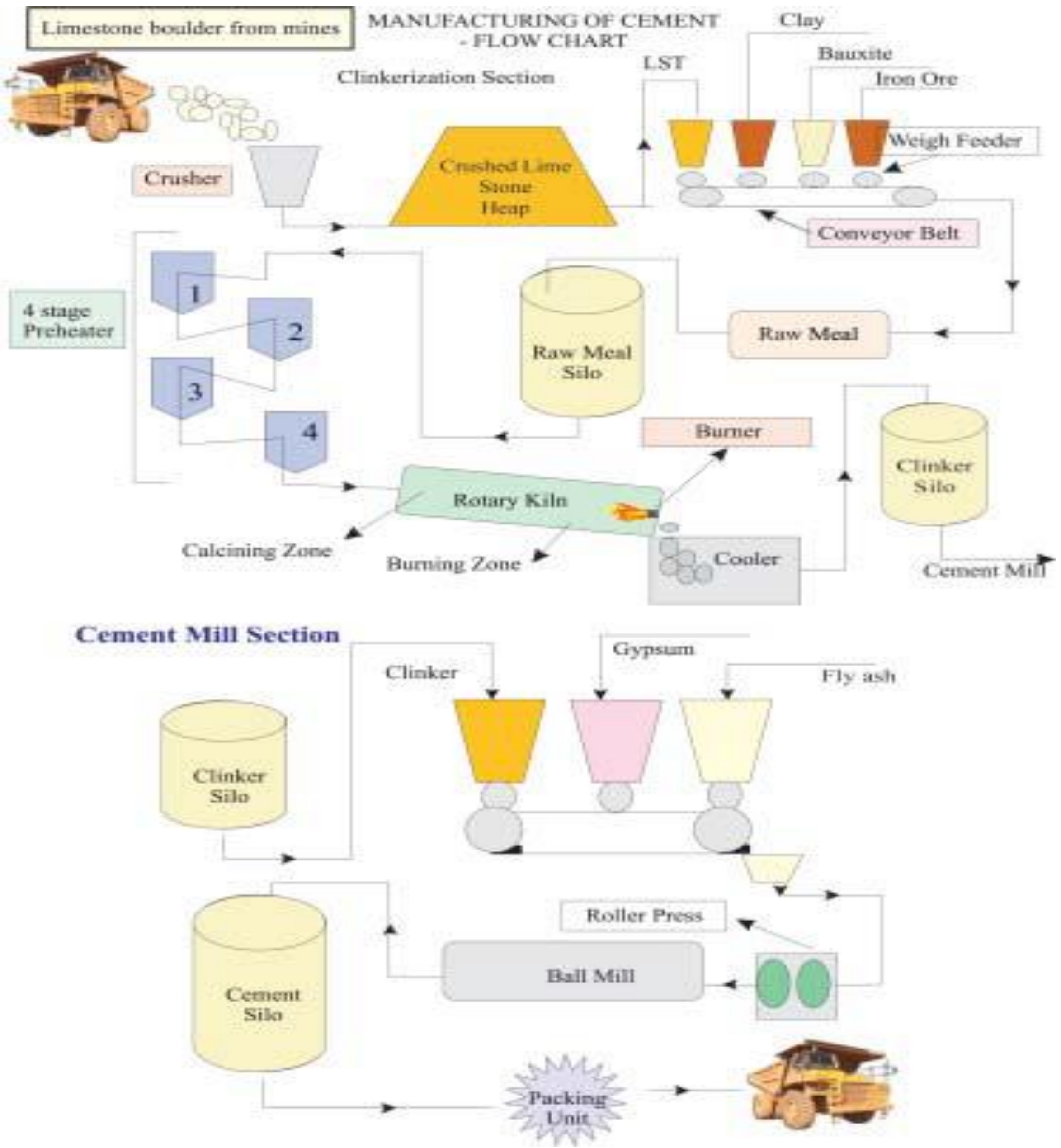
Cross-section view of kiln	Nodulization process	Clinkering reactions
1150-1200°C Particles start to become "sticky" 	Reactions start happening between solid particles. 	When calcination is complete, temperature increases rapidly. Small belite crystals form from combination of silicates and CaO. 
1200-1350°C As particles start to agglomerate, they are held together by the liquid. The rotation of the kiln initiates coalescing of agglomerates and layering of particles. 	Capillary forces of the liquid keep particles together. 	Above 1250°C, liquid phase is formed. Liquid allows reaction between belite and free CaO to form alite. 

CEMENT – CLINKER PRODUCTION PROCESS



Wet Process


Clay
Water
Limestone
Wash mill
Crusher
Storage basins
Wet grinding mills to make slurry
Storage basins
Blending of slurry to correct composition
Storage of corrected slurry
Powdered coal, oil or gas
Corrected slurry fed to Rotary klin
Slurry is converted into clinker
Addition of 2 to 3% of gypsum
Clinker is ground in Ball mill
Cement silos
Packing plant


Limestone boulder from mines
MANUFACTURING OF CEMENT - FLOW CHART
Clinkerization Section
Clay
Bauxite
LST
Iron Ore
Weigh Feeder
Crusher
Crushed Lime Stone Heap
Conveyor Belt
4 stage Preheater
1
2
3
4
Raw Meal Silo
Raw Meal
Burner
Clinker Silo
Rotary Kiln
Calcining Zone
Burning Zone
Cooler
Cement Mill
Cement Mill Section
Clinker
Gypsum
Fly ash
Clinker Silo
Roller Press
Ball Mill
Cement Silo
Packing Unit

Chemical Composition

- The raw materials used for the manufacture of cement consist mainly of lime , silica alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds.

Oxide	Percentage content
CaO	60-27
SiO_2	17-25
Al_2O_3	3.0-8.0
Fe_2O_3	0.5-6.0
MgO	0.1-4.0
Alkalies (K_2O, Na_2O)	0.4-1.3
SO_3	1.3-3.0

- As mentioned earlier the oxides present in the raw materials when subjected to high clinkering temperature combine with each other to form complex compounds. The identification of the major compounds is largely based on R.H.Bogue's work and hence it is called "Bogue's Compounds".

Name of compound	Formula	Abbreviated Formula
Tricalcium silicate	$3\ CaO.SiO_2$	C_3S
Dicalcium silicate	$2\ CaO.SiO_2$	C_2S
Tricalcium aluminate	$3\ CaO.Al2O_3$	C_3A
Tetracalcium aluminoferrite	$4\ CaO.Al2O_3.Fe2O_3$	C_4AF

Hydration of Cement

- Anhydrous Cement does not bind fine and coarse aggregate. It acquires adhesive property only when mixed with water. The chemical reactions that take place between cement and water is referred as hydration of cement. The reaction of cement with water is exothermic. The reaction liberates a considerable quantity of heat. This liberation of heat is called heat of hydration. Different compounds (C_3S, C_2S, C_3A, C_4AF)hydrate at different rates and liberate different quantities of heat. During the course of reaction of C_3S, C_2S with water, calcium silicate hydrate, abbreviated C-S-H and calcium hydroxide, $Ca(OH)_2$ formed. Calcium silicate hydrates are the most important products. It is the essence that determines the good properties of concrete.

Transition zone

- Concrete is generally considered as two phase material i.e paste phase and aggregate phase. At macro level it is seen that aggregate particles are dispersed in a matrix of cement paste. At the microscopic level, the complexities of the concrete begin to show up, particularly in the vicinity of large aggregate particles. This area can be considered as a third phase, the transition zone, which represents the interfacial region between the particles of coarse aggregate and hardened cement paste. Transition zone is generally a plane of weakness and therefore, has far greater influence on the mechanical behavior of concrete.
- Although transition zone is composed of same bulk cement paste, the quality of paste in the transition zone is poorer quality. Firstly due to internal bleeding, water accumulate below elongated, flaky and Large pieces of aggregates. This reduces the bond between paste and aggregate.

TYPES OF CEMENT

- How cement is modified
- Codes for modified cement
- Properties of all the cement

TYPES OF CEMENT – Ordinary Portland Cement

- OPC is by far the most important type of cement. The OPC was classified into three grades.
- 33 Grade, 43 Grade , 53 Grade depending upon the strength of the cement at 28 days when tested as per IS 4031-1988.
- If the 28 days strength is not less than 33N/mm2 , it is called 33 grade cement.
- It has been possible to upgrade the qualities of cement by using high quality limestone, modern equipments, closer on line control of constituents, maintaining better particle size distribution , finer grinding and better packing.

Portland Pozzolana Cement

What does a Pozzolanic material mean??

- A siliceous or siliceous and aluminous material which, in itself, possesses little or no cementitious value but which will, in finely divided form in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties.

Calcium Hydroxide + Pozzolana + Water → C – S – H (Gel)

Portland Pozzolana Cement

- Advantages:
  - Economical
  - Provides durability characteristics
  - Reduced heat of hydration at low rate
  - Reduces the micro cracks at transition stage
  - Reduction in permeability
  - Increased volume of mortar
- Disadvantages:
  - Development of strength is lower at early stages.
  - Reduces resistance to corrosion
  - Setting time is longer

Portland Slag Cement

- It is obtained by mixing Portland cement cement clinker, gypsum and granulated blast furnace slag in suitable proportions and grinding the mixture to get a through and intimate mixture between the constituents. It may also be manufactured by separately grinding Portland cement clinker , gypsum and ggbfs and later mixing them intimately.
- It has low heat of hydration and is relatively better resistant to chlorides, soils and water containing excessive amount of sulphates or alkali metals, alumina and iron.
- Reduced heat of hydration
- Refinement of pore structure
- Reduced permeability
- Increased resistance to chemical attack

Rapid Hardening Cement

- As the name indicates it develops strength rapidly and as such it may be more appropriate to call it as high early strength cement. It is pointed out that rapid hardening cement which develops higher rate of development of strength should not be confused with quick setting cement which only sets quickly. It develops at the age of 3 days, the same strength as that is expected of ordinary Portland cement at 7 days.
- In pre-fabricated concrete construction
- Where formwork is required to be removed early for re-use elsewhere
- In cold weather concrete where the rapid rate of development of strength reduces the vulnerability of concrete to the frost damage.

Sulphate Resisting Cement

- OPC is susceptible to the attack of sulphates, in particular to the action of magnisum sulphates. Sulphates react both with the free calcium hydroxide in set cement to form calcium sulphate and with hydrate of calcium aluminate to form calcium sulphoaluminate.
- To remedy the sulphate attack, the use of cement with low C_3A content is found to be effective. Such cement with low C_3A and comparatively low C_4AF content is known as sulphate resisting cement.
- Concrete to be used in marine condition
- Concrete to be used in the construction of sewage treatment works.
- Concrete to be used in foundation and basement, where soil is infested with sulphates.

Low heat cement

- It is well known that hydration of cement is an exothermic action which produces large quantity of heat during hydration. Because of it formation of cracks in large body of concrete.
- Cement having this property was developed in U.S.A. during 1930 for use in mass concrete construction, such as dams, where temperature rise by the heat of hydration can become excessively large. A low heat evolution is achived by reducing the contents of C_3S and C_3A which are the compounds evolving the maximum heat of hydration and increasing C_2S.

TESTING OF CEMENT

- Field Test
- Laboratory Tests
  - Fineness test, standard consistency test, setting time tests, strength test, soundness test, heat of hydration test, chemical composition test.

Testing of Cement – Field Tests

The field test that proves to be sufficient for minor works are as listed below:

- There should not be any lumps and colour shall be greenish grey.
- The cement shall give the cool feeling on inserting hand in the bag.
- Feel the smoothness of a pinch of cement between fingers.
- Take a handful of cement and throw it on the bucket full of water, the particle should float before sinking for some time.
- The pat prepared of 100gms of cement shall maintain its shape as well as it should set and gain some strength when immersed in water for 24 hours.

Testing of Cement – Laboratory Tests

- ***1) FINENESS TEST:***
  - Why to test for fineness of cement??

    The fineness of cement has an effective influence on rate of hydration and hence on rate of gain of strength and on rate of evolution of heat.

    The disadvantage of finely grounded cement are that it is susceptible to air set and early deterioration. Increase in fineness of cement is also found to increase the drying shrinkage of concrete.

  - Fineness of cement is tested in two ways:

a) By sieving

b) By determination of specific surface (total surface area of all the particles in one gram of cement) by air – permeability apparatus (generally Blaine air – permeability apparatus). Units are, cm^2/gm or m^2/kG.

Testing of Cement – Laboratory Tests

- ***1) FINENESS TEST BY SIEVING :***

Procedure:-

- Take 100 grams of cement on IS Sieve No. 9 (90 microns).
- Break down the lumps, if exists, with fingers.
- Sieve the sample for a period of 15 mins.
- Weigh the residue left on the sieve.
- This weight shall not exceed 10% for ordinary cement.

Testing of Cement – Laboratory Tests

- ***1) FINENESS TEST BY AIR – PERMEABILITY APPARATUS :***
  - The principle is based on the relation between the flow of air through the cement bed and the specific area of the particles comprising the cement bed.
  - Hence, the surface area per unit weight of the body material can be related to the permeability of a bed of a given porosity.

Procedure:-

- The dimension of the bed are : 1 cm high and 2.5 cm in diameter.
- Knowing density of cement, the weight of the cement required to make a cement bed of 0.475 porosity can be calculated.
- Pass the air slowly through the cement bed at a constant velocity.
- Adjust the air flow such that the difference in h_1 of manometer and h_2 of flow meter maintains the constant value of h_1/h_2.

Testing of Cement – Laboratory Tests

- ***1) FINENESS TEST BY AIR – PERMEABILITY APPARATUS :***
  - Specific surface can be calculated by following expression.

$$S_w = K\sqrt{h_1 / h_2} \quad \text{and} \quad K = \frac{14}{d\,(1-x)}\sqrt{\frac{x^3 A}{CL}}$$

where, ξ = Porosity, *i.e.*, 0.475

A = Area of the cement bed

L = Length (cm) of the cement bed

d = Density of cement, and

C = Flowmeter constant.

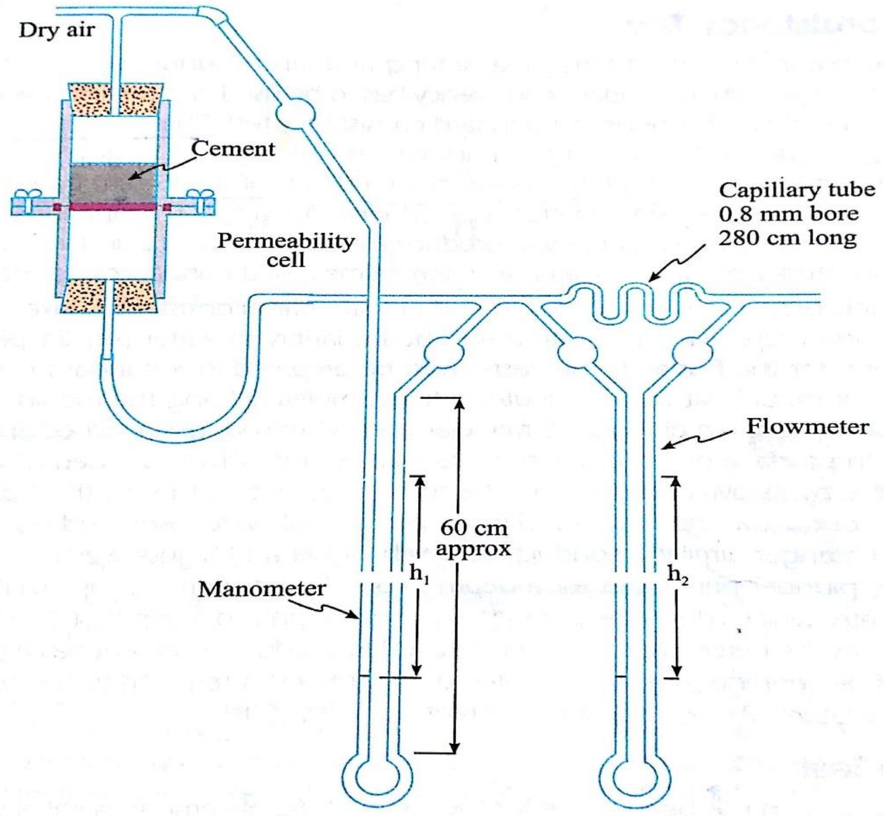
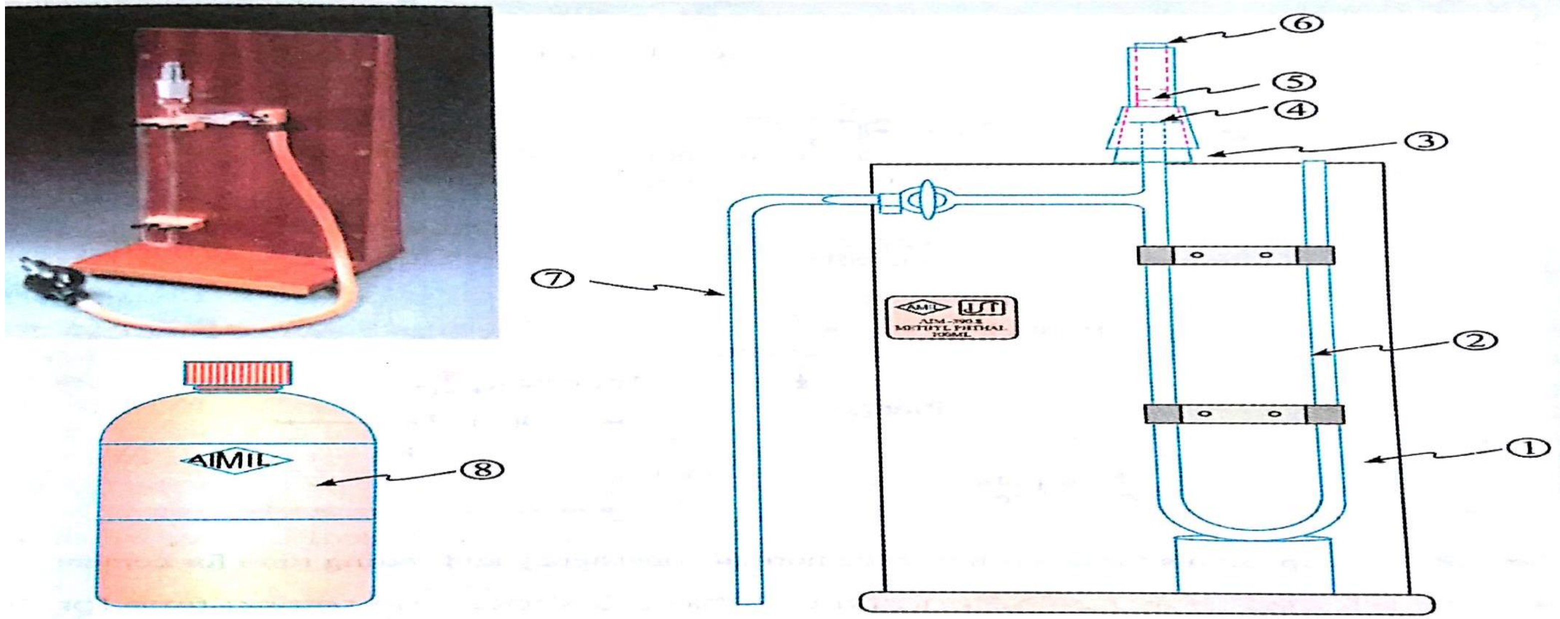


Fig. 2.6. Permeability apparatus with manometer and flowmeter.

Testing of Cement – Laboratory Tests



S.No.	Description
1.	Wooden stand
2.	Manometer
3.	Rubber cork
4.	Permeability cell

AIMIL INSTRUMENTATION

S.No.	Description
5.	Perforated disc
6.	Plunger
7.	Tube
8.	Dibutylphthalate

Fig. 2.7. Air permeability apparatus (Blaine type).

Testing of Cement – Laboratory Tests

- **Standard values for some of the cement are as tabulated below:**

Sr. No	Type of Cement	Fineness (m^2/kG)
1	33 Grade OPC	225
2	43 Grade OPC	225
3	53 Grade OPC	225
4	SRC	225
5	PPC	300
6	RHC	325
7	Slag Cement	225
8	Low Heat Cement	320

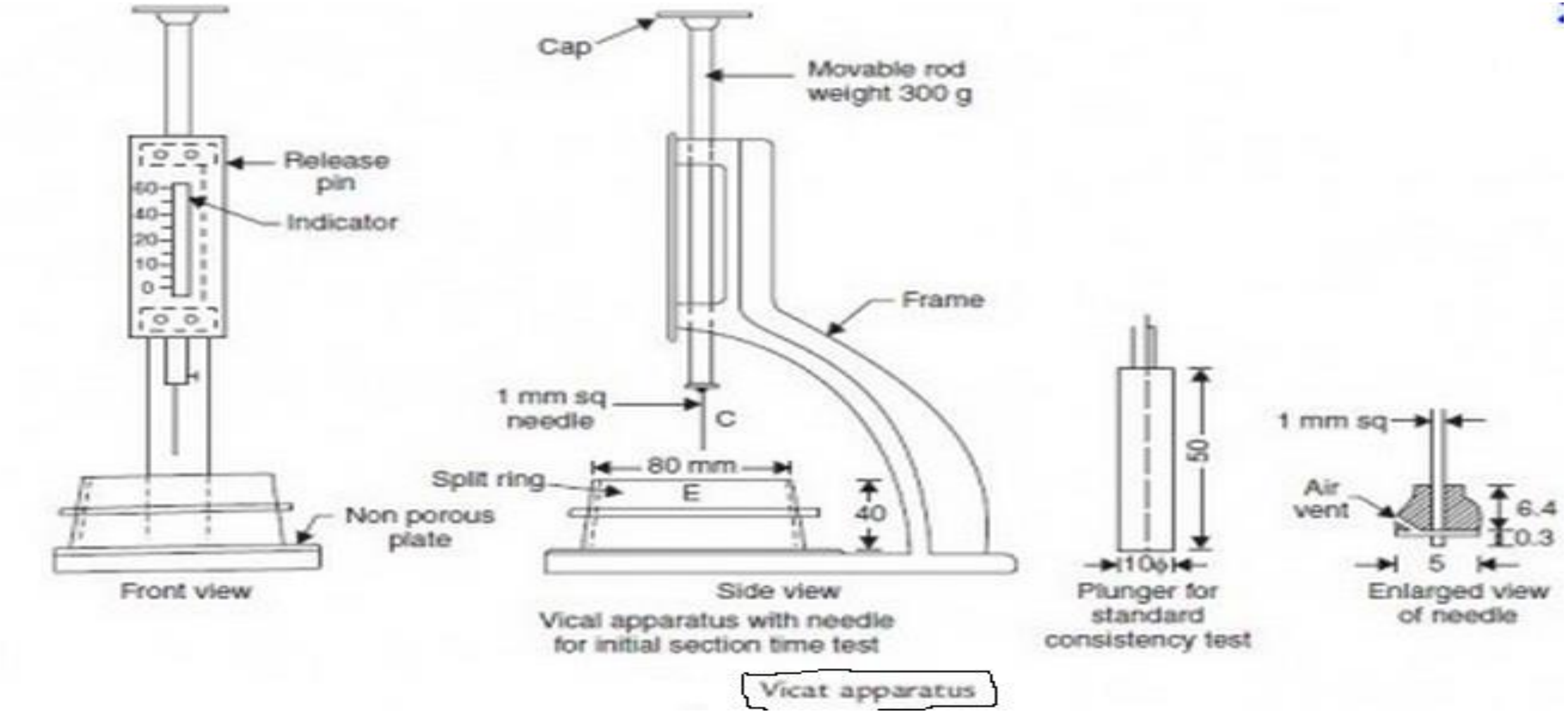
Testing of Cement – Laboratory Tests

- ***2) STANDARD CONSISTENCY TEST:***
  - The standard consistency of the cement paste is defined as the consistency which will permit a Vicat plunger of 10 mm diameter and 50 mm in length to penetrate to a depth of 33-35 mm from the top of the mould.
  - This would yield us the water required to produce the cement paste of the standard consistency.

Procedure:-

- Take 500 grams of cement, and 24 % water (for 1st trial).
- The paste must be filled into the VICAT mould within 3 – 5 mins.
- A standard plunger, 10 mm in diameter and 50 mm long is attached and brought down to the surface of the paste, and quickly released allowing it to penetrate the sample by its own weight. Take the reading by noting the depth of penetration of the plunger.
- The water content at which the penetration value is 33 – 35 mm from the top is known as the water content (p %) at which the cement paste of standard consistency can be prepared.

Testing of Cement – Laboratory Tests



Testing of Cement – Laboratory Tests

- ***3) SETTING TIME TEST:***
  - The setting times are : a) Initial setting time and, b) Final Setting time
  - INITIAL SETTING TIME:

  The time elapsed between the moment that the water is added to the cement and that at which the cement start losing its plasticity is known as initial setting time.

  - FINAL SETTING TIME:

  The time elapsed between the moment that the water is added to the cement and that at which the cement has completely lost its plasticity is known as final setting time.

  - Apparatus used for the test is VICAT apparatus only.

Testing of Cement – Laboratory Tests

- ***3) SETTING TIME TEST:***

<u>Procedure:-</u>

- Take 500 gram weight of cement and mix 0.85 times the water required to produce a cement paste of standard consistency.
- Fill the paste in VICAT's mould within 3 – 5 mins.
- Start the stop watch, the moment water is added to the cement.

<u>Initial setting time:</u>

- Lower the needle and bring it in contact with the surface of the test block and quickly release.
- Allow it to penetrate the test block. Note the time at which the needle has penetrated the depth of 33 – 35 mm from the top of the mould.
- This time will be known as initial setting time.

Testing of Cement – Laboratory Tests

- ***3) SETTING TIME TEST:***

Procedure:-

Final setting time:

- Replace the attachment, now the cement is considered to be set when, upon, lowering the attachment gently over the surface of the block. The central needle can pierce the block through 0.5 mm and the exterior assembly fails to do so.
- This time will be representing final setting time.

Testing of Cement – Laboratory Tests

- **Standard values for some of the cement are as tabulated below:**

Sr. No	Type of Cement	Initial Setting Time (mins)	Final Setting Time (mins)
1	33 Grade OPC	30	600
2	43 Grade OPC	30	600
3	53 Grade OPC	30	600
4	SRC	30	600
5	PPC	30	600
6	RHC	30	600
7	Slag Cement	30	600
8	Low Heat Cement	60	600

Testing of Cement – Laboratory Tests

- ***4) STRENGTH TEST :-***
  - Strength test are made to obtain the compressive strength of the hardened cement paste.
  - Test is to be performed on the cement sand mortar by taking the ratio of 1:3 (C : S).

Procedure:-

- Take 555 grams of sand (Ennore Sand – conforming to IS 650 – 1991), and 185 grams of cement on which the test is to be carried out.
- After mixing the above mixture for about one minute, the water quantity of (p/4 + 3) is to be added and mixed to obtain uniform colour.
- Mixing of the three ingredients as specified above shall be carried out for 3-4 mins.
- Fill the mixed mortar into a cube size of 7.06 cm and compact it either manually or by vibrating equipment (12000 RPM) for 2 mins.

Testing of Cement – Laboratory Tests

- ***4) STRENGTH TEST :-***

Procedure:-

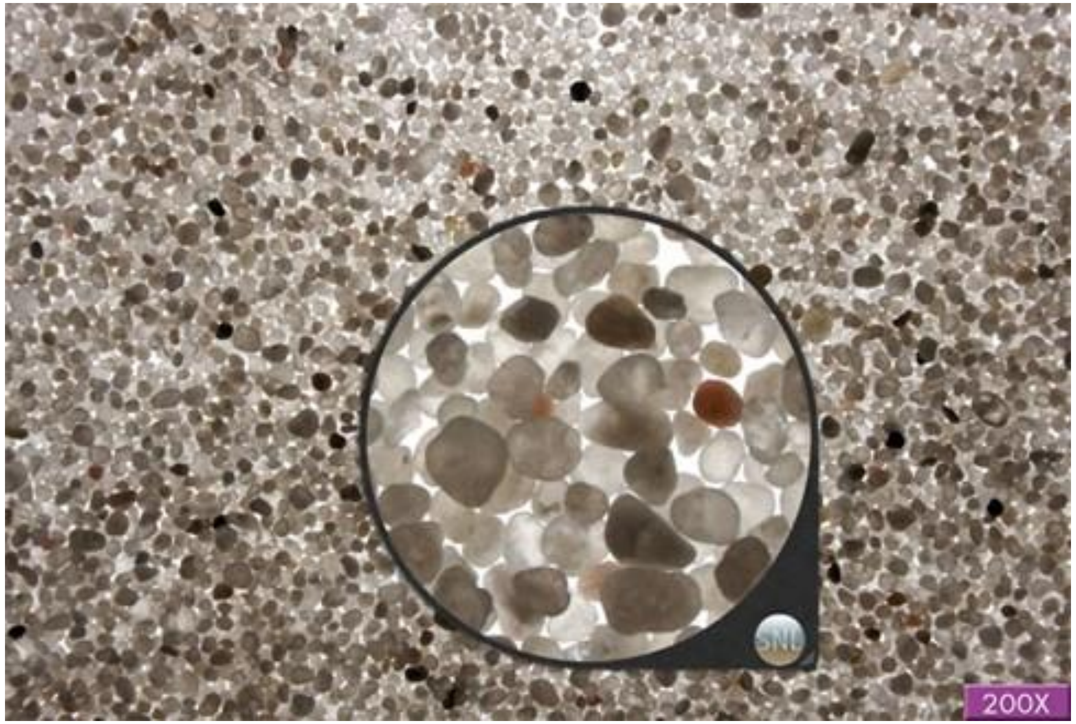
- Place the mould in 90% relative humidity for 24 hours. After 24 hours the cubes are removed from the mould and immersed in clean water until taken out for tests.
- Three cubes are to be tested for compressive strength at 3, 7 and 28 days. This period shall be considered after the completion of the vibration.
- Compressive strength shall be taken as an average of all the three cubes.

Testing of Cement – Laboratory Tests

Sr. No	Type of Cement	1 Day	3 Days	7 Days	28 Days
1	33 Grade OPC	N. S.	16	22	33
2	43 Grade OPC	N. S.	23	33	43
3	53 Grade OPC	N. S.	27	37	53
4	SRC	N. S.	10	16	33
5	PPC	N. S.	16	22	33
6	RHC	16	27	N. S.	N. S.
7	Slag Cement	N. S.	16	22	33
8	Low Heat Cement	N. S.	10	16	35

Testing of Cement – Laboratory Tests

- ***Characteristics of Standard Sand:***
  - Standard sand shall be of quartz material
  - Colour of the standard sand is light grey or whitish
  - It should be free from silt
  - The sand grains should be angular, but a small percentage of flaky or rounded particle is permissible



Testing of Cement – Laboratory Tests

- ***Particle size distribution of standard sand :-***
  - All the particles shall fall between 90 micron to 2 mm size range as specified below

Particle Size	Percentage
2 mm to 1 mm	33.33%
1 mm to 500 micron	33.33%
500 micron to 90 micron	33.33%

AGGREGATES

- Classification, source, size, shape, texture, strength, sp. Gravity and bulk density, moisture content, etc…

Aggregates

- **Aggregates** are the important constituents in concrete. They give **body** to the concrete, **reduce shrinkage** and effect **economy**.
- The aggregates **occupy 70–80 per cent** of the **volume** of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable.
- Concrete can be considered as two phase materials for convenience**; paste phase and aggregate phase.**

Aggregates

The study of aggregates can best be done under the following sub-headings:

- Classification
- Source
- Size
- Shape
- Texture
- Strength
- Specific gravity and bulk density
- Moisture content
- Bulking factor
- Cleanliness
- Soundness
- Chemical properties
- Thermal properties
- Durability
- Sieve analysis
- Grading

Aggregates – Classification

- Normal weight aggregates
- Light weight aggregates
- Heavy weight aggregates

Normal Weight Aggregates

- **Natural Aggregates**
  Sand, Gravel, Crushed Rock such as Granite, Quartzite,Basalt , Sandstone
- **Artificial Aggregates**
  Broken Brick, Air-Colled slag, Sintered Fly ash, Bloated Clay

Aggregates – Classification

Sr No.	Category	Unit wt. of dry agg. (kg/m^3)	Unit wt. of concrete (kg/m^3)	Application
1	Ultra lightweight	<500	300 – 1100	Non – Structural
2	Lightweight	500 – 800	1100 – 1600	Insulating Material
3	Structural Lightweight	650 – 1100	1450 – 1900	Masonary units (structural)
4	Normal weight	1100 – 1750	2100 – 2550	Structural
5	Heavy Weight	>2100	2900 – 6100	Radiation Shielding

Aggregates – Source

- Almost all **natural aggregate** materials originate from **bed rocks**. There are three kinds of rocks, namely, **igneous, sedimentary and metamorphic.**

<u>Aggregates from Igneous Rocks</u>

- Most **igneous rocks** make highly satisfactory concrete aggregates because they are normally **hard, tough and dense.**
- They may be **acidic or basic** depending upon **the percentage of silica content.**
- They may occur **light coloured or dark coloured**.
- The igneous rocks as a class are the most **chemically active** concrete aggregate and show a tendency to **react** with the **alkalis** in cement.

Aggregates – Source

<u>Aggregates from Sedimentary Rocks</u>

- Sedimentary rocks vary from **soft to hard, porous to dense and light to heavy**.
- The **degree of consolidation, the type of cementation, the thickness of layers and contamination**, are all important factors in determining the suitability of sedimentary rock for concrete aggregates.

<u>Aggregates from Metamorphic Rocks</u>

- Both **igneous rocks and sedimentary rocks** may be **subjected to high temperature and pressure** which causes **metamorphism** which changes the structure and texture of rocks.
- Metamorphic rocks particularly **quartizite and gneiss** have been used for production of good concrete aggregates

Aggregates – Size

- The largest maximum size of aggregate **practicable to handle** under a given set of conditions should be used.
- Perhaps, **80 mm size** is the maximum size that could be conveniently used for concrete making.

Using the largest possible maximum size will result in

- Reduction of the cement content
- Reduction in water requirement
- Reduction of drying shrinkage.

Aggregates – Size

Aggregates are divided into two categories from the consideration of size

- Coarse aggregate (The size of aggregate **bigger** than **4.75 mm** is considered as coarse aggregate)
- Fine aggregate (Aggregate whose size is **4.75 mm and less** is considered as fine aggregate)

The maximum size of aggregate that can be used in any given condition may be limited by the following conditions

- Thickness of section
- Spacing of reinforcement;
- Clear cover
- Mixing, handling and placing techniques

Aggregates – Shape

- The **shape of aggregates** is an important characteristic since it affects the **workability of concrete**.
- For **water/cement ratio**, **rounded aggregates** are **preferable** to **angular aggregates.**
- **Additional cement** required for **angular aggregate** due to **higher strengths** and sometimes by **greater durability** as a result of the **interlocking texture** of the **hardened concrete** and **higher bond** between aggregate and cement paste.
- **Flat particles** in concrete aggregates will have particularly **objectionable influence on the workability**, **cement requirement, strength and durability.** In general, excessively **flaky aggregate** makes very **poor concrete**.

Aggregates – Shape

Classification	*Description*	*Examples*
Rounded	Fully water worn or completely shaped by attrition	River or seashore gravels; desert, seashore and wind-blown sands
Irregular or Partly rounded	Naturally irregular or partly shaped by attrition, having rounded edges	Pit sands and gravels; land or dug flints; cuboid rock
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces	Crushed rocks of all types; talus; screes
Flaky	Material, usually angular, of which the thickness is small relative to the width and/or length	Laminated rocks

Aggregates – Shape

Round (spherical) concrete aggregate. | Flaky concrete aggregate. | Crushed concrete aggregate.

Aggregates – Shape

- Methods of expressing the **angularity** qualitatively is by a figure called **Angularity Number**
- A quantity of single sized aggregate is filled into metal cylinder of three litre capacity. The aggregates are compacted in a standard manner and the **percentage of void is found out.**
- The void can be found out by knowing the **specific gravity of aggregate and bulk density** or by **pouring water to the cylinder** to bring the level of water upto the brim.
- If the **void is 33 percent** (i.e. 67 percent solid volume) the **angularity of such aggregate is considered zero.**
- If the **void is 44 percent** (i.e. 56 percent solid volume) **the angularity number of such aggregate is considered 11.**

Aggregates – Shape

- The **normal aggregates** which are **suitable for making the concrete** may have angularity number anything from **zero to 11.**
- **Angularity number zero** represents the most practicable **rounded aggregates** and the **angularity number 11** indicates the **most angular aggregates** that could be tolerated for making concrete not so unduly harsh and uneconomical

- Murdock suggested a different method for expressing the shape of aggregate by a parameter called Angularity Index 'f_A'.

$$f_A = \frac{3fH}{20} + 1.0$$

f_h = Angularity Number

Aggregates – Shape

The angular aggregates are superior to rounded aggregates from the following two points of view:

- **Angular aggregates** exhibit a **better interlocking effect in concrete**, which property makes it **superior in concrete** used for roads and pavements.
- The **total surface area** of **rough textured** angular aggregate is **more** than **smooth rounded aggregate** for the given volume. By having **greater surface area**, the **angular aggregate** may show **higher bond strength** than rounded aggregates

Aggregates – Shape

- The higher surface area of angular aggregate with rough **texture requires more water** for a given workability than rounded aggregates.
- For a given set of conditions from the point of view of water/cement ratio, rounded aggregate gives higher strength.
- For water/cement ratio **below 0.4** the use of **crushed aggregate** has resulted in strength up to **38 per cent higher** than the **rounded aggregate.**
- With an increase in water/cement ratio the influence of roughness of surface of the aggregate gets reduced, presumably **because the strength of the paste itself becomes paramount.**
- At a **water/cement ratio of 0.65**, **no difference** in **strength** of concrete made with **angular aggregate** or **rounded aggregate** has been observed.

Aggregates – Texture

- **Surface texture** degree to which particle surfaces are **polished or dull, smooth or rough.**
- Surface texture depends on **hardness, grain size, pore structure, structure of the rock**, and the **degree to which forces** acting on the **particle surface have smoothed or roughened it.**
- As **surface smoothness increases**, **contact area decreases**, hence a **highly polished particle** will have **less bonding area** with the **matrix** than a **rough particle** of the same volume.
- A **smooth particle**, however, will require a **thinner layer of paste** to **lubricate** its movements with respect to other aggregate particles.
- It will, therefore, permit **denser packing** for **equal workability** and hence, will require **lower paste content** than rough particles.

Aggregates – Strength

- The **strength of the parent rock** from which aggregate are produced **does not** exactly **represent the strength of the aggregate** in concrete.

Strength mainly depends upon

1. Strength of the cement paste
2. Bond between cement paste and aggregate

- But when **cement paste** of **good quality** is provided and its **bond** with the **aggregate** is **satisfactory**, then the mechanical properties of the rock or aggregate will influence the strength of concrete.
- From the above it can be concluded that while **strong aggregates cannot make strong concrete**, for making **strong concrete, strong aggregates** are an essential requirement.

Aggregates – Crushing Value

- **Aggregate crushing value** gives a relative measure of the **resistance** of an aggregate sample to **crushing** under gradually applied compressive load.
- This test helps to determine the aggregate crushing value of coarse aggregates as per IS: 2386 (Part IV) – 1963.
- The apparatus used is **Cylindrical measure** and **plunger**, **Compression testing machine**, IS Sieves of sizes – 12.5mm, 10mm and 2.36mm.
- Strength of rock is found out by making a test specimen of cylindrical shape of size **25 mm diameter and 25 mm height.**

Aggregates – Crushing Value

Procedure to determine Aggregate Crushing Value

- The aggregates passing through **12.5**mm and retained on **10**mm IS Sieve are oven-dried at a temperature of 100 to 110°C for 3 to 4hrs.
- The cylinder of the apparatus is filled in **3 layers**, each layer tamped with **25 strokes** of a tamping rod.
- The weight of aggregates is measured (Weight 'A').
- The **surface of the aggregates** is then levelled and the **plunger inserted**. The apparatus is then placed in the compression testing machine and loaded at a **uniform rate** so as to achieve **40t load** in **10 minutes**. After this, the load is released.
- The sample is then sieved through a **2.36mm** IS Sieve and the fraction passing through the sieve is weighed **(Weight 'B').**

Aggregates – Crushing Value

- Two tests should be conducted.

Aggregate crushing value = (B/A) x 100%

- The crushing value of aggregate is restricted to **30 per cent** for concrete used for roads and pavements and **45 per cent** may be permitted for other structures

Aggregates – Impact Value

PREPARATION OF TEST SAMPLE

- Test sample consist of aggregate passing a 12.5mm IS sieve and retained on a 10mm IS sieve. The aggregate to be tested is dried in oven for a period of not less than 4hours.

PROCEDURE

- The cylindrical steel cup is filled with **3 equal layers** of aggregate and each layer is tamped **25 strokes** by the rounded end of tamping rod and the surplus aggregate struck off, using the tamping rod as a straight edge.
- The **net weight of aggregate** in the cylindrical steel cup is determined to the nearest gram **(W_A)** and this weight of aggregate is used for the **duplicate test** on the same material
- The cup is fixed firmly in position on the base of the machine and **the whole of the test sample** is placed in it.

Aggregates – Impact Value

- The **hammer(13.5 to 14 kg)** is raised until its lower face is **380 mm** above the upper surface of the aggregate in the cup, and allowed to fall freely onto the aggregate for **15 times**, each being delivered at an interval of not less than **one second.**
- The crushed aggregate is removed from the cup and sieved on **2.36 mm**. IS sieve until no further significant amount passes in one minute.
- The fraction passing the sieve is weighed to an accuracy of 0.1 g (W_B)

CALCULATION

- The ratio of the weight of fines formed to the total sample weight in each test is to be expressed as a percentage, to the first decimal place.
- ***Aggregate impact Value =*** $(W_B / W_A) \times 100$
- Aggregate impact value shall not exceed **45 per cent** by weight for aggregate used for concrete **other than wearing surface** and **30 per cent** by weight, for concrete for **wearing surfaces**, such as run ways, roads and pavements.

Aggregates – Deval Abrasion Value

Test Sample - The test sample shall consist of dry coarse aggregate made up of percentages of the various sizes conforming to one of the gradings shown below:

Grading	*Passing IS Sieve*	*Retained on IS Sieve*	*Percentage of Sample*
A	20-mm	12·5-mm	25
	25-mm	20-mm	25
	40-mm	25-mm	25
	50-mm	40-mm	25
B	20-mm	12·5-mm	25
	25-mm	20-mm	25
	40-mm	25-mm	50
C	20-mm	12·5-mm	50
	25-mm	20-mm	50
D	12·5-mm	4·75-mm	50
	20-mm	12·5-mm	50
E	10-mm	4·75-mm	50
	12·5-mm	10-mm	50

Aggregates – Deval Abrasion Value

Apparatus

Deval abrasion testing machine :The inside diameter of the cylinders shall be **20 cm** and depth **34 cm**. The cylinders shall be mounted on a shaft at an angle of **30 degrees** with the axis of rotation of the shaft.

Abrasive Charge : The abrasive charge shall consist of **6 cast iron spheres** or **steel spheres** approximately **48 mm** in diameter, each weighing between **390 and 445 g.**

Aggregates – Deval Abrasion Value

Procedure

- The test sample and the abrasive charge shall be placed in the Deval abrasion testing machine and the machine rotated for 10000 revolutions at a speed of **30 to 33 rev/min.**
- At the completion of the test, the material shall be removed from the machine and sieved on a **1.70-mm** IS Sieve. The material retained on the sieve shall be washed, dried, and accurately weighed to the nearest gram.

Calculations

- Percentage of wear - The loss by abrasion shall be considered as the **difference between** the original weight of the test sample and the weight of the material retained on the 1.70-mm IS Sieve, expressed as **percentage of the original weight of the test sample**.

Aggregates – Los Angeles Test

Test Sample - The test sample shall consist of clean aggregate which has been dried in an oven at 105 to 110°C to substantially constant weight and shall conform to one of the gradings shown below

Procedure

- The test sample and the abrasive charge shall be placed in the Los Angeles abrasion testing machine and the machine rotated at a speed of **20 to 33 rev/min.**
- For gradings A, B, C and D, the machine shall be rotated for **500 revolutions**; for gradings E, F and G, it shall be rotated for **1000 revolutions**.

Aggregates – Los Angeles Test

TABLE II GRADINGS OF TEST SAMPLES

(*Clause* 5.3.3)

Sieve Size (Square Hole)		Weight in g of Test Sample for Grade						
Passing	Retained on	A	B	C	D	E	F	G
mm	mm							
80	63	—	—	—	—	2 500*	—	—
63	50	—	—	—	—	2 500*	—	—
50	40	—	—	—	—	5 000*	5 000*	—
40	25	1 250	—	—	—	—	5 000*	5 000*
25	20	1 250	—	—	—	—	—	5 000*
20	12·5	1 250	2 500	—	—	—	—	—
12·5	10	1 250	2 500	—	—	—	—	—
10	6·3	—	—	2 500	—	—	—	—
6·3	4·75	—	—	2 500	—	—	—	—
4.75	2·36	—	—	—	5 000	—	—	—

*Tolerance of ±2 percent permitted.

Grading	*Number of Spheres*	*Weight of Charge* g
A	12	5 000±25
B	11	4 584±25
C	8	3 330±20
D	6	2 500±15
E	12	5 000±25
F	12	5 000±25
G	12	5 000±25

Aggregates – Los Angeles Test

- The material coarser than the **1.70-mm IS Sieve** shall be washed dried in an oven at 105 to 110°C to a substantially constant weight, and accurately weighed to the nearest gram.

Calculations

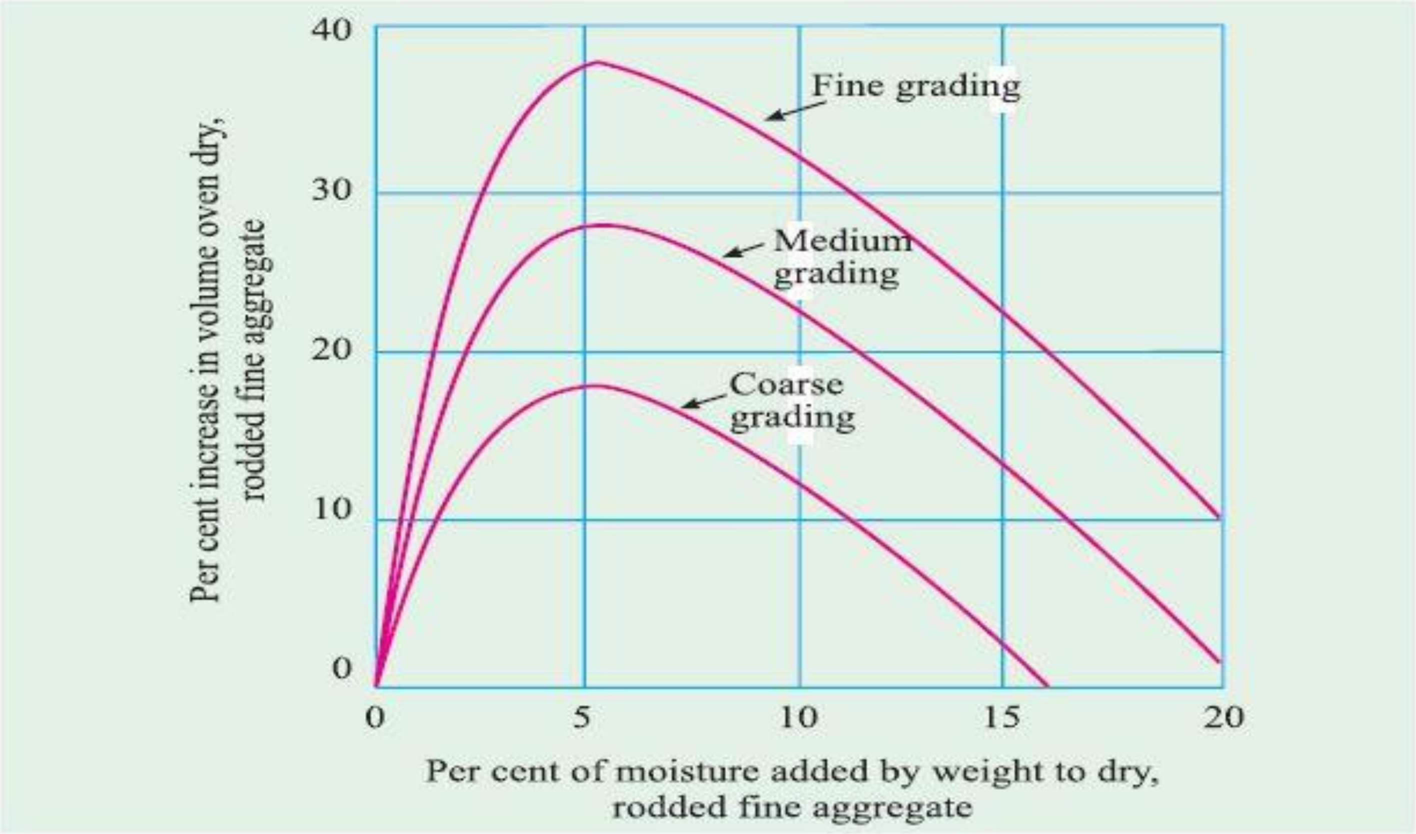
- Difference between the original weight and the final weight of the test sample shall be expressed as a **percentage of the original weight of the test sample.** This value shall be reported as the percentage of wear.

Aggregates – Bulking

- The **free moisture content** in fine aggregate results in **bulking of volume**
- **Free moisture** forms a film around each particle. This film of **moisture** exerts what is known as **surface tension** which keeps the neighboring particles away from it.
- Therefore, **no point contact** is possible between the particles. This causes bulking of the volume.
- Bulking depend upon the **percentage of moisture content** and the **particle size** of the fine aggregate
- **Bulking increases** with the **increase in moisture content** upto a certain limit and **beyond that** the **further increase** in the **moisture content** results in the **decrease** in the **volume** and at a **moisture content** representing **saturation point**

Aggregates – Bulking

- Extremely fine sand and particularly the manufactured fine aggregate bulks as much as about **40 per cent**.



Aggregates – Test for bulking

- A sample of moist fine aggregate is filled into a measuring cylinder in the normal manner. Note down the level, say h1.
- Pour water into the measuring cylinder and completely inundate the sand and shake it.
- Since the volume of the saturated sand is the same as that of the dry sand, the inundated sand completely offsets the bulking effect.
- Note down the level of the sand say, h_2. Then $h_1 - h_2$ shows the bulking of the sample of sand under test.

Percentage of bulking $= \frac{h_1 - h_2}{h_2} X100$

Aggregates – Measurement of moisture content

- **Drying Method**
- **Displacement Method**
- **Electrical Meter Method**

  It works on the principle that the **resistance gets changed with the change in moisture content of the aggregate**

Aggregates – Measurement of moisture content

Calcium Carbide Method

- Weigh 6 grams of representative sample of wet sand and pour it into the container. Take one scoop full of **calcium carbide powder** and put it into the container. Close the lid of the container and shake it rigorously.
- Calcium carbide reacts with **surface moisture and produces acetylene gas**, the pressure of which drives the indicator needle on the **pressure gauge.**
- The pressure gauge is so calibrated, that it gives **directly percentage of moisture**. The whole job takes only less than 5 minutes

Aggregates – Soundness

- **Soundness** refers to the ability of aggregate to **resist excessive changes in volume** as a result of changes in physical conditions.
- These physical conditions that affect the soundness of aggregate are the **freezing the thawing, variation in temperature, alternate wetting and drying under normal conditions and wetting and drying in salt water.**
- The soundness test consists of immersion of carefully graded and weighed test sample in a **solution of sodium or magnesium sulphate** and oven drying it under specified conditions.
- The accumulation and growth of **salt crystals** in the **pores of the particles** is thought to produce disruptive internal forces similar to the **action of freezing of water or crystallization of salt**. **Loss in weight**, is measured for a specified **number of cycles.**
- It can be taken that the average loss of weight after **10 cycles** should not exceed **12 percent** and **18 percent** when tested with **sodium sulphate and magnesium sulphate respectively.**

Aggregates – Alkali Reaction

- Aggregates contain reactive silica, which reacts with alkalies present in cement i.e., sodium oxide and potassium oxide.
- The reaction starts with attack on the reactive siliceous minerals in the aggregate by the alkaline hydroxide derived from cement.
- As a result, the alkali silicate gels of unlimited swelling.
- Results in disruption of concrete with the spreading of pattern cracks and even failure of concrete structures.

Factors Promoting the Alkali-Aggregate Reaction

- Reactive type of aggregate
- High alkali content in cement;
- Availability of moisture
- Optimum temperature conditions.

Aggregates – Alkali Reaction

Reactive type of aggregate

- The potential reactivity of an aggregate with alkalis in Portland cement is indicated by the amount of reaction taking place during 24 hours at 80°C between sodium hydroxide solution and the aggregate
- Aggregate is sieved to pass a 300 micron IS Sieve and retained on 150 micron IS Sieve.
- The solution after 24 hours is analysed for silica dissolved and reduction in alkalinity, both expressed as millimoles per litre
- The values are plotted as shown in Fig
- Generally, a potentially deleterious reaction is indicated if the plotted test result falls to the right of the boundary line
- if plotted result falls to the left side of the boundary line, the aggregate may be considered as less reactive.

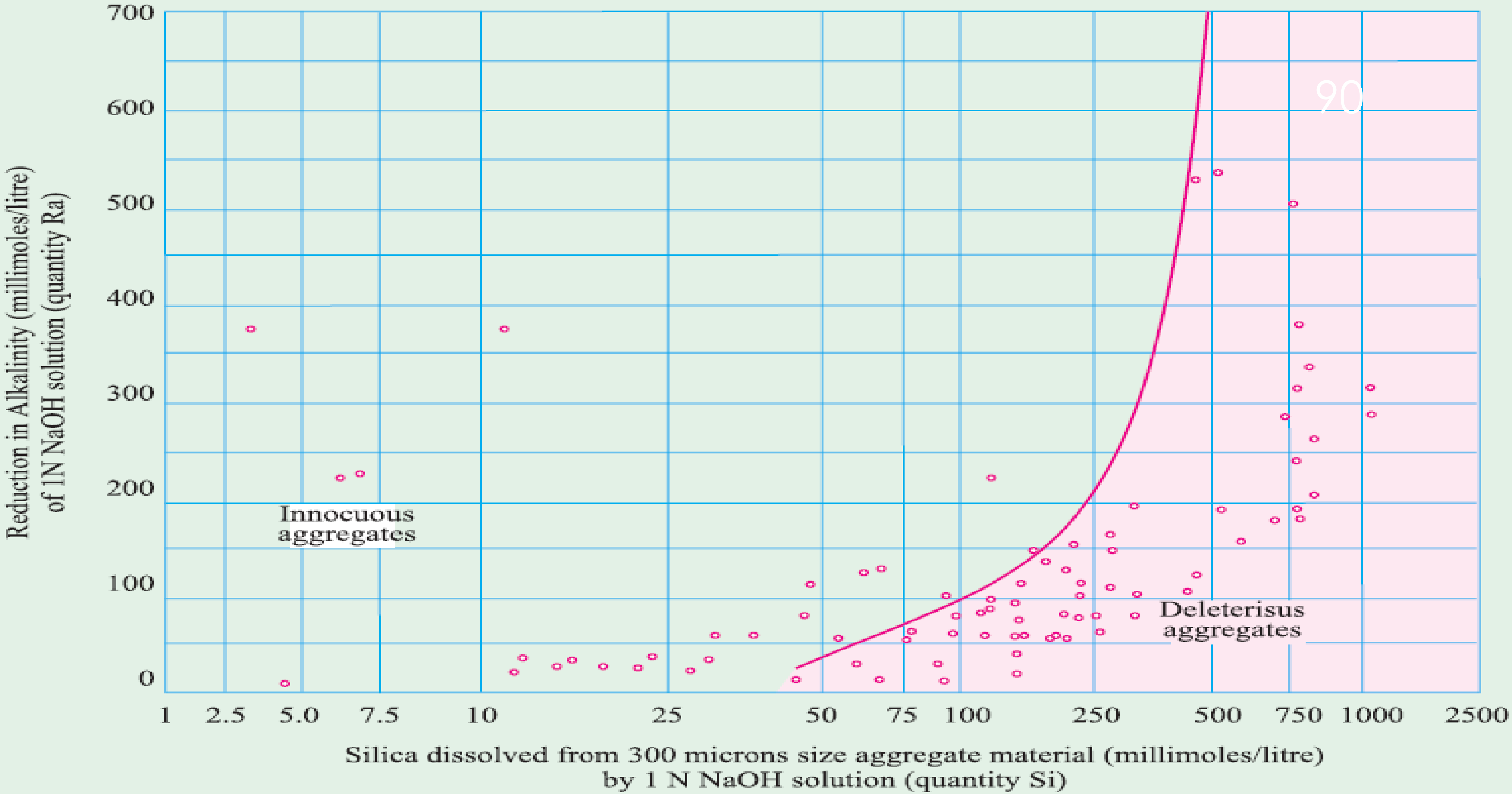


Fig. 3.3. Illustration of division between innocuous and deleterious aggregates on basis of reduction in alkalinity test.

Aggregates – Alkali Reaction

Availability of Moisture

- Progress of chemical reactions involving alkali-aggregate reaction in concrete requires the presence of water.
- It has been seen in the field and laboratory that lack of water greatly reduces this kind of deterioration.

Temperature Condition

- The ideal temperature for the promotion of alkali-aggregate reaction is in the range of 10 to 38°C.

Aggregates – Alkali Reaction

Mechanism of Deterioration of Concrete Through the Alkali-Aggregate Reaction

- The mixing water turns to be a strongly **caustic solution** due to solubility of alkalis from the cement.
- This caustic liquid attacks reactive silica to form **alkali-silica gel** of unlimited swelling type.
- The reaction proceeds more rapidly for highly reactive substances. If **continuous supply of water and correct temperature** is available, the formation of silica gel continues.
- The continuous growth of silica gel exerts **osmotic pressure** to cause **pattern cracking** particularly in thinner sections of concrete like pavements.
- The formation of pattern cracks results in subsequent **loss in strength and elasticity.**
- Alkali-aggregate reaction also accelerates other process of **deterioration of concrete due to the formation of cracks.**
- Solution of dissolved carbon dioxide, converts **calcium hydroxide to calcium carbonate with consequent increase in volume.**

Aggregates – Alkali Reaction

- Selection of non-reactive aggregates
- By the use of low alkali cement
- By the use of corrective admixtures such as pozzolanas
- By controlling the void space in concrete
- By controlling moisture condition and temperature

Aggregates – Thermal Properties

Rock and aggregate possesses three thermal properties which are significant in establishing the quality of aggregate for concrete constructions.

- Coefficient of expansion
- Specific heat
- Thermal conductivity

Aggregates – Grading

- Aggregate comprises about 55 per cent of the volume of mortar and about 85 per cent volume of mass concrete.
- Mortar contains aggregate of size of 4.75 mm and concrete contains aggregate upto a maximum size of 150 mm.
- A sample of the well graded aggregate containing minimum voids will require minimum paste to fill up the voids in the aggregates.
- Minimum paste will mean less quantity of cement and less quantity of water, which will further mean increased economy, higher strength, lower-shrinkage and greater durability
- If concrete is viewed as a two phase material, paste phase and aggregate phase, it is the paste phase
- it is the paste which is a weak link in a mass of concrete.
- The lesser the quantity of such weak material, the better will be the concrete.

Aggregates – Sieve Analysis

- Dividing a sample of aggregate into various fractions each consisting of particles of the same size.
- The sieve analysis is conducted to determine the **particle size distribution** in a sample of aggregate, which we call gradation.
- The aggregates used for making concrete are normally of the maximum size 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm, 600 micron, 300 micron and 150 micron.
- The aggregate fraction from 80 mm to 4.75 mm are termed as coarse aggregate and those fraction from 4.75 mm to 150 micron are termed as fine aggregate
- The size 4.75 mm is a common fraction appearing both in coarse aggregate and fine aggregate (C.A. and F.A.).

Aggregates – Sieve Analysis

- Grading pattern of a sample of C.A. or F.A. is assessed by sieving a sample successively through all the sieves mounted one over the other in order of size, with larger sieve on the top.
- The material retained on each sieve after shaking, represents the fraction of aggregate coarser than the sieve in question and finer than the sieve above.
- Sieving can be done either manually or mechanically.
- In the manual operation the sieve is shaken giving movements in all possible direction to give chance to all particles for passing through the sieve.
- Operation should be continued till such time that almost no particle is passing through.
- Mechanical devices are actually designed to give motion in all possible direction, and as such, it is more systematic and efficient than handsieving.
- For assessing the gradation by sieve analysis, the quantity of materials to be taken on the sieve is given Table .

Minimum weight of sample for sieve analysis

Maximum size present in substantial proportions	*Minimum weight of sample to be taken for sieving*
mm	kg
63	50
50	35
40 or 31.5	15
25	5
20 or 16	2
12.5	1
10	0.5
6.3	0.2
4.75	0.2
2.36	0.1

Aggregates – Fineness Modulus

- From the sieve analysis the particle size distribution in a sample of aggregate is found out.
- In this connection a term known as "Fineness Modulus" (F.M.) is being used. F.M. is a ready index of coarseness or fineness of the material.
- Fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate retained on each of the standard sieves ranging from 80 mm to 150 micron and dividing this sum by an arbitrary number 100. The larger the figure, the coarser is the material.
- Table shows the typical example of the sieve analysis, conducted on a sample of coarse aggregate and fine aggregate to find out the fineness modulus.

IS Sieve Size	Coarse Aggregate				Fine Aggregate			
	Weight retained weight kg	Cumulative weight retained kg	Cumulative percentage retained	Cumulative percentage passing	Weight retained gm	Cumulative weight retained gm	Cumulative percentage weight retained	Comulative percentage passing
80 mm	0	0	0	100	-	-	-	-
40 mm	0	0	0	100	-	-	-	-
20 mm	6	6	40	60	-	-	-	-
10 mm	5	11	73.3	26.7	0	0	0	100
4.75 mm	4.0	15.00	100	00	10	10	2	98
2.36 mm	-	-	100	00	50	60	12	88
1.18 mm	-	-	100	00	50	110	22	78
600 micron	-	-	100	00	95	205	41	59
300 micron	-	-	100	00	175	380	76	24
150 micron	-	-	100	00	85	465	93	7
lower than 150 micron	-	-	-	00	35	500	-	-
Total	15 kg		713.3		500 gm	—	246	
	F.M. = $\frac{7133}{100}$ = 7.133				F.M. = $\frac{246}{100}$ = 2.46			

Aggregates – Fineness Modulus

Fine sand	:	Fineness Modulus	:	2.2 - 2.6
Medium sand	:	F.M.	:	2.6 - 2.9
Coarse sand	:	F.M.	:	2.9 - 3.2

A sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete.

Aggregates – Specific Surface and Surface Index

- The surface area per unit weight of the material is termed as specific surface. This is an indirect measure of the aggregate grading.
- Specific surface increases with the reduction in the size of aggregate particle so that fine aggregate contributes very much more to the surface area than does the coarse aggregate.
- Greater surface area requires more water for lubricating the mix to give workability.
- The workability of a mix is, therefore, influenced more by finer fraction than the coarser particles in a sample of aggregates

Aggregates – Specific Surface and Surface Index

- This will not hold good for very fine particles in F.A. The every fine particles in F.A. i.e., 300 micron and 150 micron particles, being so fine, contribute more towards workability.
- Their over-riding influence in contributing to the better workability by acting like ball bearings to reduce the internal friction between coarse particles, far out-weigh the reduction in workability owing to the consumption of mixing water for wetting greater surface area.
- Murdock has suggested the use of "Surface Index" which is an empirical number related to the specific surface of the particle with more weightage given to the finer fractions.
- The total surface index (fx) of a mixture of aggregate is calculated by multiplying the percentage of material retained on its sieve by the corresponding surface index and to their sum is added a constant of 330 and the result is divided by 1000.

Sieve size within which particles lie	Surface Index for Particles within Sieve Size indicated
80-40 mm	- 2.5
40-20 mm	- 2
20-10 mm	- 1
10-4.75 mm	+ 1
4.75-2.36 mm	4
2.36-1.18 mm	7
1.18-600 micron	9
600-300 micron	9
300-150 micron	7
Smaller than 150 micron	2

Sieve size within which Particles lie	Percentage of particles within sieve size	Surface Index for particles within sieve size	Surface Index (fx)
20—10 mm	55	-1	-55
10—4.75 mm	15	1	15
4.75—2.36 mm	7	4	28
2.36—1.18 mm	7	7	49
1.18—600 micron	7	9	63
600—300 micron	7	9	63
300—150 micron	2	7	14
		Total	177
		Add constant	330
			507

Aggregates – Specific Surface and Surface Index

Surface Index (fx) =507/1000 = 0.507

- Similarly, surface index can be calculated for standard grading curve, and this value of surface index can be taken as the desirable surface index of the combined aggregate.
- x = surface index of fine aggregate
- y = surface index of coarse aggregate
- z = surface index of combined aggregate
- a = proportion of fine to coarse aggregate

$$\text{Then } a = \frac{(z-y)}{(x-z)}$$

Aggregates – Specific Surface and Surface Index

Sieve size within which particles lie	Percentage of particles within sieve size	Surface index for partcles for sieve size	Surface Index (fx)
Coarse Aggregate			
20 mm — 10 mm	65	-1	-65
10 mm — 4.75	35	1	35
		Total =	-30
		Add constant =	330
		=	300

Surface Index of Corase Aggregate = $\frac{300}{1000}$ = 0.30

Fine Aggregate			
4.75 mm — 2.36	10	4	40
2.36 mm — 1.18	20	7	140
1.18 mm — 600 micron	20	9	180
600 micron — 300 micron	30	9	270
300 micron — 150 micron	15	7	105
		Total =	735
		Add constant =	330
		=	1065

Surface Index of fine Aggregate = $\frac{1065}{1000}$ = 1.065

Let the surface index of combined aggregate required= 0.6.

x = surface index of F.A. = 1.065

y = surface index of C.A. = 0.30

z = surface index of combined aggregate = 0.60

If a = proportion of fine to coarse aggregate, $a = \frac{(z-y)}{(x-z)} = \frac{(0.60-0.30)}{(1.065-0.60)} = \frac{1}{1.55}$

Therefore, F.A. : C.A. = 1 : 1.55