UNIT- 1

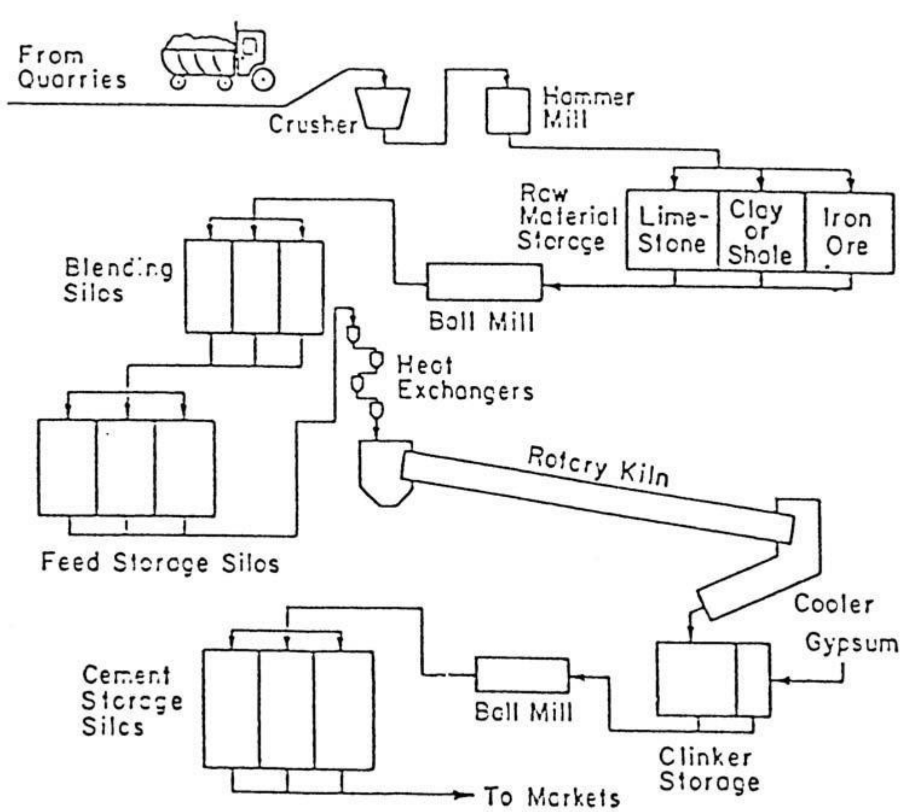
Cement, Aggregates and Admixtures

1.1 Portland Cement

Concrete is made by portland cement, water and aggregates. Portland cement is a hydraulic cement that hardens in water to form a water-resistant compound. The hydration products act as binder to hold the aggregates together to form concrete. The name portland cement comes from the fact that the colour and quality of the resulting concrete are similar to Portland stone, a kind of limestone found in England.

1.1.1 Manufacture of Portland cement

Portland cement is made by blending the appropriate mixture of limestone and clay or shale together and by heating them at 1450ºC in a rotary kiln. The sequence of operations is shown in following figure. The preliminary steps are a variety of blending and crushing operations. The raw feed must have a uniform composition and be a size fine enough so that reactions among the components can complete in the kiln. Subsequently, the burned clinker is ground with gypsum to form the familiar grey powder known as Portland cement.



The raw materials used for manufacturing Portland cement are limestone, clay and Iron ore.

a) Limestone (C_aCO_3) is mainly providing calcium in the form of calcium oxide (CaO)

$$C_aCO_3\ (1000^oC) \rightarrow CaO + CO_2$$

b) Clay is mainly providing silicates (SiO_2) together with small amounts of $Al_2O_3 + Fe_2O_3$

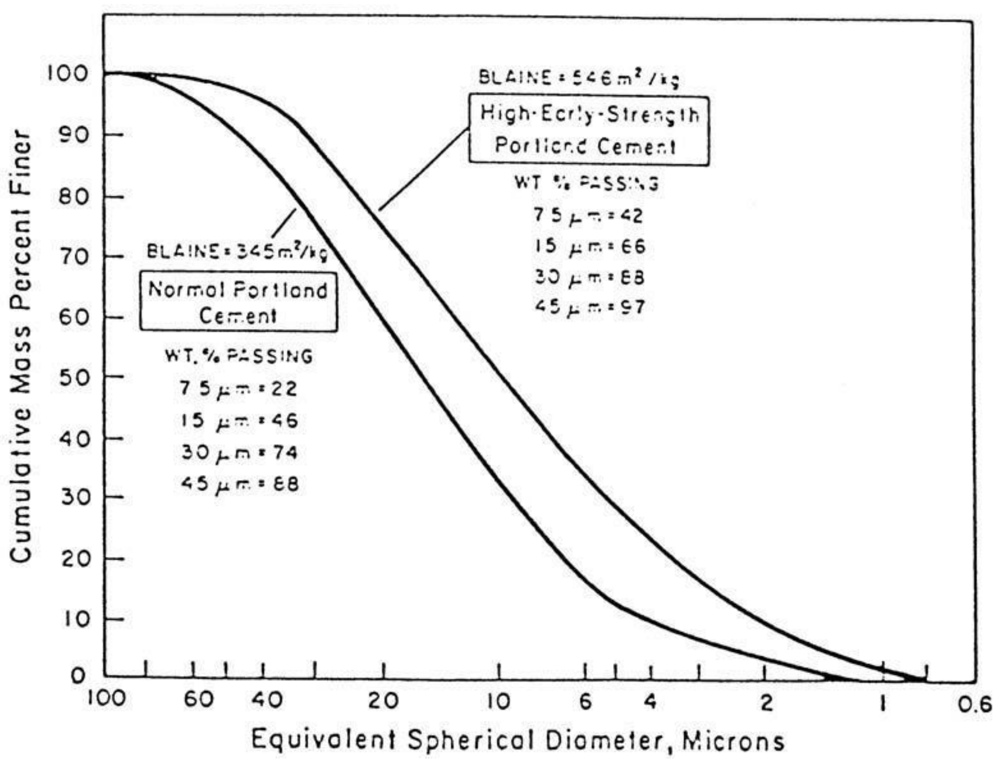
$$Clay\ (1450^oC) \rightarrow SiO_2 + Al_2O_3 + Fe_2O_3 + H_2O$$

c) Iron ore and Bauxite are providing additional aluminium and iron oxide (Fe_2O_3) which help the formation of calcium silicates at low temperature. They are incorporated into the raw mix.

Limestone		$3\ CaO^oSiO_2$
	High temperature	$2\ CaO^oSiO_2$
Clay	⟶	
	(1,450 ^oC)	$3\ CaO^oAl_2O_3$
Iron Ore, Bauxite		$4\ CaO^oAl_2O_3{}^oFe_2O_3$

d) The clinker is pulverized to small sizes (< 75 μm). 3-5% of gypsum (calcium sulphate) is added to control setting and hardening.

The majority particle size of cement is from 2 to 50 μm. A plot of typical particle size distribution is given below. (Note: "Blaine" refers to a test to measure particle size in terms of surface area/mass)



1.1.2 Chemical composition

a) Abbreviation:

$CaO = C$, $SiO_2 = S$, $Al_2O_3 = A$; $Fe_2O_3 = F$, $Ca(OH)_2 = CH$,

$H_2O = H$, $SO_3 = \bar{S}$ (sulphur trioxide)

Thus we can write 3 CaO = C_3 and 2 $CaO^oSiO_2 = C_2S$.

b) Major compounds:

Compound	Oxide composition	colour	Common name	Weight percentage
Tricalcium Silicate	C_3S	white	Alite	50%
Dicalcium Silicate	C_2S	white	Belite	25%
Tricalcium Aluminate	C_3A	white/grey	---	12%
Tetracalcium Aluminoferrite	C_4AF	black	Ferrite	8%

Since the primary constituents of Portland cement are calcium silicate, we can define Portland cement as a material which combine CaO SiO_2 in such a proportion that the resulting calcium silicate will react with water at room temperature and under normal pressure.

c) Minor components of Portland cement

The most important minor components are gypsum, MgO, and alkali sulphates.

Gypsum ($2CaSO_4{}^o2H_2O$) is an important component added to avoid flash set.

Alkalies (MgO, Na_2O, K_2O) can increase pH value up to 13.5 which is good for reinforcing steel protection. However, for some aggregates, such a high alkaline environment can cause alkali aggregate reaction problem.

1.1.3 Hydration

The setting and hardening of concrete are the result of chemical and physical processes that take place between Portland cement and water, i.e. hydration. To understand the properties and behaviour of cement and concrete some knowledge of the chemistry of hydration is necessary.

A) Hydration reactions of pure cement compounds

The chemical reactions describing the hydration of the cement are complex. One approach is to study the hydration of the individual compounds separately. This assumes that the hydration of each compound takes place independently of the others.

I. Calcium silicates

Hydration of the two calcium silicates gives similar chemical products, differing only in the amount of calcium hydroxide formed, the heat released, and reaction rate.

$2\ C_3S + 7\ H \rightarrow C_3S_2H_4 + 3\ CH\ 2\ C_2S + 5\ H \rightarrow C_3S_2H_4 + CH$

The principal hydration product is $C_3S_2H_4$, calcium silicate hydrate, or C-S-H (non-stoichiometric). This product is not a well-defined compound. The formula $C_3S_2H_4$ is only an approximate description. It has amorphous structure making up of poorly organized layers and is called glue gel binder. C-S-H is believed to be the material governing concrete strength. Another product is CH - $Ca(OH)_2$, calcium hydroxide. This product is a hexagonal crystal often forming stacks of plates. CH can bring the pH value to over 12 and it is good for corrosion protection of steel.

II. Tricalcium aluminate

Without gypsum, C_3A reacts very rapidly with water:

$C_3A + 6\ H \rightarrow C_3AH_6$

The reaction is so fast that it results in flash set, which is the immediate stiffening after mixing, making proper placing, compacting and finishing impossible.

With gypsum, the primary initial reaction of C_3A with water is :

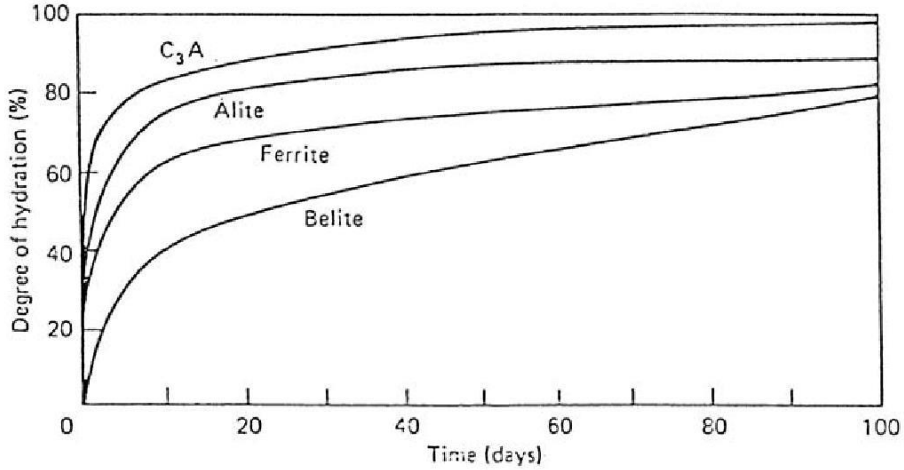
$C_3A + 3\ (C\ \bar{S}\ H_2) + 26\ H \rightarrow C_6A\ \bar{S}_3H_{32}$

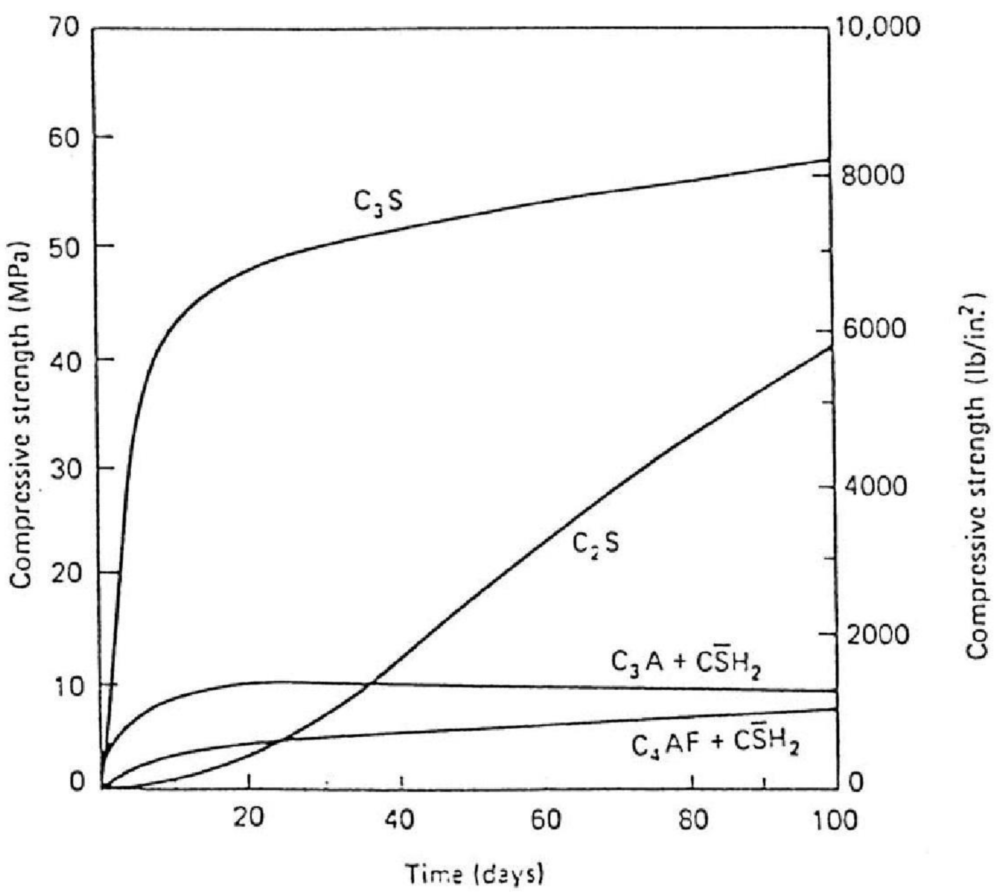
The 6-calcium aluminate trisulfate-32-hydrate is usually called ettringite. The formation of ettringite slows down the hydration of C_3A by creating a diffusion barrier around C_3A. Flash set is thus avoided. Even with gypsum, the formation of ettringite occurs faster than the hydration of the calcium silicates. It therefore contributes to the initial stiffening, setting and early strength development. In normal cement mixes, the
ettringite is not stable and will further react to form monosulphate ($C_4A\bar{S}H_{18}$).

B) Kinetics and Reactivities

The rate of hydration during the first few days is in the order of $C_3A > C_3S > C_4AF > C_2S$.

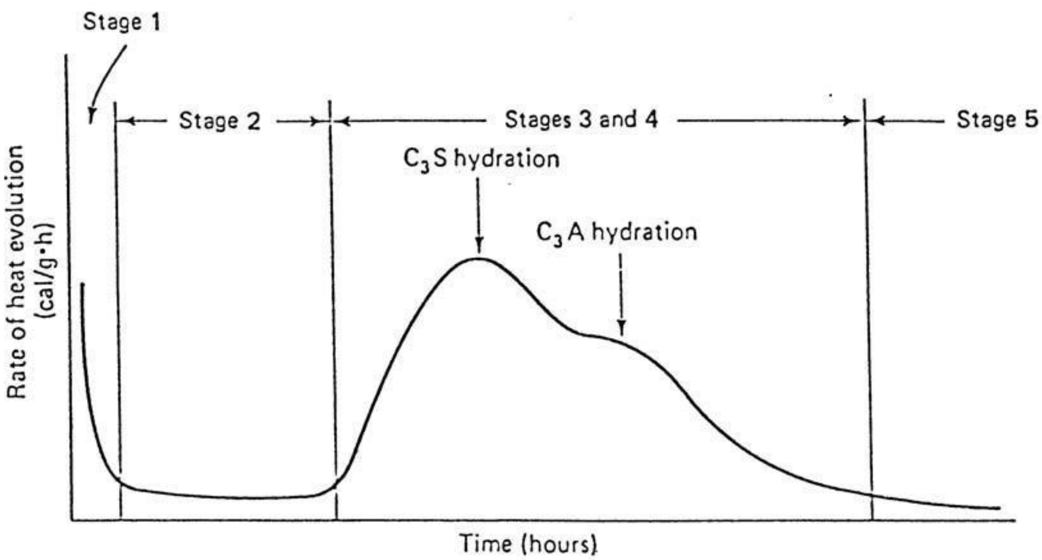
Their reactivities can be observed in the following figures.





C) Calorimetric curve of Portland cement

A typical calorimetric curve of Portland cement is shown in the following figure. The second heat peaks of both C_3S and C_3A can generally be distinguished, although their order of occurrence can be reversed.



From the figure, five stages can be easily identified. Since C_3S is a dominating component in cement, the five stages above can be explained using the reaction process of C_3S by the following table.

Reaction Stage	Kinetics of Reaction	Chemical Processes	Relevance to Concrete
1. Initial hydrolysis	Chemical control; rapid	Initial hydrolysis; dissolution of ions	-
2. Induction period	Nucleation control; slow	Continued dissolution of ions	Determines initial set
3. Acceleration	Chemical control: rapid	Initial formation of hydration products	Determines final set and rate of initial hardening
4. Deceleration	Chemical and diffusion control; slow	Continued formation of hydration products	Determines rate of early strength gain
5. Steady State	Diffusion control; slow	Slow formation of hydration products	Determines rate of later strength gain

On first contact with water, calcium ions and hydroxide ions are rapidly released from the surface of each C_3S grain; the pH values rises to over 12 within a few minutes. This hydrolysis slows down quickly but continues throughout the induction period. The induction (dormant) period is caused by the need to achieve a certain concentration of ions in solution before crystal nuclei are formed for the hydration products to grow from. At the end of dormant period, CH starts to crystallize from solution with the concomitant formation of C-S-H and the reaction of C_3S again proceeds rapidly (the third stage begin). CH crystallizes from solution, while C-S-H develops from the surface of C_3S and forms a coating covering the grain. As hydration continues, the thickness of the hydrate layer increases and forms a barrier through which water must flow to reach the unhydrated C_3S and through which ions must diffuse to reach the growing crystals. Eventually, movement through the C-S-H layer determines the rate of reaction. The process becomes diffusion controlled.

D) Setting and Hydration

Initial set of cement corresponds closely to the end of the induction period, 2-4 hours after mixing. Initial set indicates the beginning of forming of gel or beginning of solidification. It represents approximately the time at which fresh concrete can no longer be properly mixed, placed or compacted. The final set occurs 5-10 hours after mixing, within the acceleration period. It represents approximately the time after which strength develops at a significant rate.

In practice, initial and final set are determined in a rather arbitrary manner with the penetration test. While the determination of initial and the final set has engineering significance, there is no fundamental change in hydration process for these two different set conditions.

1.1.4 Types of Portland cements

According to ASTM standard, there are five basic types of Portland cement.

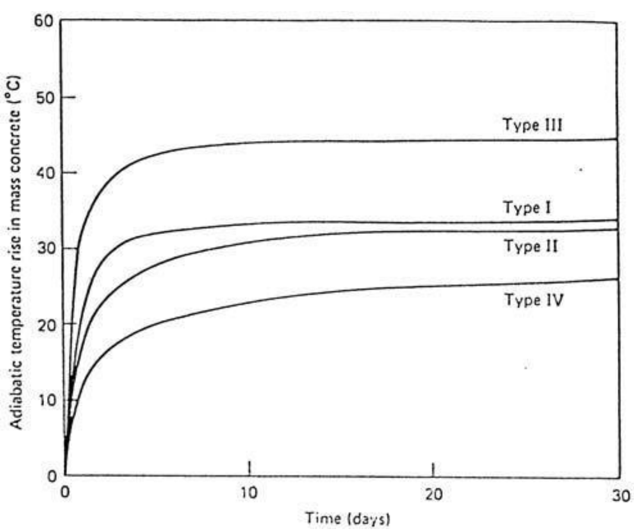
Type I Regular cement, general use, called OPC
Type II Moderate sulphate resistance, moderate heat of hydration, $C_3A < 7\%$
Type III With increased amount of C_3S, High early strength
Type IV Low heat
Type V High sulphate resistance

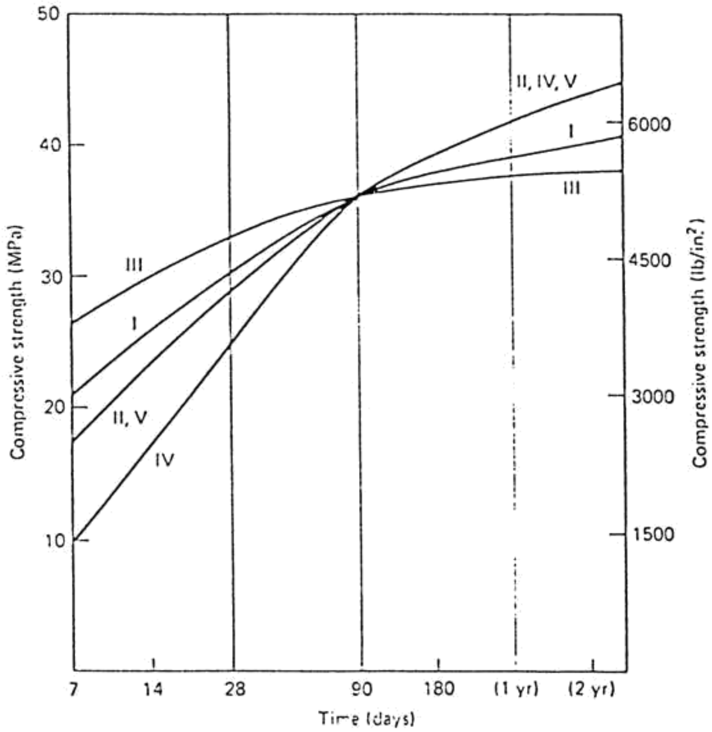
(Note: sulphates can react with $C_4A\bar{S}H_{18}$ to from an expansive product. By reducing the C_3A content, there will be less $C_4A\bar{S}H_{18}$ formed in the hardened paste)

Their typical chemical composition is given in the following table:

	I	II	III	IV	V
C_3S	50	45	60	25	40
C_2S	25	30	15	50	40
C_3A	12	7	10	5	4
C_4AF	8	12	8	12	10
$C\bar{S}H_2$	5	5	5	4	4
Fineness (Blaine, m^2/kg)	350	350	450	300	350
Compressive strength at 1 day, MPa (psi)	7 (1,000)	6 (900)	14 (2,000)	3 (450)	6 (900)
Heat of hydration (7 days, J/g)	330	250	500	210	250

From the above table, we can evaluate the behaviour of each type of cement and provide the standard in selecting different cement types. The following figures show the strength and temperature rise for the different types of cement.





These graphs provide the basic justification in selecting the cement for engineering application. For instance, for massive concrete structure, hydration heat is an important consideration because excessive temperature increase (to above 50-60^{o}C) will cause expansion and cracking. Hence, type IV cement should be the first candidate and Type III should not be used. For a foundation exposed to groundwater with high concentration of sulphates, high sulphate resistance is needed. Thus, type V should be selected. If high early strength is needed, type III will be the best choice. But, generally, type I is the most popular cement used for civil engineering.

1.1.5 Porosity of hardened cement paste and the role of water

Knowledge of porosity is very useful since porosity has a strong influence on strength and durability. In hardened cement paste, there are several types of porosity, trapped or entrained air (0.1 to several mm in size), capillary pores (0.01 to a few microns) existing in the space between hydration products, and gel pores (several nanometres or below) within the layered structure of the C-S-H. The capillary pores have a large effect on the strength and permeability of the hardened paste itself. Of course, the presence of air bubbles can also affect strength.

From experiments, the porosity within the gel for all normally hydrated cements is the same, with a value of 0.26. The total volume of hydration products (cement gel) is given by

$$V_g = 0.68\alpha \text{ cm}^3\text{/g of original cement}$$

Where, α represents the degree of hydration.

The capillary porosity can be calculated by

$$P_c = (w/c) - 0.36\alpha \quad \text{cm}^3\text{/g of original cement}$$

Where, *w* is the original weight of water and *c* is the weight of cement and w/c is the water-cement ratio. It can be seen that with increase of w/c, the capillary pores increase.

The gel / space ratio (X) is defined as

$$X = \frac{\text{volume of gel (including gel pores)}}{\text{volume of gel + volume of capillary pores}}$$

$$= \frac{0.68\alpha}{0.32\alpha + w/c}$$

The minimum w/c ratio for complete hydration is usually assumed to be 0.36 to 0.42. It should be indicated that complete hydration is not essential to attain a high ultimate strength. For pastes of low w/c ratio, residual unhydrated cement will remain.

To satisfy workability requirements, the water added in the mix is usually more than that needed for the chemical reaction. Part of the water is used up in the chemical reaction. The remaining is either held by the C -S-H gel or stored in the capillary pore. Most capillary water is free water (far away from the pore surface). On drying, they will be removed, but the loss of free water has little effect on concrete. Loss of adsorbed water on surfaces and those in the gel will, however, lead to shrinkage. Movement of adsorbed and gel water under load is a cause of creeping in concrete

1.1.6 Basic tests of Portland cement

a) Fineness (= surface area / weight): This test determines the average size of cement grains. The typical value of fineness is 350 m^2 / kg.
Fineness controls the rate and completeness of hydration. The finer a cement, the more rapidly it reacts, the higher the rate of heat evolution and the higher the early strength.

	I	III	V
Fineness (m^2 / kg)	350	450	350
f'_c 1-day (MPa)	6.9	13.8	6.2

b) Normal consistency test: This test is to determine the water required to achieve a desired plasticity state (called normal consistency) of cement paste. It is obtained with the Vicat apparatus by measuring the penetration of a loaded needle.

c) Time of setting: This test is to determine the time required for cement paste to harden. Initial set cannot be too early due to the requirement of mixing, conveying, placing and casting. Final set cannot be too late owing to the requirement of strength development. Time of setting is measured by Vicat apparatus. Initial setting time is defined as the time at which the needle penetrates 25 mm into cement paste. Final setting time is the time at which the needle does not sink visibly into the cement paste.

d) Soundness: Unsoundness in cement paste refers to excessive volume change after setting. Unsoundness in cement is caused by the slow hydration of MgO or free lime.
Their reactions are $MgO + H_2O = Mg(OH)_2$ and $CaO + H_2O = Ca(OH)_2$. Another factor that can cause unsoundness is the delayed formation of ettringite after cement and concrete have hardened. The pressure from crystal growth will lead to cracking and damage. The soundness of the cement must be tested by accelerated methods. An example is the Le Chatelier test (BS 4550). This test is to measure the potential for volumetric change of cement paste. Another method is called Autoclave Expansion test (ASTM C151) which use an autoclave to increase the temperature to accelerate the process.

e) Strength: The strength of cement is measured on mortar specimens made of cement and standard sand (silica). Compression test is carried out on a 2" cube with S/C ratio of 2.75:1 and w/c ratio of 0.485 for Portland cements. The specimens are tested wet, using a loading rate at which the specimen will fail in 20 to 80 s. The direct tensile test is carried out on a specimen shaped like a dumbbell. The load is applied through specifically designed grips. Flexural strength is measured on a 40 x 40 x 160 mm prism beam test under a centre-point bending.

f) Heat of hydration test. (BS 4550: Part 3: Section 3.8 and ASTM C186). Cement hydration is a heat releasing process. The heat of hydration is usually defined as the amount of heat evolved during the setting and hardening at a given temperature measured in J/g. The experiment is called heat of solution method. Basically, the heat of solution of dry cement is compared to the heats of solution of separate portion of the cement that have been partially hydrated for 7 and 28 days. The heat of hydration is then the difference between the heats of solution of dry and partially hydrated cements for the appropriate hydration period. This test is usually done on Type II and IV cements only, because they are used when heat of hydration is an important concern.
Excessive heating may lead to cracking in massive concrete construction.

g) Other experiments. Including sulphate expansion and air content of mortar.

h) Cement S. G and U. W.: The S.G. for most types of cements is 3.15, and UW is 1000-1600 kg/m^3.

1.2 Aggregates

Aggregates are defined as inert, granular, and inorganic materials that normally consist of stone or stone-like solids. Aggregates can be used alone (in road bases and various types of fill) or can be used with cementing materials (such as Portland cement or asphalt cement) to form composite materials or concrete. The most popular use of aggregates is to form Portland cement concrete. Approximately three-fourths of the volume of Portland cement concrete is occupied by aggregate. It is inevitable that a constituent occupying such a large percentage of the mass should have an important effect on the properties of both the fresh and hardened products. As another important application, aggregates are used in asphalt cement concrete in which they occupy 90% or more of the total volume. Once again, aggregates can largely influence the composite properties due to its large volume fraction.

1.2.1 Classification of Aggregate

Aggregates can be divided into several categories according to different criteria.

a) **In accordance with size:**

Coarse aggregate: Aggregates predominately retained on the No. 4 (4.75 mm) sieve. For mass concrete, the maximum size can be as large as 150 mm.

Fine aggregate (sand): Aggregates passing No.4 (4.75 mm) sieve and predominately retained on the No. 200 (75 μm) sieve.

b) **In accordance with sources:**

Natural aggregates: This kind of aggregate is taken from natural deposits without changing their nature during the process of production such as crushing and grinding. Some examples in this category are sand, crushed limestone, and gravel.

Manufactured (synthetic) aggregates: This is a kind of man-made materials produced as a main product or an industrial by-product. Some examples are blast furnace slag, lightweight aggregate (e.g. expanded perlite), and heavy weight aggregates (e.g. iron ore or crushed steel).

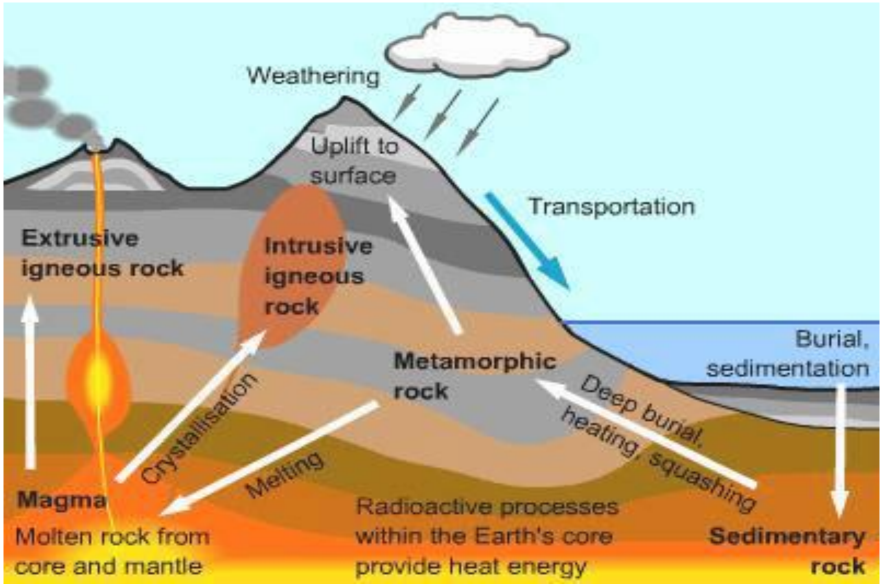
c) In accordance with unit weight:

Light weight aggregate: The unit weight of aggregate is less than 1120kg/m^3. The corresponding concrete has a bulk density less than 1800kg/m^3. (cinder, blast-furnace slag, volcanic pumice).

Normal weight aggregate: The aggregate has unit weight of 1520-1680kg/m^3. The concrete made with this type of aggregate has a bulk density of 2300-2400 kg/m^3.

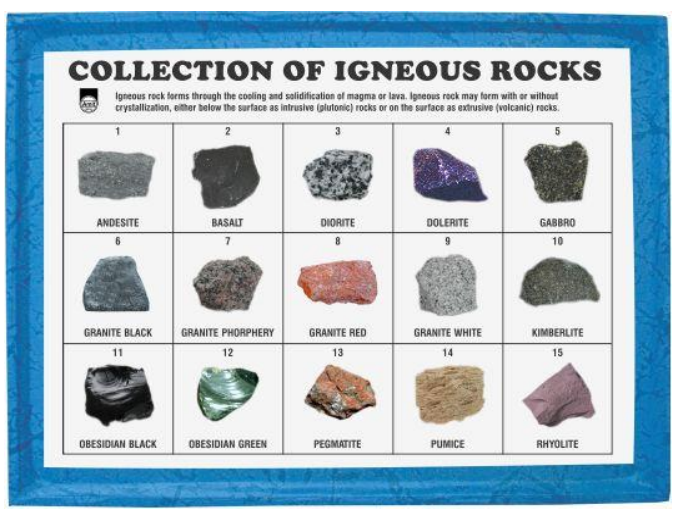
Heavy weight aggregate: The unit weight is greater than 2100 kg/m^3. The bulk density of the corresponding concrete is greater than 3200 kg/m^3. A typical example is magnesite limonite, a heavy iron ore. Heavy weight concrete is used in special structures such as radiation shields.

d)In accordance with origin:



Igneous rock Aggregate:

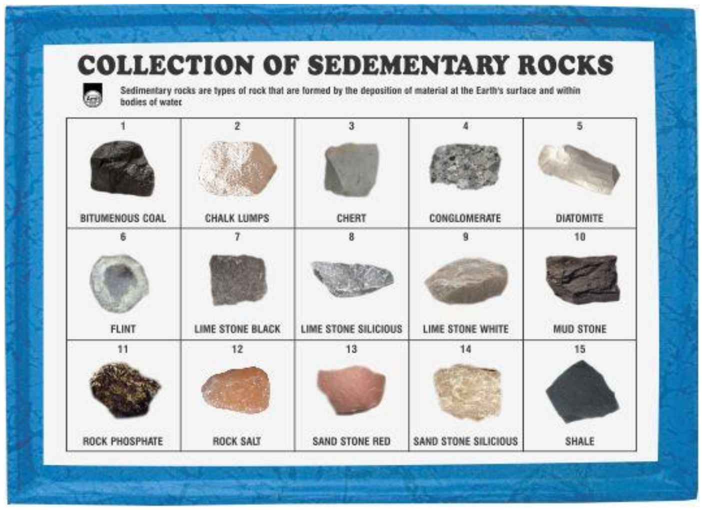
- Hard, tough and dense.
- Massive structures: crystalline, glassy or both depending on the rate at which they are cooled during formation.
- Acidic or basic: percentage of silica content.
- Light or dark coloured.
- Chemically active: react with alkalis.



Sedimentary rock Aggregates:

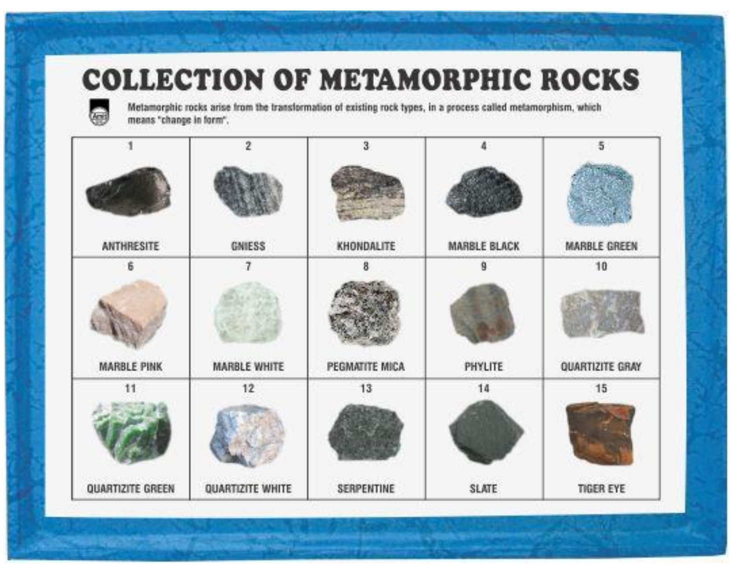
- Igneous or metamorphic rocks subjected to weathering agencies.

- Decompose, fragmentise, transport and deposit deep beneath ocean bed are cemented together.
- Can be flaky.
- Range from soft-hard, porous-dense, light-heavy.
- Suitability decided by: degree of consolidation, type of cementation, thickness of layer and contamination.



Metamorphic rock Aggregate:

- Rocks subjected to high temperature and pressure.
- Economic factor into consideration.
- Least overall expense.



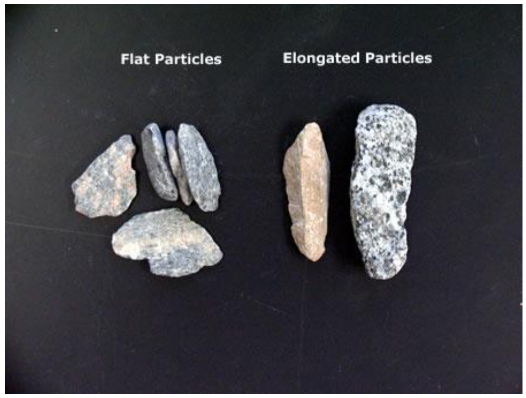
e) **Particle shape:**

- **Rounded Aggregate:** Good workability, low water demand, poor bond

- **Angular Aggregate:** Increased water demand, good bond

- **Flaky Aggregate:** Aggregate stacks give workability problems

- **Elongated Aggregate:** May lack cohesion and require increased fines



- **Irregular Aggregate:** Fair workability, low water demand. Irregular shape with rounded edges.

- **Angularity number (IS:2386-Part 1-1963):**
  - The concept of angularity number was suggested by Shergold.
  - It gives a qualitative representation of shape of aggregate.
  - In angularity number test, a quantity of single sized aggregate is filled into metal cylinder of 3 litres capacity. Then the aggregate is compacted in a standard manner and the percentage of void found out.
  - If the void content of the aggregate is 33% the angularity of such aggregate is considered 0.
  - If the void is 44%, the angularity number of such aggregate is considered 11.

- **Importance of Angularity Number:**

- The normal aggregate which are suitable for making concrete may have angularity number anything from 0 to 11.
- Angularity number 0 represents the most practicable rounded aggregate
- Angularity number 11 indicates the most angular aggregate that could be used for making concrete.

- **Angularity Index:**

  - Suggested by Murdock for expressing shape of aggregate.
  - Angularity index = fA = $\frac{3\,fH}{20}$ + 1.0

    Where, fH is the angularity number.

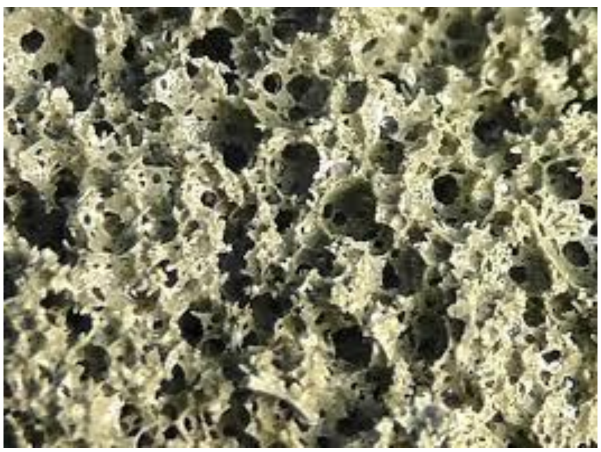
f) Texture:

- It depends on hardness, grain size, pore structure, structure of the rock and degree to which forces acting on the particle surface have smoothened 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.

Glassy textured aggregate

Smooth textured aggregate

Granular textured aggregate **Crystalline textured aggregate**



Porous textured aggregate

1.2.2 Strength of Aggregates

- When the cement paste is of good quality & its bond with the aggregate is satisfactory, then the mechanical properties of rock or aggregate will influence the strength of concrete.
- The test for strength of aggregate is required to be made in the following situations:
  i. For production of high strength & ultra -high strength concrete.
  ii. When contemplating to use aggregates manufacture from weathered rocks.
  iii. Aggregates manufactured by industrial process.

1.3 Admixtures

Admixtures are those ingredients in concrete other than portland cement, water, and aggregates that are added to the mixture immediately before or during mixing.

1.3.1 Admixtures can be classified by function as follows:

1. Air-entraining admixtures
2. Water-reducing admixtures
3. Plasticizers
4. Accelerating admixtures
5. Retarding admixtures
6. Hydration-control admixtures
7. Corrosion inhibitors
8. Shrinkage reducers
9. Alkali-silica reactivity inhibitors
10. Colouring admixtures
11. Miscellaneous admixtures such as workability, bonding, dampproofing, permeability reducing, grouting, gas forming, anti-washout, foaming, and pumping admixtures.

Concrete should be workable, finishable, strong, durable, watertight, and wear resistant. These qualities can often be obtained easily and economically by the selection of suitable materials rather than by resorting to admixtures (except air-entraining admixtures when needed).

1.3.2 The major reasons for using admixtures

1. To reduce the cost of concrete construction
2. To achieve certain properties in concrete more effectively than by other means
3. To maintain the quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather conditions
4. To overcome certain emergencies during concreting operations

1.3.4 Classification of admixtures

Type of admixture	Desired effect	Material
Accelerators (ASTM C 494 and AASHTO M 194, Type C)	Accelerate setting and early-strength development	Calcium chloride (ASTM D 98 and AASHTO M 144) Triethanolamine, sodium thiocyanate, calcium formate, calcium nitrite, calcium nitrate
Air detrainers	Decrease air content	Tributyl phosphate, dibutyl phthalate, octyl alcohol, water-insoluble esters of carbonic and boric acid, silicones
Air-entraining admixtures (ASTM C 260 and AASHTO M 154)	Improve durability in freeze-thaw, deicer, sulfate, and alkali-reactive environments Improve workability	Salts of wood resins (Vinsol resin), some synthetic detergents, salts of sulfonated lignin, salts of petroleum acids, salts of proteinaceous material, fatty and resinous acids and their salts, alkylbenzene sulfonates, salts of sulfonated hydrocarbons
Alkali-aggregate reactivity inhibitors	Reduce alkali-aggregate reactivity expansion	Barium salts, lithium nitrate, lithium carbonate, lithium hydroxide
Antiwashout admixtures	Cohesive concrete for underwater placements	Cellulose, acrylic polymer
Bonding admixtures	Increase bond strength	Polyvinyl chloride, polyvinyl acetate, acrylics, butadiene-styrene copolymers
Coloring admixtures (ASTM C 979)	Colored concrete	Modified carbon black, iron oxide, phthalocyanine, umber, chromium oxide, titanium oxide, cobalt blue
Corrosion inhibitors	Reduce steel corrosion activity in a chloride-laden environment	Calcium nitrite, sodium nitrite, sodium benzoate, certain phosphates or fluosilicates, fluoaluminates, ester amines
Dampproofing admixtures	Retard moisture penetration into dry concrete	Soaps of calcium or ammonium stearate or oleate Butyl stearate Petroleum products
Foaming agents	Produce lightweight, foamed concrete with low density	Cationic and anionic surfactants Hydrolized protein
Fungicides, germicides, and insecticides	Inhibit or control bacterial and fungal growth	Polyhalogenated phenols Dieldrin emulsions Copper compounds
Gas formers	Cause expansion before setting	Aluminum powder
Grouting admixtures	Adjust grout properties for specific applications	See Air-entraining admixtures, Accelerators, Retarders, and Water reducers
Hydration control admixtures	Suspend and reactivate cement hydration with stabilizer and activator	Carboxylic acids Phosphorus-containing organic acid salts
Permeability reducers	Decrease permeability	Latex Calcium stearate
Pumping aids	Improve pumpability	Organic and synthetic polymers Organic flocculents Organic emulsions of paraffin, coal tar, asphalt, acrylics Bentonite and pyrogenic silicas Hydrated lime (ASTM C 141)
Retarders (ASTM C 494 and AASHTO M 194, Type B)	Retard setting time	Lignin Borax Sugars Tartaric acid and salts
Shrinkage reducers	Reduce drying shrinkage	Polyoxyalkylene alkyl ether Propylene glycol
Superplasticizers* (ASTM C 1017, Type 1)	Increase flowability of concrete Reduce water-cement ratio	Sulfonated melamine formaldehyde condensates Sulfonated naphthalene formaldehyde condensates Lignosulfonates Polycarboxylates

Type of admixture	Desired effect	Material
Superplasticizer* and retarder (ASTM C 1017, Type 2)	Increase flowability with retarded set Reduce water–cement ratio	See superplasticizers and also water reducers
Water reducer (ASTM C 494 and AASHTO M 194, Type A)	Reduce water content at least 5%	Lignosulfonates Hydroxylated carboxylic acids Carbohydrates (Also tend to retard set so accelerator is often added)
Water reducer and accelerator (ASTM C 494 and AASHTO M 194, Type E)	Reduce water content (minimum 5%) and accelerate set	See water reducer, Type A (accelerator is added)
Water reducer and retarder (ASTM C 494 and AASHTO M 194, Type D)	Reduce water content (minimum 5%) and retard set	See water reducer, Type A (retarder is added)
Water reducer—high range (ASTM C 494 and AASHTO M 194, Type F)	Reduce water content (minimum 12%)	See superplasticizers
Water reducer—high range—and retarder (ASTM C 494 and AASHTO M 194, Type G)	Reduce water content (minimum 12%) and retard set	See superplasticizers and also water reducers
Water reducer—mid range	Reduce water content (between 6 and 12%) without retarding	Lignosulfonates Polycarboxylates

* Superplasticizers are also referred to as high-range water reducers or plasticizers. These admixtures often meet both ASTM C 494 (AASHTO M 194) and ASTM C 1017 specifications.

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \end{bmatrix}$$