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Civil Eng. Dept
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Concrete Technology

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تكنولوجيا الخرسانة

2

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Chapter One

Portland Cement

Cement: is a material with adhesive cohesive properties which make it capable of bonding minerals fragments into a compact whole.

For constructional purposes, the meaning of the term "cement" is restricted to the bonding materials used with stones, sand, bricks, building stones, etc.

The cements of interest in the making of concrete have the property of setting and hardening under water by virtue of a chemical reaction with it and are, therefore, called hydraulic cement.

The name "Portland cement" given or d in England.

Manufacture of Portland cement

Raw materials

- Calcareous material – such as limestone or chalk, as a source of lime (CaO).
- Clayey material – such as clay or shale (soft clayey stones), as a source of silica and alumina.

Methods of cement manufacturing

- 1- **Wet process:** grinding and mixing of the raw materials in the existence of water.
- 2- **Dry process** : grinding and mixing of the raw materials in their dry state.

The process to be chosen, depend on the nature of the used raw materials.

Wet process – the percentage of the moisture in the raw materials is high.

Dry process –

- The raw materials is so hard (solid) that they do not disintegrate by water
- Cold countries, because the water might freeze in the mixture
- Shortage of the water needed for mixing process.

Wet process

When chalk is used, it is finely broken up and dispersed in water in a wash mill. **The clay** is also broken up and mixed with water, usually in a similar wash mill. The two mixtures are now pumped so as to mix in predetermined proportions and pass through a series of screens. The resulting – cement slurry – flows into storage tanks.

When limestone is used, it has to be blasted, then crushed, usually in two progressively smaller crushers (initial and secondary crushers), and then fed into a ball mill with the clay dispersed in water. The resultant slurry is pumped into storage tanks. From here onwards, the process is the same regardless of the original nature of the raw materials.

The slurry is a liquid of creamy consistency, with water content of between 35 and 50%, and only a small fraction of material – about 2% - larger than a 90 μm (sieve No. 170).

The slurry mix mechanically in the storage tanks, and the sedimentation of the suspended solids being prevented by bubbling by tanks. The slurry analyze chemically to check the achievement of the required chemical composition, and if necessary changing the mix constituents to attain the required chemical composition.

Finally, the slurry with the desired lime content passes into the **rotary kiln**. This is a large, refractory-lined steel cylinder, up to 8 m in diameter, sometimes as long as 230 m, which is slightly inclined to the horizontal.

The slurry is fed in at the upper end while pulverized coal (oil or natural gas also might be used as a fuel) is blown in by an air blast at the lower end of the kiln, where the temperature reaches about 1450°C. The slurry, in its movement, lime, silica and alumina recombine. The mass then fuses into balls, 3 to 25 mm in diameter, **known as clinker**. The clinker drops into coolers.

Dry process

The raw materials are crushed and fed in the correct proportions into a grinding mill, where they are dried and reduced in size to a fine powder. The dry powder, **called raw meal**, is then pumped to a blending silo, and final adjustment is now made in the proportions of the materials required for the manufacture of cement. To obtain a uniform mixture, the raw meal is blended in the silo, usually by means of compressed air.

The blended meal is sieved and fed into a rotating dish called a **granulator**, water weighing about 12% of the meal being added at the same time. In this manner, hard pellets about 15 mm in diameter are formed.

The pellets are baked hard in a pre-heating grate by means of hot gases from the kiln. The pellets then enter the kiln, and subsequent operations are the same as in the wet process of manufacture.

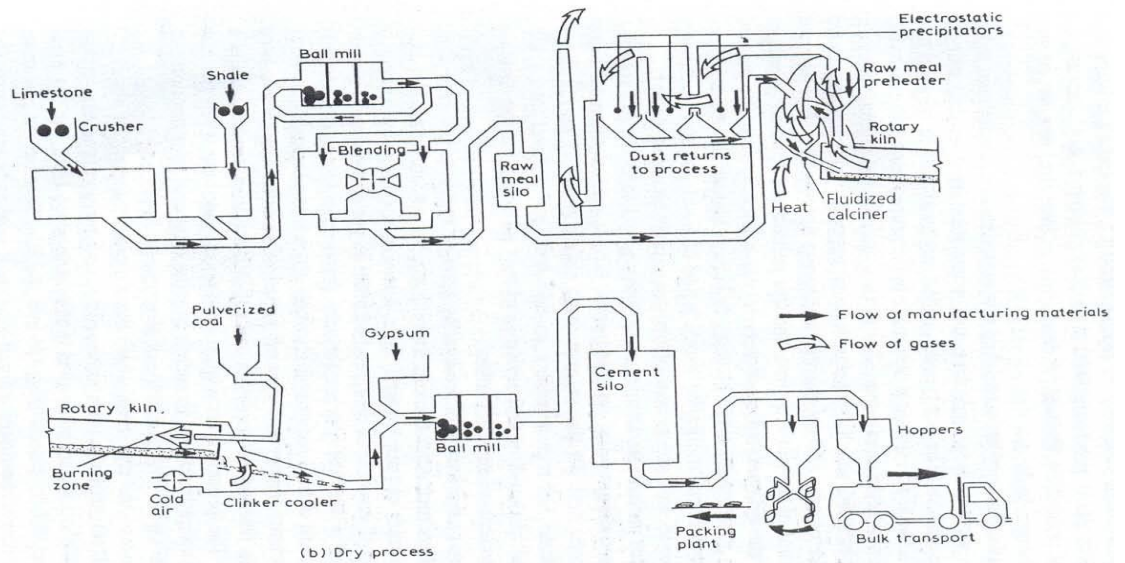
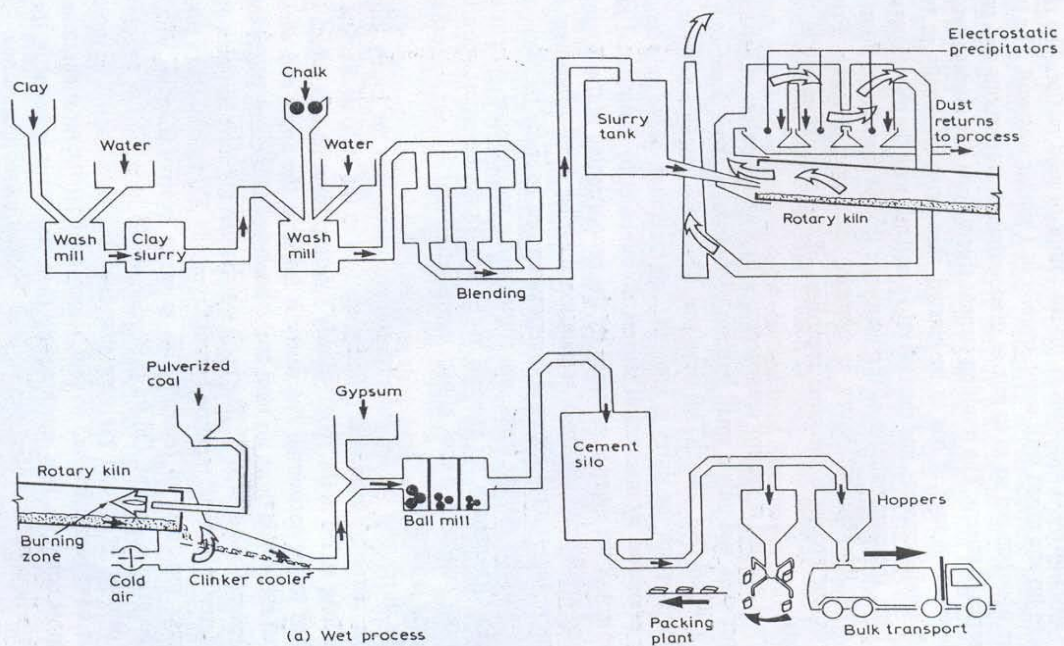


Fig. 1.1 Diagrammatic representation of: (a) the wet process and (b) the dry process of manufacture of cement



Grinding of the clinker

The cool clinker (produced by wet or dry process), which is characteristically black and hard, is **interground with gypsum** $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ in order to prevent **flash setting** of the cement, and to facilitate the grinding process. The grinding is done. It is passed through a separator, fine particles being removed to the storage silo by an air current, while the coarser particles are passed through the mill once again.

Comparison between wet and dry process:

Wet process	Dry process
1- Moisture content of the slurry is 35-50%	1- Moisture content of the pellets is 12%
2- Size of the kiln needed to manufacture the cement is bigger	2- Size of the kiln needed to manufacture the cement is smaller
3- The amount of heat required is higher, so the required fuel amount is higher	3- The amount of heat required is lower, so the required fuel amount is lower
4- Less economically	4- More economically
5- The raw materials can be mix easily, so a better homogeneous material can be obtained	5- Difficult to control the mixing of raw materials process, so it is difficult to obtain homogeneous material
6- The machinery and equipment do not need much maintenance	6- The machinery and equipment need more maintenance

Chemical composition of Portland cement

The raw materials used in the manufacture of Portland cement consist mainly of lime, silica, alumina and iron oxide. These compounds interact with one another in the kiln to form a series of more complex products and, apart from a small residue of uncombined lime which has not had sufficient time to react, a state of chemical equilibrium is reached. The resultant of firing is the clinker.

Four compounds are usually regarded as the major constituents of cement:

- Tricalcium silicate $3\text{CaO} \cdot \text{SiO}_2 - (\text{C}_3\text{S})$
- Dicalcium silicate $2\text{CaO} \cdot \text{SiO}_2 - (\text{C}_2\text{S})$
- Tricalcium aluminate $3\text{CaO} \cdot \text{Al}_2\text{O}_3 - (\text{C}_3\text{A})$
- Tetracalcium aluminoferrite $4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3 - (\text{C}_4\text{AF})$ Where

each oxide symbol with one letter:

$\text{CaO} - \text{C}$ $\text{SiO}_2 - \text{S}$

$\text{Al}_2\text{O}_3 - \text{A}$ $\text{Fe}_2\text{O}_3 - \text{F}$

$\text{H}_2\text{O} - \text{H}$

The rate of cooling affect the degree of crystallization and the amount of amorphous material present in the cooled clinker. The properties of this amorphous material, known as glass, differ considerably from those The percentage of the main composition of cement can be calculated according to the **Bogue equations**, based on the assumption that the reactions reached the chemical equilibrium state

$$\text{C}_3\text{S} = 4.07 (\text{CaO}) - 7.6 (\text{SiO}_2) - 6.72 (\text{Al}_2\text{O}_3) - 1.43 (\text{Fe}_2\text{O}_3) - 2.85 (\text{SO}_3) \quad \text{C}_2\text{S} = 2.87(\text{SiO}_2) - 0.754 (\text{C}_3\text{S})$$

$$\text{C}_3\text{A} = 2.65 (\text{Al}_2\text{O}_3) - 1.69 (\text{Fe}_2\text{O}_3) \quad \text{C}_4\text{AF} = 3.04 (\text{Fe}_2\text{O}_3)$$

Where, the terms in brackets represent the percentage of the given oxide in the total mass of cement. Recently, these compositions are determined by **x-ray** diffraction.

On cooling below 1250°C , C_3S decomposes slowly **but**, if cooling is not too slow, C_3S remains unchanged and is relatively stable at ordinary temperatures.

C₃S which is normally present in the largest amount, occurs as small equidimensional grains.

C₂S is known to have three forms: α - **C₂S**, which exists at high temperatures, inverts to the β -form at about 1450°C. β -**C₂S** undergoes further inversion to γ -**C₂S** at about 670°C but, at the rates of cooling of commercial cements, β -**C₂S** is preserved in the clinker.

Usually, silicates in the cement are not pure. It contains second convenient simplification.

Minor compounds

In addition to the main compounds mentioned above, there exist minor compounds, such as **MgO**, **TiO₂**, **Mn₂O₃**, **K₂O** and **Na₂O**. Two of the minor compounds are of particular interest: **K₂O** and **Na₂O**, known as the **alkalis** (about 0.4-1.3% by weight of cement). They have been found to react with the reactive silica found in some aggregates, the products of the reaction causing increase in volume leading to disintegration of the concrete. The increase in the alkalis percentage has been observed to affect the setting time and the rate of the gain of strength of cement.

SO₃ form low percentage of cement weight. **SO₃ comes from** the gypsum added (2-6% by weight) during grinding of the clinker, and from the impurities in the raw materials, also from the fuel used through firing process.

Iraqi specification no. 5 limited max. **SO₃** by 2.5% when **C₃A** \leq 7%, and by 3% when **C₃A** $>$ 7%.

MgO, present in the cement by 1-4%, which comes from the magnesia compounds present in the raw materials. Iraqi specification no. 5 limited max. **MgO** by 5%, to control the expansion resulted from the hydration of this compound in the hardened concrete. When the magnesia is in amorphous form, it has no harmful effect on the concrete.

Other minor compounds such as TiO_2 , Mn_2O_3 , P_2O_5 represent $< 1\%$, and they have little importance.

Usual Composition Limits of Portland Cement

Oxide	Content, %
CaO	60-67
SiO_2	17-25
Al_2O_3	3-8
Fe_2O_3	0.5-6
MgO	0.5-4
Alkalis (as Na_2O)	0.3-1.2
SO_3	2.0-3.5

Typical compound composition in ordinary Portland cement

Compound	Content, %
C_3S	54
C_2S	17
C_3A	11
C_4AF	9

Loss on Ignition (L.O.I)

It is the loss of the cement sample weight when **at 1000°C** . It shows the extent of carbonation and hydration of free lime and free magnesia due to the exposure of cement to the atmosphere. Also, part of the loss in weight comes from losing water from the gypsum composition. The maximum loss on ignition permitted by Iraqi specification no. 5 is 4% by weight.

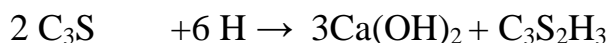
Insoluble residue

It is that part of cement sample that is insoluble in HCl. It comes from the unreacted silica, to form soluble cement compounds diluting in this acid, largely arising from impurities in gypsum. The maximum insoluble residue permitted by Iraqi specification no. 5 is 1.5% by weight.

Hydration of cement

It is the reaction (series of chemical reactions) of cement with water to form the binding material. In other words, in the presence of water are two ways in which compounds of the type present in cement can react with water. In the **first**, a direct addition of some molecules of water takes place, this being a **true reaction of hydration**. The **second type** of reaction with water is **hydrolysis**, in which its nature can be illustrated using the C_3S hydration equation

$3CaO.SiO_2 + H_2O \rightarrow Ca(OH)_2 + xCaO.ySiO_2.aq.$ (calcium silicate hydrate)



The reaction of C_3S with water continues even when the solution is saturated with lime and the resulted amounts of lime precipitate in crystals form $Ca(OH)_2$.

Calcium silicate hydrate → remains stable when it is in contact with the solution saturated with lime.

Calcium silicate hydrate → hydrolyzed when being in water – some of lime form, and the process continues until the water saturate with lime.

If the calcium silicate hydrate remains in contact with water → it will leave the hardened compound only as hydrated silica due to the hydrolysis of all of the lime.

The rates of the chemical reactions of the main compounds are different:

Aluminates - React with the water in the beginning

- Affect the route of the chemical reactions at early periods of hydration.

Silicates – Affect the later stage reactions.

The main hydrates of the hydration process are:

- **Calcium silicates hydrate**, including hydrated products of C_3S (not pure) named as **Alite**, and C_2S (not pure) named as **Belite**.
- **Tricalcium aluminate hydrate**
- **C_4AF** hydrates to tricalcium aluminate hydrate and calcium ferrite $CaO.Fe_2O_3$ in amorphous form.

Since calcium silicates (C_3S and C_2S) – are the main cement compounds (occupies about 75% of cement weight) – they are responsible for the final strength of the hardened cement paste.

With time:

- The rate of hydration decreases continuously.
- The size of unhydrated cement particles decrease.

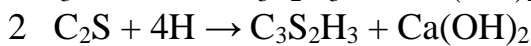
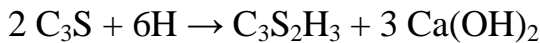
For instance, after 28 days in contact with water, grains of cement have been found to have hydrated to a depth of only 4 μm , and 8 μm after a year.

This is due to:

- 1) Accumulation of hydration products around the unhydrated of the amount of cement due to reaction.

The progress of hydration of cement can be determined by different means:

- The measurement of the amount of Ca(OH)_2 in the paste resulted from the hydration of the silicates.



- The heat evolved by hydration.
- The specific gravity of the paste.
- The amount of chemically combined water.
- The amount of unhydrated cement present (using X-ray quantitative analysis).
- Also indirectly from the strength of the hydrated paste.

Tricalcium aluminate hydrate and the action of gypsum:

The amount of C_3A present in most cements is comparatively small but its behavior and structural relationship with the other phases in cement make it of interest. The tricalcium aluminate hydrate forms a prismatic dark interstitial material in the form of flat plates individually surrounded by the calcium silicate hydrate.

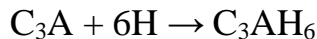
The reaction of pure C_3A with water is very violent with evolution hydrate is formed, although this is preceded by a metastable $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{CaSO}_4 \cdot 12\text{H}_2\text{O}$, produced at the expense of the original high-sulfate calcium sulfoaluminate.

The reaction of gypsum with C_3A continues until one of them exhausted, while C_3S continue in hydration.

- If C_3A exhausted before gypsum

The surplus gypsum \rightarrow expand \rightarrow become an agent assist the disruption and deterioration of cement paste.

- If gypsum exhausted before C_3A The remaining C_3A begins in hydration:



C_3AH_6 is stable –cubical crystals- with high sulfate resistance.

Calcium aluminate hydrate : Be at many forms before transforming to the stable state (C_3AH_6). It is probably forming hexagonal crystals (C_4AH_8 , C_4AH_{10} , C_4AH_{12}) before the cubical crystals.

When the hexagonal crystals expose to sulfates (inside concrete from sand or external from soil or ground water) \rightarrow react with it forming calcium sulfoaluminate \rightarrow with increase in volume, depending on the stable cubical form is accompanied with – change in the density and size of the crystals – leading to decrease in the late ages strength of the cement paste due to

- lose the adhesion and cohesion in the microstructure
- increase the porosity of the hardened cement paste.

The presence of C_3A in cement is undesirable: it contributes little to the strength of cement except at early ages (1-3 days) and, when hardened cement paste is attacked by sulfates, expansion due to the formation of calcium sulfoaluminate from C_3A may result in a disruption of the hardened paste compound

Gypsum reacts with C_4AF to form calcium sulfoaluminates and calcium sulfoferrite. C_4AF – work as flux material and also it accelerates the hydration of silicates.

Using the optimum percentage of gypsum is very important because:

- It regulates the speed of the chemical reactions in the early ages.
- Prevent the local concentration of the hydration products.

The necessary gypsum content increase with the increase of:

- C_3A content in the cement.
- Alkalis content in the cement.
- Fineness of cement.

Iraqi specification No. 5 limits the maximum gypsum content (expressed as the

mass of SO_3 present) to be not more than 2.5% when $\text{C}_3\text{A} \leq 7\%$ and 3% when $\text{C}_3\text{A} > 7\%$.

Calcium silicates hydrate C_3S :

$\text{C}_3\text{S} + \text{water} \rightarrow$

- lime and silica ions in the solution with molecular weight of 3:1
- $\text{Ca}(\text{OH})_2$ crystals
- Calcium silicate hydrate gel (**tobermorite**)

Hydration of C_3S – take about one year or more

This initial gel form an external layer over C_3S causing the delay of the reaction. After few hours, this initial C-S-H undergo hydrolysis equation:

$$2(3\text{CaO}.\text{SiO}_2) + 6\text{H}_2\text{O} \rightarrow 3\text{CaO}.2\text{SiO}_2.3\text{H}_2\text{O} + 3\text{Ca}(\text{OH})_2$$

C_2S

There are three main crystal forms of C_2S (α , β , γ) but the β -form is the only one occurred in the Portland cement and it react slowly with water.

—

- Its reaction is slower than C_3S .
- The amount of $\text{Ca}(\text{OH})_2$ from its hydration is less.

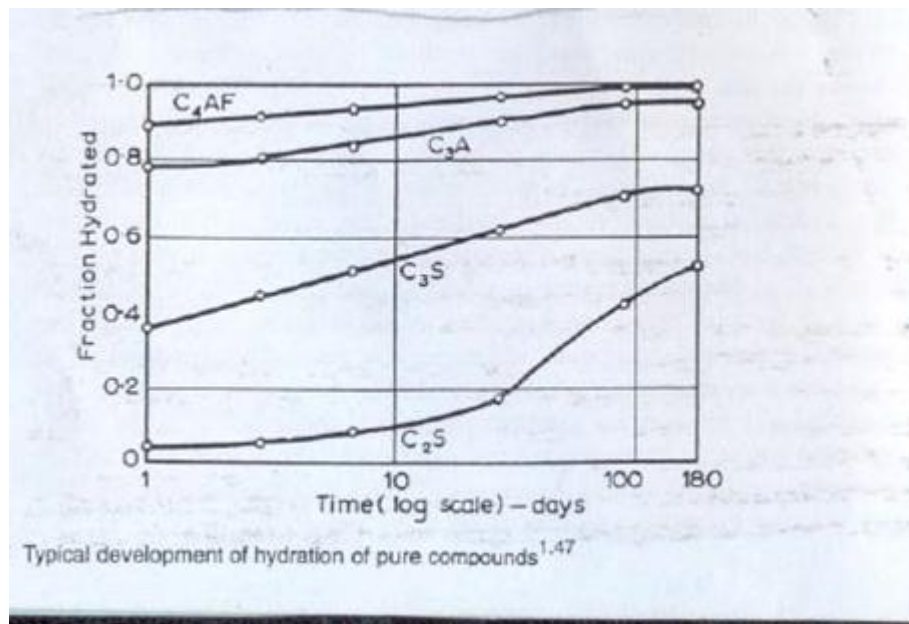
Its formed gel is similar to that produced from C_3S , but there is difference in the route of the chemical reactions between the two compounds – the lime: silica during the hydration of C_2S differs than that formed during the the stable C-S-H II form with C:S equal 1.65-1.8 at 25°C .

- Hydration of C_2S – takes more than 4 years.

The full hydration of C_2S can be expressed approximately by the following equation:



The rates of hydration of the two compounds are different as shown in the figure below:



The gel formed after the completion of hydration of the two compounds is → $C_3S_2H_3$ – Tobermorite.

C_3S and C_2S – require approximately the same amount of water for hydration, but C_3S produces more than twice as much $Ca(OH)_2$ as is formed by the hydration of C_2S , as shown in the equations below:

For C_3S hydration



The corresponding masses involved are:

$$100 + 24 \rightarrow 75 + 49$$

For C_2S hydration



The corresponding masses involved are:

$$100 + 21 \rightarrow 99 + 22$$

Setting

Setting refers to a change from a fluid to a rigid stage

Cement + water → cement paste → lose its plasticity gradually → when it lose its plasticity completely → setting occurs.

The **stages of setting** include:

- Initial setting
- Final setting

It is important to distinguish setting from **hardening**, which refers to the gain of strength of a set cement paste.

The two first to react are C_3A and C_3S .

The setting time of cement decreases with a rise in temperature.

The importance of setting in concrete works comes from the importance to

keep the fresh concrete in the plastic stage for enough time necessary to complete its mixing and placing under practical conditions. But, from the economical side, it is important that the concrete hardens at convenient period after casting.

There are four main stages during setting First stage

- Takes only few minutes after the addition of water to the cement.
- The rate of heat generation is high, due to wetting of cement particles with water, and the beginning of hydrolysis and reaction of the cement compounds. After that the rate decreases to relatively low value.

Second stage (dormant period)

- Takes 1-4 hours with relatively low speed.
- The initial layer of the hydration begins slowly to build on the cement particles.
- Bleeding and sedimentation appears at this period.

Third stage

- Heat of hydration begins to rise again due to the dissolution of the weak gel layer formed in the beginning (first) on the surface of C_3S crystals – so the water able to surround the particles surfaces again – and forming gel of calcium silicates with enough amount to increase setting.
- The activity reach its peak after about 6 hours for cement paste, with standard consistency, and might be late for paste with higher w/c ratio.
- At the end of the stage, the paste reaches the final setting stage.

Fourth stage

- hardening and gain of strength

Vicat apparatus – use to measure the setting time for cement paste.

Initial setting time – refers to the beginning of the cement paste setting.

Final setting time – refers to the beginning of hardening and gain of strength.

Iraqi Standard Specification No. 5 limits:

- Initial setting time not less than 45 minutes.
- Final setting time not more than 10 hours.

Factors affecting the setting

- 1- **Water/cement (w/c) ratio** – The setting time of cement increases with the increase of w/c ratio.
- 2- **Temperature and relative humidity** - The setting time of cement decreases with a rise in temperature and decrease of relative humidity.
- 3- **Fineness of cement** - The setting time of cement decreases with a rise in fineness of cement.
- 4- **Chemical composition**

False setting

It is abnormal premature stiffening of cement within a few minutes of mixing with water. – It differs from **flash set** in that:

- No appreciable heat is evolved.
- Remixing the cement paste without addition of water restores plasticity of the paste until it sets in the normal manner and without a loss of strength.

Causes of false setting

- 1- **Dehydration of gypsum** – when interground with too hot a clinker - formed:
 - hemihydrates ($\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) – when temperature between $100-190^\circ\text{C}$
 - or anhydrite (CaSO_4) - when temperature $>190^\circ\text{C}$ And when the cement is mixed with water these hydrate to form

gypsum, with a result stiffening of the paste.

2- Reaction of alkalis of the cement

During bad storage – alkalis in the cement react with CO_2 (in the atmosphere) to form alkali carbonates, which they react with $\text{Ca}(\text{OH})_2$ liberated by the hydrolysis of C_3S to form CaCO_3 . This precipitates and induces a rigidity of the paste.

**3- Activation of C_3S subjected to wet atmosphere**

During bad storage – water is adsorbed on the grains of cement (the water stick on their surfaces) and activates them, and these activated surfaces can combine very rapidly with more water during mixing: this rapid hydration would produce false set.

Flash setting – Occurs when there is no gypsum added or exhausting the gypsum (added with little amount), so C_3A reacts violently with water causing liberation high amount of heat causing rapid setting of cement, and leading to form porous microstructure that the product of hydration of the other compounds

precipitate through, unlike the **normal (ordinary) setting** that have much lower porosity microstructure.

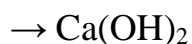
Soundness of cement

The cement considers unsound if it undergo a large change in volume (expansion) – that cause cracking of hardened cement paste when it is under condition of restraint.

Causes of expansion

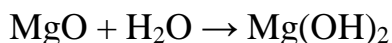
1- Free lime CaO

If the raw materials fed into the kiln contain more lime that can combine with the acidic oxides, or if burning or cooling are unsatisfactory, the excess lime will remain in a free condition. This hard-burnt lime hydrates only very slowly and, because slaked lime occupies a larger volume than the original free calcium oxide, expansion takes place. Cements which exhibit this expansion are described as unsound. $\text{CaO} + \text{H}_2\text{O}$



2- Free MgO

Cement can also be unsound due to the presence of MgO, which reacts with water in a manner similar to CaO. However, only periclase, that is, 'dead-burnt' crystalline MgO, is deleteriously reactive, and MgO present in glass is harmless, because it hydrates quickly transforming to the stable state in the hardened paste.



Up to about 2 per cent of periclase, (by mass of cement) combines with the main cement compounds, but excess periclase generally causes expansion and can lead to slow disruption.

3- Calcium sulfates (gypsum)

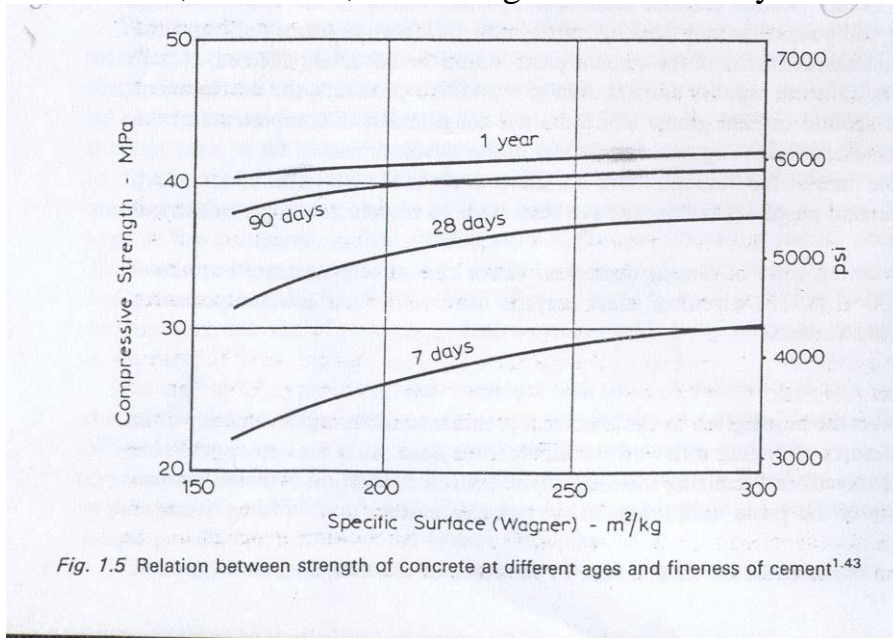
Gypsum added to the clinker during its grinding in order to prevent flash set, but if gypsum is present in excess of the amount that can react with C_3A during setting, unsoundness in the form of a slow expansion will result.

Fineness of cement

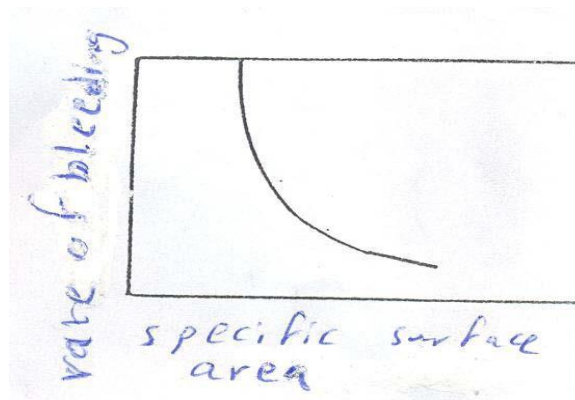
The last step in the manufacture of cement is the grinding of clinker mixed with gypsum.

Because hydration starts at the surface of the cement particles, it is the total surface area of cement that represents the material available for hydration. Thus, the rate of hydration depends on the fineness of the cement particles. The high fineness is necessary for:

- Rapid development of strength, as shown in the figure below; although the long-term strength is not affected. A higher early rate of hydration means, of course, also a higher rate of early heat evolution



- To cover surfaces of the fine aggregate particles at better manner – leading to better adhesion and cohesion between cement mortar constituents.
- To improve the workability of the concrete mix, but it will increase the amount of water required for the standard consistency.
- To reduce the water layer that separate on the mixture surface due to bleeding, as shown in the figure below.



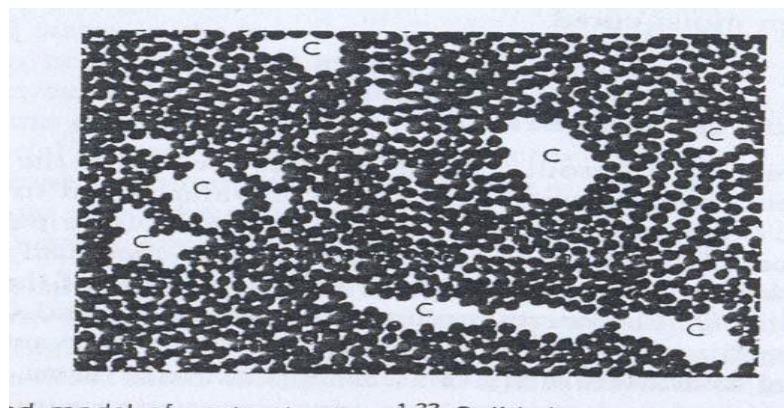
The disadvantage of high fineness, include:

- The cost of grinding to a higher fineness is considerable.
- The finer the cement the more rapidly it deteriorates on exposure to the atmosphere during bad storage.
- Finer cement increases the surface area of its alkalis – leads to stronger reaction with alkali- reactive aggregate – cracks and deterioration of concrete.

- Finer cement exhibits a higher shrinkage and a greater proneness to cracking.
- An increase in fineness increases the amount of gypsum required for proper retardation because, in finer cement, more C_3A is available for early hydration (due to the increase of its surface area).

Structure of hydrated cement

At any stage of hydration, the hardened paste consists of very poorly crystallized hydrates of the various compounds (calcium silicates hydrate, tricalcium aluminates hydrate and calcium ferrite), referred to collectively as gel, of crystals of $Ca(OH)_2$ produced from the hydration of the silicates, some minor components, unhydrated cement, and the residue of the water-filled spaces in the fresh paste. These voids are called **capillary pores** but, within the gel itself, there exist interstitial voids, called **gel pores**. The nominal diameter of gel pores is about 3 nm while capillary pores are one or two orders of magnitude larger. There are thus, in hydrated paste, two distinct classes of pores represented diagrammatically in the figure below.



Simplified model of paste structure. Solid dots represent gel particles; interstitial spaces are gel pores; spaces such as those marked C are capillary pores

Capillary pores

At any stage of hydration, the capillary pores represent that part of the gross volume which has not been filled by the products of hydration. Because these products occupy more than twice the volume of the original solid phase (i.e. cement) alone, the volume of the capillary system is reduced with the progress of hydration.

Thus the capillary porosity of the paste depends on:

- The water/cement ratio of the mix
When w/c ratio > 0.38 – The gel volume is not enough to fill all the available voids.
- The degree of hydration, which influence by the type of cement.

Capillary pores:

- cannot be viewed directly but their median size was estimated to be about 1.3 μm .
- They vary in shape and form an interconnected system randomly distributed throughout the cement paste.
- These interconnected capillary pores are mainly responsible for the permeability of the hardened cement paste and for its vulnerability to cycles of freezing and thawing.

However, hydration increases the solid content of the paste and in mature and dense pastes - the capillaries can become blocked by gel and segmented so that they turn into capillary pores interconnected solely by the gel pores.

The absence of continuous capillaries is due to:

- Using a suitable water/cement ratio
- Sufficiently long period of moist curing

The degree of maturity required for different water/cement ratios for ordinary Portland cements is indicated in figure below.

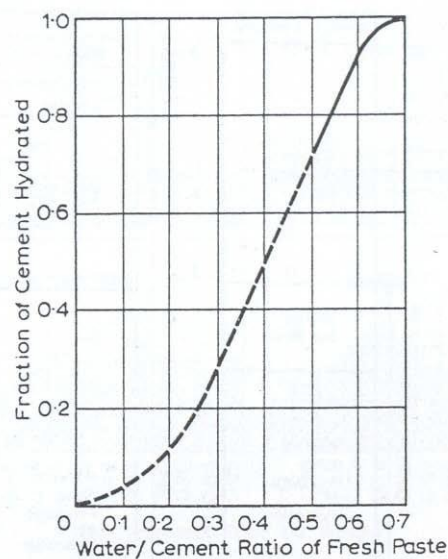


Fig. 1.12 Relation between the water/cement ratio and the degree of hydration at which the capillaries cease to be continuous^{1,26}

It can be seen that the estimated required time for maturity of cement paste are:

w/c ratio	time
0.4	3 days
0.7	One year
More than 0.7	Not possible

Gel pores

- The gel pores are interconnected interstitial spaces between the gel particles.
- The gel pores are much smaller than the capillary pores: Less than 2 or 3 nm in nominal diameter. This is only one order of magnitude greater than the size of molecules of water. For this reason, the vapor pressure and mobility of adsorbed water are different from the corresponding properties of free water.
- The gel pores occupy about 28 per cent of the total volume of gel (gel particles + gel pores).
- The actual value is characteristic for a given cement but is largely independent of the water/cement ratio of the mix and of the progress of hydration. This would indicate that gel of similar properties is formed at all stages and that continued hydration does not affect the products already in existence. Thus, as the total volume of gel increases with the progress of hydration, the total volume of gel pores also increases. On the other hand, as mentioned earlier, the volume of capillary pores decreases with the progress of hydration.

Water held in hydrated cement paste

The hydrated cement paste – contains sub-microscopic pores – that can absorb water from the ambient area. The actual water content of the paste depends on the ambient humidity.

Capillary pores, because of their comparatively large size, empty when the ambient relative humidity falls below about 45 per cent, but water is adsorbed in the gel pores even at very low ambient humidities, because it is too small compared with the capillary pores.

We can thus see that water in hydrated cement is held with varying degrees of firmness:

- **Free water** – present in the capillary pores – with weak firmness, and evaporate quickly leaving the paste.
- **Chemically combined water** – form a definite part of the hydrated compounds.
- **Gel water** – present in gel pores – part of it is held by the surface force of the gel particles - It is known as **the adsorbed water**.

There is no technique available for determining how water is distributed between these different states, nor is it easy to predict these divisions from theoretical considerations as the energy of binding of combined water in the hydrate is of the same order of magnitude as the energy of binding of the adsorbed water.

A convenient division of water in the hydrated cement, necessary for

investigation purposes, though rather arbitrary, is into two categories:

- **Evaporable water** – includes water in the capillary pores and some water in the gel pores.
- **Non-evaporable water** – includes nearly all chemically combined water and also some water not held by chemical bonds.

The amount of non-evaporable water increases as hydration proceeds. In **well-hydrated cement**, the non-evaporable water is about **18 per cent** by mass of the anhydrous material; this proportion rises to about **23 per cent** in **fully hydrated cement**. The evaporable water can be measured from – loss in weight of cement paste sample through drying at 105°C to the equilibrium state.

Heat of hydration of cement

The quantity of evolved heat when the cement hydrated completely at a given temperature – Joule/gram or calorie/gram of unhydrated cement.

The hydration of cement compounds - accompanied with heat evolution, energy of up to 120 cal/g of cement being liberated. Because the thermal conductivity of concrete is comparatively low - it acts as an insulator, and in the interior of a large concrete mass, hydration can result in a large rise in temperature. At the same time, the exterior of the concrete mass loses some heat so that a steep temperature gradient may be established and, during subsequent cooling of the interior, serious cracking may result due to the generated stresses.

At the other extreme, the heat produced by the hydration of cement may prevent freezing of the water in the capillaries of freshly placed concrete in cold weather, and a high evolution of heat is therefore advantageous. The most common method of determining the heat of hydration is by measuring the heats of solution of unhydrated and hydrated cement in a mixture of nitric and hydrofluoric acids: the difference between the two values represents the heat of hydration. This method is described in BS 4550:Section 3.8:1978, and is similar to the method of ASTM C 186-94. The **heat of hydration**, as measured, **consists of** the chemical heat of the reactions of hydration and the heat of adsorption of water on the surface of the gel formed by the processes of hydration. The latter heat accounts for about a quarter of the total heat of hydration. Thus, the heat of hydration is really a composite quantity.

For practical purposes, it is not necessarily the total heat of hydration that matters but the rate of heat evolution. The same total heat produced over a longer period can be dissipated to a greater degree with a consequent smaller rise in temperature.

The actual value of the heat of hydration depends on:

1- The chemical composition of the cement

Heat of hydration of cement = sum of the heats of hydration of the individual compounds when hydrated separately.

The contribution of individual compounds to the total heat of hydration of cement can

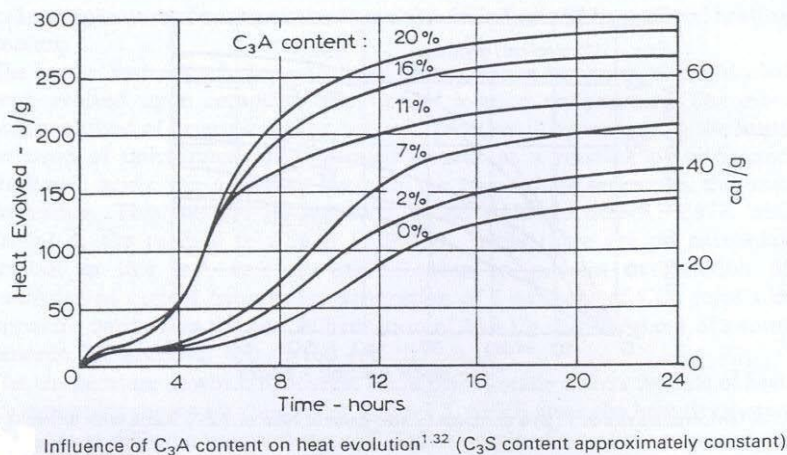
be measured from the following equation:

Heat of hydration of 1 g of cement =

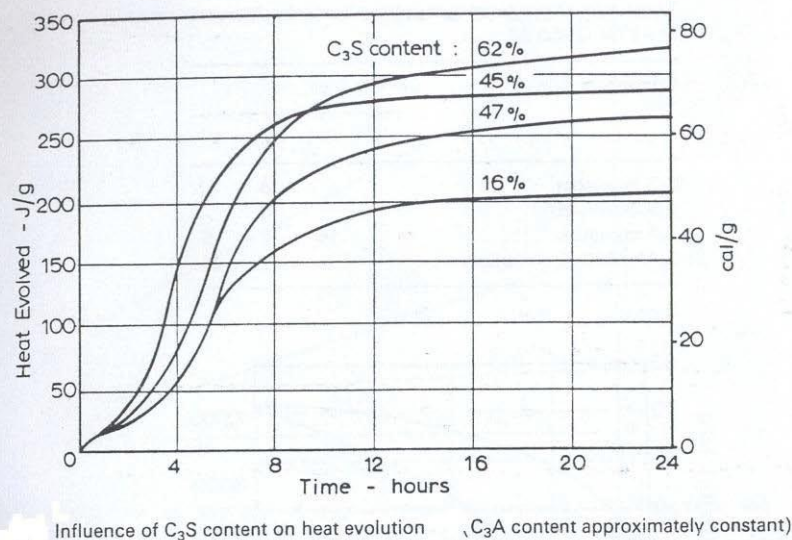
$$136(C_3S) + 62(C_2S) + 200(C_3A) + 30(C_4AF)$$

Where the terms in brackets denote the percentage by mass of the individual compounds in cement. Because in the early stages of hydration the different compounds hydrate at different rates, the rate of heat evolution, as well as the total heat depends on the compound composition of the cement.

It follows that by reducing the proportions of the compounds that hydrate most rapidly (C_3A and C_3S) the high rate of heat evolution in the early life of concrete can be lowered. The effect of C_3A on heat of hydration of cement is shown in the Fig. below.



The effect of C_3S on heat of hydration of cement is shown in the Fig. below.



1. Separation the aggregate particles from concrete mixture, and this one happening in the poor and dry mixtures
2. Separation the cement paste from the aggregate and this may accrue in the wet mixtures.

Segregation may accrue when using wrong handling and casting methods like:

1. Transporting concrete for long distance.
2. Falling the concrete from high places.
3. Transporting concrete through a big size open channels and changing its direction suddenly.
4. It's not right to move the concrete into the sides of mold by shovels or planning machines.
5. Using vibratos for a long time impact the concrete may cause segregation.

The measure that should be taken minimize the segregation its necessary to insure the following details:

1. Using as suitable water content and do not use dry mixtures.
2. Using aggregate particles with similar specific weight.
3. Considering the field grading curves which are recommended by the standards specification.
4. Using air entraining admixture may be decrease the probability of segregation.

Bleeding:

Which means climbing some of the mix water to the roof of the new concrete. It's considered as a type of segregation which is followed by a decrease in concrete height inside the molds

The most important reasons of bleeding are:

1. The inability for some hard parts of the mixture to keep all mixture water
2. In erasing water content in the mixture.

Because of bleeding may have such situations.

1. If the concrete is costing in layers then a weak levels will be created between these layers.
2. If the evaporation average on the concrete surface was higher than the average of water climbing to the surface by bleeding, the retraction fission will be created.
3. In the case remixing and finishing the surface layers to treat high level of water then these layer will have a small resistance for retraction.

2- **Ambient temperature** – has great effect on the rate of heat evolution – The rate of heat evolution increase with increase in the ambient temperature.

3- **Type of cement**

Types of cement can be arranged in descending order with respect to their rate of heat evolution, as follows:

- Rapid hardening Portland cement.
- Ordinary Portland cement.
- Modified Portland cement.
- Sulfate resistant Portland cement.
- Low heat Portland cement. 4-

Fineness of cement

An increase in fineness speed up the reactions of hydration and therefore the heat evolved. It is reasonable to assume that the early rate of hydration of each compound in cement is proportional to the surface area of the cement. However, at later ages, the effect of the surface area is negligible and the total amount of heat evolved is not affected by the fineness of cement.

5- **Amount of cement in the mixture**

The quantity of cement in the mix also affects the total heat development: thus the richness of the mix, that is, the cement content, can be varied in order to help the control of heat development.

Influence of the compound composition on properties of cement

Main compounds

C₃S and C₂S – are the most important compounds – responsible for strength.

C₃S – contributes most to the strength development during the first four weeks.

C₂S – influences the gain in strength from 4 weeks onwards.

At the age or about one year, the two compounds, contribute approximately equally to the ultimate strength.

cement on the basis of its compound composition. This would be in the form of an expression of the type:

$$\text{Strength} = a (\text{C}_3\text{S}) + b (\text{C}_2\text{S}) + c (\text{C}_3\text{A}) + d (\text{C}_4\text{AF})$$

Where the symbols in brackets represent the percentage by mass of the compound, and a, b, etc. are constants representing the contribution of 1 per cent of the corresponding compound to the strength of the hydrated cement paste.

Alkalis

Tests on the influence of alkalis have shown that the increase in strength beyond the age of 28 days is strongly affected by the alkali content: the greater the amount of alkali presents the lower the gain in strength. The poor gain in strength between 3 and 28 days can be attributed more specifically to water-soluble K_2O present in the cement. On the other hand, in the total absence of alkalis, the early strength of cement paste can be abnormally low.

The alkalis are known to react with the so-called alkali-reactive aggregates – the product of reaction accompanied with increase in volume – leads to cracking of concrete mass, and cements used under such circumstances often have their alkali content limited to 0.6 per cent (measured as equivalent Na_2O). Such cements are referred to as low-alkali cements.

Chapter Two

Types of Cement

The properties of cement during hydration vary according to:

- Chemical composition
- Degree of fineness

It is possible to manufacture different types of cement by changing the percentages of their raw materials.

Types of Cement

- Portland cement
- Natural cement
- Expansive cement
- High-alumina cement

Types of Portland Cement

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

It is possible to add some additive to Portland cement to produce the following types:

- Portland blast furnace cement – Type IS
- Pozzolanic cement - Type IP
- Air-entrained cement - Type IA
- White Portland cement
- Colored Portland cement

Ordinary Portland cement

This type of cement use in constructions when there is no exposure to sulfates in the soil or groundwater.

The chemical composition requirements are listed in Iraqi specification NO. 5., as shown below:

Lime Saturation Factor =

$$\{\text{CaO}-0.7(\text{SO}_3)\} / \{2.8(\text{SiO}_2)+1.2(\text{Al}_2\text{O}_3)+0.65(\text{Fe}_2\text{O}_3)\}$$

L.S.F. : is limited between 0.66-1.02 Where each term in brackets denotes the percentage by mass of cement composition.

This factor is limited – to assure that the lime in the raw materials, used in the cement manufacturing is not so high, so as it cause the presence of free lime after the occurrence of chemical equilibrium. While too low a L.S.F. would make the burning in the kiln difficult and the proportion of C₃S in the clinker would be too low.

Free lime – cause the cement to be unsound.

- Percentage of (**Al₂O₃/Fe₂O₃**) is not less than 0.66
- **Insoluble residue** not more than 1.5%
- **Percentage of SO₃** limited by 2.5% when C₃A ≤ 7%, and not more than 3% when C₃A > 7%
- **Loss of ignition L.O.I.** – 4% (max.)
- **Percentage of MgO** - 5% (max.)
- **Fineness** – not less than 2250 cm²/g

Rapid Hardening Portland Cement

- This type develops strength more rapidly than ordinary Portland cement. The initial strength is higher , but they equalize at 2-3 months
- Setting time for this type is similar for that of ordinary Portland cement
- The rate of strength gain occur due to increase of C₃S compound, and due to finer grinding of the cement clinker (the min. fineness is 3250 cm²/g (according to IQS 5)
- Rate of heat evolution is higher than in ordinary Portland cement due to the increase in C₃S and C₃A, and due to its higher fineness

- Chemical composition and soundness requirements are similar to that of ordinary Portland cement.

Uses

- The uses of this cement is indicated where a rapid strength development is desired (to develop high early strength, i.e. its 3 days strength equal that of 7 days ordinary Portland cement), for example:
 - When formwork is to be removed for re-use
 - Where sufficient strength for further construction is wanted as quickly as practicable, such as concrete blocks manufacturing, sidewalks and the places that can not be closed for a long time, and repair works needed to construct quickly.
- For construction at low temperatures, to prevent the frost damage of the capillary water.
- This type of cement does not use at mass concrete constructions.

Special Types of Rapid Hardening Portland Cement A-Ultra High Early Strength Cement

The rapid strength development of this type of cement is achieved by grinding the cement to a very high fineness: 7000 to 9000 cm^2/g . Because of this, the gypsum content has to be higher (4 percent expressed as SO_3). Because of its high fineness, it has a low bulk density. High fineness leads to rapid hydration, and therefore to a high rate of heat generation at early ages and to a rapid strength development (7 days strength of rapid hardening Portland cement can be reached at 24 hours when using this type of cement). There is little gain in strength beyond 28 days.

It is used in structures where early prestressing or putting in service is of importance. This type of cement contains no integral admixtures.

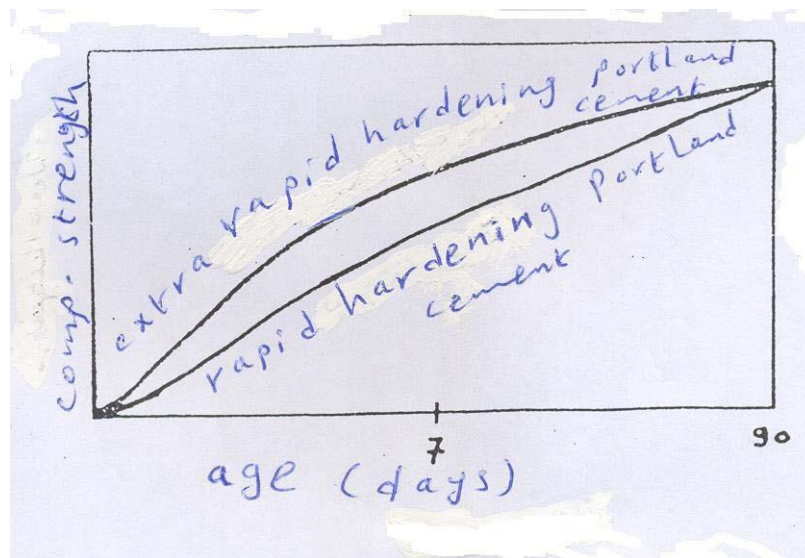
B- Extra Rapid Hardening Portland Cement

This type prepare by grinding CaCl_2 with rapid hardening Portland

cement. The percentage of CaCl_2 should not be more than 2% by weight of the rapid hardening Portland cement.

By using CaCl_2 :

- The rate of setting and hardening increase (the mixture is preferred to be casted within 20 minutes).
- The rate of heat evolution increase in comparison with rapid hardening Portland cement, so it is more convenient to be use at cold weather.
- The early strength is higher than for rapid hardening Portland cement, but their strength is equal at 90 days.
- Because CaCl_2 is a material that takes the moisture from the atmosphere, care should be taken to store this cement at dry place and for a storage period not more than one month so as it does not deteriorate.



Low Heat Portland Cement

Composition

It contains less C_3S and C_3A percentage, and higher percentage of C_2S in comparison with ordinary Portland cement.

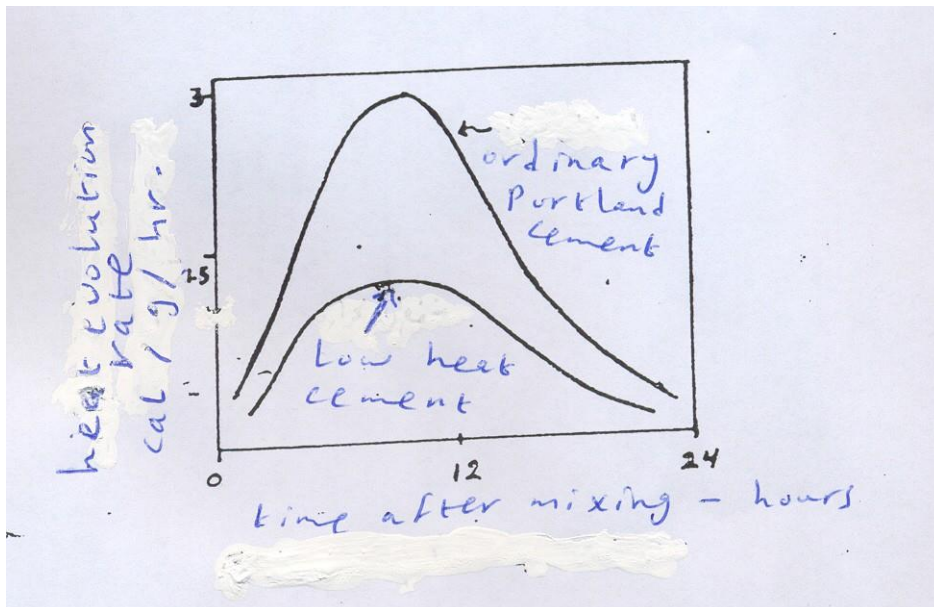
Properties

- 1) Reduce and delay the heat of hydration. British standard (B. S. 1370 : 1974) limit the heat of hydration of this cement by:

- 60 cal/g at 7 days age
 - 70 cal/g at 28 days age
- 2) It has lower early strength (half the strength at 7 days age and two third the strength at 28 days age) compared with ordinary Portland cement.
- 3) Its fineness is not less than $3200 \text{ cm}^2/\text{g}$ (according to B. S. 1370:

Uses

It is used in mass concrete constructions: the rise of temperature in mass concrete due to progression in heat of hydration -- cause serious cracks. So it is important to limit the rate of heat evolution in this type of construction, by using the low heat cement.



Sulfate- resisting Cement

Composition

It contains:

- Lower percentage of C_3A and C_4AF – which considers as the most affected compounds by sulfates.
- Higher percentage of silicates – in comparison with ordinary Portland cement.

- For this type of cement – C₂S represents a high proportion of the silicates.
- Iraqi specification no. (6) limits – max. C₃A content by 3.5%
_ min. fineness by 2500 cm²/g.

Properties

- Low early strength.
- Its resulted heat of hydration is little higher than that resulted from low heat cement.
- Its cost is higher than ordinary Portland cement – because of the special requirements of material composition, including addition of iron powder to the raw materials.

For the hardened cement, the effects of sulfates are on two types:

1- Hydrated calcium aluminates in their semi-stable hexagonal form (before its transformation to the stable state – C₃AH₆ as cubical crystal form – which have high sulfate resistance) react with sulfates (present in fine aggregate, or soil and ground water), producing hydrated calcium sulfoaluminate, leading to increase in the volume of the reacted materials by about 227% causing gradual cracking.

2- Exchange between Ca(OH)₂ and sulfates resulting gypsum, and leading to increase in the volume of the reacted materials by about 124%.

- The cure of sulfates effect – is by using sulfate-resisting cement.
- The resultant of reaction C₄AF with sulfates is calcium sulfoaluminate and calcium sulfoferrite, leading to expansion.

But an initial layer will form which surround the free C₃A leading to reduce its affect by sulfates, so C₄AF is more resistant to sulfates effect than C₃A.

Portland Blastfurnace Cement

Production

This type of cement consists of an intimate mixture of Portland cement

and ground granulated blastfurnace slag.

Slag – is a waste product in the manufacture of pig iron.

Chemically, slag is a mixture of 42% lime, 30% silica, 19% alumina, 5% magnesia, and 1% alkalis, that is, the same oxides that make up Portland cement but not in the same proportions.

The maximum percentage of slag use in this type of cement is limited by British standard B.S. 146: 1974 to be 65%, and by American standard ASTM C595-76 to be between 25-65%.

Properties

- Its early strength is lower than that of ordinary cement, but their strength is equal at late ages (about 2 months).
- The requirements for fineness and setting time and soundness are similar for those of ordinary cement (although actually its fineness is higher than that of ordinary cement).
- The workability is higher than that of ordinary cement.
- Heat of hydration is lower than that of ordinary cement.
- Its sulfate resistance is high.

Uses

- Mass concrete
- It is possible to be use in constructions subjected to sea water (marine constructions).
- May not be use in cold weather concreting.

Types of Pozzolana

- Natural Pozzolanic materials, such as – volcanic ash
- Industrial Pozzolanic materials, such as – fired clay, rice husks ash

Properties & Uses

They are similar to those of Portland blastfurnace cement.

White Cement

White Portland cement is made from raw materials containing very little iron oxide (less than 0.3% by mass of clinker) and magnesium oxide (which give the grey color in ordinary Portland cement). China clay (white kaoline) is generally used, together with chalk or limestone, free from specified impurities.

- Its manufacture needs higher firing temperature because of the absence of iron element that works as a catalyst in the formation process of the clinker. In some cases kreolite (sodium-aluminum fluoride) might be added as a catalyst.
- The compounds in this cement are similar for those in ordinary Portland cement, but C₄AF percentage is very low.
- Contamination of the cement with iron during grinding of clinker has also to be avoided. For this reason, instead of the usual ball mill, the expensive nickel and molybdenum alloy balls are used in a stone or ceramic-lined mill. The cost of grinding is thus higher, and this, coupled with the more expensive raw materials, makes white cement rather expensive.
- It has a slightly lower specific gravity (3.05-3.1), than ordinary Portland cement.
- The strength is usually somewhat lower than that of ordinary Portland cement.

- Its fineness is higher ($4000-4500 \text{ cm}^2/\text{g}$) than ordinary Portland cement.

Other Cements

1- Colored Portland Cement

It is prepared by adding special types of pigments to the Portland cement. The pigments added to the white cement (2-10% by weight of the cement) when needed to obtain light colors, while it added to ordinary Portland cement when needed to obtain dark colors.

The 28-day compressive strength is required to be not less than 90% of the strength of a pigment-free control mix, and the water demand is required to be not more than 110% of the control mix.

It is required that pigments are insoluble and not affected by light. They should be chemically inert and don't contain gypsum that is harmful to the concrete.

2- Anti-bacterial Portland Cement

It is a Portland cement interground with an anti-bacterial agent which prevents microbiological fermentation. This bacterial action is encountered in concrete floors of food processing plants where the leaching out of cement by acids is followed by fermentation caused by bacteria in the presence of moisture.

3- Hydrophobic Cement

It is prepared by mixing certain materials (stearic acid, oleic acid, ... etc by 0.1-0.4%) with ordinary Portland cement clinker before grinding, to form water repellent layer around the cement particles, so as the cement can be store safely for a long period. This layer removes during mixing process with water.

4- Expansive Cement

It has the property of expanding in its early life so as to counteract contraction induced by drying shrinkage.

Chapter Three

(Aggregate)

Aggregate was originally viewed as an inter material dispersed throughout the cement paste largely for economic reasons, at last three quarters of the volume of concrete is occupied by aggregate.

Aggregate is cheaper than cement and it is, therefore, economical to put into mix. But economy is not only reason for using aggregate it confers considerable technical advantages on concrete which has a higher volume stability and better durability than hydrated cement paste alone.

General classification of aggregate:

A. Fine aggregate:

It is the aggregate most of which passes (95-100) through a 4.75 mm sieve and contains only so much coarser material as is permitted by specification. Sand considered having lower size limit of about 0.075mm.

The fine aggregate may be one of the following

1. Natural Sand: is resulting from disintegration of rock
2. Crushed stone sand: produced by crushing natural hard stone.
3. Crushed gravel sand: the fine aggregate produced by crushing natural gravel
4. Silt particle size material between 0.075mm-0.002mm.
5. Clay particle size material smaller than 0.002mm.

B. Coarse aggregate:

The aggregate most of which retained on the 4.75mm sieves the coarse aggregate may be one of the following:

1. Uncrushed gravel: resulting from natural disintegration of rock
2. Crushed gravel: obtained by the crushing gravel or hard stone
3. Partially crushed stone obtained as product of blending of the above two types

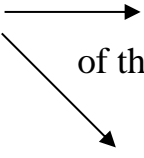
C. All in aggregate:

Sometimes combined aggregate are available in nature comprise different fractions of fine and coarse aggregate.

Properties of Aggregate :

1. shape of aggregate :

- a. Roundness : its measure the relative sharpness or angular of the edges and corner of particle .

Roundness depend on  strength and a bras on resistance of the parent rock.

The amount of wear to which the particle has been subjected

In the case of crushed aggregate ,the particle shape depends on - nature of the parent material.

- Types of crushed.
- Reduction ratio (the ratio of the size of material fed into crushed , the size of finished product)

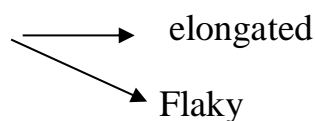
The angularity of aggregate can be estimated from the proportion of voids in sample compacted in a prescribed way.

b. sphencity :

its defined as a function of the ratio of the surface area of the particale to its volume .

Partials with a high ratio of surface area to volume of particular interest as they increase the water demand for given workability of the concrete mix.

Two types of particles which depart from equidimensional shape are interest



It can also affect adversely the durability of concrete because flaky particles tend to be obtained in one plane with bleeding water and air voids forming underneath.

Bond between aggregate and Cement Paste

Is an important factor in the strength of cone rate it is depend on :

1. interlocking of aggregate and hydrated Cement Paste: due to (the roughness of the surface of the former, such as that of crushed particles , results in better bond due to mechanically interlocking

2. physical and chemical properties of aggregate :

Related to its mineralogical and chemical composition. For instance, some chemical bond may exist in the case of limestone, dolomite .

3. Strength of the hydrated Cement Paste :

Bond strength increases with the age of concrete , it seem that the ratio of bond strength to the strength of hydrated Cement Paste increase with age .

c. Specific gravity :

Because aggregate generally contains pores:

- Permeable.
- Impermeable.

There are several types of specific gravity :

- Absolute specific gravity : refers to the volume of the solid material exuding all pores ,and can, therefore , be defined as the ratio of the mass of the solid ,refer to vacuum, to the mass of an equal volume of gas-free distilled water, both taken at a stated temperature .
- Surface texture :

Surface texture of the aggregate affects its bond to the cement paste and also influences the water demand of the mix, especially in the case of fine aggregate.

The majority of natural aggregates have specific gravity of between 2.6 and 2.7.

Bulk Density:

The bulk density of aggregate is defined as the mass of the material in given volume and it expressed kg/m^3

The bulk density clearly depends on how densdy the aggregate is packed , the size distribution, and shape of particles .

For coarse aggregate of given specific gravity, a higher bulk density means that there are fewer voids to be filled by fine aggregate and cement.

Porosity and Absorption of Aggregate:

The porosity of aggregate, its permeability, and absorption influence:

- bond between the aggregate and cement paste
- The resistance of concrete to freezing and thawing.

- Chemical stability.
- Resistance.

The pores in aggregate vary in size over wide range:

The largest being large enough to be seen under micro-scope or even with the naked eye.

But even the smallest aggregate pores are larger than the gel pores in the cement paste.

Classification of aggregate depend on its moisture:

1. Bone-dry aggregate :

Drying an even at 100-110 °C, still further until, when no moisture whatever is left

2. Air dry aggregate :

Some of the water contain in pores will evaporate and the aggregate will be less than saturated.

3. Saturated surface dry aggregate.

When all the pores in the aggregate are, full without moisture on the surface

4. Wet aggregate:

When all the pores in particles are full, and surrounded by films of water.

Moisture content of aggregate:

In the fresh concrete the volume occupied by the aggregate is the volume of particles including all the pores.

If no water movement into the aggregate mast being saturated condition. On the other hand, any water on the surface of aggregate will contribute to the water in the mix

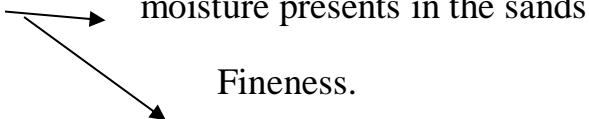
The Basic state of the aggregate is thus saturated and surface dry.

The total water content of moist = absorption + moisture

Bulking of fine aggregate:

The presence of moisture in aggregate necessitates correction of the actual mix proportion the mass of water added to the mix has to be decreased by the mass of the free moisture in the aggregate, and the mass of the wet aggregate must be increased by a like amount.

In the case of sand, there is a second effect of the presence of moisture: bulking: This is increase in the volume of a given mass of sand caused by films of water pushing the sand particles apart.

The bulking depends up on: 

Deleterious substances in Aggregate:

a. Organic impurities :

If the aggregate contain organic impunities which interfere with the chemical reactions of hydration.

Such materials are more likely to be present in sand than in coarse aggregate which is easily washed.

The organic matter found in aggregate consists usually of products of decay of vegetable matter, and appears in the form of humans or organic loam

b. Clay and other fine material :

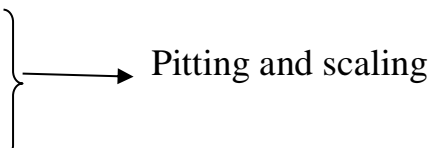
- Clay < 0.002mm(diameter)
- Silt : is material between (2-60)mm
- Crusher dust: is a fine material form during the process of communion of rock in to crushed stone or, less frequently, of gravel in to crushed fine aggregate.

Clay may be present in aggregate in the form surface coating which interfere with the bond between aggregate and cement paste. Because good bond is essential to ensure a satisfactory strength and durability of concrete, the problem of clay coatings is an important one.

c. Unsound particles:

It's lead to disruptive expansion on freezing or eve exposure to water .

Shale and other particles of low density regarded as unsound , and so are soft inclusions:

- Clay lumps.
 - Wood lumps.
 - Coal lumps.
- 

If present large quantities (over 2-5% of mass of the aggregate), these particles may adversely affect the strength of concrete and should certainly not be permitted in concrete which is exposed to abrasion.

Coal, in addition to being a soft inclusion, is undesirable for other reasons:

It can swell, causing disruption of concrete and, if present in large quantities in a finally divided form it can disturb the process of hydration of the cement paste.

Mica should be avoided because, in presence of active chemical agents produced during the hydration of cement alteration of mica to other forms can occur, and it affects adversely the water requirement and the strength of concrete.

Soundness of aggregate

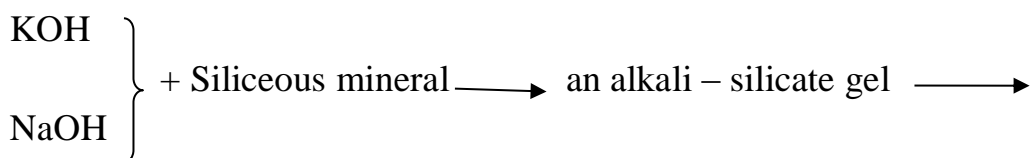
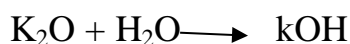
This is the term used to describe the ability of aggregate to resist excessive change in volume as result of changes in physical condition lack of soundness is thus distinct from expansion from expansion caused by the chemical reactions between the aggregate and alkalis in cement .

The physical cause of large or permanent volume changes of aggregate are freezing and thawing , thermal changes of temperature above freezing , and alternating wetting and drying .

Aggregate is said to be unsound when volume changes, induced by the above causes, result in deterioration concrete.

Alkali – Silica Reaction:

The siliceous minerals in the aggregate + Alkaline hydroxides (K_2O , Na_2O) in cement



Swelling \longrightarrow gel confined by the surrounding cement paste \longrightarrow internal pressure expansion \longrightarrow cracking and disruption of the hydrated cement paste.

The rate of alkali _ aggregate reaction depend on:

1. Particle size and porosity.
2. Alkali content and fineness of cement.
3. Affected by availability non – evaporable water in the paste.
4. The reaction is accelerated under the condition of alternating wetting and drying.

Table 3.18 Example of Sieve Analysis

Sieve size		Mass retained	Percentage retained	Cumulative percentage passing	Cumulative percentage retained
BS	ASTM	g	(3)	(4)	(5)
(1)		(2)			
10.0 mm	$\frac{3}{8}$ in.	0	0.0	100	0
5.00 mm	4	6	2.0	98	2
2.36 mm	8	31	10.1	88	12
1.18 mm	16	30	9.8	78	22
600 μm	30	59	19.2	59	41
300 μm	50	107	34.9	24	76
150 μm	100	53	17.3	7	93
<150 μm	<100	21	6.8	—	—
		Total = 307		Total = 246	
				Fineness modulus = 2.46	

The cumulative percentage (to the nearest 1 percent) passing each sieve can be calculated (column (4)), and it is this percentage that is used in the plotting of grading curves.

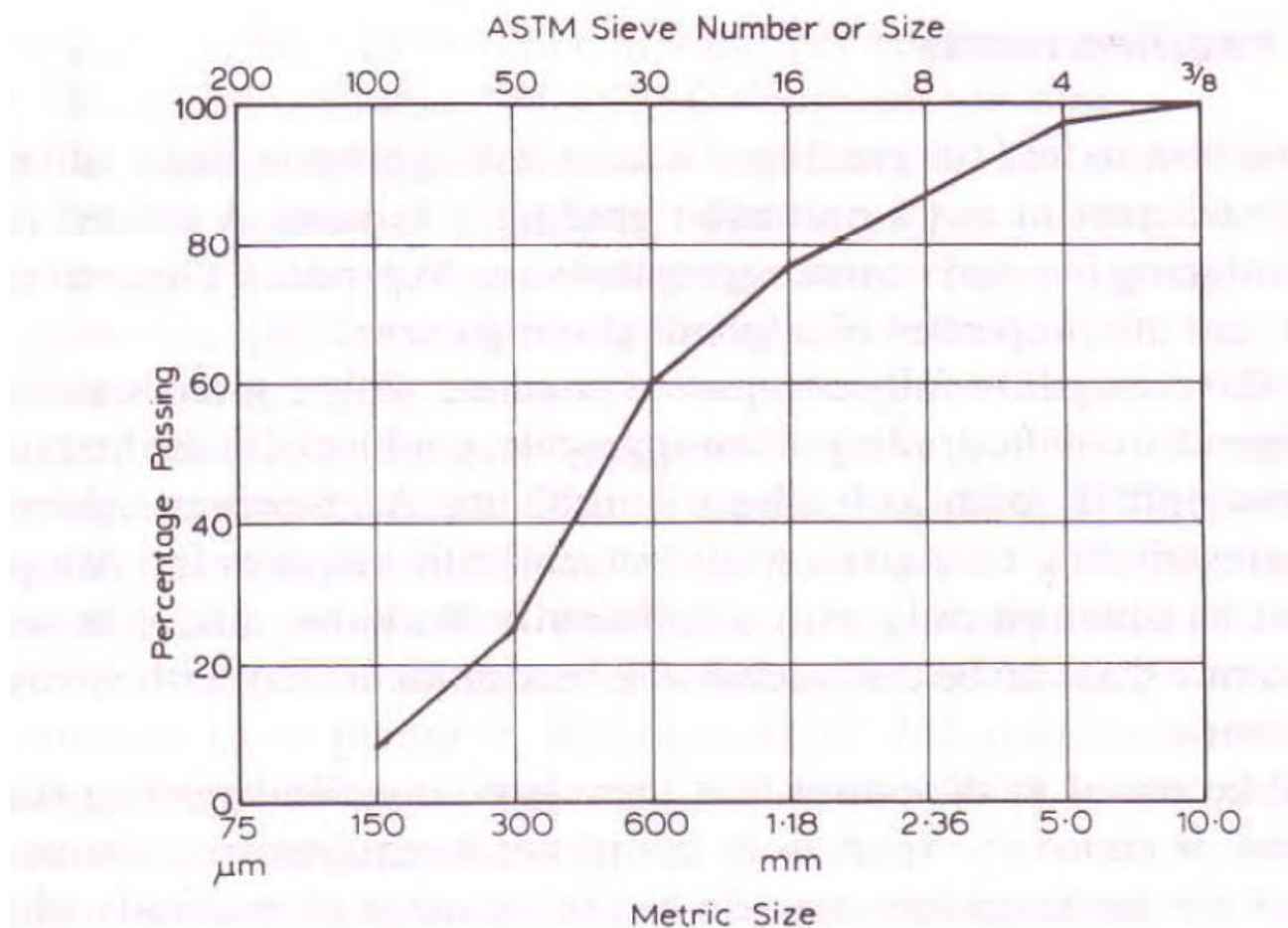
Fineness modulus:

The fineness modulus, defined as 1/100 of the sum of the cumulative percentage retained on the sieves of the standard series from smallest sieve size up to largest sieve size used.

The fineness modulus be looked up on as a weighted average size of sieve, on which the material is retained.

Grading curves and it's Requirements:

In the grading chart commonly used the ordinates represent . abscissa . show the sieve opening plotted logarithmic scale .



0 Example of a grading curve (see Table 3.18)

- The main factors covering the desired aggregate grading are:
 - Workability of mix and the tendency to segregation.
 - The relative volume occupied by the aggregate.
 - The surface area of the aggregate, which determines the amount of water necessary to wet all the solids.

The economic aspect must not be forgotten:

Concrete has not be made of material which can be produced cheaply so that no narrow limits can be imposed on aggregate.

Because the strength of fully completed concrete with a given w/c ratio is in dependent of the grading of the aggregate, grading is, in the first instance, of importance only in so far as it affects workability

Requirements of workability and absence of segregation tend to be partially opposed to one another, the easier it is for particles of different sizes to pack smaller particles passing into the voids between the large particles.

When the considers the surface area of the aggregate particles. The w/c ratio of the mix is generally fixed from strength consideration at the same time, the amount of the fresh cement paste has to be sufficient to cover the surface of all the particles so that the lower the surface area of the aggregate the less paste, and therefore the less water, is required.

Increase in maximum size of aggregate —————> led to decrease in specific surface —————> the water requirement decreases.

Four curves are shown for each maximum size of aggregate but, due to the presence of over. and under – size aggregate and also because of variation within any fraction size practical grading are more likely to lie in the vicinity of these zones, and these are marked on all diagram .

Curve No. 1:

- Represent the coarsest grading.
- Such a grading is comparatively workable.
- It can be used for mixes with a low water cement ratio.

It is necessary to make sure that segregation does not take place.

Curve No.4 :

- Represents a fine grading.
- It will be cohesive but not very workable.

*if the same workability is to be obtained (have the same aggregate / cement ratio) using aggregates with grading curve No 1 and 4. The latter would require a considerably higher water content this would mean a lower strength.

*If the same strength is required, the concrete made with the finer aggregate would more cement than when the coarsest grading is used.

The change between the extreme grading is progressive. In the case of gradings lying partly in one tone party in another, there is, however, a danger of segregation when too many intermediate size are missing (gap grading). If on the other hand, there is an excess of middle size aggregate, the mix will be harsh and difficult to compact by hand and possibly even by vibration. For this reasons, it is preferable to use aggregate with grading similar to type, rather than totally dissimilar ones.

Sieve size seives Bs .882:1973	Percentage by mass passing			
	Zone(1)	Zone(2)	Zone(3)	Zone(4)
9.5mm	100	100	100	100
4.75mm	90-100	90-100	90-100	95-100
2.36mm	60-95	75-100	85-100	95-100
1.18mm	30-70	55-90	75-100	90-100
600mm	34-15	35-59	60-79	80-100
300mm	5-20	8-30	12-40	15-50
150mm	0-10	0-10	0-10	0-15

Factors Affecting workability:***1. Water content in the mix :***

Mixed water (Kg/m^3) is considered as the main factor affecting for the workability. There is directly proportion in the stability of maximum size of aggregate.

In the case of maximum size of aggregate decrease (surface area increasing) the quantity of need water increasing.

2. Proportional quantity of cement paste and aggregate :

Workability increases become better when increases the ratio of cement paste to aggregate become this will permit the cement paste to cover most granules better which will decrease the friction between these granules and will decrease the needed work for mixing .

3. Fineness of cement :

The increase of cement fineness will increase the workability to a specific limit but the costs of increasing fineness may be high and does not suit with the increasing of workability.

4. Grading of aggregate :

It is necessary to use the aggregate grading so we have the highest density and with a reasonable amount of work. This can be done when the little granules overlaps with the spaces of the big granules. According to that, every zone of the suggested grading zones in qualifications has its limits workability which suits with the suggested grading. According to some researches, it was suggested to consider fineness modulus for aggregate as standard for concrete mixture work degrees.

5. Shape of aggregate :

The round shape of aggregate particles make the concrete mixture easy to be worked and need less water content, while using aggregate particles that the ratio of its surface area to its size high will cause to decrease in workability and cause increase in the mixture water demands .

6. Surface texture of aggregate :

The increase in touch roughness of the surface texture of aggregate will cause increase in the surface area of aggregate which may make the cement paste in

sufficient to cover all the surface of aggregate. Also, the increase of roughness will case increase in internal friction between the aggregate particles which may lead to increase the work needed to mix the concrete ingredients (decrease the workability of concrete mixture).

7. Using minerals admixture :

Mineral addition which had a high degree of fineness. Addition of this material to concrete mixture will be help to decrease the friction between the concrete ingredients will be lead to improve the workability of the mixture. Some examples of these additions are silica fume, crushed limestone, and rice husk ash.

8. Using air entraining addition :

Using such materials may cause tiny air ball bubbles creation. These bubbles walk like water bubbles and like granules of sand inside the mixture which will increase the workability. By using these materials we can decrease the water content of the mixture.

9. Time and Temperature Effects:

Concrete may loss its plasticity with time and its workability may decrease because:

- a. Absorption apart of mixing water by the aggregate.
- b. Evaporation some mixing water especially when it expose to wind and increases in environment temperature
- c. Combined part of the free water in chemical reactions (by hydration of cement).

The relationship between mixture workability and environment temperature is opposite, there for, in the hot days, mixing water must be increased to much the required work to fix (remain) the state of the concrete workability.

Segregation:

It is a process of mixture element separation which is not homogeneous in its structure so its distribution is not organized.

Some of the reasons of that is:

1. The high difference in the granules measurement (particle size of aggregate) and the specific gravity of the concrete contents.
2. Using wrong methods of handling.

Most important types of segregation:

4. Some of the rising water restricted under the aggregate particles and arming steel rein for cement which cause some leak point in the bonding .
5. Rising water may take some fine particles of cement creating a layer of laitance which must be removed for its weakness. Also this process may be cause small open channels inside the body of concrete mixture which lead to decrease its strength.

The important factors for concrete capability for bleeding are:

1. Bleeding decreases by increment of fineness of cement
2. Bleeding may decrease by adding alkalis and A_3C in cement or when adding $CaCl_2$.
3. Bleeding increases by increment of temperature but the total bleeding will remain stable.
4. The increment of sand quantity, especially the particles that is smaller the 0.15 will decrease from the bleeding in the concrete.
5. Using Pozzolana and air entraining admixture will decrease the bleeding of the concrete.

Mixing Concrete:

Isa process of mixing the concrete contents in a way that guarantees the homogeneity in constitution and all aggregate particles must be covered by the cement paste at the end of mixing process.

There are two types of mixing:

1. Manual Mixing:

Which is used for small and unimportant businesses. The mixture in this method is not homogenous and need for a lot of care and work. Mixing process contains mixing aggregate on a clean plan then cement will be added and these elements have to be combined for at least 3 times. After that, a hole has to be made in the center of the mixture and addition of water. The water must be not allowed to go out of the mixture.

2. Mechanical Mixing:

Which is the public one in big projects. It uses mechanical mixtures to mix concrete, and the homogeneity of the mix depends on the way of deflection and the mixing time

Time Mixing:

- c. Have high velocities.
- 2. *External vibrators*: which is established on the molds and shakes the concrete and the mold. So there is a loss in the work. It's preferred to be used in:
 - a. Little thickness sections (like walls).
 - b. Producing precast concrete.
- 3. *Vibrator table*: Molds of concrete are putted on its surface and there is also lose in the efforts. These vibrators are:
 - a. Producing pre-cast concrete.
 - b. In the laps.
- 4. *Other types such as*:
 - a. Surface vibrators: which is used in compacting mass concrete?
 - b. Vibrating roller: which is used in road jobs.

Re-vibrations of Concrete:

Re-vibrations of concrete were done after putting the concrete and compaction it in the molds but before hardening (about 4 hours). It has been found that best result can be have when vibration is done after (1-2) hours from putting the concrete in the molds so it can be to:

- 1. Decrease the cracks of varying precipitation resulted from aggregate and steel rein for cement.
- 2. Decrease the effects of plastic shrinkage.
- 3. Decrease the effects of bleeding.
- 4. Make better bonding between steel rein for cement and the concrete.
- 5. Increasing strength of concrete mixture.

Hot weather concreting:

Producing concrete in hot weather, the temperature of concrete increases and the average of water evaporation from the concrete is increasing (water of the mix or the water for the curing) which may causing a lot of problem during the process of mixing casting, and curing. Some of these important problems are:

- 1. The increase in hydration and sitting time, which causes a loss in the strength of concrete because of the bad quality of hydration results.
- 2. The occurrence of shrinkage which follow fast evaporation.
- 3. Water evaporation that is used for curing that will decrease of the quality of curing.

The following steps must be doing to reduce the effect of hot weather on concrete mixture.

1. Decrease the amount of cement and cement fineness to control the heat of hydration.
2. Cooling the concrete contents by:
 - a. Using ice with mix water. It's necessary to be sure of melting all the ice before starting mixing.
 - b. Cooling aggregate particles by cold water.
 - c. Cement temperature must not be more over 75 degree centigrade.
 - d. Using wind and direct sunlight protectors.
 - e. Taking care of the curing processes.

In all cases, the temperature of founded concrete must not get over 30 digress centigrade.

Ready-mixed concrete:

Is the concrete that produced in central mixing plants and been moved to the location by deferent ways like track, or transporting belts....etc.

This concrete has many advantages such as:

1. It can be produced by a large quantity.
2. It's prepared in a high quantity control circumstance.
3. It's preferred to be used in the crowded field location so there is no place to accumulate the primary.

The main problem in producing ready mixed concrete is how to keep it's workability till the time of the costing because the concrete will be lose water by evaporation and being hard by time.

Pumped concrete:

Pumped concrete considering as the most using way in transporting concrete by a large quantity weather transporting was from the central factory or from the transporting we hides to the casting place.

The pump it built mainly from a container figure like frustum and a compressor and cylinder pipes to transport concrete.

Some of pumping benefits are:

1. Ability to equip the concrete to places that is distributed in wind areas that is hard to be reach.
2. A voiding handling over the concrete cause it has to be moving directly to the molds.

3. It's useful in the crowded places or in the special places like tunnels.

Pumped concrete has to have some qualifications like:

1. Pumped concrete has to be mixed totally and homogenous before pumping.
2. Mixture have to be rich with cement and a significant ratio of sand
3. No isolation is allowed in the mixture.
4. For poor mixture we have to use an assistant factor to improve the workability.