

Concrete Technology

Lecture # 1

Manufacturing of Portland Cement

Introduction

- Portland cement was invented in 1824 by Joseph Aspdin, an English mason.
- Joseph Aspdin named his patented product as “Portland cement” because it produced a concrete that resembled the color of the natural limestone quarried at Portland in England.

What is cement?

- Cement, any material that hardens and becomes strongly adhesive after application.
- Portland cements are hydraulic cements primarily composed of hydraulic calcium silicates .
- Hydraulic cements set and harden by reacting chemically with water.
- Most of the hydration and strength development take place within the first month of mixing (28 days), but they continue, though more slowly, for a long time.

Raw Materials used in Manufacture of Portland Cement

The raw materials are generally a mixture of calcareous (calcium oxide, CaO) and argillaceous (silica and alumina, SiO₂ and Al₂O₃).

The raw materials used in the manufacture of Portland cement contain appropriate proportions of the following:

Calcium oxide (CaO)

Sources: Limestone, Shale, Marl, Calcite, Argonite, Clay, Chalk, etc.

Function;

- Makes the cement sound and strong
- In excess quantity makes unsound, expand of cement and disintegrate.

Silica (SiO₂)

Sources: Clay, Marl, Shale, Sand, Fly ash, Calcium silicate, etc.

Function;

- It gives strength of cement due to formation of dicalcium and tricalcium silicates.
- In excess quantity- slow set of cement.

Alumina (Al_2O_3)

Sources: Aluminum-ore refuse, Clay, Fly ash, Shale, etc.

Function;

- Provide quick setting property to the cement.
- Lowers the clinkering temperature.

Iron (Fe_2O_3)

Sources: Iron ore, Clay, Shale, etc.

Function;

- Gives color, hardness and strength to cement.
- Helps the fusion of the raw materials during the manufacture of cement.

Magnesia (MgO)

Sources: Limestone, Slag, etc

Function;

- Small quantity, hardness and color
- Excess quantity; makes cement unsound.

Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)

Sources: Calcium sulfate, Gypsum, etc.

Function of Gypsum? In appropriate quantity and in excess quantity?

Alkalis

- Small quantity required
- Excess quantity cause efflorescence.

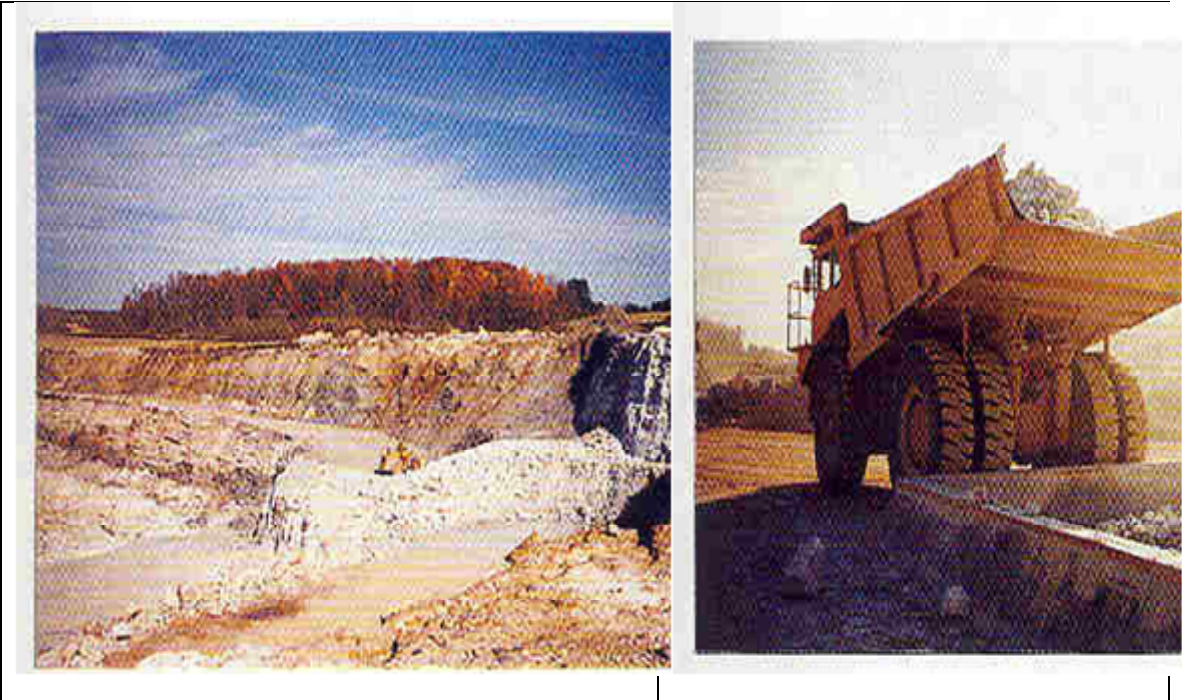
Other minor compounds such as MgO, TiO₂, Mn₂O₃, K₂O and Na₂O not more than few percent of the mass of cement are present. Although minor in quantity but they are relatively important.

Sources of Raw Materials

Table 2-1. Sources of Raw Materials Used in Manufacture of Portland Cement

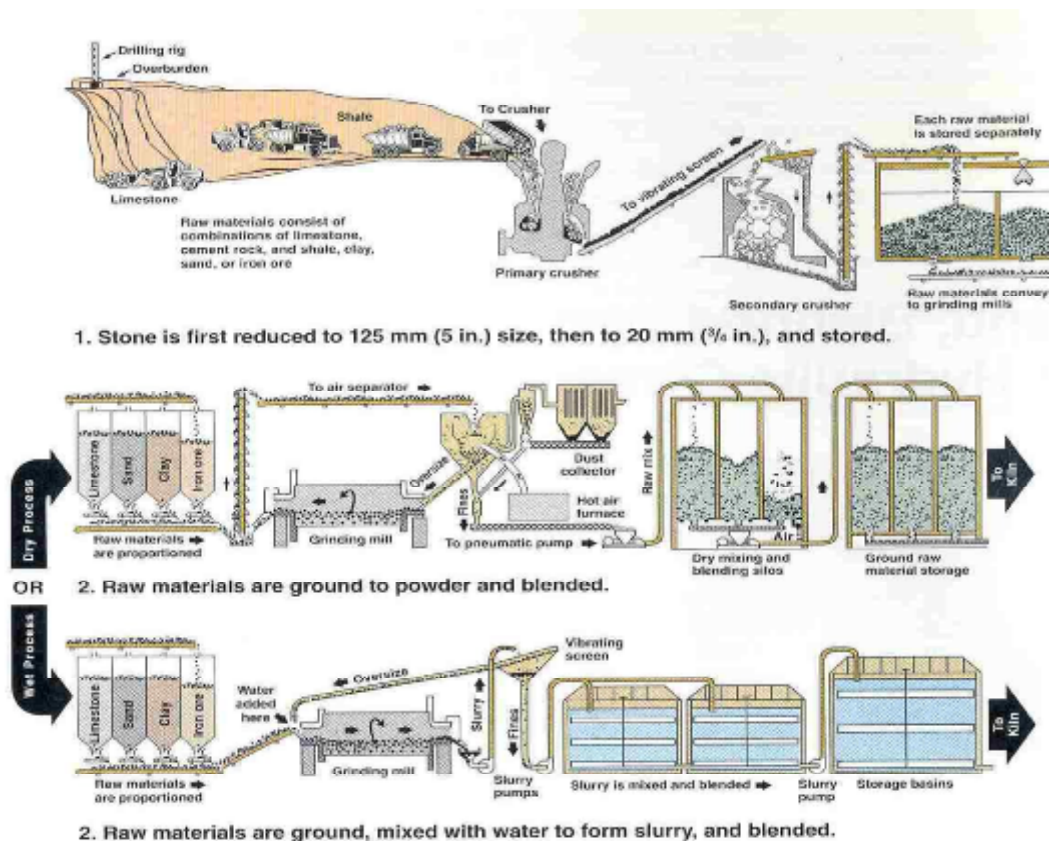
<u>Calcium</u>	<u>Iron</u>	<u>Silica</u>	<u>Alumina</u>	<u>Sulfate</u>
Alkali waste	Blast-furnace flue dust	Calcium silicate	Aluminum-ore refuse*	Anhydrite
Aragonite*	Clay*	Cement rock	Bauxite	Calcium sulfate
Calcite*	Iron ore*	Clay*	Cement rock	Gypsum*
Cement-kiln dust	Mill scale*	Fly ash	Clay*	
Cement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

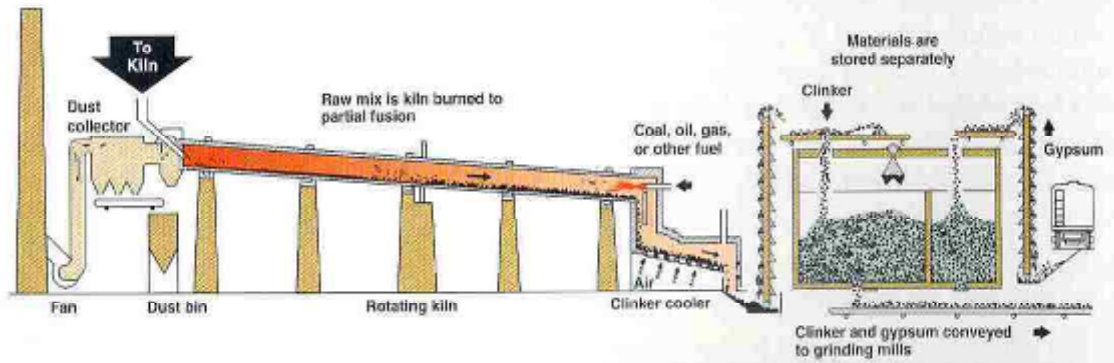
Note: Many industrial byproducts have potential as raw materials for the manufacture of portland cement.
 *Most common sources.



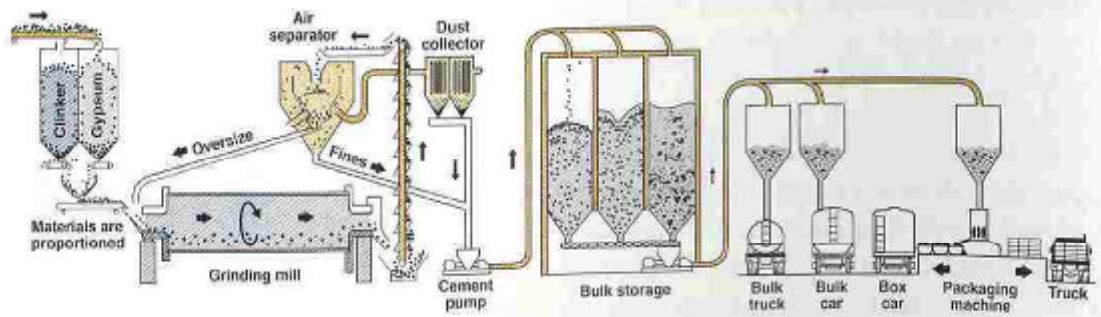
Steps used in Manufacture of Portland Cement

- ❖ Raw materials stones in appropriate proportions are first crushed to 125 mm size, then to 20 mm, and stored.
- ❖ Crushed raw materials are ground to powder and either blended in dry condition (dry process or mixed with water to form slurry, and blended (wet process).
- ❖ Wet process requires more energy and thus it has been replaced by the dry process where the fuel requirements can be decreased.
- ❖ After blending the raw materials the same is sent to a rotating kiln for burning at a temperature in the range of 1350°C to 1450°C.
- ❖ Mixing the raw materials while burning in the kiln lead to the chemical reactions between oxides of the raw materials by fusion, forming cement clinker.
- ❖ The clinker is cooled and then pulverized. During this operation a small amount of gypsum is added to regulate the setting time of the cement and to improve the shrinkage and strength properties.
- ❖ Clinker with gypsum are mixed and ground to a desirable fineness, that passes through a 45 micrometer No. 325 mesh) sieve. This grounded product is the Portland cement.





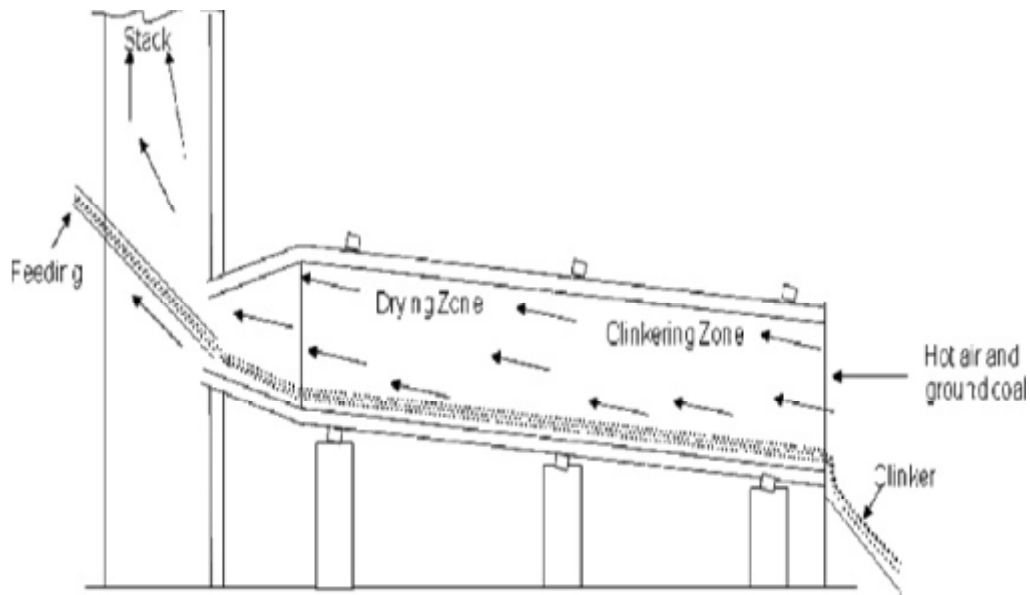
3. Burning changes raw mix chemically into cement clinker.



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

Rotary Kiln (Furnace)





Clinker



The final product of a Portland cement contains the following four chemical compounds:

Tricalcium silicate (C_3S)

Dicalcium silicate (C_2S)

Tricalcium aluminate (C_3A)

Tetra calcium aluminoferrite (C_4AF)

$C = CaO, S = SiO_2, A = Al_2O_3, F = Fe_2O_3$

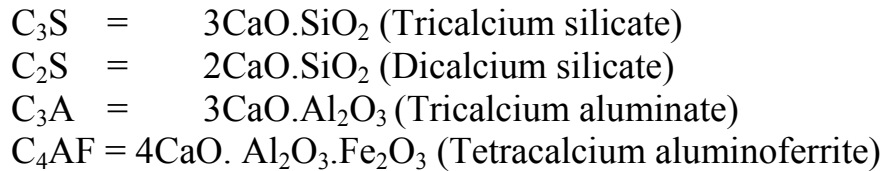


some points to find out

1. When would clay materials losses their water, decomposition?
2. At what temp. does CaO losses its CO_2 ?
3. At what temp. clinkering begins?

Chemical Compounds in Portland Cement

As indicated earlier the burning operation of the raw materials results into the reaction between the oxides and four compound compositions are formed in the final cement product, as follows:



In general:

C_3S Constitutes 50% to 70% of the clinker.
 C_2S Constitutes 15% to 30% of the clinker.
 C_3A Constitutes 5% to 10% of the clinker.
 C_4AF Constitutes 5% to 15% of the clinker.

Role of Compound Composition

1- C_3S

- Hydrates and hardens rapidly and is largely responsible for initial set and early strength.
- Early strength of cement is higher with increased percentages of C_3S .

2- C_2S

- Hydrates and hardens slowly.
- Contributes largely to strength increase at ages beyond one week

3- C_3A

- Liberates a large amount of heat during the first few days of hydration and hardening.
- Also contributes slightly to early strength development.

Gypsum added to the cement slows down the hydration rate of C_3A .

Cements with low percentages of C_3A are especially resistant to soils and waters containing sulfates.

4- C_4AF

- Does not play any significant role on hydration
- Hydration of Cement

Hydration of Cement

- In the presence of water the cement compounds chemically combined with water (hydrate) to form new compounds that are the infrastructure of the hardened cement paste in concrete.
- Both C_3S and C_2S hydrate to form calcium hydroxide and calcium silicate hydrate (CSH). Hydrated cement paste contains 15% to 25% Calcium hydroxide and about 50% calcium silicate hydrate by mass. The strength and other properties of hydrated cement are due primarily to calcium silicate hydrate.
- C_3A reacts with water and calcium hydroxide to form tetracalcium aluminate hydrate.
- C_4AF reacts with water and calcium hydroxide to form calcium aluminoferrite hydrate.
- For all the Portland cement compound hydration reactions see Table 2-5:

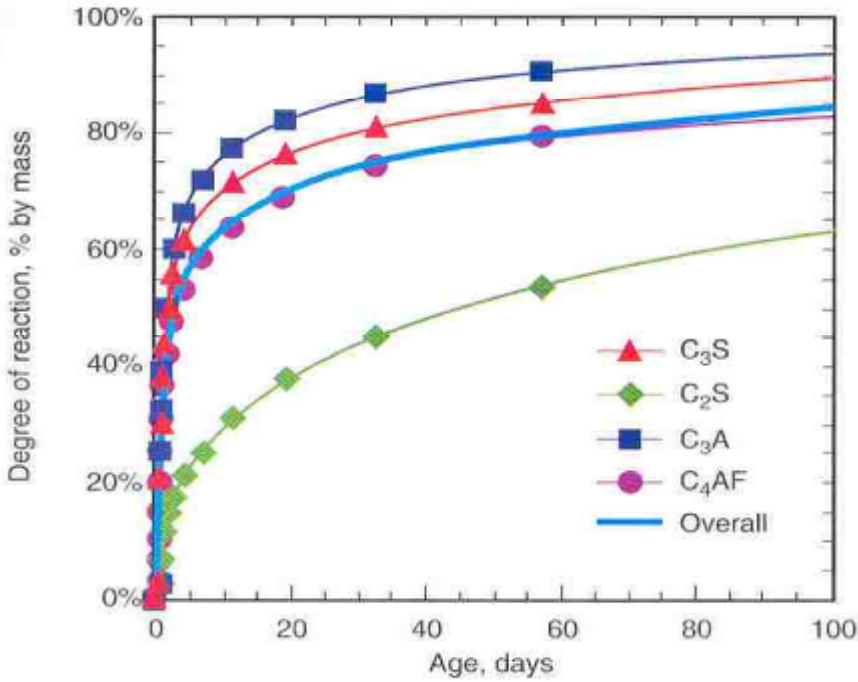
Hydration Reactions

Table 2-5. Portland Cement Compound Hydration Reactions (Oxide Notation)

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

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

Relative Reactivity of Cement compounds



Relative volume of major compounds in hydrated cement paste

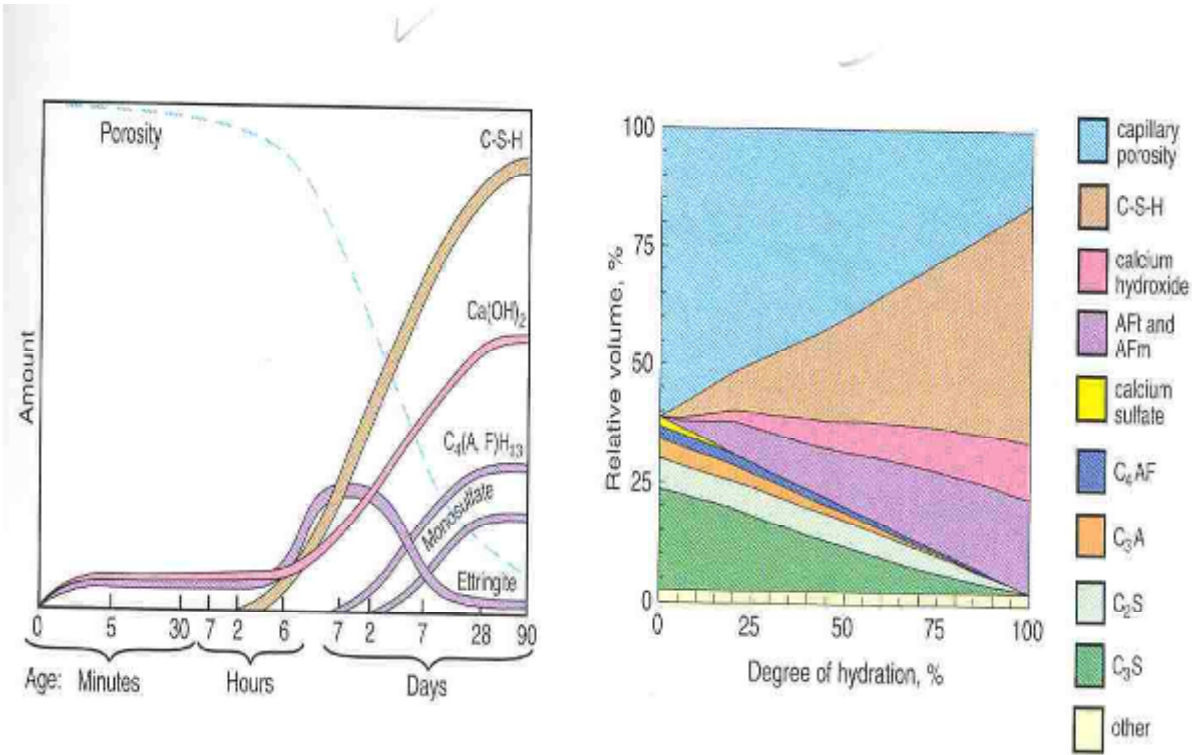
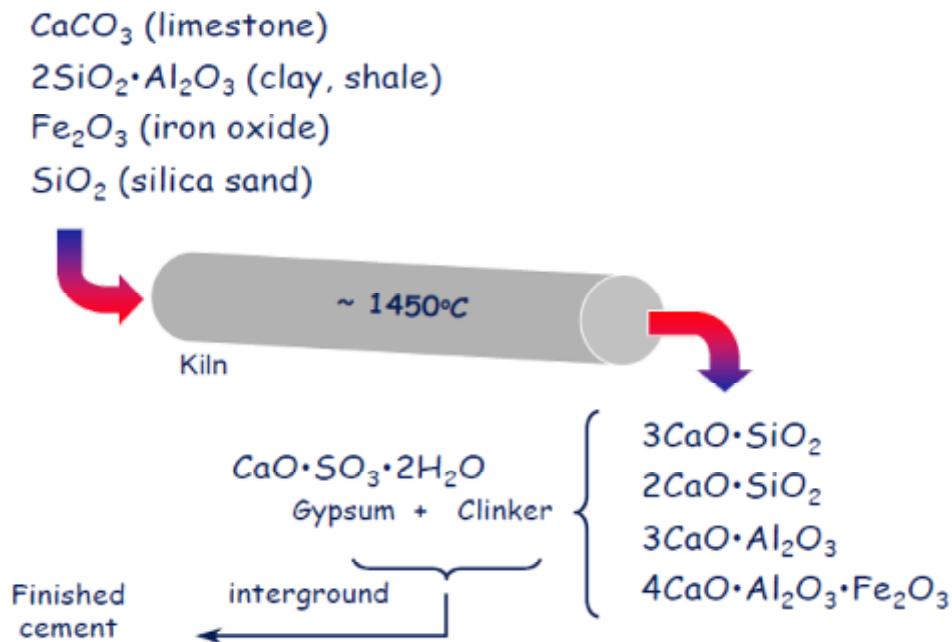


Fig. 2-28 Relative volumes of the major compounds in the hydrated cement paste

Hydration

Cement Composition



Note:

- The degree of cooling clinker affecting its characteristics (rapidly or slowly).
- we use Bogue equations to calculate the percent of the four main compounds
- Also, X-rays diffraction methods are used to calculate these compounds in the lab.

Bogue's Compound Composition •

- $\text{C}_3\text{S} = 4.07(\text{CaO}) - 7.6(\text{SiO}_2) - 6.72(\text{Al}_2\text{O}_3) - 1.43(\text{Fe}_2\text{O}_3) - 2.85(\text{SO}_3)$
- $\text{C}_2\text{S} = 2.87(\text{SiO}_2) - 0.75(3\text{CaO} \cdot \text{SiO}_2)$
- $\text{C}_3\text{A} = 2.65(\text{Al}_2\text{O}_3) - 1.69(\text{Fe}_2\text{O}_3)$
- $\text{C}_4\text{AF} = 3.04(\text{Fe}_2\text{O}_3)$

Significance of Compound Composition

Compound	Mass Percentage		
	Cement 1	Cement 2	Cement 3
C_3S	65	33	73
C_2S	8	38	2
C_3A	14	15	7
C_4AF	4	10	14

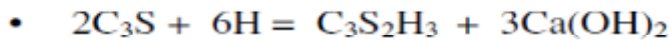
- C_3S represent the largest compound in cement
- C_2S can be found in different forms:
 - αC_2S βC_2S γC_2S
 - at high temp. at less than $1456^\circ C$ at $675\sim^\circ C$
 - βC_2S is the stable form of C_2S during cooling of the clinker.
- ❖ The amount of the main compounds differs from cement to another.
- ❖ We can get different types of cement by altering the amount of raw materials used in cement production.
- ❖ In addition to the main compound there are secondary compounds like:
- ❖ Na_2O , K_2O , MgO , TiO_2 , Mn_2O_3 , SO_3 , these oxides represent small percent of cement weight.
- ❖ K_2O , Na_2O are very important as they called alkalis (0.4 - 1.3 %), these alkalis can be very harmful to concrete as they react with silica found in aggregate within the hardened concrete, and their reaction accompanied with volume increase causing cracking and deterioration of concrete. This problem can be overcome by mixing fine silica powder to react with alkalis before hardening of concrete. Alkaline should not be more than 0.6 %.
- ❖ SO_3 is produced from the added gypsum (2-6 %) to the clinker during grinding. B.S 12 and IS 5 determine SO_3 by 2.5 – 3 % according to C_3A % and type of cement (Ordinary or Rapid hardening).
- ❖ MgO come from raw materials (1-4 %). the max according to the most standards is 5%.

- ❖ MgO is very important as its reaction can be also accompanied with volume increase; the reaction can be very slow and continue until 28 days age of the hardened concrete (or cement past).
- ❖ Other oxides like Mn₂O₃, TiO₂, P₂O₅, are of less important as they form less than 1 % by weight of cement.

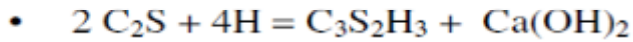
Hydration: is the chemical reaction of cement and water resulting in the formation of new compounds and hardening of cement past.

- ❖ Through hydration, evolution of heat (J/g) and development of compressive and tensile strength within the past to produce a hard and strong binding mechanism for aggregate particles.
- ❖ The rate of hydration depends on the relative properties of silicates and aluminates. Cement fines and the ambient conditions (i.e. temperature and moisture).
- ❖ The release of heat depends on the varying composing of cement mix. This can be explained by noting that the main compounds of cement have different heat of hydration values.
- ❖ The release of heat cause objectionable rises in concrete temperature. About 50% is liberated during 1-3 days, about 75% in 7 days, and nearly 90% in 6 months. Reducing the proportions of C₃A and C₃S can lead to reducing heat of hydration (and its rate).
- ❖ Hydration starts as soon as the cement and water mix.
- ❖ The rate of hydration and heat liberated by the reaction of each compound is different.
- ❖ Each compound produced different product when it hydrates.

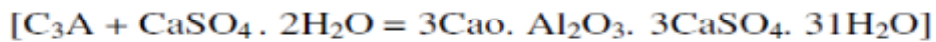
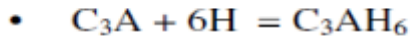
- **Reactions of Hydration**



(100 + 24 = 75 + 49)



(100 + 21 = 99 + 22)



Calcium Sulfoaluminate

- ❖ Both C3S and C2S react with water to produce an amorphous calcium silicate hydrate known as C-S-H gel which is the main (glue) which bind the sand and aggregate particles together in concrete.
- ❖ C3S is the much more reactive than C2S.

Methods of measuring hydration development:-

- 1) The amount of Ca(OH)₂ produced from hydration of silicates.
- 2) Heat liberated through hydration (heat of hydration).
- 3) Specific weight for hydrated cement paste.
- 4) Amount of water combined chemically within cement.
- 5) Amount of unhydrated cement (through using X-ray analysis).
- 6) Indirect through measuring strength of hydrated cement paste.

Hydration of C₃S and C₂S :-

- ❖ Both C3S and C₂S produces calcium silicates hydrates or (Tobermorite gel) with Ca(OH)₂ .
- ❖ C/S (CaO/SiO₂) in tobermorite is different.
- ❖ C3S produces Ca(OH)₂ much more than C2S (almostly 2- times).
- ❖ Since C3S and C2S represent 70% from cement, therefore, properties of the produced cement depends largely on the hydration products for these two compounds.

- ❖ The presence of $\text{Ca}(\text{OH})_2$ leads to high PH values in concrete, hence, protection of steel reinforcement from corrosion in reinforced concrete with sensitivity to acidic materials.
- ❖ بالعودة لمعادلات الاماهة لكلا المركبين والكميات النوعية
- ❖ For C3S [100% + 24% 75%+49%]
- ❖ C2S [100%+21% 99%+22%]
- ❖ C3S needs 24% H₂O to produce 49% $\text{Ca}(\text{OH})_2$ while C2S needs 21% water to produce 22% $\text{Ca}(\text{OH})_2$.

Hydration of C3A and addition of gypsum:-

- Tricalcium aluminates hydrate and harden the quickest. It liberates a large amount of heat almost immediately and contributes to early strength.
- Gypsum is added to Portland cement to retard C3A hydration, without gypsum, C3A hydration would cause Portland cement set immediately after adding water (flash set).
- The reaction of gypsum with C3A forms a layer around C3A particles preventing or delaying the reaction until completion of C3S reaction which is slower than C3A.
- 1) $\text{C}_3\text{A} + \text{CaSO}_4 \cdot 2\text{H}_2\text{O} \rightarrow \text{C}_3\text{A} \cdot 3\text{CaSO}_4 \cdot (30-32)\text{H}_2\text{O}$ Ettringite (calcium sulfo-aluminates with high sulphate)
- 2) $\rightarrow \text{C}_3\text{A} \cdot \text{CaSO}_4 \cdot 12\text{H}_2\text{O}$ Calcium sulfo-aluminates with low sulphate (Monosulphate)
- In case of low C3A in cement, the ettringite would be produced more than monosulphate, therefore, the concentration of SO₃ and calcium will be higher.
- In case of high C3A, monosulphate will be produced earlier.
- The depletion of SO₃ earlier during chemical reactions, ettringite will change to monosulphate.

- *The reaction of C3A and gypsum continue till one of them is depleted, while the reaction of C3S is continue.
- In case of C3A depletion, the sulphates in gypsum or the exceeded gypsum will lead to tear up the cement paste.
- In case of gypsum depletion, C3A continue in reaction and produce the stable form C3AH6
- $C_3A + 6H \rightarrow C_3AH_6$
- If C3A is available before formation of stable C3AH6 , and exposed to sulphates in ground water or soil, then calcium sulfo-aluminate will produced and the reaction is accompanied with volume increase, cracking and deterioration of concrete.
- The reaction of C3A is undesirable and its effect on strength is at early age (1-3) days, but, it work as catalyst for fusion in cement industry (reduce the required heat in kiln).
- The optimum rate of gypsum is very important and necessary to regulate the reactions in early ages.
- The depletion of gypsum and continuous reaction of C3A with small quantities of water is required.

Gypsum added to cement will be increased when:-

- a) Percent of C3A in cement is increased.
- b) Alkalis in cement increased.
- c) Fineness of cement is high which lead to high surface area of C3A exposed to reaction.

Hydration of C4AF:-

- C4AF also works as catalyst for fusion and speed up the reactions of the silicates.
- C4AF also react with gypsum but in different manner to C3A.

Structure of hydrated cement:

Mechanical properties of hardened cement and concrete depend on:

- a) Chemical composition of hydrated cement.
- b) Physical structure of hydration products.

Fresh cement paste is a plastic network of cement particles in water, but the paste has set its apparent or gross volume remains approximately constant.

At any stage of hydration, the hardened paste consist of :

- 1) Crystals of Ca(OH)_2 .
- 2) Some minor components.
- 3) Unhydrated cement.
- 4) Residue of the water-filled space in the fresh paste.

There are two types of pores in hydrated paste:

- 1- Capillary pores; within the fresh cement paste
- 2- Gel pores; within the gel itself.

During hydration process:

- 1) Surface area of the solid products of hydration increases.
- 2) Large amount of free water becomes adsorbed on this surface.
- 3) If no water movement to or from the cement paste is permitted, the reactions of the hydration use up the water until too little is left to saturate the solid surfaces.
- 4) The relative humidity within the paste decreases, this known as self-desiccation.
- 5) Since gel can form only in water-filled space, self-desiccation leads to a lower hydration compared to moist cured paste.
- 6) In self-desiccated paste with water to cement ratios(w/c) in excess of 0.5, the amount of mixing water is sufficient for hydration to proceed at the same rate as when moist-cured.

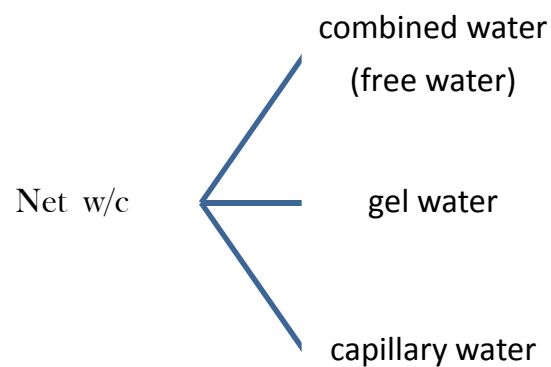
Porosity:-

Total w/c ratio : contains water used for

- ✓ hydration
- ✓ Absorption
- ✓ Evaporation

Net w/c contains water used only for hydration .

Net w/c takes 3 forms



*Pores in concrete causes stress concentration and so, lower strength.

*Pores in cement paste can be classified as :

- a) gel pores
- b) capillary pores
- c) air entrapped

* A measure of pores is porosity, which is relative pores or voids in cement paste.

* Capillary pores :(empty pores)

- ❖ 18.5% of dry cement volume (fully hardened, no excess water)
- ❖ Capillary pores might be :

- | | | |
|-----------------------------------------------------------------------------------------------|---|------------------------------------------------------------------------------------------------------|
| <ol style="list-style-type: none"> 1. Empty of water 2. Full of water | } | Depending on quantity of original mix and weather the addition of water can ingress during hydration |
|-----------------------------------------------------------------------------------------------|---|------------------------------------------------------------------------------------------------------|

Notes;

- ✚ Capillary pores and gel pores are always exist in concrete.
- ✚ Compacting is done not to reduce theses pores but to reduce air entrapped voids.
- ✚ Specific gravity of dry cement = 3.15.
- ✚ Increasing w/c ratio will increase capillary pores.
- ✚ Min. w/c ratio necessary for full hydration 0.4, when the paste is cured under water (we always have to determine the min w/c).
- ✚ When the paste is uncured (sealed) cement paste requires larger min. w/c because we need the capillaries to contain water not only for chemical reactions, but also to ensure a sufficiently internal relative humidity.
- ✚ Volume of hydrated cement is larger than the volume of cement before hydration (due to the presence of pores).

Capillary pores:

Capillary pores: represent the space between hydration products and any stage of hydration process.

- 🌐 Capillary pores affect both durability and strength especially if they were connected.
- 🌐 Interconnected capillary pores are very dangerous on strength and durability.
- 🌐 Segmenting capillary pores is done by providing enough degree of hydration (we do the curing process and not by adding more water because it will increase porosity).
- 🌐 Volume of C.P decreases with proceeding of hydration process.
- 🌐 Volume of hydration products is double the volume of the original dry cement (and may be more).

Capillary pores depend on :

1. W/c ratio for the mix; increasing w/c increases C.P because beyond specific limit of w/c the gel will not be enough to fill the spaces in cement paste.
 2. Degree of hydration; this depends on all factors affecting hydration.
- ❖ C.P are very small, and responsible for hardened concrete.
 - ❖ Continuous hydration process leads to more production of gel, hence, C.P. will be closed or disconnected (until specific limit of w/c beyond which the gel solve the problems).

Gel Pores :

Are interconnected pores within gel particles and can hold evaporable water.

- ✚ Gel pores do not affect the durability as they are very small (only affect strength).
- ✚ G.P. are smaller than C.P.
- ✚ Do not depend on w/c in the mix, but on the type of used cement to a large degree.
- ✚ Do not depend on proceeding of hydration process.
- ✚ The reason for the above because, gel products are similar to each other, and proceeding of hydration do not affect these products type and composition.
- ✚ With increasing hydration rate, volume of gel increases (because hydration products occupy double volume of dry cement , therefore, volume of C.P decreases as they represent the space empty of hydration products.

Water in hydrated cement paste:

Water held in hydrated cement paste can be classified into:

1. Evaporable water; which is the water in C.P. and some water in gel pores.

Evaporable water can be measured by calculating the loss in weight during drying of hydrated cement paste to equilibrium.

2. Gel water; water held physically (adsorbed) between solid products of hydration. It is non-evaporable amount of water = 28% volume of cement gel.

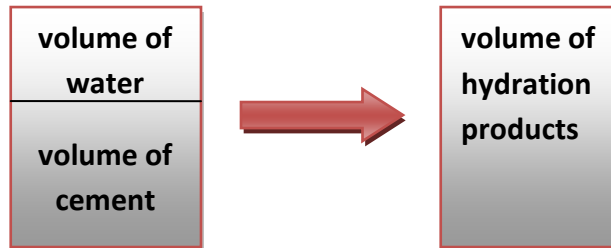
Gel water  gel pores (very small)

Cement gel (hydrated cement) consist of:

- a. Solid products of hydration
 - b. Gel water
3. Combined water; water combined chemically or physically with the products of hydration. It is non- evaporable water. In fully hardened 23% of the mass of dry cement.

Volumes of Hydration products:-

Volume of hydration products = volume of cement+ volume of water



Note: the amount of water lost in bleeding or plastic shrinkage will be ignored.

The volume of combined water (non-evaporated water) will be calculated by:-

$$W_{cw} = 0.23 * \text{weight of cement (dry)}$$

W_{cw} : weight of combined water = volume of combined water

V_c = volume of cement

V_w = volume of water

V_{sp} = volume of solid products

V_{gw} = volume of gel water

V_g = volume of gel

V_{cw} = volume of combined water

V_{uc} = volume of unhydrated cement

V_{cp} = volume of capillary pores

V_{wcp} = volume of water filled C.P

V_{ecp} = volume of empty capillary pores

W_c = weight of cement

W_w = weight of water

❖ hydration products occupy volume double of that for dry cement (unhydrated) but less than the sum of cement volume and volume of combined water by 0.254 from the volume of non- evaporable water.

$$\begin{aligned}V_{\text{sp}} &= V_c + V_{\text{cw}} - 0.254 V_{\text{cw}} \\ &= V_c + V_{\text{cw}} (1 - 0.254) \\ &= \frac{W_c}{3.15} + 0.23 W_c (1 - 0.254)\end{aligned}$$

$$V_g = V_{\text{sp}} + V_{\text{gw}}$$

$$V_{\text{gw}} = 0.28 V_g$$

$$0.28 = \frac{V_{\text{gw}}}{V_g} = \frac{V_{\text{gw}}}{V_{\text{gw}} + V_{\text{sp}}}$$

Example (1)

calculate the volumes of hydration products for mix contain (100 mg) cement and (42 ml) of water, knowing that the hydration process occur inside tube (closed) and there is no movement to or from the tube ?

Solution:

$$V_{\text{sp}} = V_c + V_{\text{cw}} (1 - 0.254)$$

$$V_c = \frac{W_c}{3.15} = \frac{100}{3.15} = 31.8 \text{ ml}$$

$$V_{cw} = 0.23 * W_c = 0.23 * 100 = 23 \text{ ml}$$

$$V_{sp} = 31.8 + 23 (1 - 0.254) = 48.9 \text{ ml}$$

$$0.28 = \frac{V_{gw}}{V_g} \longrightarrow 0.28 = \frac{V_{gw}}{V_{gw} + V_{sp}} \longrightarrow V_{gw} = 19 \text{ ml}$$

$$V_g = V_{sp} + V_{gw} \longrightarrow V_g = 48.9 + 19 = 67.9 \text{ ml}$$

$$V_{cp} = V_c + V_w - V_{sp} - V_{gw}$$

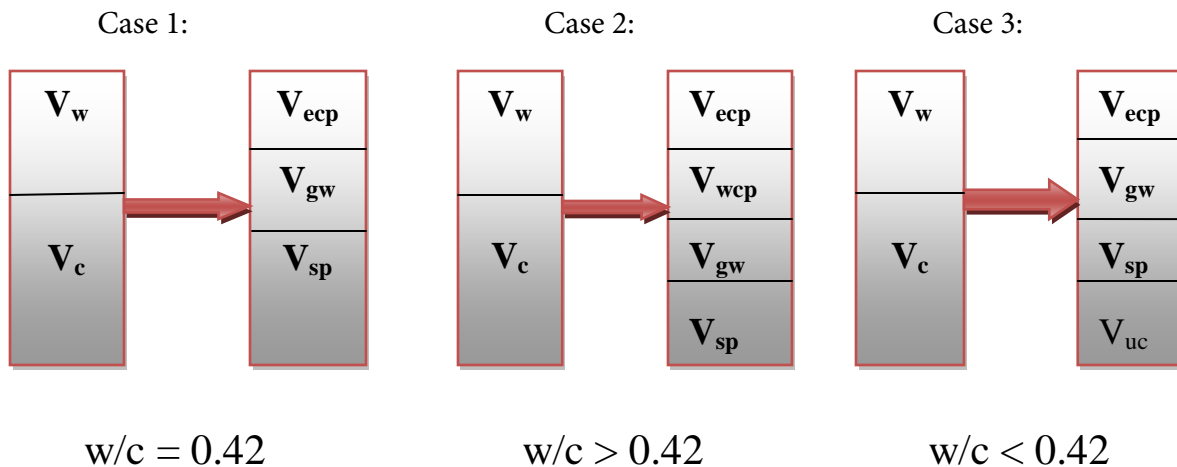
$$= 31.8 + 42 - 48.9 - 19 = 5.9 \text{ ml}$$

$$V_{cp} = V_{wcp} + V_{ecp}$$

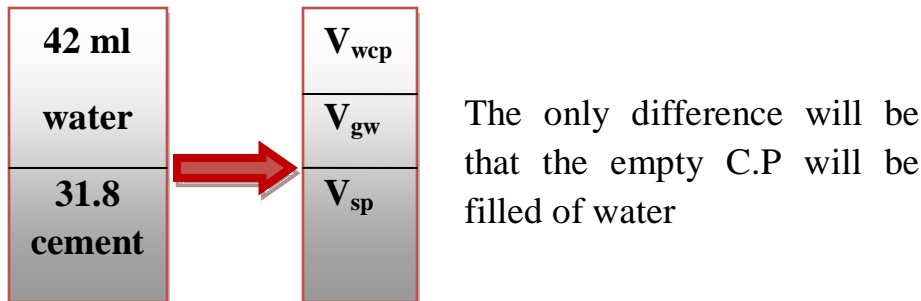
$$V_{wcp} = V_w - W_{cw} - V_{gw} = 42 - 23 - 19 = 0$$

$$\therefore V_{cp} = V_{ecp} = 5.9 \text{ ml}$$

- This means that for $w/c = 0.42$ then cement and water will be fully hydrate and there will be no excess water in capillary pores, hence, no dry cement (unhydrate cement) in closed media.
- If w/c is less than 0.42, the water will be not enough for full hydration and the hydration process stop.
- For sealed specimen :-



- For open media (movement of water is permitted to or from the tube).



Example (2):

Calculate the volumes of hydration products for a mix consist of 100 mg cement and 30 mg water, in closed media?

Solution. :-

$w/c = 30/100 = 0.3 < 0.42$ this means that cement will not be fully hydrate

assume the amount of hydrated cement is X

$$V_{sp} = V_c + V_{cw}(1-0.254)$$

$$= X/3.15 + 0.23 * X(1-0.254) = 0.49X$$

$$0.28 = 0.28 = \frac{V_{gw}}{V_{gw} + V_{sp}} = \frac{V_{gw}}{V_{gw} + 0.49x}$$

$$V_{gw} = 0.19X$$

$$V_w = V_{cw} + V_{gw} + V_{wcp}$$

$$30 = 0.23X + 0.19X + 0$$

$$30 = 0.42X$$

$$X = 71.5 \text{ gm}$$

$$\text{Volume of hydrated cement} = 71.5/3.15 = 22.7 \text{ ml}$$

$$V_{gw} = 0.19 * 71.5 = 13.5 \text{ ml}$$

$$V_{sp} = 0.49 * 71.5 = 35 \text{ ml}$$

$$V_{uc} = 31.8 - 22.7 = 9.1 \text{ ml}$$

$$V_{cp} = V_c + V_w - [V_{uc} + V_{sp} + V_{gw}] \quad (\text{closed media and the amount of water is not enough for hydration of all cement})$$

$$\text{So; } V_{cp} = V_{ecp} = 61.8 - [9.1 + 35 + 13.5] = 4.2 \text{ ml}$$

$$V_g = V_{sp} + V_{gw} = 35 + 13.5 = 48.5 \text{ ml}$$

Concrete Technology
Subject: Properties of Cement
And Physical Tests on Cement
Paste

Objectives of Lecture

To explain briefly the properties of Portland cement.

The quality of a Portland cement is assessed in terms of different physical properties determined through the laboratory tests on the cement samples collected in accordance with ASTM C 183.

- **1. Fineness**
- **2. Soundness**
- **3. Consistency,**
- **4. Setting time**
- **5. Compressive Strength**
- **6. Tensile strength test**
- **7. Heat of Hydration**
- **8. Loss on Ignition (LOI)**
- **9. Density and Specific Gravity (ASTM C 188)**

Storage of Cement

1. Fineness

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

95% of cement particles are smaller than 45 micrometer, with the average particle around 15 micrometer.

Fineness, or particle size of Portland cement affects Hydration rate and thus the rate of strength gain. The smaller the particle size, the greater the surface area-to-volume ratio, and thus, the more area available for water-cement interaction per unit volume. The effects of greater fineness on strength are generally seen during the first seven days.

When the cement particles are coarser, hydration starts on the surface of the particles. So the coarser particles may not be completely hydrated. This causes low strength and low durability.

Fineness of cement affects heat released and the rate of hydration. More is the fineness of cement more will be the rate of hydration.

Thus the fineness accelerates strength development principally during the first seven days.

Fineness of cement is also important; it affects:

1. rate of hydration
2. rate of setting
3. rate of hardening
4. durability (ASR)
5. rate of carbonation during storage
6. cost
7. rate of gypsum addition
8. bleeding

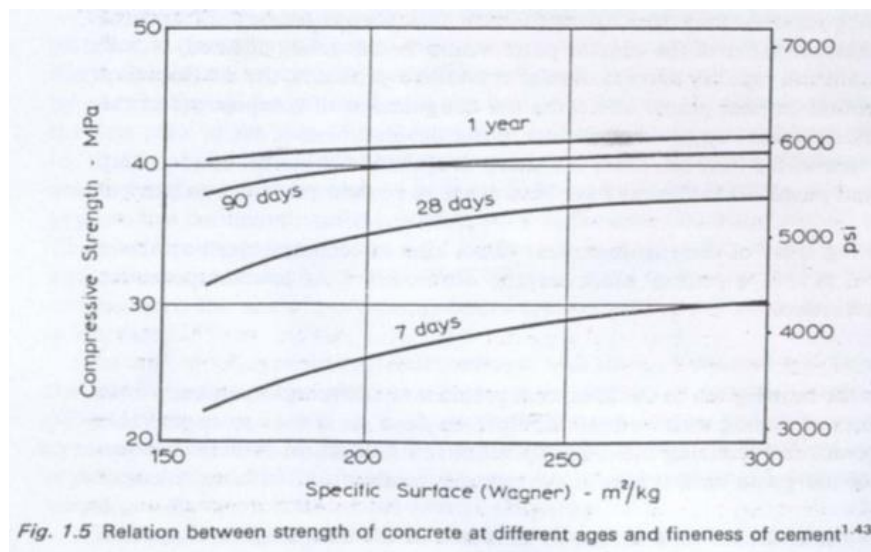
• However, later strength is not directly affected.

- Fineness tests indirectly measures the surface area of the cement particles per unit mass :
 - Wagner turbidimeter test (ASTM C 115).
 - Blaine method this method is adopted by both BS and IQS. The specific surface area is measured through measuring time required to pass limited amount of air through layer of cement with specific porosity . IQS recommend that the fineness of ordinary portland cement should not be less than 2300 cm²/gm and for sulfate resistance cement 2500 cm²/gm.

Sieving using No. 325 (45 μm) sieve (ASTM C 430). This test do not give accurate results about size of particles that are smaller than sieve size and these are of importance role in early hydration process, and if we use smaller sieves the openings will be closed by the large cement particles. This method is very rarely used in cement fineness.

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.



Fineness Testing

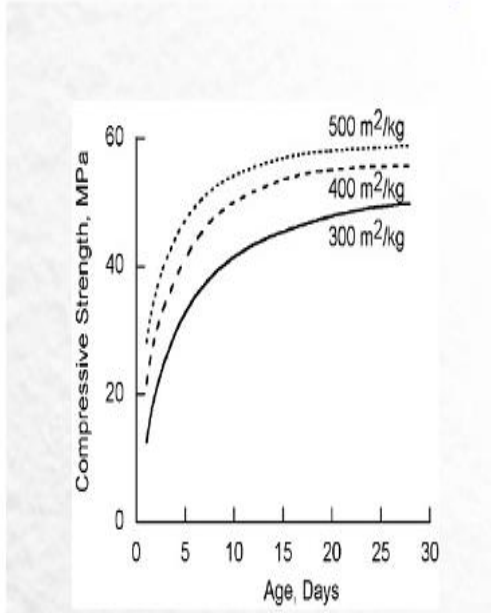
Blaine test apparatus.



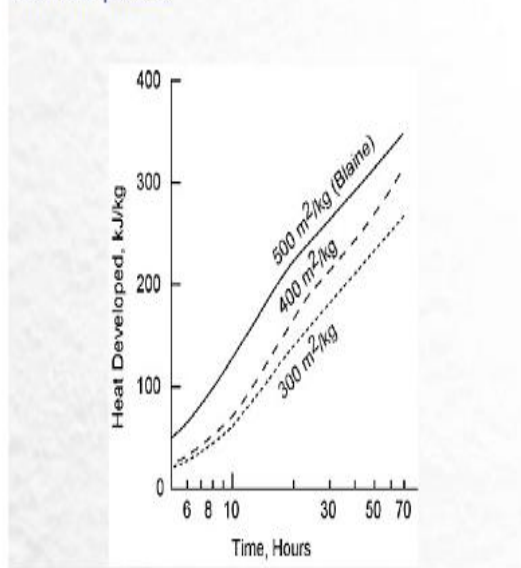
Wagner turbidimeter



Influence of cement fineness on strength



Influence of fineness on heat development in cement pastes



2. Soundness

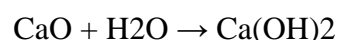
- Soundness is the ability of a hardened paste to retain its volume after setting.
- A cement is said to be unsound (i.e. having lack of soundness) if it is subjected to delayed destructive expansion.
- Unsoundness of cement is due to presence of excessive amount of hard-burned free lime or magnesia

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.

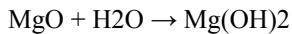
Causes of expansion 1- Free lime CaO

- 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.



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.



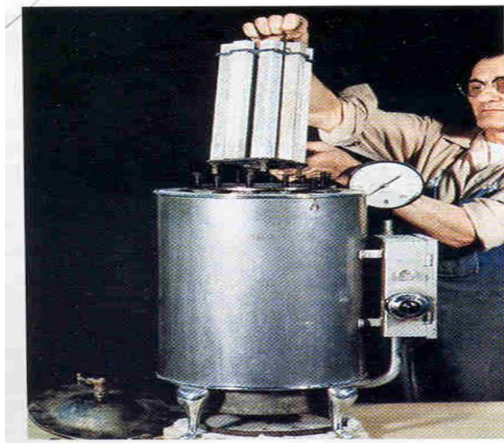
- Up to about 2 per cent of periclase, (by mass of cement) combines with the main cement compounds, but excess periclase generally causes expansion and can lead to slow disruption

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 C3A during setting, unsoundness is in the form of a slow expansion will result.

Test Soundness

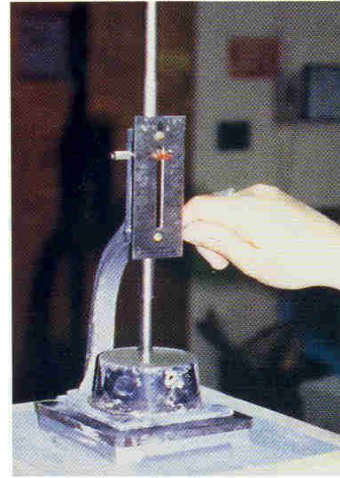
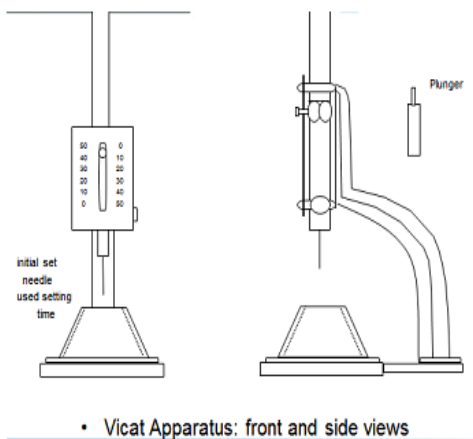
- Unsoundness of a cement is determined by the following tests:
 - Le-Chatelier accelerated test (BS 4550: Part 3)
 - Autoclave-expansion test (ASTM C 151)



3. Consistency

- Consistency refers to the relative mobility of a freshly mixed cement paste or mortar or its ability to flow.
- Normal or Standard consistency of cement is determined using the Vicat's Apparatus. It is defined as that percentage of water added to form the paste which allows a penetration of 10 ± 1 mm of the Vicat plunger.
- The consistency is measured by the Vicat apparatus using a 10mm diameter plunger. A trial paste of cement and water is mixed and placed in the mold having an
- inside diameter of 70mm at the base and 60mm at the top, and a height of 40mm.
- The plunger is then brought into contact with the top surface of the paste and released. Under the action of its weight the plunger will penetrate the paste. The depth depending on the consistency.
- The water content of the paste is expressed as a percentage by weight of dry cement. The usual range of values being between 26% and 33%.

Vicat Plunger Consistency Test



4. Setting

- **Setting time**
- **The setting time test is conducted by using the same Vicat apparatus, except that a 1mm diameter needle is used for penetration.** •
- The test is started about 15 minutes after placing the cement paste (which has normal consistency) into the mold. Trials for penetration of the needle are made. •
- The final setting time is defined as the length of time between the penetration of the paste and the time when the needle (with annular ring) no longer sinks visibly into the paste.
- The initial setting time is defined as the length of time between the penetration of the paste and the time when the needle penetrates 25mm into the cement paste.

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 C3A and C3S.

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 C3S 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

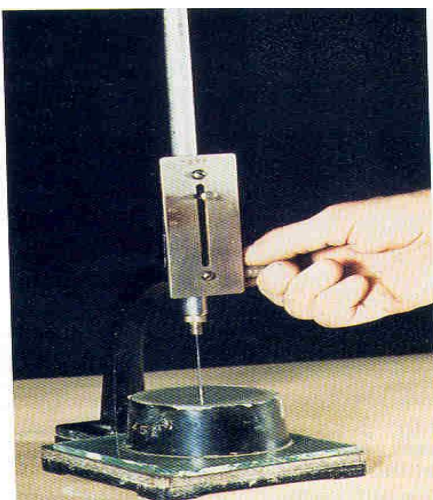
.Final setting time – refers to the beginning of hardening and gain of strength

Iraqi Standard Specification No. 5 limits: - Initial setting time not less than 45 minutes. - Final setting time not more than 10 hours.

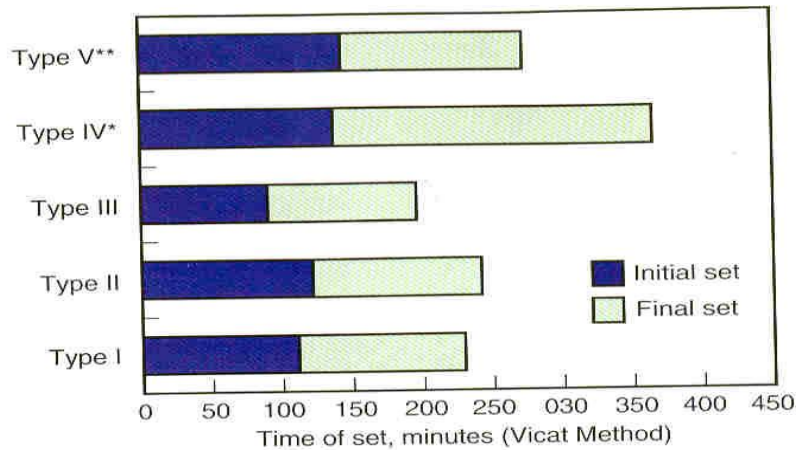
- **Factors affecting the setting**
- **1- Water/cement (w/c) ratio** – The setting time of cement increases with the increase of w/c ratio.
- **2- Temperature and relative humidity** - The setting time of cement decreases with a rise in temperature and decrease of relative humidity.
- **3- Fineness 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 C3S to form CaCO_3 . This precipitates and induces a rigidity of the paste.
 - K_2O or $\text{Na}_2\text{O} + \text{CO}_2 \rightarrow \text{K}_2\text{CO}_3$ or Na_2CO_3
 - K_2CO_3 or $\text{Na}_2\text{CO}_3 + \text{Ca}(\text{OH})_2 \rightarrow \text{CaCO}_3$
- **3- Activation of C3S 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 C3A 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.

Vicat Needle



Time of Set for Portland Cements

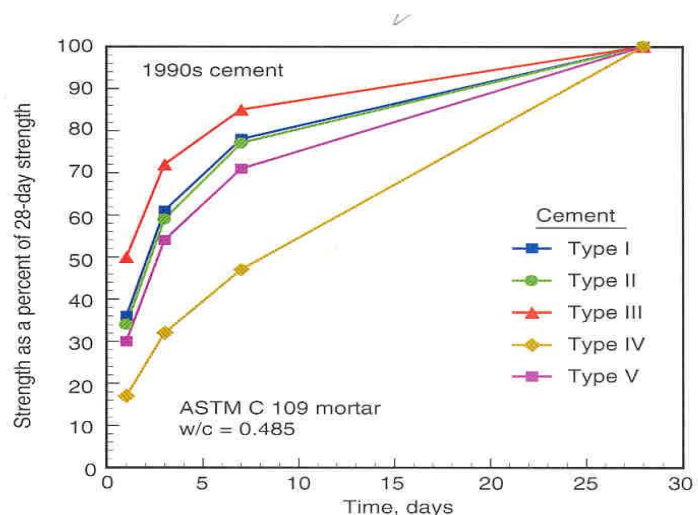


5. Compressive Strength

- Compressive strength of cement is the most important property.
- Cement paste strength is typically defined in three ways: compressive, tensile and flexural. These strengths can be affected by a number of items including: water/cement ratio, cement-fine aggregate ratio, type and grading of fine aggregate, curing conditions, size and shape of specimen, loading conditions and age.
- It is determined by compression tests on standard 70.7 mm mortar cubes in accordance with IQS 5 and (50 mm cubes according to ASTM C 109).
- This test is conducted using standard sand.
- Compressive strength of 3 days \geq 15 Mpa
- Compressive strength of 28 days \geq 23 MPa
- The compressive strength test is conducted on mortar cubes.. After finding the breaking load in compression, P, Compressive Strength is calculated by the relation

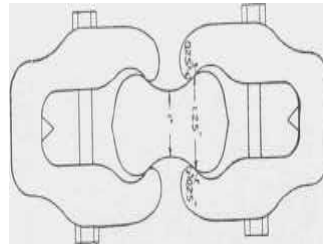
$$\sigma_c = P_{\max} / A, \text{ where } A = 50\text{cm}^2$$

Strength
Development of
PC mortar cubes



6. Tensile strength test

- This test includes a method to specify tensile strength of rapid hardening cement at 1 day age using molds with (number 8) shape. In this test 6 samples are prepared with 1:3 (cement:sand) mix using standard sand. IQS no.5 specifies tensile strength for rapid hardening portland cement within 1 day ≥ 2.1 Mpa.



7. Heat of Hydration

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

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



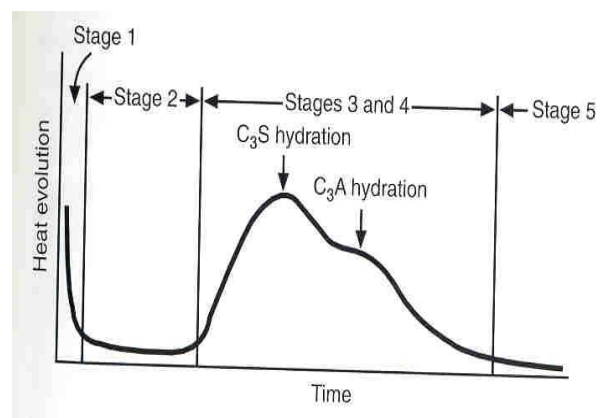
Cont. on Heat of Hydration

- The amount of heat generated depends upon the chemical composition of cement. Following are the heat of hydration generated on hydration of the four compounds of cement.
- Compound Heat of hydration Remarks C_3S 502 j/g-- C_2S 260 j/gMinimum C_3A 867 j/g Maximum C_4AF 419 j/g-- C_3S and C_3A are the compounds responsible for the high heat evolution.
- The approximate amount of heat generated using ASTM C 186, during the first 7 days (based on limited data) are as follows:

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

Cont. on Heat of Hydration

- Cements do not generate heat at constant rate as illustrated in Figure for a typical type I Portland cement



Stage 1: heat of wetting or initial hydrolysis

C_3A and C_3S Hydration. 7 min after mixing.

Stage 2: dormant period related to initial set.

Stage 3. accelerated reaction of the hydration products. That determine the rate of hardening and final set.

Stage 4: decelerates formation of hydration products and determines the rate of early strength gain.

Stage 5: is a slow, steady formation of hydration products.

8. Loss on Ignition (LOI)

- The test for loss on ignition is performed in accordance with ASTM C 114.
- A high weight loss on ignition of a cement sample (between 900 to 1000°C) is an indication of pre-hydration and carbonation, which may be caused by:
 - Improper and prolonged storage
 - Adulteration during transport and transfer
- Loss on ignition values range between 0 to 3%

Loss on Ignition Test of cement



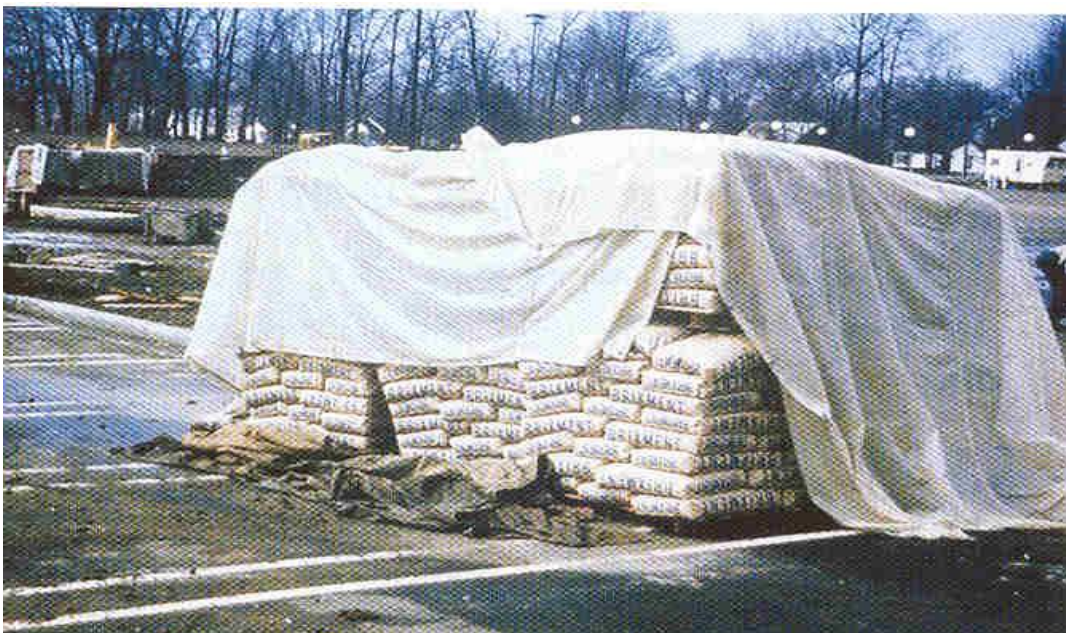
9. Density and Specific Gravity

(ASTM C 188)

- Density is the mass of a unit volume of the solids or particles, excluding air between particles. The particle density of Portland cement ranges from 3.10 to 3.25 Mg/m³, averaging 3.15 Mg/ m³.
- It is used in concrete mixture proportioning calculations.
- For mixture proportioning, it may be more useful to express the density as relative density (specific gravity). On an average the specific gravity of cement is 3.15.

Storage of Cement

- Cement is moisture-sensitive material; if kept dry it will retain its quality indefinitely.
- When exposed to moisture, cement will set more slowly and will have less strength compared to cement that kept dry.
- At the time of use cement should be free-flowing and free of lumps.



Concrete Technology

Chapter Two: Types of Cement

Cement is a pulverized material that develops binding forces due to a reaction with water

The properties of cement vary according to:

- ◆ Chemical composition (Ratio of Raw Materials (C₃S, C₂S, C₃A, C₄AF))
- ◆ Degree of fineness
- ◆ Rate of cooling of the clinker
- ◆ Clinkering temperature

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

Why several types?

a - Rate of Strength gain, b - Volume Stability, and c - Resistance to Sulfate Deterioration

There are two main types of cement:

- 1) Hydraulic Cement → Stable under water
- 2) Nonhydraulic Cement → Products of hydration are not resistant to water (i.e. limestone)

Hydraulic cements

Cements that harden by reaction with water and form a water-resistant product.

Types of Cement: Portland, Natural cement, Expansive cement, and, High-alumina cement

Portland Cement (PC.)

Portland cement is a hydraulic cement capable of setting, hardening and remains stable under water. It is composed of calcium silicates and some amount of gypsum.

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

Blended Portland Cements

Blended cement, as defined in ASTM C 595, is a mixture of portland cement and blast furnace slag (BFS) or a "mixture of portland cement and a pozzolan (most commonly fly ash)."

The benefits for using blended cements in concrete may include:

- 1) reduces mixing water and bleeding,
- 2) improves finishability and workability,
- 3) enhances sulfate resistance,

- 4) inhibits the alkali-aggregate reaction,
- 5) and lessens heat evolution during hydration, thus moderating the chances for thermal cracking on cooling.

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

1. Portland blast furnace cement -Type IS
2. Pozzolanic cement -Type IP
3. Air-entrained cement -Type IA
4. White Portland cement
5. Colored Portland cement

Ordinary Portland cement

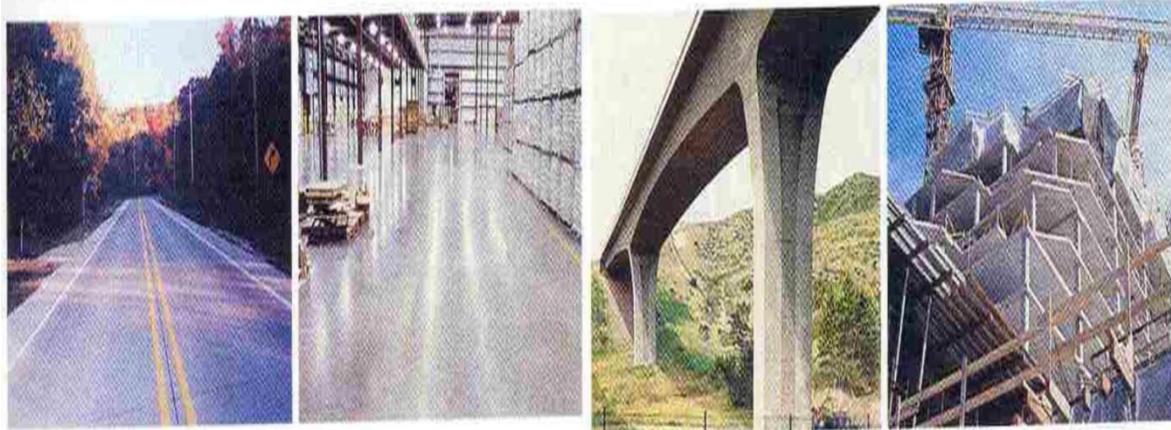
This type of cement use in constructions when there is no exposure to sulfates in the soil or ground-water, i.e, we don't have any special case for the future concrete. The chemical composition requirements are listed in Iraqi specification NO. 5., as shown below:

Lime Saturation Factor =

$$\frac{\{CaO-0.7(SO_3)\}}{\{2.8(SiO_2)+1.2(Al_2O_3)+0.65(Fe_2O_3)\}}$$

L.S.F. is limited between 0.66-1.02

- Percentage of (Al_2O_3/Fe_2O_3) is not less than 0.66
- **Insoluble residue** not more than 1.5%
Percentage of SO_3 limited by 2.5% when $C_3A < 7\%$, and not more than 3% when $C_3A > 7\%$
- **Loss of ignition L.O.I.** - 4% (max.)
- **Percentage of MgO** - 5% (max.)
- **Fineness** - not less than $2250 \text{ cm}^2/\text{g}$



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 C_3S compound, and due to finer grinding of

the cement clinker (the min. fineness is $3250 \text{ cm}^2/\text{g}$ (according to IQS 5)

- Rate of heat evolution is higher than in ordinary Portland cement due to the increase in C_3S and C_3A , and due to its higher fineness
- Chemical composition and soundness requirements are similar to that of ordinary Portland cement
The problem of this type of cement is that: The early gained strength is on expense of the later strength.

Uses of Rapid Hardening Portland Cement

- a) 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:
 - i) When formwork is to be removed for re-use
 - ii) 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.
- b) For construction at low temperatures, to prevent the frost damage of the capillary water
- c) This type of cement does not use at mass concrete constructions.
- d) for precast 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 $9000 \text{ cm}^2/\text{g}$. 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 :

- 1) The rate of setting and hardening increase (the mixture is preferred to be casted within 20 minutes).
- 2) The rate of heat evolution increase in comparison with rapid hardening Portland cement, so it is more convenient to be use at cold weather.
- 3) The early strength is higher than for rapid hardening Portland cement, but their strength is equal at 90 days.

- 4) 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: 1974).

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.

Moderate cement

it compromise between type III and IV

it has a higher rate of hydration than type IV.

its rate of gaining strength is similar to that of type III. It is used in construction where:

Moderately low heat of hydration. Moderate sulphate attack may occurs.

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 - C_2S represents a high proportion of the silicates.
- Iraqi specification no. (6) limits - max. C_3A content by 3.5% , min. fineness by $2500 \text{ cm}^2/\text{g}$

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 - C_3AH_6 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 C_4AF with sulfates is calcium sulfoaluminate and calcium sulfoferrite, leading to expansion.
But an initial layer will form which surround the free C_3A leading to reduce its affect by sulfates, so C_4AF is more resistant to sulfates effect than C_3A .

Portland Blast furnace Cement**Production**

This type of cement consists of an intimate mixture of Portland cement and ground granulated blast furnace 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%.

Portland Blast furnace Cement**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.

Pozzolanic Cement**Production**

This type of cement consists of an intimate mixture of Portland cement and pozzolana.

American standard limit the pozzolana content by 15-40% of Pozzolanic cement.

Pozzolana, according to American standard ASTM C618, can be defined as – a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

It is essential that pozzolana be in finely divided state as it is only then that silica can combine with calcium hydroxide (produced by the hydrating Portland cement) in the presence of water to form stable calcium silicates which have cementitious properties.

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 blast furnace cement.

White Cement

- ♦ It has composition same as Type I or Type III cement, except that it has a white color instead of gray color.
 - ♦ It is made of selected raw materials containing negligible amounts of iron and magnesium oxides-the substances that give cement its gray colors.
 - ♦ It is used primarily for architectural purposes.
- Its fineness is higher ($4000-4500 \text{ cm}^2/\text{g}$) than ordinary Portland cement.

In general, it is used for architectural purposes and it is very costly (twice of the price of OPC).

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

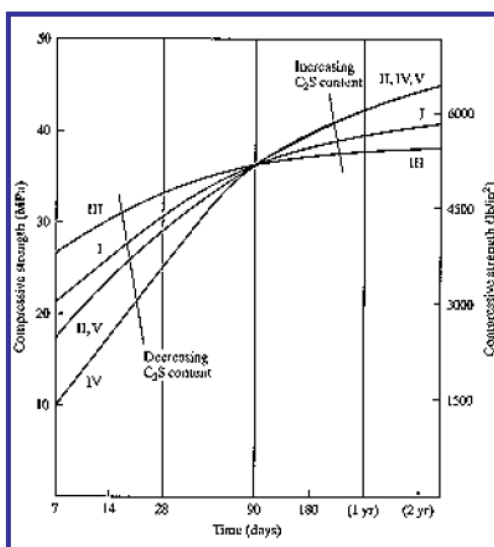
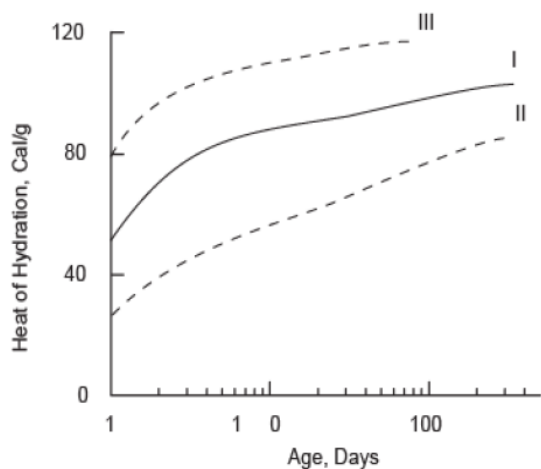
It has the property of expanding in its early life. Expansive cement, as well as expansive components, is a cement containing hydraulic calcium silicates (such as those characteristic of portland cement) that, upon being mixed with water, forms a paste, that during the early hydrating period occurring after setting, increases in volume significantly more than does portland cement paste. Expansive cement is used to compensate for volume decrease due to shrinkage and to induce tensile stress in reinforcement. Expansive cement concrete used to minimize cracking caused by drying shrinkage in concrete slabs, pavements, and structures is termed shrinkage-compensating concrete.

	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
Fine	35	35	45	30	35
	0	0	0	0	0

Typical chemical composition and properties of Portland cement

	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
Gypsum	5	5	5	4	4
Fineness (m ² /kg)	350	350	450	300	350
CCS (psi)	1000	900	2000	450	900
Heat of Hydration (J/g)	330	250	500	210	250

Heat of hydration for different cements



Supplementary Cementing Materials (Mineral Admixtures)

Introduction

Fly ash, ground granulated blast-furnace slag, silica fume, and natural pozzolans, such as calcined shale, calcined clay or metakaolin, are materials that, when used in conjunction with Portland or blended cement, contribute to the properties of the hardened concrete through hydraulic or pozzolanic activity or both. These materials are also generally categorized as supplementary cementing materials (SCM's) or mineral admixtures.

A pozzolan: is a siliceous or alumino-siliceous material that, in finely divided form and in the presence of moisture, chemically reacts with the calcium hydroxide released by the hydration of Portland cement to form calcium silicate hydrate and other cementing compounds.



Fig. 3-1. Supplementary cementing materials. From left to right, fly ash (Class C), metakaolin (calcined clay), silica fume, fly ash (Class F), slag, and calcined shale. (69794)

Supplementary cementing materials are added to concrete as part of the total cementing system. They may be used in addition to or as a partial replacement of Portland cement or blended cement in concrete, depending on the properties of the materials and the desired effect on concrete.

Supplementary cementing materials are used to improve a particular concrete property, such as the mitigation of deleterious alkali-aggregate reactivity.

Traditionally, fly ash, slag, silica fume and natural pozzolans such as calcined clay and calcined shale were used in concrete individually. Today, due to improved access to these materials, concrete producers can combine two or more of these materials to optimize concrete properties. Mixtures using three cementing materials, called ternary mixtures, are becoming more common.

Fly Ash

Fly ash is a finely divided residue (a powder resembling cement) that results from the combustion of pulverized coal in electric power generating plants (See Fig. 3-2).

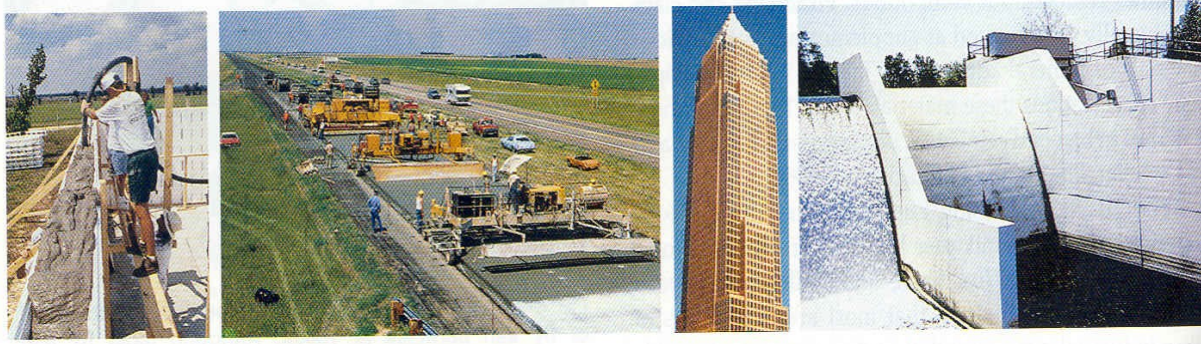


Fig. 3-2. Fly ash, a powder resembling cement, has been used in concrete since the 1930s. (69799)

Fly ash is primarily silicate glass containing silica, alumina, iron, and calcium. Minor constituents are magnesium, sulphur, sodium, potassium, and carbon. Crystalline compounds are present in small amounts. The relative density (specific gravity) of fly ash generally ranges between 1.9 and 2.8 and is generally tan or grey in colour.

Class F and Class C fly ashes are commonly used as Pozzolanic admixtures for general purpose concrete.

Uses of fly ash, slag, and calcined clay



Silica Fume

Silica fume, also referred to as microsilica or condensed silica fume, is a byproduct material that is used as a pozzolan (See Fig. 3-7). This byproduct is a result of the reduction of high-purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy.

Silica fume rises as an oxidized vapor from the 2000°C furnaces. When it cools it condenses and is collected in huge cloth bags. The condensed silica fume is then processed to remove impurities and to control particle size.

The relative density of silica fume is generally in the range of 2.20 to 2.25, but can be as high as 2.5. The bulk density of silica fume varies from 130 to 430 kg/m³. Silica fume is sold in powder form but is more commonly available in a liquid.



Fig. 3-7. Silica fume powder. (69801)

Silica fume is used in amounts between 5% and 10% by mass of the total cementing material. It is used in applications where a high degree of impermeability is needed (See Fig. 3-9) and in high-strength concrete. In cases where the concrete must be deicer-scaling resistant.

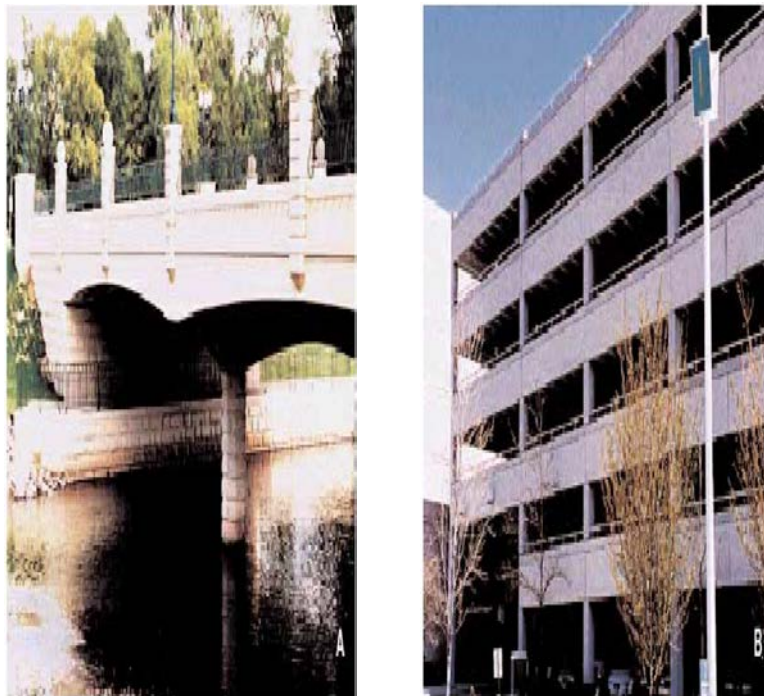


Fig. 3-9. Although they can be used in general construction, silica fume and metakaolin are often used in applications such as (left) bridges and (right) parking garages to minimize chloride penetration into concrete. (68681, 69542)

Slag

Ground granulated blast furnace slag, also called slag cement, is made from iron blast-furnace slag; it is a nonmetallic hydraulic cement consisting essentially of silicates and aluminosilicates of calcium developed in a molten condition simultaneously with iron in a blast furnace.

The slag cement has rough and angular-shaped particles, and in the presence of water and $\text{Ca}(\text{OH})_2$ or NaOH supplied by Portland cement, it hydrates and sets in a manner similar to Portland cement.

Natural Pozzolans

Natural pozzolans have been used for centuries. Many of the Roman, Greek, Indian, and Egyptian pozzolana concrete structures can still be seen today.

The most common natural pozzolans used today are process materials, which are heat treated in a kiln and then ground to a finer powder, they include:

Calcined clay, Calcined shale, and Metakaolin.

Metakaolin (calcined clay):



Chemical analysis of fly ash, slag, silica fume, calcined clay, calcined shale, and Metakaolin

	Class F fly ash	Class C fly ash	Ground slag	Silica fume	Calcined clay	Calcined shale	Metakaolin
SiO ₂ , %	52	35	35	90	58	50	53
Al ₂ O ₃ , %	23	18	12	0.4	29	20	43
Fe ₂ O ₃ , %	11	6	1	0.4	4	8	0.5
CaO, %	5	21	40	1.6	1	8	0.1
SO ₃ , %	0.8	4.1	9	0.4	0.5	0.4	0.1
Na ₂ O, %	1.0	5.8	0.3	0.5	0.2	—	0.05
K ₂ O, %	2.0	0.7	0.4	2.2	2	—	0.4
Total Na eq. alk, %	2.2	6.3	0.6	1.9	1.5	—	0.3
Loss on ignition, %	2.8	0.5	1.0	3.0	1.5	3.0	0.7
Blaine fineness, m ² /kg	420	420	400	20,000	990	730	19,000
Relative density	2.38	2.65	2.94	2.40	2.50	2.63	2.50

Effects on Freshly Mixed Concrete:

Water Requirements

Concrete mixtures containing fly ash generally require less water (1% to 10% less) for a given slump than concrete containing only Portland cement. Similarly ground slag decreases water demand by 1% to 10% depending on dosage.

The water demand of concrete containing silica fume increases with increasing amounts of silica fume, unless water reducer or superplasticizer is used. Natural pozzolans have little effect on water demand at normal dosages.

Workability

Fly ash, slag, and some natural pozzolans generally improve the workability of concretes of equal slump. While silica fume may reduce the workability and contribute to the stickiness of a concrete mixture.

Bleeding and Segregation

Due to the reduced water demand, concretes with fly ash generally exhibit less bleeding and segregation than plain concretes. Ground slags (with similar fineness as cement) may increase the rate and amount of bleeding with no adverse effect on segregation. Ground slags finer than cement reduce bleeding.

Setting Time

Fly ash, ground slags, and natural pozzolans will generally increase the setting time of concrete. Silica fume may reduce the setting time of concrete.

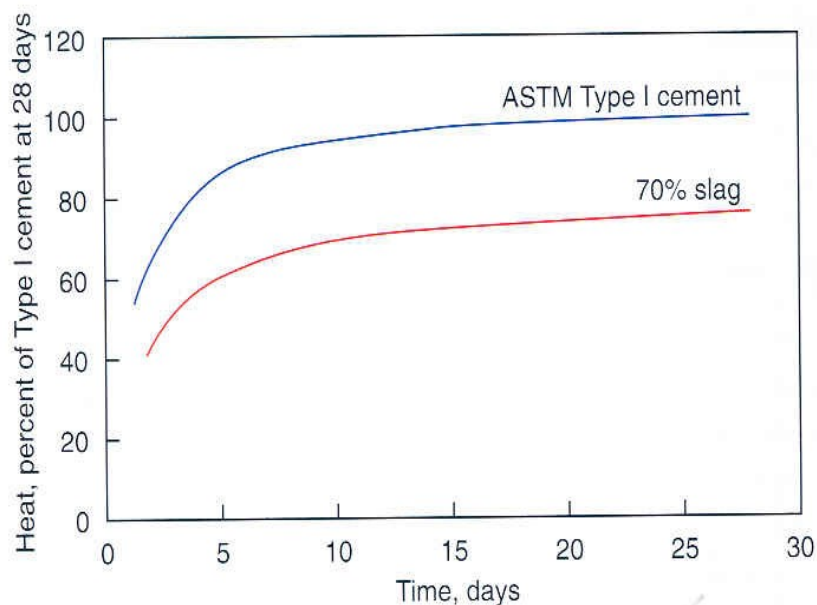
Plastic Shrinkage Cracking

Silica fume concrete may exhibit an increase in plastic shrinkage cracking due to the effect of low bleeding characteristics. Proper protection against drying is required during and after finishing. Other supplementary cementing materials that significantly increase setting time can increase the risk of plastic shrinkage.

Curing

Concrete containing supplementary cementing materials need proper curing. The curing should start immediately after finishing. A seven-day moist curing or membrane curing should be applied. Some organizations specify at least 21 days of curing for all concrete containing pozzolanic materials.

Effect of slag on heat of hydration at 20°C

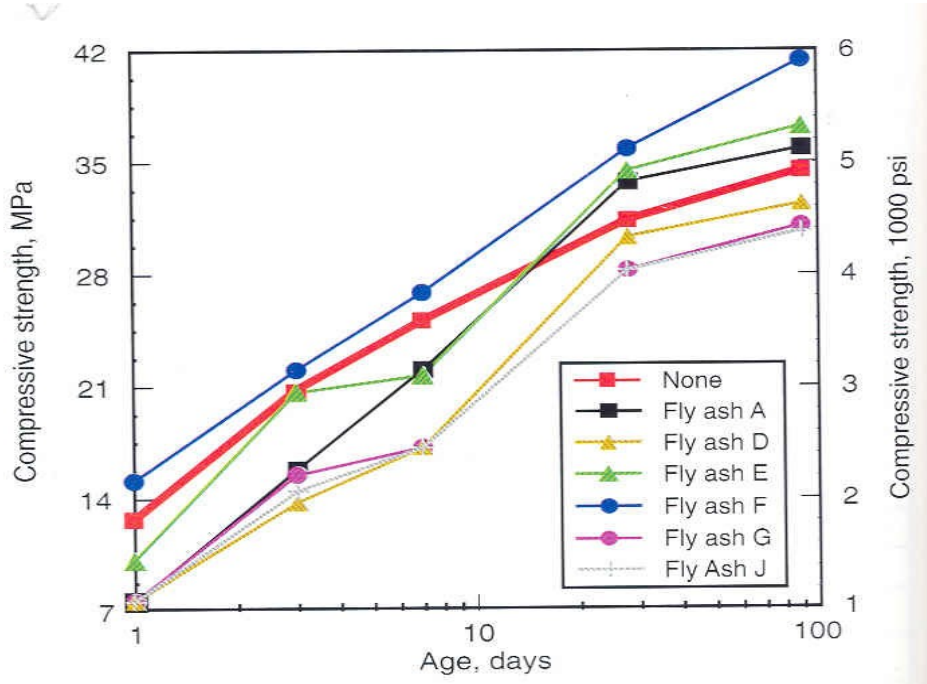


Effects on Hardened Concrete

Strength

All supplementary materials contribute to the strength gain of concrete. However, the strength of concrete containing these materials can be higher or lower than concrete with only cementing materials.

Compressive strength development of different fly ashes (25%)



Strength

The strength gain can be increased by one or combination of the following:

- 1) Increasing the amount of cementitious materials in concrete.
- 2) Adding high-early strength cementitious materials.
- 3) Decreasing the w/c ratio.
- 4) Increasing the curing temperature.
- 5) Using an accelerating admixture.

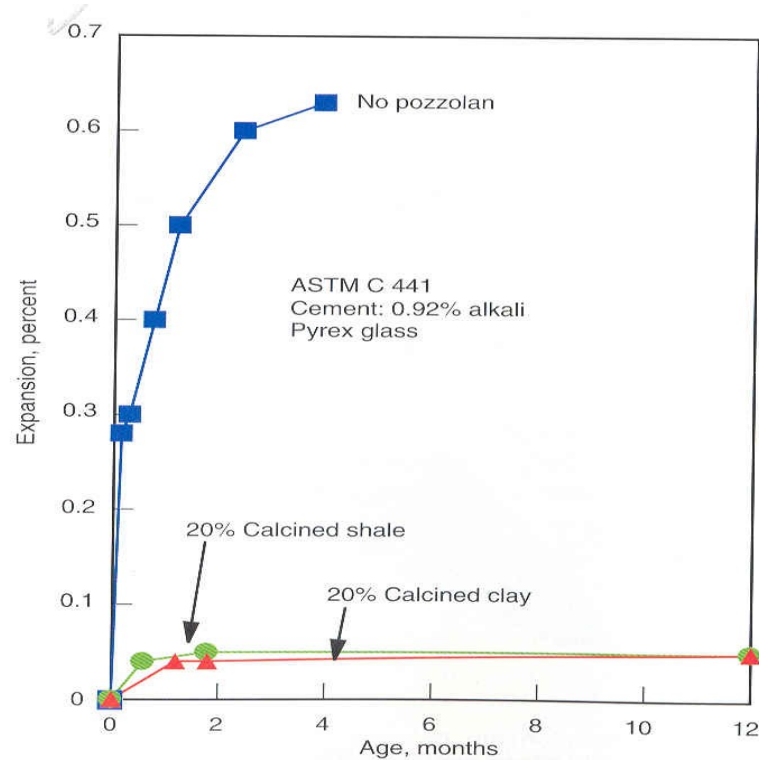
Drying Shrinkage and Creep

When used in low to moderate contents, the effect of supplementary materials on the drying shrinkage and creep is small and of little practical significance.

Permeability and Absorption

With adequate curing the concrete with supplementary materials will reduce the permeability and water absorption.

Reduction of alkali-silica reactivity



Sulfate Resistance

The sulphate and seawater damaging effect on concrete can be reduced significantly by using silica fume, fly ash, and ground slag. The improvement can be reached by reducing the permeability and reducing the reactive materials such as calcium needed for expansive sulfate reactions.

Corrosion of Embedded Steel

The improvement in corrosion resistance of concrete can be achieved by reducing the permeability and increasing the electrical resistivity of concrete. Fly ash can reduce the permeability of concrete to water, air, and chloride ions. Silica fume greatly reduce the permeability and increase the electrical resistivity.

Aggregates

- The total aggregates (fine aggregates + coarse aggregates) are used in concrete as filler and generally occupy 60 % to 75% of the concrete volume (70 % to 85 % by weight).
- Fine aggregates generally consist of natural sand or crushed stone with most particles smaller than 0.2 in.
- Coarse aggregates consist of one or a combination of gravels or crushed aggregate with particles predominantly larger than 0.2 in. and generally between $\frac{3}{8}$ and $1\frac{1}{2}$ in.
- its selection and proportioning should be given careful attention in order to control the quality of the concrete structure.

Advantages of using aggregates for concretes:

1. Gives better stability for concrete mass.
2. Resist external forces and different weather conditions (i.e., temperature, humidity, freezing)
3. Decrease volumetric changes obtained from freezing and hardening cement paste or those obtained from changes in moisture and drying.
4. Gives better durability for concrete.

When using aggregate for using with concrete, it should be noted:

1. Economy of the mix
2. Potential resistance for the hardened mass
3. Durability of concrete structure

General requirements for aggregates:

- 1- Should provide dense concrete and this depends on providing suitable grading so that spacing between aggregate particles decreased and hence, volume of cement paste will be decreased. Also, if coarse aggregate used alone, then cement paste will occupy larger space.
- 2- Provide suitable workability with minimum water requirement for mixing, hence, compressive strength increased.
- 3- Should not be affected by climate conditions like temperature and humidity that could cause or lead to decomposition.
- 4- Should be clear of impurities and clay materials as they cause; segregation, and cover the

coarse aggregate, then decreasing bond between cement and aggregate, decreasing durability.

5- Should lower the cost because if the quantity of aggregate is high in the mix then the cost of the concrete will be decreased as it is cheaper than cement.

6- Should be inert and do not react with cement compounds.

Fine Aggregates



Coarse Aggregates



Sources of Aggregates:

- Freshly mixed normal weight concrete (2200 to 2400 kg/m³) can be produced using:
- Natural gravel and sand are usually dug or dredged from a pit, river, lake, or seabed.
- Crushed aggregate is produced by crushing quarry rock, boulders, cobbles, or large size gravel.
- Crushed air-cooled blast-furnace slag is also used as fine or coarse aggregate.
- Recycled concrete, or crushed waste concrete, is a feasible source of aggregates and an economic reality where good quality aggregates are scarce.

Heavily reinforced concrete is crushed with a beam-crusher



Recycled-concrete aggregate



- Various light weight materials such as expanded shale, clay, slate, and slag are used as aggregates for producing lightweight concrete (1350 to 1850 kg/m³).
- Other lightweight materials such as pumice, scoria, perlite, vermiculite, and diatomite are used to produce insulating lightweight concretes (250 to 1450 kg/m³).
- Heavy weight aggregates such as barlite, magnetite and iron are used to produce heavy weight concrete and radiation- shielding concrete.

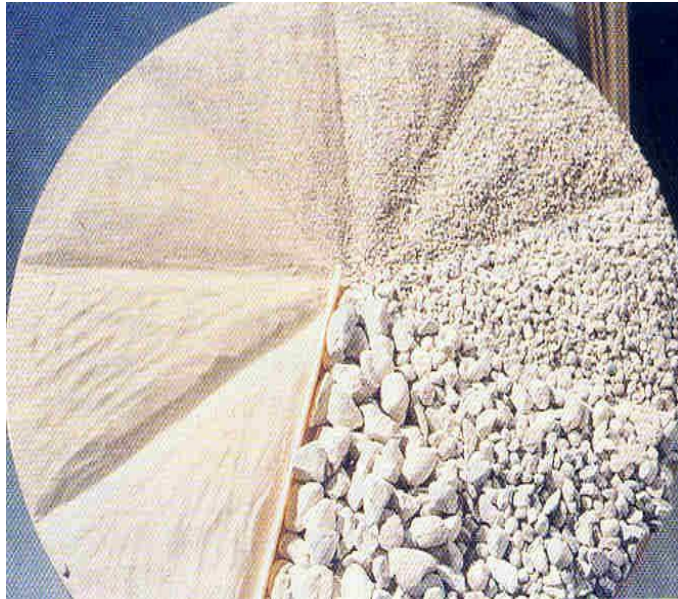
Lightweight Aggregates

Expanded clay (left)

Expanded shale (right)



Range of particle sizes found in aggregate for use in concrete



Making a sieve analysis test of coarse aggregate in a Lab

Grading

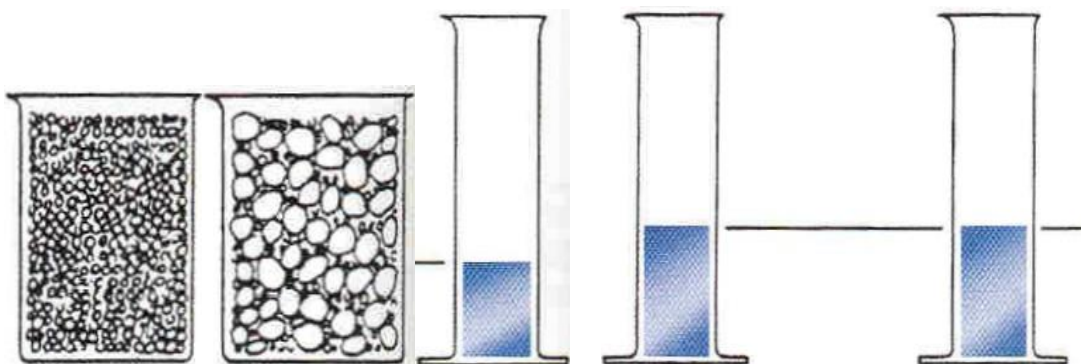
- Grading is the distribution of particles among various sizes. Grading is usually expressed in terms of cumulative percentage passing each sieve.

Different standards and specifications specify grading limits for both fine and coarse aggregates. There are several reasons for specifying grading limits and maximum aggregate size, they affect :

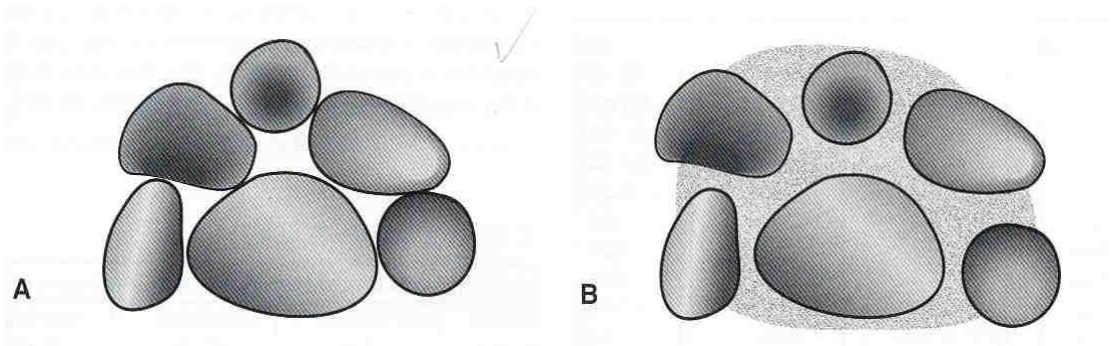
- Relative aggregate proportions
- Cement and water requirement
- Workability
- Pump ability
- Economy
- Shrinkage and durability of concrete



- Aggregates that do not have deficiency or excess of any size and give smooth grading curve will produce the most satisfactory results.
- The aggregate particle size is determined by using wire-mesh sieves with square openings:
- 7 standard sieves ranging from 150 μm to 9.5 mm (No. 100 to 3/8 in) for fine aggregates
- 13 standard sieves ranging from 1.18 mm to 100 mm (0.046 in. to 4 in) for coarse aggregates
- Proper selection of various sizes will be very effective in reducing the total volume of voids between aggregates (see Figure). The cement paste requirement is related the void content of the combined aggregates.
- Production of satisfactory; economical concrete requires aggregates of low void content, but not the lowest.



- Amount of cement paste required in concrete is greater than the volume of voids between the aggregates.



Fine Aggregate Grading

- Wide range in fine aggregate gradation is permitted by ASTM C 33. The most desirable fine-aggregate gradation depends on the type of work, the richness of the mixture, and the maximum size of coarse aggregate.
- For example, in leaner mixtures, or when small-size coarse aggregates are used, a grading that approaches the maximum recommended percentage passing each sieve is desirable for workability.

The following table shows the limits of ASTM C 33 with respect to fine aggregates, these limits are generally satisfactory for most concretes:

Sieve size		Percentage passing by mass
9.5 mm	(3/4 in)	100
4.75 mm	(No. 4)	95 to 100
2.36 mm	(No. 8)	80 to 100
1.18 mm	(No. 16)	50 to 85
600 μm	(No. 30)	25 to 60
300 μm	(No. 50)	5 to 30
150 μm	(no. 100)	0 to 10

Other requirements by ASTM C 33

- The fine aggregate must not have more than 45% retained between two consecutive standard sieves.
- The fineness modulus (FM) must not be less than 2.3 nor more than 3.1

Fineness Modulus (ASTM C 125)

- The fineness modulus (FM) for both fine and coarse aggregates is obtained by adding the cumulative percentages by mass retained on each of a specified series of sieves and dividing the sum by 100.
- The FM is an index of the fineness of the aggregate. The higher the FM, the coarser the aggregate. FM of fine aggregate is useful in estimating proportions of fine and coarse aggregate in concrete mixtures.

Coarse Aggregate Grading

- Usually more water and cement is required for small-size aggregate than for large sizes, due to an increase in total aggregate surface area.
- The optimum maximum size of coarse aggregate for higher strength depends on:
 - Relative strength of the cement paste
 - Cement-aggregate bond
 - Strength of the aggregate particles
- Maximum size of aggregate: the smallest sieve that all of a particular aggregate must pass through.
- Nominal maximum size of an aggregate: the smallest sieve size through which the major portion of the aggregate must pass (90%-100%).
- The maximum size of aggregate that must be used generally depends on the following:
 - Size and shape of the concrete member
 - The amount and distribution of reinforcing steel.
- The larger the aggregate particle the smaller the surface area to be wetted per unit mass (specific surface). Thus, extending the grading of aggregate to a larger maximum size lowers the water requirement of the mix so that, for specified workability and richness of the mix, the water/cement ratio can be reduced a consequent increase in strength. However, there is a limit of maximum size of aggregate.
- **In general the maximum size of aggregate particles should not exceed:**
 - 1/5 of the narrowest dimension of a concrete member
 - 3/4 the clear spacing between reinforcing bars and between the reinforcing bars and forms
 - 1/3 the depth of slabs

Gap-Graded aggregates

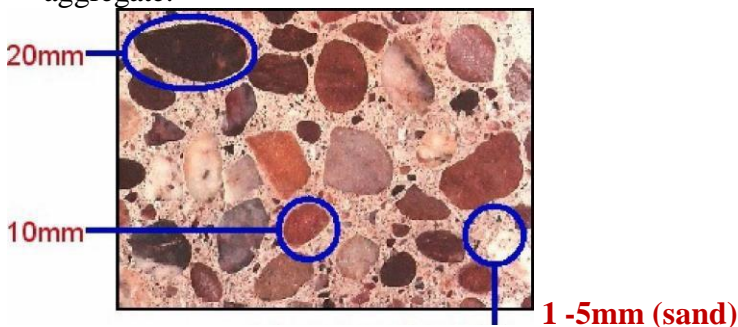
- When certain particle sizes are intentionally omitted. Ex., for an aggregate of 19 mm maximum size, the 4.75 mm to 9.5 mm particles can be omitted without making the concrete harsh subject to segregation. Gap- graded mixes are used in architectural concrete to obtain uniform textures in exposed –aggregate finishes.

Classification of aggregates:

- Aggregates can be classified as to :

1- Size:

- a- Fine aggregate: Aggregate smaller than (5 or 4.75 mm) in diameter is classified as fine aggregate or sand.
- b- Coarse aggregate: Aggregate larger than (5 or 4.75mm) in diameter is classified as coarse aggregate.



2- Source:

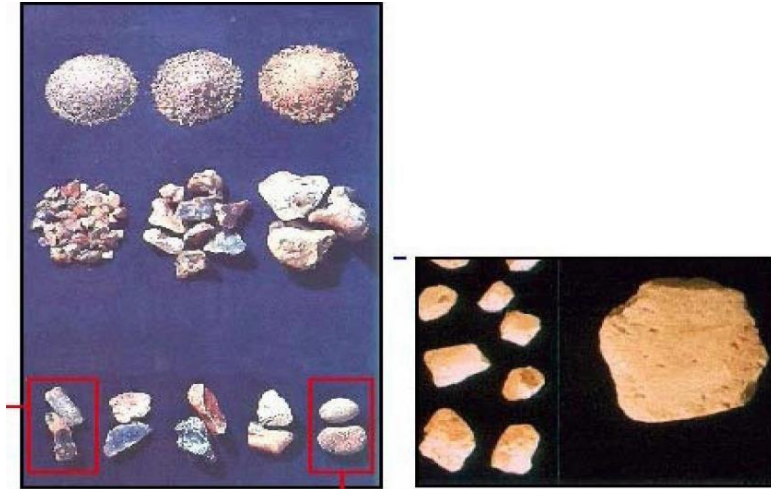
- a- Natural aggregate: The natural sands and gravels are the product of weathering and the action of running water, while the stone sands and crushed stones are reduced from natural rock by crushing and screening of quarried material. Example, volcanic rocks and sedimentation rocks.
- b- Artificial aggregate: usually produced for some special purposes, for example: burned expanded clay aggregate for making lightweight concrete. Some artificial aggregates are a by-product of industrial process such as blast furnace slag.

Recycled-concrete aggregate



3- Unit weight:

a- Normal weight aggregate: It is usually the natural aggregate for which the unit weight is between (1500 to 1800) kg/m³. The concrete produced from this type has a density of 2400-2600 kg/m³.



Normal weight aggregate

Lightweight aggregate (Pumic)

b- Lightweight aggregate:

It can be artificial or natural. The artificial lightweight aggregates are produced as both coarse and fine materials. They have a lower density due to an increase in porosity which results in an overall lowering of the concrete strength ceiling. Lightweight aggregates are not as dense as normal weight aggregates (unit weight less than 1000 kg/m³) and because their elastic modulus is lower, produce concrete with a lower elastic modulus and a higher creep and shrinkage. Lightweight aggregates can be of natural sources such as Pumic (a volcanic rock).

c- Heavyweight aggregate: Where concrete of a high density is required, in radiation shielding for example, heavyweight aggregates can be used. The unit weight can be larger than 1800 kg/m³. Concrete densities of 3500- 4500 kg/m³ are obtained by using Barytes (a barium sulphate ore). Even greater concrete densities are obtained using lead shot - around 7000 kg/m³.






Barytes Coarse Aggregate



Lead Shot Aggregate
Used for Radiation Shielding.

4- Particle Shape.

The particle shape is important in that it affects the workability of the plastic concrete. The more rounded an aggregate the lower the inter particle friction, the smaller the surface/unit volume and therefore less water is required for a given workability. Therefore, a potentially higher strength is possible. Crushed aggregates can be used to produce higher strength concrete (greater than about 80 N/mm^2) as a greater bond strength can be achieved between the aggregate and the paste due to the rough angular texture of the aggregate surface. Natural gravels and sands tend to have a more rounded shape as a result of attrition water, whereas crushed rock aggregates tend to be more angular in shape. Aggregates can be classified as to shape into:

Description of Aggregates	
Shape	
	Rounded Water worn or shaped by attrition
	Irregular Naturally irregular or partly shaped
	Angular Well-defined
	Flaky Thickness is small relative to other two dimensions
	Elongated Length is larger relative to other two dimensions

Note: Rounded, Irregular and Angular particles are more suitable for concrete mixes.

5- Surface Texture

Smother particles tend to produce a more workable concrete. The bond strength is, however likely to be higher with rough textured materials. The particles can be Glassy, smooth, granular, rough, crystalline or honeycombed.

Iraqi Aggregate:

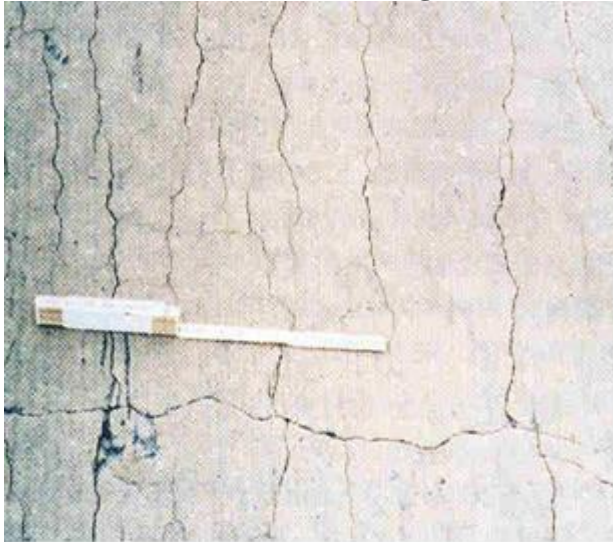
Most of the Iraqi aggregates are sedimentation rocks . it contains some impurities or materials that react with cement compounds and lead to increase in volume and crack of the concrete.

Alkali silica reaction: between silica in aggregate and alkalis in cement.

Sulphates reactions: between sulphates in aggregates and some cement

compounds.

Cracking of concrete from alkali silica reactivity



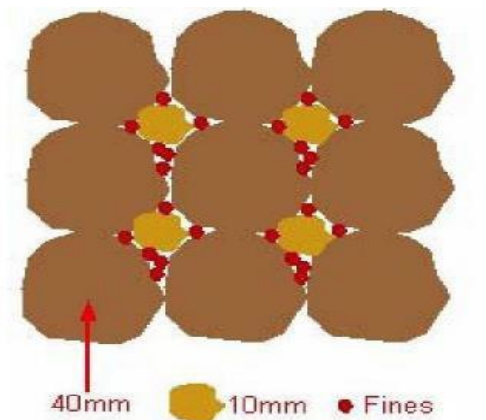
Properties of Aggregate

In fact, aggregate is not truly inert because its physical, thermal and, sometimes, chemical properties influence the performance of the concrete, for example, by improving its volume stability and durability over that of the cement paste. Generally Specifications require certain properties of aggregate to be tested to accept the using of aggregate in the concrete mixes. Other properties can be required for calculating concrete mix proportions.

1- Particle size distribution:

- The actual size of the aggregate particles influence the concrete mix. In practice it is desirable to have particles of different sizes.
- The aggregate is usually split into at least two different portions for ease of batching: The common dividing point is 5mm (or 4.75mm).
- Material larger than 5mm is termed coarse aggregate or gravel and the material smaller than 5mm is termed fine aggregate, fines or sand.
- The distribution of the different sizes of particles in the coarse or fine aggregates is termed grading. The grading may be coarse or fine depending on the distribution of the particles and may be continuous (particles of different sizes) or single sized (particles of predominantly one size).
- The particle size distribution is extremely important in the design of any concrete mix.
- For most practical concretes it is desirable to have the particle sizes evenly distributed from the maximum size of coarse aggregate down to the smallest sand particles. This will enable the aggregate to compact in the densest form leaving the minimum number of voids to be filled by the more expensive cement paste. It will also minimize the risk of segregation of the plastic concrete during handling & placing.
- The test method covers the determination of the particle size distribution of fine and coarse aggregates by sieving, is Sieve Analysis of Fine and Coarse Aggregates, (ASTMC 136 - 96a)

or (BS 812-103.1).



Benefits of good grading are

1. Provide dense concrete with minimal voids.
2. Provide better workability.
3. Minimize the need for water and cement.
4. Provide economic concrete mix.
5. Provide the need for durable concrete as it minimize the volumetric changes.

2- Shape of Aggregate

A- Roundness: is a measure of angularity of ends(edges) for aggregate particles.

Roundness depends on:

1. Strength or hardness of original rocks.
2. Abrasion resistance for weathering effects.
3. Amount of friction that aggregate particles will be exposed to.

The angularity or losing roundness for the aggregate particles is a very important property as it affects:

1. Concrete workability, increasing angularity leads to decreasing workability.
2. Increasing surface area and hence increasing cement needed for to cover aggregate surface and the mix therefore loses its economy.
3. Shape of aggregate particles affects quantity of water for the mix , increasing angularity increases water demand.
4. Increasing angularity increases voids in the mix.
5. Affects concrete durability.

On the other hand, increasing angularity increases bond between cement and aggregate due to increasing surface area which finally leads to increasing strength and producing better concrete.

B- Sphericity

The particle shape is of importance with regard to the properties of fresh and hardened concrete. Particles with high ratio of surface area to volume are of particular interest as they lower the workability of the mix.

Flakiness or Elongation of the aggregate particles.

- ❖ Elongated and flaky particles are of this type. The latter can also adversely affect the durability of concrete as they tend to oriented in one plane, with water and air voids forming underneath.
- ❖ The presence of elongated or flaky particles in excess of 10 to per cent of the mass of coarse aggregate is generally considered undesirable, although no recognized limits are laid down.
- ❖ Methods for determination of particle shape (BS 812-105.1) for Flakiness index and (BS 812-105.2) for Elongation index of coarse Aggregate.
- ❖ Flakiness index is the ratio between weight of flaky particles to the total weight of the sample. The thickness of flaky particles is 0.6 of the total average thickness of particles.
- ❖ Elongation index is the ratio between weight of elongated particles to the total weight of the sample. The elongated particles have length more than 1.8 the average particles length.

3- Surface texture of aggregate

Surface texture of aggregate particles depends on:

1. Hardness
2. Grain size distribution for aggregate itself.
3. Porosity of aggregate.

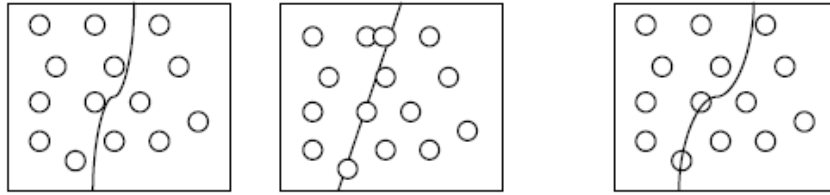
Surface texture of aggregate affect on:

1. Strength of concrete, aggregate particles with rough surfaces have better bond between cement and aggregate.
2. Workability, particles with smooth surfaces improves workability as it decrease internal friction between mix ingredients during mixing.

4- Bond of aggregate:

It is the most important property and it depend on :

- a) Interfere between aggregate and cement paste due to surface texture.
- b) Physical and chemical properties of aggregates due to mineral and chemical composition.
- c) Strength of bonding, depend on paste strength and it increases with age. To measure quality of bonding between aggregate and cement particles, cube or cylinder will crushed and the following cases will be resulted:
 1. Good aggregate and weak bond when aggregate did not broke.
 2. Good bond and weak aggregate when all aggregate is broken.
 3. Good bond and good aggregate when part of aggregate is broken and the other is still as it is.



5- Hardness

- Hardness is the resistance of an aggregate to wear and is normally determined by an abrasion test, while the toughness of an aggregate is defined as its resistance to failure by impact. Hardness and toughness are particularly important when aggregates are to be used in a concrete road pavement or heavy duty wearing surfaces.
- A test used as a measure of degradation of mineral aggregates of standard grading resulting from a combination of actions including abrasion or attrition, impact, and grinding is "Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine" ASTM C 131 - 96). Another test used for the determination of the aggregate crushing value (ACV) which gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load is "Methods for determination of aggregate crushing value (ACV)" (BS 812-110).

Deleterious Substances in aggregate

These are classified in aggregate into three categories:

A- Presence of Organic Impurities in Fine Aggregates.

Natural aggregates may be sufficiently strong and resistant to wear and yet may not be satisfactory for concrete-making if they contain organic impurities which interfere with the hydration process. The organic matter consists of products of decay, which is usually present in sand rather than in coarse aggregate, and is easily removed by washing. A test method used for that is "Organic Impurities in Fine Aggregates for Concrete" (ASTM C 40 - 99) using NaOH detector.

Organic impurities could affect chemical reactions during hydration. Organic impurities could lead to early age strength due to its effect on chemical reactions of hydration and combining of some compounds with each other resulting in constituents weakening strength of the past. This does not mean never using sand containing organic impurities with concrete, but it can be used if the compressive strength for cubes at 7 days age is not less than (95%) of the strength of concrete uses clean sand empty of impurities.

B- Presence of Clay lumps and materials finer than 75um

Clay may be present in aggregate in the form of surface coatings which interfere with the bond between the aggregate and the cement paste. In addition, silt and crusher dust may be present either as surface coatings or as loose material. Even in the latter form. Silt and free dust should not be present in large quantities because, owing to their fineness and therefore large surface area, they increase the amount of water necessary to wet all the particles in the mix.

Material finer than the 75-um (No. 200) sieve can be separated from larger particles much more efficiently and completely by wet sieving than through the use of dry sieving. Therefore, accurate determinations of material finer than 75 um in fine or coarse aggregate are desired. Materials Finer than 75-um (No. 200) Sieve in Mineral Aggregates by Washing (ASTM C 117 - 95) and for clay lumps, the test is "Clay Lumps and Friable Particles in Aggregates" (ASTM C 142-97).

Negative effect of fine materials:

- 1- Increase water demand due to its fineness or high surface area.
- 2- Decrease bond strength between aggregate and paste, the worst fine materials is the clay especially if it has surface coatings for coarse aggregate particles that inhibit good bond aggregate and cement paste.
- 3- Cause expansion and shrinkage of concrete increasingly, hence cracking of concrete.

C- Unsound particles in coarse aggregate:

These are unsound particles with low density such as clay, coal and wood. If aggregate contains these particles at (2-5)% from its weight, it should not be used with concrete exposed to abrasion because it leads to decrease strength of concrete.

Coal is a soft material and its presence in concrete is undesirable because it can swell causing cracking of concrete, also its presence in large quantities in a finely divided form (high fineness) can disturb the process of hardening of the cement paste. However, the presence of hard coal particles at (25%) from weight of aggregate has no adverse effect on strength of concrete.

The presence of coal and other materials of low density can be determined by floating in a liquid of suitable specific gravity according to ASTM C123- 69 and (IQS-33).

D- Salt contaminations (Presence of sulfate or chloride ions in aggregates)

Because of the danger of chloride- induced corrosion of steel reinforcement, the BS specifications specifies the maximum total chloride content in the mix, While ASTM specify 0.06% by weight of cement (total aggregate and cement) for pre-stressed concrete, and (0.1-0.15) by weight of cement for other types of concrete. .

Sulphate resistance cement resist sulphate salts and not chlorides salts. The chlorides may arise from all ingredient of the mix. Apart of the danger of corrosion of steel reinforcement, if salt is not removed, it will absorb moisture from the air and cause efflorescence- unsightly white deposits on the surface of the concrete. The presence of Sulphates will cause low ultimate strength and disintegration due to expansion. Sulphates came from salts in aggregate and from gypsum added to the cement. Sulphates react with C3A forming (ettringite) which cause expansion and deflection in concrete."Methods for determination of sulphate content"(BS 812-118) For chloride ions: "Method for determination of water-soluble chloride salts" (BS 812-117).

SO₃ max: 0.5% by weight of sand

0.1% by weight of coarse aggregate 4.5-5% by weight of cement

Soundness.

The soundness of an aggregate is a measure of its durability, which is defined as: "The ability of individual particles to retain their integrity and not suffer physical, mechanical or chemical changes to extents which could adversely affect the properties of the

concrete in either engineering or aesthetic respects."

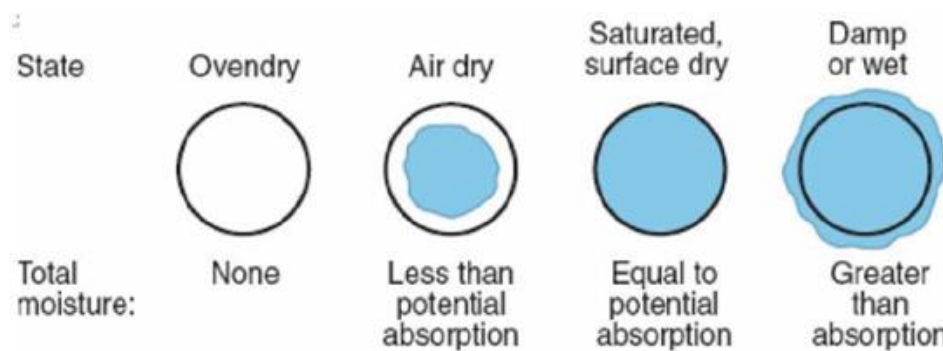
The physical causes of large or permanent volume changes of aggregate are freezing and thawing, thermal changes at temperatures above freezing, and alternating wetting and drying. If the aggregate is unsound such changes in physical conditions result in a deterioration of the concrete in the form of local scaling, and even extensive surface cracking. Unsoundness is exhibited by porous flints and cherts, especially lightweight ones with a fine-textured pore structured by some shales, and by other particles containing clay minerals. The degree of unsoundness is expressed by the reduction in particle size after a specified number of cycles.

A test method covers the testing of aggregates to estimate their soundness when subjected to weathering action in concrete or other applications. This is accomplished repeated immersion in saturated solutions of sodium or magnesium sulfate followed by oven drying to partially or completely dehydrate the salt precipitated in permeable pore spaces. The internal expansive force, derived from the rehydration of the salt upon re-immersion, simulates the expansion of water on freezing. "Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate"(ASTM C 88 - 99a)

Moisture Conditions of aggregate

The porosity, permeability and absorption of aggregate influence the bond between it and the cement paste, the resistance of concrete to freezing and thawing, as well as chemical stability, resistance to abrasion, and specific gravity.

When all the pores in the aggregate are full, it is said to be saturated and surface-dry. If this aggregate is allowed to stand free in dry air, some water will evaporate so that the aggregate is air-dry. Drying in an oven will remove the moisture; the aggregate is now oven dry. The aggregate can be also moist or wet when all voids are full of water and the surface is wet :



Moisture conditions of aggregate.

Deleterious Materials

These are materials that can prove harmful to the concrete if present in sufficient quantity.

Impurity Harmful Effects

- 1 - Clay, Silt & Fine dust..... Increased water demand and reduction of bond between aggregate and cement paste, leading to increased drying shrinkage, creep and

lower tensile strengths.

- 2 Organic matter..... Retardation of setting and rate of gain of strength.
- 3 -Coal, Lignite.....Low strength and poor durability. Surface staining and pop-outs.
- 4 – Chlorides.....Increased risk of corrosion of steel, efflorescence, increased rate of strength development.
- 5 – Sulphates.....Low ultimate strength and disintegration due to expansion.
- 6 – Shell.....Increased water demand, low strength and poor durability.
- 7 – Chalk.....Low strength and poor durability.
- 8 – Mica.....Increased water demand and low strength.
- 9 - Iron pyrites.....Surface staining and pop-outs.

Some impurities can be removed by careful washing and screening at the aggregate production plant.

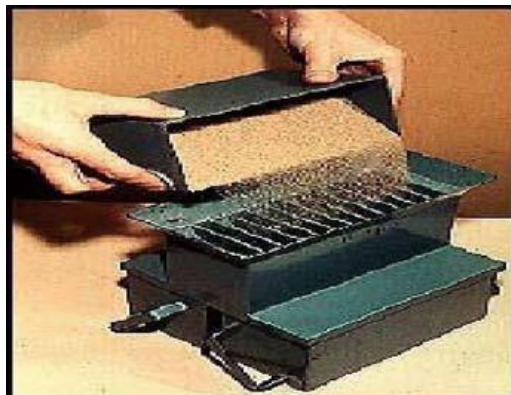
Sampling and testing

Two things to remember when performing a test on any material are:

1. The test must be performed in exactly the same way each time so that any change in the result is only indicative of a change in the property being measured.
2. The sample being tested must be truly representative of the total quantity.

When testing aggregates the total weight of the sample being tested is no more than a few kilogram's yet it has to be representative of a stockpile of several tonnes. Sampling aggregates for concrete is usually based on random selection with each part of the stock pile having an equal chance of being sampled.

The first requirement is to define the batch or stockpile quantity to be sampled, then to take a number of scoopfuls which are then combined into a representative sample to be reduced into one or more laboratory samples. At the laboratory, the sample is reduced to an appropriate size using a riffle box or a quartering board.



Tests on Aggregates

Bulck Density (ASTM C 29)

- Defined as the weight of the aggregate particles that would fill a unit volume. The term *bulk* is used since the volume is occupied by both the aggregates and voids. The typical bulk density used in making normal concrete ranges from 1200 to 1750 kg/m³.
- The void contents range between 30% to 45% for coarse aggregate and 40% to 50% for fine aggregate. Void content increases with angularity and decreases with well graded aggregate.

Relative Density (Specific Gravity)

- The relative density of an aggregate (ASTM C 127 and C 128) is defined is the ratio of its mass to the mass of an equal absolute of water. It is used in certain computations for mixture proportioning and control. Most natural aggregates have relative densities between 2.4 and 2.9 (2400 and 2900 kg/ m³).
- The density of aggregate used in mixture proportioning computations (not including the voids between particles) is determined by multiplying the relative density of the aggregate times the density of water (1000 kg/m³).

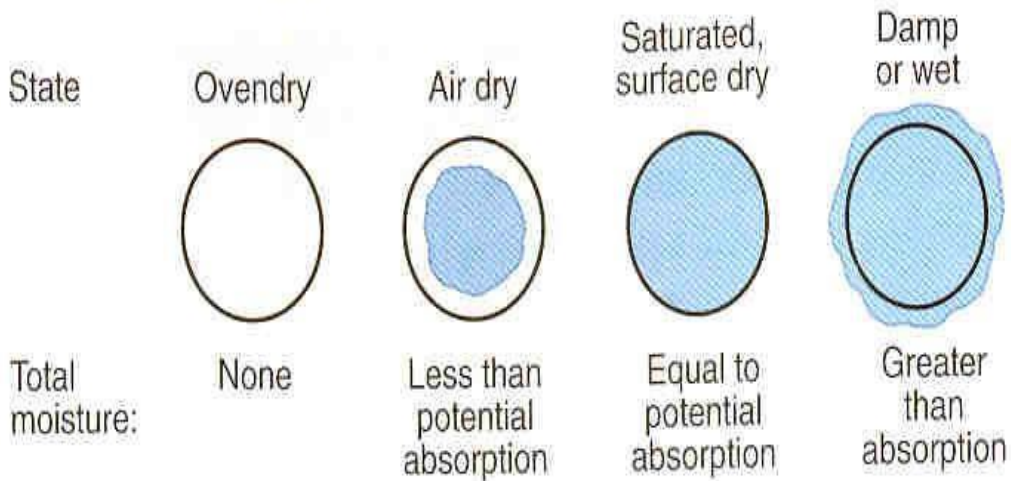
Absorption and Surface Moisture

- The absorption and surface moisture of aggregates should be determined using ASTM C 70, C127, C128, and C 566 so that the total water content of the concrete can be controlled and the batch weights determined. The moisture conditions of aggregates are:
 - Oven dry
 - Air dry
 - Saturated surface dry (SSD)
 - Damp or wet

Absorption levels

Aggregate	Moisture content at SSD (%)	Free-water content (%)
Coarse	0.2-4	0.5-2
Fine	0.2-2	2-6

Moisture conditions of aggregate



Wetting and Drying

- Alternate wetting and drying can develop severe strain in some aggregates, and with certain types of aggregate this can cause a permanent increase in volume of concrete and eventual breakdown. Clay lumps and other friable particles can degrade when subjected to wetting and drying cycles. Also, moisture swelling of clay and shales can cause popouts in concrete.

Abrasion and Skid Resistance (ASTM C 131)

- Abrasion resistance of an aggregate is used as a general index of its quality. This characteristic is important when concrete is going to be subjected to abrasion, as in heavy duty floors or pavements.
- Low abrasion resistance may increase the quantity of fines in the concrete during mixing; and hence increases the water requirement and require an adjustment in w/c ratio.
- Los Angeles abrasion test as per ASTM C 131 is the most common test for abrasion test.

Strength

- Generally, strength of aggregate does not influence the strength of conventional concrete as much as the strength of the paste and the paste-aggregate strength. However, aggregate strength becomes important in high strength concrete.

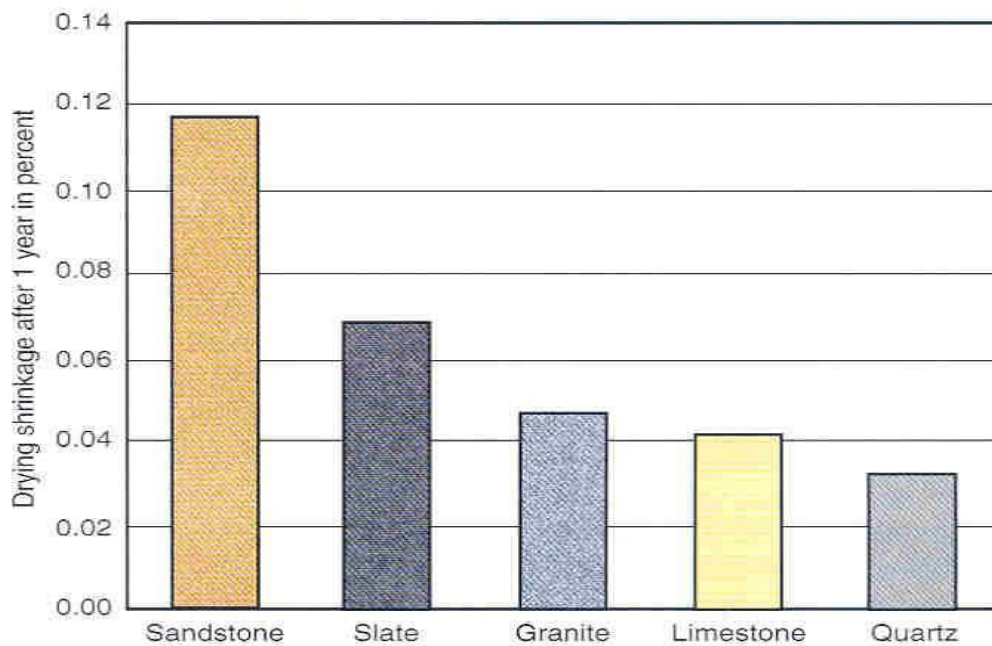
- Aggregate tensile strengths range between 2 to 15 MPa, and compressive strengths range between 65 to 270 MPa.

Shrinkage

- Usually aggregates with high absorption may have high shrinkage on drying.

Low shrinkage aggregates	High shrinkage aggregates
Quartz, feldspar, dolomite, granite, limestone,	Sandstone, hornblende, shale, slate,

Effect of type of aggregate on shrinkage



Resistance to Acid and other Corrosive Substances

- Acid solutions (pH less than 6.0) attack the calcium compounds of the cement paste, the rate of attack depends on the acidity of the solution. Siliceous aggregates may not be attacked by acidic solutions, however, calcareous aggregates often reacts with acids resulting in reduction of the solution acidity.
- Other gases and salts may attack and disintegrate concrete. Therefore, concrete structures subjected to harsh conditions should be protected and aggressive agents should be prevented from coming into contact with the concrete by using protective coatings.

Fire Resistance and Thermal Properties

- The fire resistance and thermal properties of concrete depend on the mineral constituents of the aggregates. Lightweight aggregates are more fire resistance than normal weight aggregates due to their insulation properties.
- Concrete containing calcareous coarse aggregates performs better under fire exposure than siliceous aggregate (granite or quartz).

Potentially Harmful Materials

- Aggregates are potentially harmful if they contain compounds known to react chemically with Portland cement and produce:
 - Volume change of the paste, aggregates, or both.
 - Affect the normal hydration of cement.
 - Harmful byproducts.
- Harmful materials present in aggregates are listed in Table 5-6:

Table 5-6. Harmful Materials in Aggregates

Substances	Effect on concrete	Test designation
Organic impurities	Affects setting and hardening, may cause deterioration	ASTM C40(AASHTO T 21) ASTM C 87 (AASHTO T 71)
Materials finer than the 75 µm (No. 200) sieve	Affects bond. increases water requirement	ASTM C 117 (AASHTO T 11)
Coal, lignite, or other lightweight materials	Affects durability, may cause stains and popouts	ASTM C 123 (AASHTO T 113)
Soft particles	Affects durability	
Clay lumps and friable particles	Affects work- ability and durability, may cause popouts	ASTM C 142 (AASHTO T 112)
Chert of less than 2.40 relative density	Affects durability, may cause popouts	ASTM C 123 (AASHTO T 113) ASTM C 295
Alkali-reactive aggregates	Causes abnormal expansion, map cracking, and popouts	ASTM C 227 ASTM C 289 ASTM C 295 ASTM C 342 ASTM C 586 ASTM C 1260 (AASHTO T 303) ASTM C 1293

Sieve Analysis

Sieve analysis: is the classification of aggregates according to its particle size OR a process in which an aggregate is separated into its various sizes by passing it through screens of various size openings for the purpose of determining the distribution of the quantities separated.

The opening of sieves are square and their sizes are as follow:

Coarse aggregate			Fine aggregate		
ASTM	BS	mm	ASTM	BS	mm, μm
3"	3"	75mm	No. 4	3/16"	4.75(5)mm
2"	2"	50mm	No. 8	No. 7	2.36mm
1 1/2"	1 1/2"	37.5mm	No. 16	No. 14	1.18(1.2)mm
3/4"	3/4"	19(20)mm	No. 30	No. 25	600 μm
0.53"	1/2"	14(16)mm	No. 50	No. 52	300 μm
3/8"	3/8"	9.5(10)mm	No. 100	No. 100	150 μm
			No. 200	No. 200	75 μm

In sieve analysis we use air dry aggregate for the following purposes:

1. To prevent clustering or lump of aggregate particles.
2. To prevent clogging of the sieve openings.

Fineness Modulus : is the accumulative percentages by mass retained on standard sieves starting from sieve No.(150 μm) up to the largest sieve available divided by 100.

- ❖ The FM is an index of the fineness of the aggregate. For example if F.M is (3) this means that the average aggregate size is (600 μm).
- ❖ The higher the FM, the coarser the aggregate.
- ❖ FM of fine aggregate is useful in estimating proportions of fine and coarse aggregate in concrete mixtures.

The Fineness modulus is useful in :

1. Knowing the slight changes in aggregates from the same source.
2. Used in some methods of concrete mix design

Example for the calculations of fineness modulus:

Sieve size BS	Mass retained	Retained %	Accumulative passing %	Accumulative retained %
10	3/8	0	100	0
5	4	$(6/307)*100=2$	$100-2=98$	$0+2=2$
2.36	8	10.	$98-10=88$	$2+10=12$
1.18	16	9.	7	2
600	30	19.	5	4
300	50	34.	2	7
150	100	17.	7	9
<15	<10	6.	0	
	$\Sigma=307$ gr			Σ 246

$$\text{Fineness modulus} = 246/100 = 2.46$$

Grading Curves and Their Requirements:

Grading curve: the cumulative percentage passing is plotted against the sieve size. The grading might be:

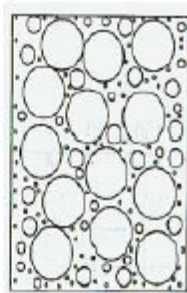
1. Continuous (dense) gradation: The aggregate contains every size of fraction between the maximum and minimum particle size.
2. Uniform (open) gradation: Aggregates contain particles of only one size fraction
3. Gap gradation:
 - Aggregates are missing particles of one or more size fraction.
 - As mentioned earlier, aggregate particles of a given size pack so as to form voids that can be penetrated only if the next smaller size of particles is sufficiently small. This means that there must be a minimum difference between the sizes of any two adjacent particle fractions.
 - On the grading curve, gap-grading is represented by a horizontal line over the range of sizes omitted.
 - Gap-graded aggregate can be used in any concrete, but there are particular uses: preplaced aggregate concrete and exposed aggregate concrete where a pleasing finish is obtained, since a large quantity of only one size of coarse aggregate becomes exposed after treatment.
 - However, to avoid segregation, gap-grading is recommended mainly for mixes of relatively low workability that are to be compacted by vibration; good control and care in handling are essential.



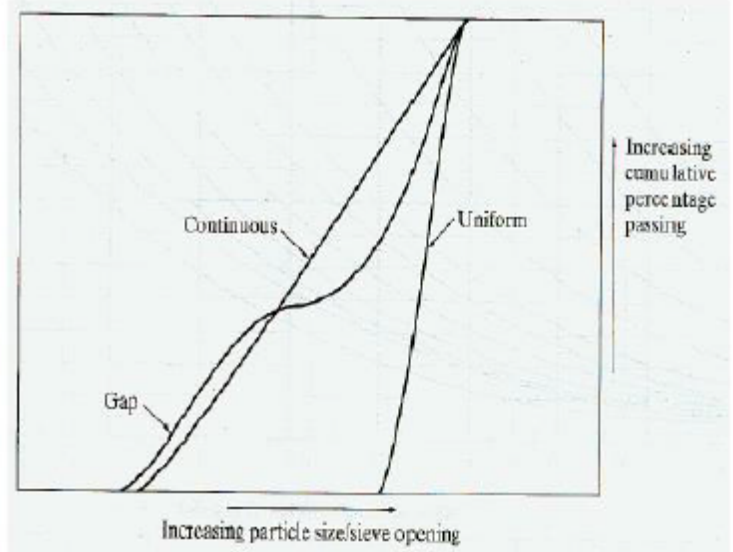
Continuous



Uniform



Gap

Ref: Young *et al.*, 1998

Fineness Modulus of CA

Sieve Size	Mass retained (gm).	Cumulative mass retained (gm)	Cumulative % mass retained	Cumulative % of mass passing through
40 mm	0	0	0	100
20 mm	80	80	4	96
10 mm	1320	1400	70	30
4.75 mm	600	2000	100	0
2.36 mm	0	2000	100	0
1.18 mm	0	2000	100	0
600 micron	0	2000	100	0
300 micron	0	2000	100	0
150 micron	0	2000	100	0
<150 micron	0	-	-	-
Total	2000	-	674	-

$$\text{FINENESS MODULUS} = \frac{\text{Sum of cum. \% retained}}{100} = \frac{674}{100} = 6.74$$

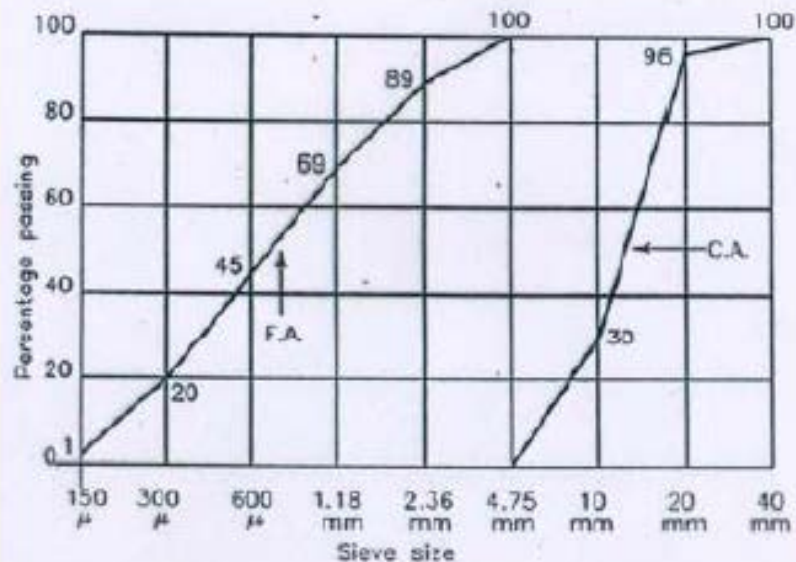
Fineness Modulus of FA

Sieve Size	Mass retained (gm).	Cumulative mass retained (gm)	Cumulative % mass retained	Cumulative % of mass passing through
4.75 mm	0	0	0	100
2.36 mm	110	110	11	89
1.18 mm	200	310	31	69
600 micron	240	550	55	45
300 micron	250	800	80	20
150 micron	190	990	99	01
<150 micron	10	-	-	-
Total	1000	-	270	-

$$\text{FINENESS MODULUS} = \frac{\text{Sum of cum. \% retained}}{100} = \frac{276}{100} = 2.76$$

Example :- If FM = 3 : the third sieve 600 micron is the average size.

Limits :- For Fine sand 2.2 to 2.6 : For Medium sand 2.6 to 2.9 :
For Coarse sand 2.9 to 3.2, FM > 3.2 Not Acceptable



Compare the graphs with standard grading curves

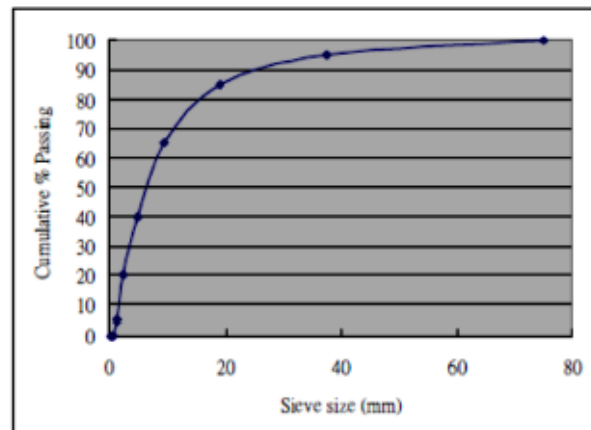
TABLE 10.4 Example of Sieve Test Results and the Calculation of Grading Curve and Fineness Modulus

Sieve Size (mm)	No.	Weight Retained (g)	% Retained	Cumulative % Retained	Cumulative % Passing
4.75	4	0	0	0	100.0
2.36	8	241.9	11.9	11.9	90.6
1.18	16	388.9	19.1	31.0	74.0
0.60	30	505.5	24.9	55.9	51.7
0.30	50	543.4	26.7	82.6	25.1
0.15	100	340.8	16.8	99.4	8.4
Pan*		11.3	0.6	100.0	0

$$FM = \frac{11.9 + 31.0 + 55.9 + 82.6 + 99.4}{100} = \frac{280.8}{100} = 2.81.$$

One sample of different sands was found to have the following amounts retained on each sieve: 3 in=0g, 3/2 in=50g, 3/4 in=100g, 3/8 in=200g, No. 4=250g, No. 8=200g, No. 16=150g, No.30=50g. (a) Plot the aggregate grading curve. (b) Calculate the Fineness Modulus of the sample.

sieve size	weight retained	weight retained %	Cumulative % retained	Cumulative % passing
3 in	0	0	0	100
3/2 in	50	5	5	95
3/4 in	100	10	15	85
3/8 in	200	20	35	65
4	250	25	60	40
8	200	20	80	20
16	150	15	95	5
30	50	5	100	0
50	0	0	100	0
100	0	0	100	0
pan	0	0		
	1000			
			F.M.	5.9



F.M.=5.9

The results of sieve analysis for aggregate are represented by curves illustrate the relationship between the sieve opening size and cumulative percentage passing. Using these curves it can be possible to determine the conformity of a specific aggregate sample with the standards or, if there is lack in specific size of aggregate.

The main factors determine the suitability of aggregate grading are:

- 1- Specific area of aggregate.
- 2- Relative volume which the aggregate occupy in concrete.
- 3- Workability of the mix.
- 4- Tendency for segregation.

To have good concrete, must have the following:

- 1- Good workability for concrete
- 2- Prevent segregation.

To have these two points, we must follow the following:

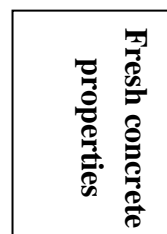
- 1- Concrete workability: there must be enough fine materials in concrete which are ($< 300\mu\text{m}$) (ASTM (No.50)) and since cement particles are within this size , therefore , mixes rich with cement needs less fine sand than mixes with poor cement. If grading of sand suffer from lack in fine particles , then increasing coarse aggregate will not be the suitable solution because it leads to increase medium sizes and form disparate mix constituents with low workability , the best solution is to use adequate quantity of fine materials passing sieve No.($300\mu\text{m}$).
- 2- Avoid segregation: to avoid segregation, the particles with different size are interact with each other , i.e., the small particles occupy the space between the larger particles which in turn prevent mortar from passing freely outside cavities or pores.
- 3- The relative volume of aggregate in concrete: for economic reasons , the aggregate should have the largest possible relative volume because it is cheaper than cement and to get higher density with higher strength.
- 4- The aggregate particles surface area: inversely proportional to its particles size:

Max size related to (1/specific area)

Note: Concrete workability can be improved when providing cement paste more than the required for filling the space between sand particles and providing more mortar (cement + sand) more than required to fill spaces between coarse aggregates(gravel).

Grading of aggregate is considered to be a main factor in controlling workability of the mix which affect:

1. Mix demand for cement and water
2. Segregation
3. Bleeding



4. Pouring and finishing concrete
5. Strength

6. Shrinkage
7. Durability

**Hardened
concrete
properties**

Practical grading:

3. It is possible to produce good concrete from any available aggregate if care and skill is provided.
4. It is better to use aggregate available in site or near site.
5. See plotted curves of different aggregate size (for British Standards and ASTM) page no. 225-end of the subject.
6. Each of these plots include 4 curves for each max. aggregate size and because aggregate contains sizes larger and smaller than standard sizes , therefore , practical grading is possibly near one of these curves instead of conforming. For this reason it is better to mention grading zone instead of individual curves.

Curve no. 1: represent coarse grading, better workability, can be used in in mixes with low (w/c), or in rich mixes.

Curve no.4: represent fine grading, better cohesion, low w/c ratio, difficult in hand mixing, better to use vibrator.

Fig. 4: Grading curves for maximum particle size 63 mm similar to SASO 378.

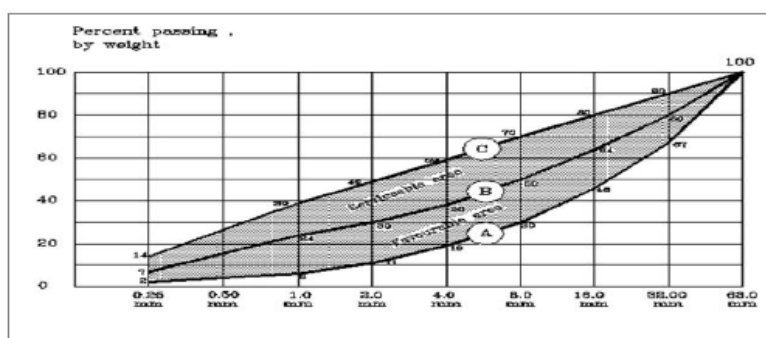


Fig. 5: Grading curves for maximum particle size 9.5 mm similar to ASTM C 33

Note:

1. in mixes with low workability, if the mix contain aggregate within zone 4 grading needs to higher water content which leads to lower strength, and to get the required strength, cement content should be increased when using fine aggregate.

2. In the case of the grading is partially in one zone and the other part in another zone , segregation may occur because of lack in medium sizes , it is called gap graded . when increasing medium sizes then the mix will have low workability with anisotropic constituents and called harsh mix which very difficult to use hand mixing and even vibratos (probably) .
3. The actual grading usually parallel to the grading lines and do not intersect with them .

Grading of fine and coarse aggregate

Practically, it is necessarily to determine the quantities of sand and gravel each separately. The British standards (BS 882) and the Iraqi Standards (IQS 45) determine the requirements of fine aggregate grading into 4 zones. The grading of fine aggregate will be suitable if the following conditions are available:

1. It should be within one of the grading zones.
 2. It is not allowed to permit more than 5% passing by weight from the percentage passing each sieve except sieve no. (600 μm).
 3. It should not be finer than grading of zone (4) or coarser than grading of zone (1).
 4. 4. In case of fine aggregate resulted from crushed stones, the percentage of the max limit for the passing from sieve no (150 μm) will be increased, also for all the grading zones (20%).
- The classification of fine aggregate grading depends on the percentage passing sieve (600 μm), the reason is, most or large amount of sand is completely classified in this size naturally.
 - The sand within any of the (4) zones can be used to produce concrete.
 - When using sand within zone (4 fine sand) to produce reinforced concrete, make sure it fits (the suitability for this sand must be checked). Moreover, since the larger part of sand in this zone is smaller than sieve size no (600 μm) then the grading is almost gap grading, therefore, the mix proportion should be selected properly.
 - The content of sand should be decreased in relative to coarse aggregate in the mix (see table in book page 233), when using sand within zone (4) to produce good concrete and vibrators should be used. In case of using coarse aggregate within zone (1) anisotropic mix with low workability will be produced, therefore, sand content must be increased to increase workability. Coarse sand is preferred to be used in mixes rich with cement content or mixes with low workability.
 - Zone no (2) represents sand with medium grading and it is suitable for standard mix (1 fine aggregate: 2 coarse aggregate) when the max aggregate size is (19 mm).
 - When using coarse sand resulted from crushed rocks, increasing sand (little increase) is needed, to compensate decrease of workability due to the angular shape of the crushed aggregate.

- The B.S (882) and the IQS (45) determine the requirements of the coarse aggregate in table page 236, according to the max aggregate size.
- In B.S (882) the fine aggregate zones were changed to three zones instead of four, these are (coarse, medium and fine). The IQS, is now similar to the BS.

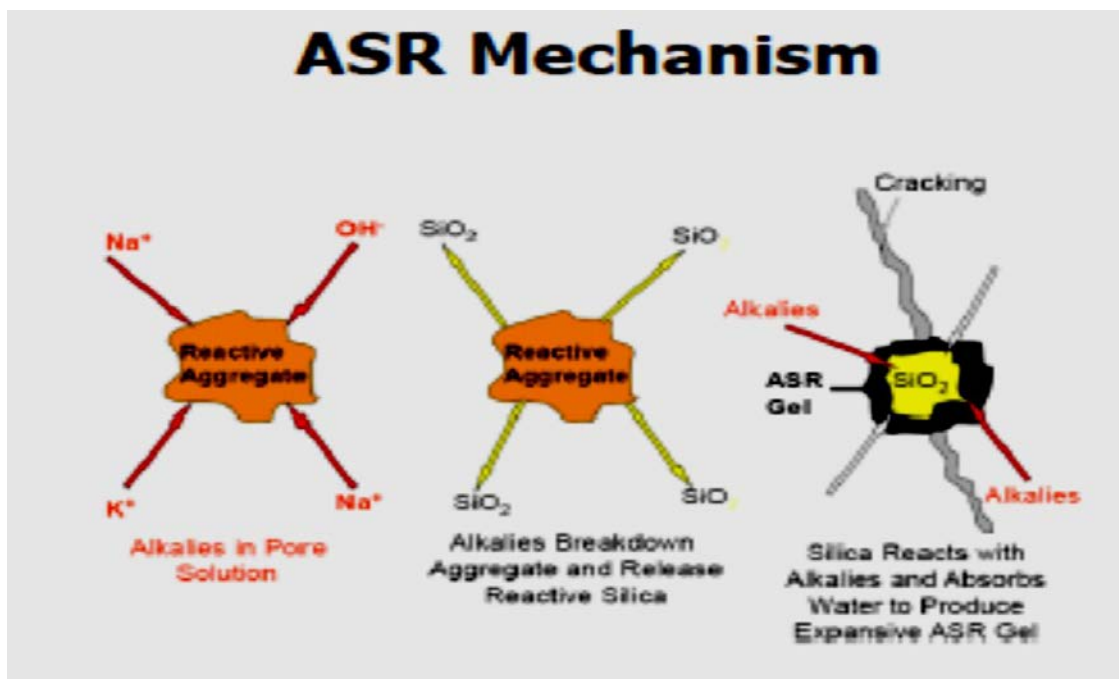
Alkali-Aggregate Reaction

Also called Alkali-Silica Reaction (ASR) is a chemical reaction between the reactive silica contained in the aggregates and the alkalis (Na_2O and K_2O) within the cement paste. The result is an alkali-silicate gel that absorbs water and increases in volume. If the gel is confined by the cement paste, it builds up pressure as it grows causing internal stresses that eventually could crack the concrete.

The cracking then allows more water to infiltrate into the concrete creating more gel, more expansion etc. Ultimately the concrete fails or disintegrates.

The reaction can be visualized as a two-step process:

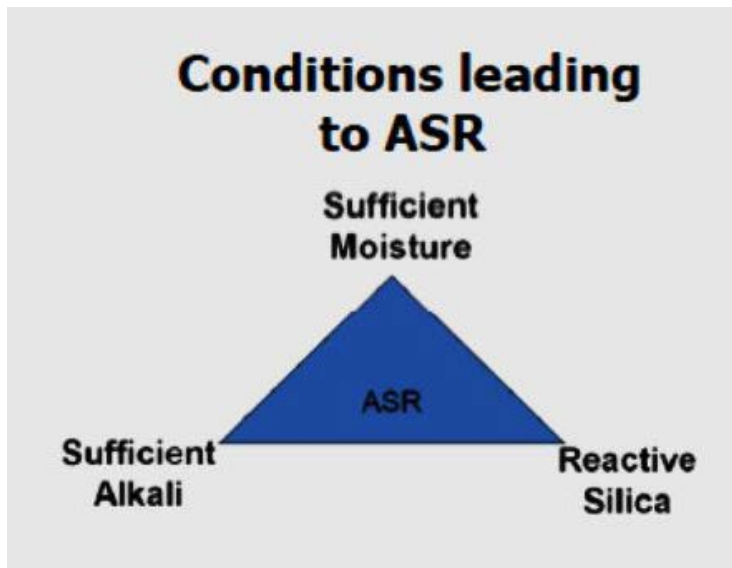
1. Alkali + reactive silica \longrightarrow alkali-silica gel
2. Alkali-silica gel + moisture \longrightarrow expansion



Factors Affecting ASR

For alkali-silica reaction to occur, three conditions must be present:

1. reactive forms of silica in the aggregate
2. high-alkali (pH) pore solution
3. sufficient moisture



The real activity of aggregate depends on:

- 1- particle size and porosity of aggregate: the particle size affect the surface area exposed to reaction with alkalis in cement.

- 2- Alkalies content in cement : increasing content for specific grading of aggregate will lead to increase expansion.
- 3- Cement fineness: increasing cement fineness lead to increase in concrete expansion, the reason is, increasing fineness increases available alkalies in the mix.
- 4- Availability of non-evaporable water and permeability of cement paste: with progress of hydration process , the amount of non-evaporable water increase and the permeability of cement paste decreased which lead to decrease the possibility of alkali-aggregate reaction.
- 5- Temperature: between (10-38 °C), alkali–aggregate reaction will be accelerated.
- 6- Exposing concrete to wet and dry cycling will accelerate reaction.

To decrease expansion (caused by ASR):

1. Prevent wetting of concrete (exposed to water).
2. Using Portland cement with alkalies percent do not exceed (0.6%).
3. Using blended mixture of Portland cement and blast furnace slag, because slag decrease the reaction of alkalies with aggregate or adding pozzolans or rice husk ash or fly ash.
4. Using aggregate with low activity or mixing it with inert type of aggregate.
5. Decreasing cement content, which leads to decrease alkalies content in concrete.
6. Adding fine ground silica to react with alkalies before hardening of concrete.

Workability

If a concrete satisfy the conditions of being transported, placed and finished sufficiently easily without segregation, it is said to be workable.



Workability determines the ease of placement and the resistance to segregation.

The desired workability in any particular case would depends on the means of compaction available, for example, a workability suitable for mass concrete is not necessarily sufficient for thin, inaccessible, or heavily reinforced sections.

Compaction is achieved by :

1. Ramming
2. Vibration

The process of vibration consists essentially of the elimination of entrapped air from the concrete until it has achieved as close a configuration as is possible for a given mix.

Thus, the work done to overcome the friction between the individual particles in the concrete and also between the concrete and the surface of the mould or of the reinforcement. These two called the internal friction and surface friction respectively.

In addition, some of the work done is used in vibrating the mould or in shock and indeed in vibrating those parts of the concrete which have already fully consolidated.

The work done consist of waste part and useful part.

The useful part comprising work done to overcome the internal friction and the surface friction.

The workability can be best defined as the amount of useful internal work necessary to produce full compaction.

The need for sufficient workability

- ❖ Workability is a very important property of concrete. This importance came from the fact that concrete must have workability such that compaction to maximum density is possible with a reasonable amount of work or with the amount of work we prepared to put in under given conditions.
- ❖ The importance of workability can be explained by the relationship between density ratio (the ratio of the actual density of the given concrete to the density of the same mix if fully compacted) and strength ratio (the strength of concrete as partially compacted to the strength of the same mix when fully compacted).(see figure page 248 your book).
- ❖ The presence of voids greatly reduces its strength, for example 5% of voids can lower strength by 30%.
- ❖ Voids in concrete are in fact either bubbles of entrapped air or spaces left after excess water has been removed. The volumes of these spaces depends only on water\cement ratio of the mix.
- ❖ Air bubbles which represent accidental air (i.e. voids within originally loose granular material) are governed by the grading of the finest particles in the mix and are most easily expelled from a wetter mix than from a dry one.
- ❖ For any given method of compaction, there may be optimum water content of the mix at which the sum of the volumes of air bubbles and water space will be a minimum. At this optimum water content the highest density ratio of the concrete

would be obtained. It can be seen, however that the optimum water content may vary for different methods of compaction.

Workability is a measure for the following characteristics:

1. Compactibility: it is the ease that a concrete can be compacted and the air void are expelled.
2. Mobility : the ease of concrete flowing in the moulds or forms and around reinforcement.
3. Stability: ability of being stable without segregation.

Measurements of workability:

1. **Slump test**
2. **Compacting factor test**
3. **Vebe test**
4. **Remoulding test**

Slump test

This test is widely used in site works all over the world. This test does not measure workability but is very useful in detecting variations in the uniformity of a mix of given nominal proportions. For example increasing water content or grading of aggregate (decreasing sand in the mix) result in increasing slump.

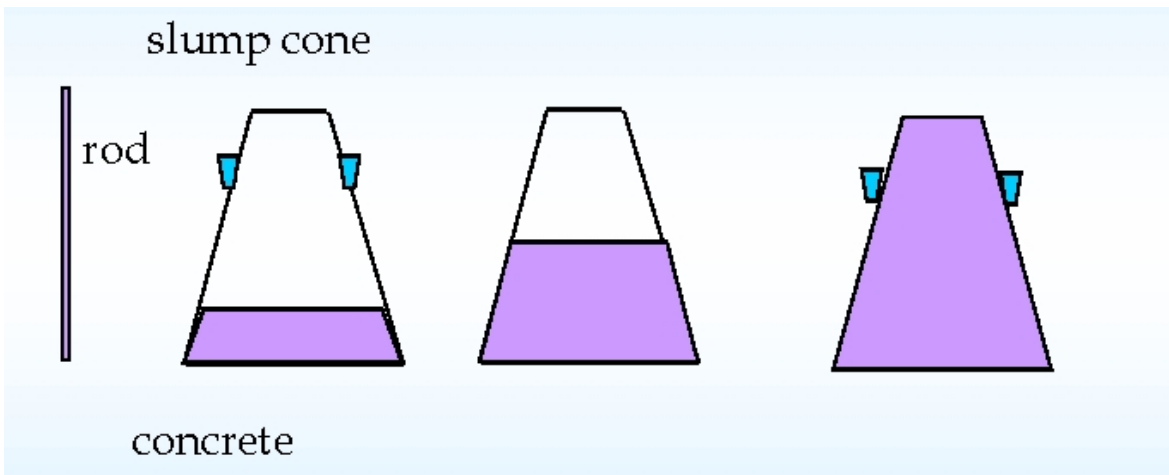
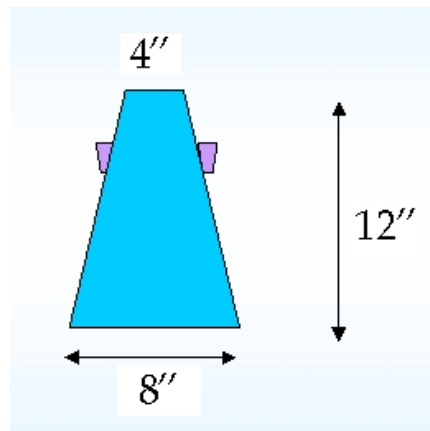
Types of slumps:

1. **True slump:** Slumping evenly all around
2. **Shear slump:** One half of the cone slides down an inclined plane, the test should be repeated. Shear slump usually occur in harsh mixes due to lack of cohesion in the mix.
3. **Collapse (zero slump) :** Occur in mixes of stiff consistence. So that in the rather dry range no variation can be detected between mixes of different workability.

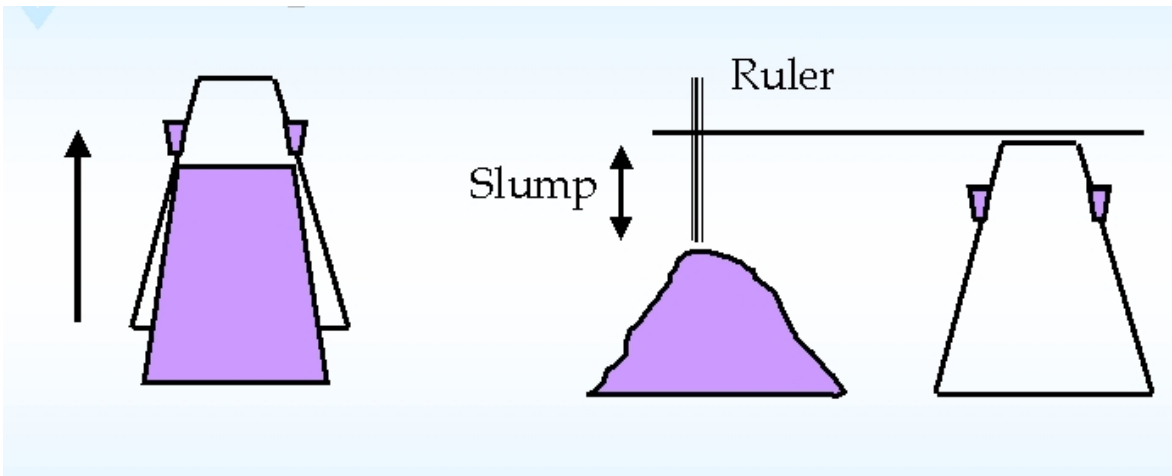
Rich mixes behave satisfactorily, their slump being sensitive to variation in workability. However, lean mixes with tendency to harshness a true slump can easily change to shear slump or even to collapse and different values of slump can be obtained in different sample from the same mix.

Slump is useful in site to check day to day or hour to hour variation in the material being fed in the mixer. Increase in slump for example, may mean increase in moisture content of aggregate unexpectedly, or change in the grading of the aggregate. Too high or too low slump gives warning to the mixer operator to remedy the situation.

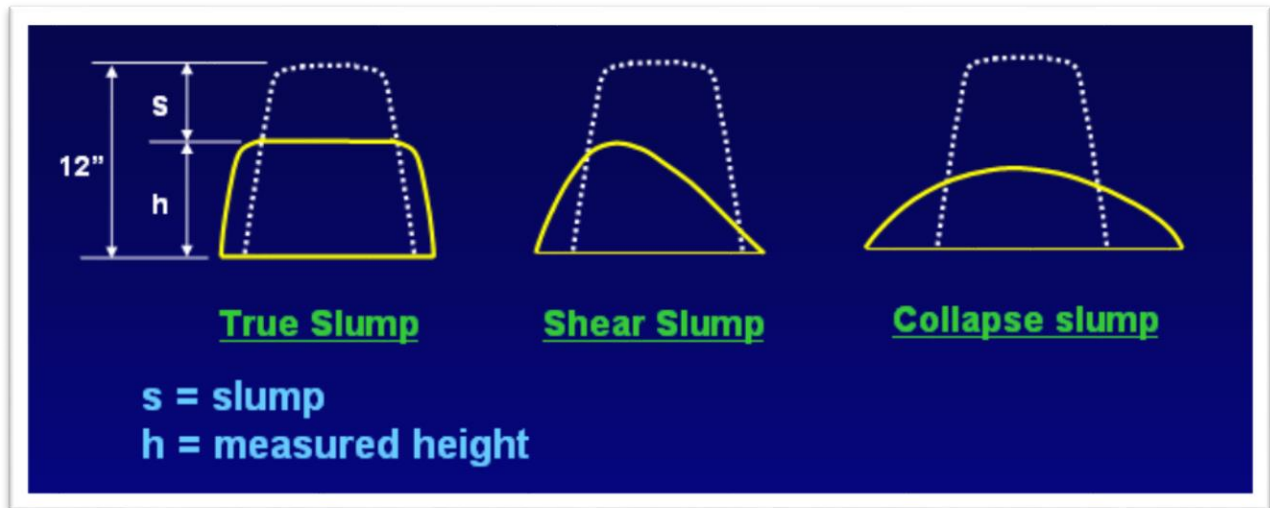




The slump cone is filled in 3 layers. Every layer is evenly rodded 25 times.



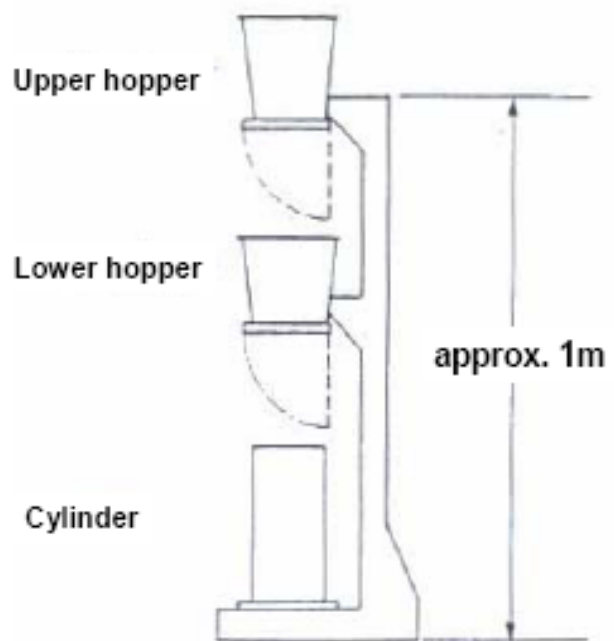
Measure the **slump** by determining the vertical difference between the top of the mold and the displaced original center of the top surface of the specimen.



Compacting factor test

(to distinguish between low slump mixes)

1. Concrete is placed in an upper
2. Dropped into a lower hopper to bring it to a standard state and then allowed to fall into a standard cylinder.
3. The cylinder and concrete weighed (partially compacted weight)
5. The concrete is fully compacted, extra concrete added and then concrete and cylinder weighed again (fully compacted weight)

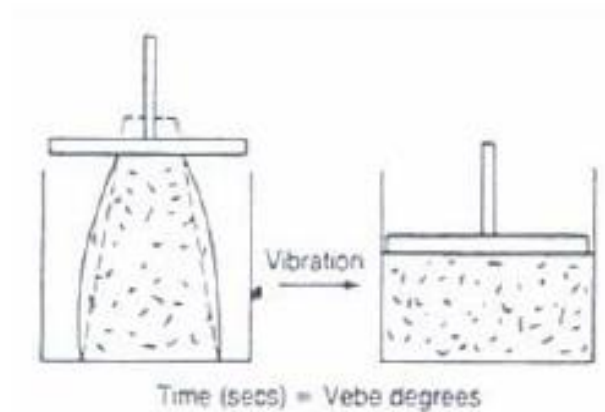


$$\text{Compacting factor} = \frac{\text{weight of partially compact concrete}}{\text{weight of fully compact concrete}}$$

- ❖ This test is not often used in precast concrete works and large sites.
- ❖ Unlike slump test, variation in the workability of dry concrete are reflected in a large change in the compacting factor, i.e the test is more sensitive at the low workability than at high workability.

- ❖ For concrete of very low workability, the actual amount of work required for full compaction depend on the richness of the mix while the compacting factor does not: leaner mixes need more work than richer ones. This means mixes with same compacting factor do not need the same work for full compaction.

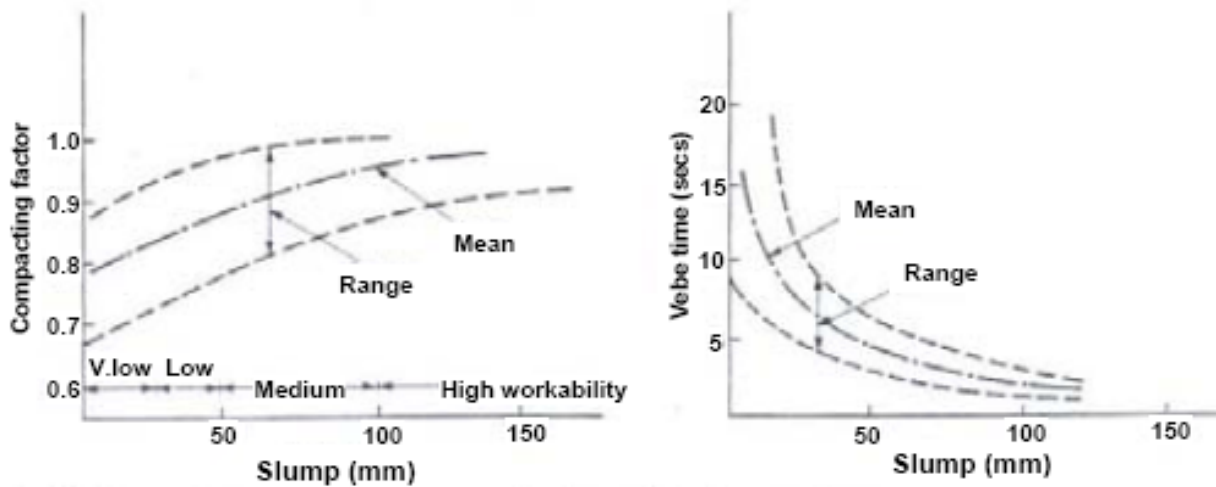
Vebe test



1. A slump test is performed in a container
2. A clear perspex disc, free to move vertically, is lowered onto the concrete surface
3. Vibration at a standard rate is applied

Vebe time is defined as the time taken to complete covering of the underside of the disc with concrete container

Correlations between compacting factor, Vebe time and slump



Some degree of correlation between the results exist, however the correlation is quite broad since each tests measures the response to different conditions

Factors affecting workability

1. Mixing water content
2. Relative amount of cement paste
3. Cement fineness
4. Aggregate grading
5. Shape of aggregate particles
6. Surface texture
7. Admixtures
8. Air entraining agents
9. Effect of time and temperature

1- Mixing water content:

Workability of the mix increases with increasing water content when the type and the maximum size of aggregate are fixed. When the maximum size of aggregate decreases (smaller) the grading of aggregate is finer and the amount of water required for specific workability increases.

2- Relative amount of cement paste:

Decreasing cement paste means difficult workability, while increasing amount of the paste make the mix more flowable, i.e increasing workability.

If the paste is not sufficient for filling the gaps between aggregates, then the mix became dry(harsh)and loses its workability and became hard to cast , hard to fully compact due to the difficulty in the movement of the particles in relative to each other.

3- Fineness of cement:

increasing fineness increases workability up to specific limit, but increasing cement fineness is very expensive and the cost comparing to improving workability is very high.

4- Grading of aggregate:

It is necessary that aggregate with different sizes gives maximum density with reasonable specific amount of done work so that the fresh concrete have good workability and the resulting hard concrete have high strength. When the fineness factor is high, this means the aggregate is coarser and the need for water decreased.

5- Shape of aggregate particles:

If the surface area of aggregate particles is high (relative to its volume), the workability decreases as in flaky and elongated particles because it needs more water to saturate (wetting) surface of all particles in order to have the required workability which leads to decreasing the compressive strength of the resulted hardened concrete. In general, the rounded particles is more workable and needs less water and less cement due to the smaller surface area while angular particles hard or difficult workability as it needs more water and more cement.

6- surface texture

Increasing in surface roughness and porosity of particles leads to decreasing movement of these particles in the mix and increase internal friction which in turn causes increasing the work done to resist internal friction. Also, in this case the amount of cement is not sufficient to cover all particles and thus, decreasing workability, for example mixes with crushed aggregates.

7- Admixtures

There are some materials that are of ultra-high fineness are added to the mixture constituents in order to improve workability and plasticity, for example:-

a- chemically inert materials: grinded sand and grinded limestone. These materials work as lubricants which increases workability.

b- pozzolanic materials: cock ash, rice husk ash, blast furnace slag and burned clay. These materials have the ability to react with $\text{Ca}(\text{OH})_2$ liberated from hydration of silicates resulting in calcium silicates hydrates which is responsible for strength of hardened cement paste and have bonding and cohesion characteristics.

c- plasticizers: these are chemical materials capable of dispersing cement particles which increase the workability of the mix within the same water/ cement ratio, they are used in hot weather and in mass concrete. Also when high workability and increasing in compressive strength of concrete are required.

8- Air entraining agents:

Admixtures that allow a controlled quantity of small, uniformly distributed air bubbles to be incorporated during mixing and which remain after hardening. Air entrainment is usually specified by the percentage of air in the mix but may also be specified by air void characteristics of spacing factor or specific surface of the air in the hardened concrete. The use of air entraining agents increases concrete workability and plasticity. Also, the uses of these agents reduce water content and segregation and simplified handling and casting. On the other hand, they cause reduction in compressive strength. This reduction can be treated by reducing the added water. Example for their application in dams.

9- Effect of time and temperature

Fresh concrete loses workability due to:

1. mix water being absorbed by the aggregate if this not in a saturated state before mixing
2. evaporation of the mix water especially if the concrete exposed to wind or heat of sun.
3. early hydration reactions (but this should not be confused with cement setting)

4. Interactions between admixtures (particularly plasticizers and superplasticizer) and the cementitious constituents of the mix.

In general, the real value for the reduction in workability depends on:

1. Cement content in the mix
2. Type of cement
3. Temperature of concrete mix
4. Initial workability of the mix

The workability is tested for the concrete mix after 15 min of mixing preferably, as it represent the true workability at casting time.

The workability also affected by the ambient temperature, it is obvious that in hot weather day, an increase in mixing water is required in order to maintain workability of concrete within acceptable limits. The temperature of concrete should be considered and ice might be used instead of water in hot weather concreting. When the temperature increase the slump decreases and it was observed that in high temperature (more than 50 C) and humidity less than (20%) there is sudden decrease in slump of concrete.