Cement: Portland cement

Cement: Cement is the mixture of calcareous, siliceous, argillaceous and other substances.

Cement is a hydraulic binder and is defined as a finely ground inorganic material which, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes which, after hardening retains its strength and stability even under water.

The name "Portland cement" given originally due to the resemblance of the color and quality of the hardened cement to Portland stone – Portland island in England.

Functions of cement:

1. Popular as building material.

2. Material with adhesive & cohesive properties.

3.To bind the fine & coarse aggregate together

4. To fill voids in between fine & coarse aggregate particle form a compact mass.

Manufacture of cement manufacturing:

1. Raw materials extraction:

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

2. Quarrying, Dredging, and Digging

Quarrying of limestone and shale is accomplished by using explosives to blast the rocks from the ground. After blasting, huge power shovels are used to load dump trucks or small railroad cars for transportation to the cement plant, which is usually nearby.

The ocean floor is dredged to obtain the shells, while clay and marl are dug out of the ground with power shovels. All of the raw materials are transported to the plant.

3. Grinding

After the raw materials have been transported to the plant, the limestone and shale which have been blasted out of the quarry must be crushed into smaller pieces. Some of the pieces, when blasted out, are quite large. The pieces are then dumped into primary crushers which reduce them to the size of a softball. The pieces are carried by conveyors to secondary crushers which crush the rocks into fragments usually no larger than 3/4 inch across.

4. Blending

After the rock is crushed, plant chemists analyse the rock and raw materials to determine their mineral content. The chemists also determine the proportions of each raw material to utilize in order to obtain a uniform cement product. The various raw materials are then mixed in proper proportions and prepared for fine grinding.

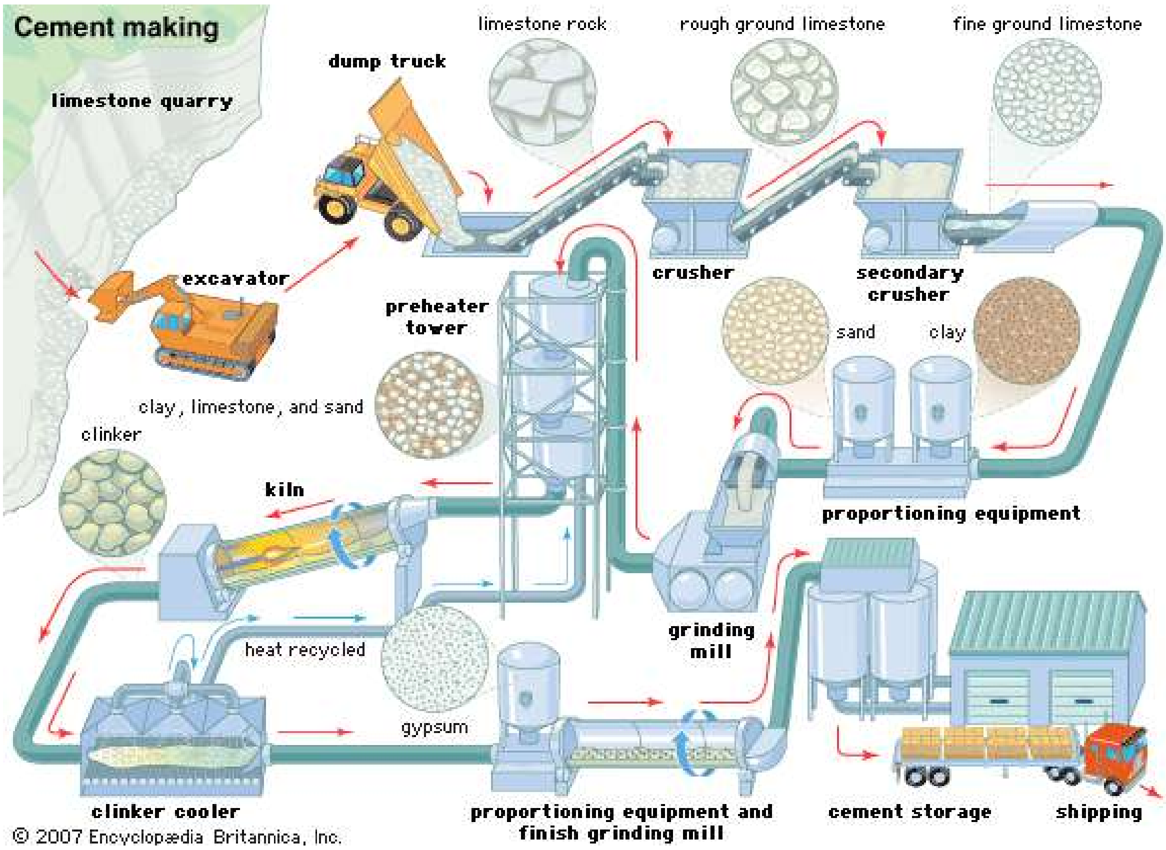
5. Fine Grinding

When the raw materials have been blended, they must be ground into a fine powder. This may be done by one of two methods:

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

1. **Wet process:**

   The wet process of fine grinding is the older process, having been used in Europe prior to the manufacture of cement in the United States. This process is used more often when clay and marl, which are very moist, are included in the composition of the cement. In the wet process, the blended raw materials are moved into ball or tube mills which are cylindrical rotating drums which contain steel balls. These steel balls grind the raw materials into smaller fragments of up to 200 of an inch. As the grinding is done, water is added until a slurry (thin mud) forms, and the slurry is stored in open tanks where additional mixing is done. Some of the water may be removed from the slurry before it is burned, or the slurry may be sent to the kiln as is and the water evaporated during the burning.



The dry and semi-dry process:

1. The raw materials are crushed dry and fed in correct proportions into a grinding mill.

2. In grinding mill, they are dried and reduced to a very fine powder. The dry powder called the raw meal.

3. The raw meal is then further blended and corrected for its right composition and mixed by means of compressed air

4. The aerated powder tends to behave almost like liquid and in about one hour of aeration a uniform mixture is obtained.

5. The blended meal is further sieved and fed into a rotating disc called granulator.

6. A quantity of water about 12 per cent by wright is added to make the blended meal into pellets.

7. Pellets is done to permit air flow for exchange of heat for further chemical reactions and conversion of the same into clinker further in the rotary kiln.

6. Burning

Burning the blended materials is the key in the process of making cement. The wet or dry mix is fed into the kiln,(rotary kiln) which is one of the largest pieces of moving machinery in the industry.

Rotary kiln : is an important component of a cement factory. It is a thick steel cylinder of diameter anything from 3 m to 8 m, lined with refractory materials, mounted on roller bearings and capable of rotating about its own axis at a specified speed. The length of the rotary kiln may vary anything from 30 m to 200 m. The kiln is fired from the lower end. The fuel is powered coal, oil or natural gas.

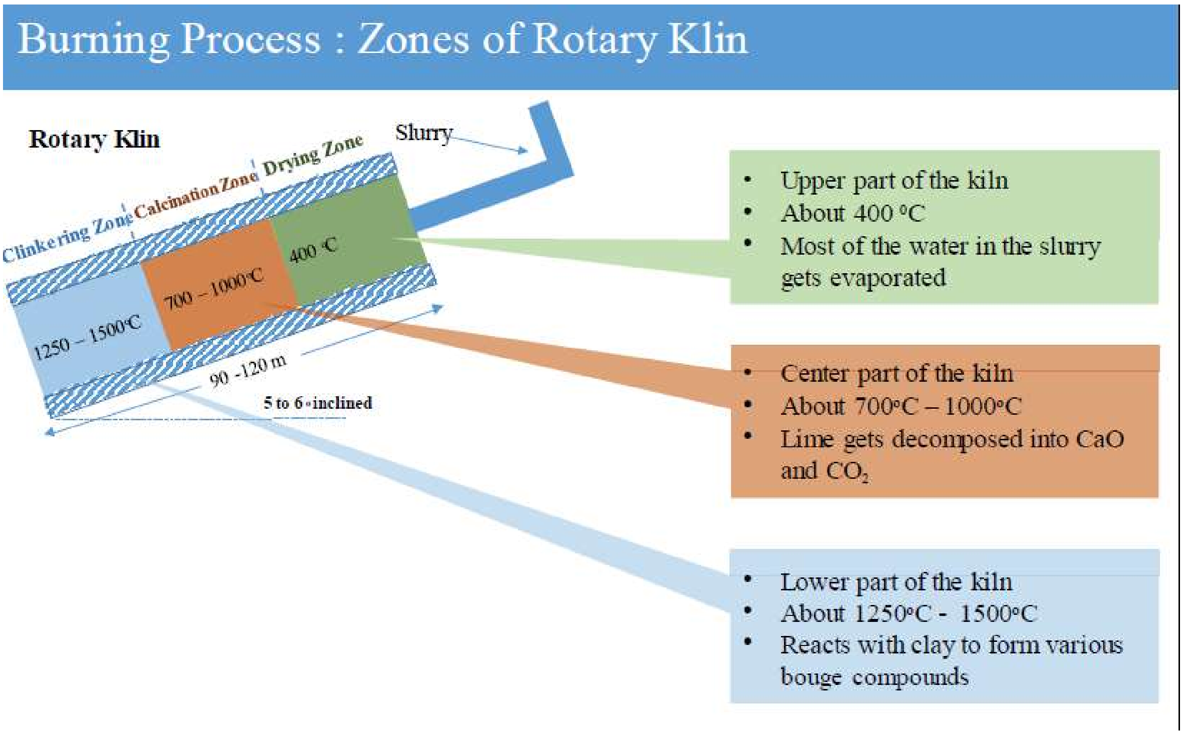
As the kiln revolves, the materials roll and slide downward for approximately four hours. In the burning zone, where the heat can reach 3,000 degrees Fahrenheit, the materials become incandescent and change in colour from purple to violet to orange. Here, the gases are driven from the raw materials, which actually change the properties of the raw materials. What emerges is “clinker” which is round, marble-sized, glass-hard balls which are harder than the quarried rock. The clinker is then fed into a cooler where it is cooled for storage.

7. Finish Grinding

The cooled **clinker** is mixed with a small amount of gypsum, which will help regulate the setting time when the cement is mixed with other materials and becomes concrete. Here again there are primary and secondary grinders. The primary grinders leave the clinker , ground to the fineness of sand, and the secondary grinders leave the clinker ground to the fineness of flour, which is the final product ready for marketing.

8. Packaging/Shipping

The final product is shipped either in bulk (ships, barges, tanker trucks, railroad cars, etc.) or in strong paper bags which are filled by machine.



Ball mill: A ball mill consists of several compartments charged with progressively smaller hardened steel balls. The particles crushed to the required fineness are separated by currents of air and taken to storage silos from where the cement is bagged or filled into barrels for bulk supply to dams or other large work sites.

** The good grading pattern of the cement particles is important for making good concrete.

Grinding of the clinker:

The cool clinker (produced by wet or dry process), which is characteristically black and hard, is inter ground with gypsum $CaSO_4.2H_2O$ in order to prevent flash setting of the cement, and to facilitate the grinding process. The grinding is done in a ball mill. The cement discharged by the mill is passed through a separator, fine particles being removed to the storage silo by an air current, while the coarser particles are passed through the mill once again.

Comparison between wet and dry process:

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

Lecture two

الخواص الفيزيائية للإسمنت البورتلاندي

Physical Properties of Portland Cement

*الاسمنت البورتلاندي عبارة عن مسحوق رمادي حبيباته لها وزن نوعي (3.15) وحجم يتراوح بين(80 -20) ما يكرون وحجم الحبيبة يعتمد على طريقة الطحن ويمكن أن يتغير حسب متطلبات الاسمنت.

*جزيئات الاسمنت ذات حجم صغير بحيث من الصعوبة قياسها بالتحليل المنخلي كما في حالة الركام ,وبذلك يتم اللجوء الى تحديد المساحة السطحية النوعية Specific Surface Area لوحدة الوزن كقياس بديل.

*يتم تعيين المساحة السطحية النوعية للإسمنت بطريقة (Blaine) وهي الأكثر شيوعا"

ومبنية على أساس قياس سرعة انتشار الهواء تحت ضغط ثابت خلال نموذج صغير مضغوط من الاسمنت . وتتراوح قيم المساحة السطحية النوعية المقاسة بهذه الطريقة بين $300\text{-}500 m^2/ Kg$ لأغلب أنواع الاسمنت المستعمل.

الخواص الكيميائية للإسمنت البورتلاندي Properties of Portland Cement Chemical

ان المواد الأولية المستعملة في صناعة الاسمنت البورتلاندي تتكون بصورة رئيسية من:-

- 1- (الحجر الجيري) CaO (ويرمز له بالحرف C)
- 2- (السليكا) SiO_2 (ويرمز له بالحرف S)
- 3- (الالومينا) Al_2O_3 (ويرمز له بالحرف A)
- 4- (اوكسيد الحديد) Fe_2O_3 (ويرمز له بالحرف F)

تتفاعل هذه المركبات مع بعضها البعض داخل الفرن الى ان يتم الوصول الى حالة التوازن الكيمياوي وينتج عن هذا التفاعل الكلنكر Clinker.

يحتوي الكلنكرعلى اربع مكونات رئيسية :

الرمز	الرمز الكيمياوي	اسم المركب	ت
C_3S	$3CaO\ SiO_2$	سليكات ثلاثي الكالسيوم	1-
C_2S	$2CaO\ SiO_2$	سليكات ثنائي الكالسيوم	2-
C_3A	$3CaO\ Al_2O_3$	الومينات ثلاثي الكالسيوم	3-
C_4AF	$4CaO\ Al_2O_3\ Fe_2O_3$	الومينات حديد رباعي الكالسيوم	4-

** These oxides interact with one another in the kiln at high temperature to form more complex compounds.

** **The relative proportions of these oxide compositions are responsible for:**

1- influencing the various properties of cement

2- the rate of cooling

3- fineness of grinding

Four main four compounds are usually regarded as the major constituents of cement

- Tricalcium silicate $3CaO.SiO_2 \longrightarrow$ **(C_3S)**
- Dicalcium silicate $2CaO.SiO_2 \longrightarrow$ **(C_2S)**
- Tricalcium aluminate $3CaO.Al_2O_3 \longrightarrow$ **(C_3A)**
- Tetracalcium aluminoferrite $4CaO.Al_2O_3.Fe2O_3 \longrightarrow$ **(C_4AF)**

Where each oxide symbol with one letter:

$CaO – C$, $SiO_2 – S$, $Al_2O_3 – A$, $Fe_2O_3 – F$, $H_2O – H$

The oxide shown within the brackets represents the percentage of the same in the raw materials.

من الممكن تحديد النسبة المئوية لهذه المركبات الرئيسية الأربعة في الاسمنت البورتلاندي من النسبة المئوية المستحصلة من التحليل الكيمياوي بواسطة معادلة (Bogue) على فرض:-

1- إن التوازن الكيمياوي حاصل عند تفاعل هذه المركبات الرئيسية الأربعة.
2- ظروف تبريد الكلنكر لا تؤثر على توازن الطور أي ان الزجاج لا يتكون في هذه الحالة.
3- نواتج التوازن الكيمياوي هي متبلورة كليا"

Minor compounds:

In addition to the main compounds mentioned above, there exist minor compounds, such as MgO, TiO_2, Mn_2O_3, K_2O and Na_2O. Two of the minor compounds are of particular interest: K_2O and Na_2O, known as the alkalis (about 0.4-1.3% by weight of cement). They have been found to react with the reactive silica found in some aggregates, the products of the reaction causing increase in volume leading to disintegration of the concrete. The increase in the alkalis percentage has been observed to affect the setting time and the rate of the gain of strength of cement.

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

Iraqi specification no. 5/2017 limited max. SO_3 by 2.5% when $C_3A \leq 7\%$, and by 3% when $C_3A > 7\%$. MgO, present in the cement by 1-4%, which comes from the magnesia compounds present in the raw materials. Iraqi specification no. 5 limited max. MgO by 5%, to control the expansion resulted from the hydration of this compound in the hardened concrete. When the magnesia is in amorphous form, it has no harmful effect on the concrete.

Usual Composition Limits of Portland Cement

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

Typical compound composition in ordinary Portland cement

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

Loss on Ignition (L.O.I): It is the loss of the cement sample weight when it expose to the **red temperature (at 1000°C).** It shows the extent of carbonation and hydration of free lime and free magnesia due to the exposure of cement to the atmosphere. Also, part of the loss in weight comes from losing water from the gypsum composition. The maximum loss on ignition permitted **by Iraqi specification no. 5/ 2017** is 4% by weight.

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

Bogue's Compounds:

The compounds responsible for strength are (Tri calcium silicate (C_3S)) and (Di calcium silicate (C_2S)). They constitute (70 to 80 %) of cement. The average (C_3S) content in modern cement is about (45%) and that of (C_2S) is about 25 %. The sum of the contents of (C_3A) and (C_4AF) has decreased slightly in modern cements. The equations suggested by Bogue for calculating the percentages of major

compounds are given below.

$C3S= 4.07\ (CaO) - 7.60\ (SiO2) - 6.72\ (Al2O3) - 1.43\ (Fe2O3) - 2.85\ (SO3)$

$C2S = 2.87\ (SiO2) - 0.754\ (3CaO.SiO2)$

$C3A = 2.65\ (Al2O3) - 1.69\ (Fe2O3)$

$C4AF= 3.04\ (Fe2O3)$

Hydration of cement: حرارة الاماهة

هي الحرارة المتولدة من تفاعل مركبات الاسمنت مع الماء ففي الحالات الاعتيادية لأنواع الاسمنت البورتلاندي فان حوالي نصف الحرارة الكلية تتولد من 1-3 يوم وحوالي ثلاثة أرباع الحرارة في (7)أيام وتقريبا 90% في ستة أشهر. والحرارة المتولدة تعتمد على التركيب الكيمياوي للإسمنت (جدول رقم 2) وهي مساوية تقريبا الى مجموع حرارة اماهة المركبات الفردية النقية عندما تتميئ نسبتها الوزنية كل على حدة. ومن الممكن تقليل حرارة الاماهة ومعدل سرعتها بتقليل نسبة C_3S , C_3A.

المركب	حرارة الاماهة	
	جول / غم	سعرة / غم
C_3S	502	120
C_2S	260	60
C_3A	867	207
C_4AF	419	100

structure of hardened cement paste تركيب عجينة الاسمنت المتصلبة

في أي مرحلة من عملية الاماهة فان عجينة الاسمنت المتصلبة تتكون مما يلي :

1- سلكيات الكالسيوم المهدرجة (C-S-H) وتسمى جل الاسمنت .

2- هيدروكسيد الكالسيوم $Ca(OH)_2$.

3- الاسمنت الغير متميئ (وهذا قد يكون موجود أو غير موجود حسب كمية الماء المستخدمة).

4- الفراغ الغير المملوء المتبقي بين حبيبات الاسمنت (المسامات الشعرية).

5- سلفو الومينات الكالسيوم (ناتجة من تفاعل الجبس مع C_3A).

6- مسامات الجل .

The main hydrates of the hydration process are:

1.. Calcium silicates hydrate, including hydrated products of C_3S (not pure) named as Alite, and C_2S (not pure) named as Belite.
2. Tricalcium aluminate hydrate
3. C_4AF hydrates to tricalcium aluminate hydrate and calcium ferrite $CaO.Fe_2O_3$ in amorphous form.
Since calcium silicates (C_3S and C_2S) – are the main cement compounds (occupies about 75% of cement weight) – they are responsible for the final strength of the hardened cement

1. **Hydration of alite (Tricalcium silicate):**

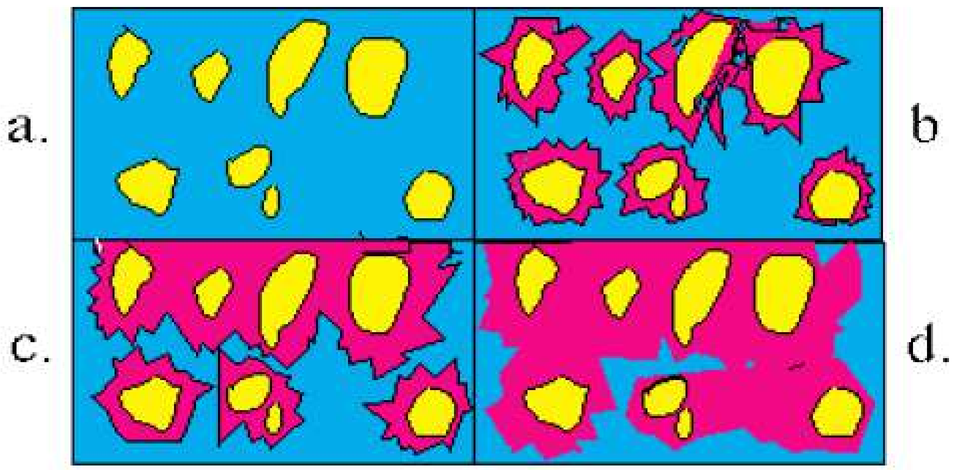


Fig. Schematic illustration of different stages of hydration.

-1- سليكات ثلاثي الكالسيوم C_3S

-*تتواجد هذه السيليكات بكميات كبيرة في الاسمنت على شكل حبيبات صغيرة متساوية الأبعاد وعديمة اللون تتحلل ببطء أثناء تبريدها إلى درجة 1250 درجة مئوية وتبقى ثابتة لا تتغير إذا لم يكن

التبريد بطيئا "وتبقى مستقرة في درجات الحرارة الاعتيادية . تبلغ نسبتها % 45 -55 وهي المسؤولة عن قوة الخرسانة للأيام الى 28.

-*ويحتاج للإماهة الكلية (24%) ماء من وزن الاسمنت ويمكن التعبير عن تفاعله مع الماء بالمعادلة التالية :

61% 39%

$$\mathbf{2C_3S + 6H \text{--------}\!\!\rightarrow C_3S_2H_3 + 3CH + 120\ Cal/g} \uparrow$$

Tricalcium silicate (Alite) + Water → Calcium Silicate Hydrate (CSH) gel + Calcium Hydroxide (lime) + Heat

-*وهو المسؤول عن المقاومة المبكرة لعجينة الاسمنت خلال الأربعة أسابيع الأولى والسبب في ذلك ان S_3C يتميه بسرعة اكبر في البداية ويتميه بشكل كامل خلال ال 28 يوم.

-*للحصول على خرسانة عالية المقاومة في وقت مبكر يستعمل الاسمنت الحاوي على نسبة عالية من C_3S.

***2.* Hydration of Dicalcium silicate (Belite) :**

-2 ثنائي سليكات الكالسيوم C_2S

-*ويشارك في اكتساب المقاومة للإسمنت بعد (28) يوم (لأنه يتميه ببطيء خلال الاربع اسابيع الاولى) ولغاية سنة وتبلغ نسبتها % 15 – 25 وهي المسؤولة ظاهرة الالتئام الذاتي حيث تقوم بأغلاق الشقوق الشعرية في المونة والخرسانة وكذلك قوة الشد للخرسانة.

-*يحتاج للإماهة الكلية (% 21) ماء من وزن الاسمنت ويمكن التعبير عن تفاعله مع الماء بالمعادلة التالية-:

$$\mathbf{2C_2S + 4\ H\text{---------------}\ C_3S_2H_3 + CH + 62\ Cal/gm} \uparrow$$

82 % 18%

***3.* Hydration of Tricalcium Aluminate (Celite) :**

C3A + 3CSH2 + 13H → C6AS3H32 + 207 Cal/g ↑

Tricalcium Aluminate (Celite) + Gypsum + water → Ettringite + Heat

2C3A + 3 C6AS3H32 + 22H → 3C4ASH18

-3 ثلاثي الومينات الكالسيوم C_3A

يتواجد هذا المركب بكمية قليلة في معظم أنواع الاسمنت مقارنة مع باقي المركبات وذو بلورات منشوريه غامقة اللون وعند تفاعله مع الماء بصورة منفردة يبعث كمية كبيرة من الحرارة مكونا بلورات صناعية سداسية من الومينات الكالسيوم ألمانية. تبلغ نسبتها % 12 - 15

C3A + 3CSH2 + 13H → C6AS3H32 + 207 Cal/g ↑

Tricalcium Aluminate (Celite) + Gypsum + water → Ettringite + Heat

2C3A + 3 C6AS3H32 + 22H → 3C4ASH18

-*هذا النوع من التفاعل يؤدي الى حدوث التجمد الفجائي flash setting ولكن لوجود الجبس الذي يضاف الى الكلنكر قبل عملية طحن الاسمنت حيث يتفاعل الجبس مع C_3A مكونا "سلفو الومينات الكالسيوم الغير ذائبة حول حبيبات أل C_3A فيؤخر تفاعلها مع الماء وبذلك سيتحدد هيكل عجينة الاسمنت بنواتج المركب C_3S حيث تكون مساميته قليلة جدا "مقارنة مع الهيكل المتكون من المركب C_3A .

-*يتفاعل هذا المركب مع أملاح السلفات (الكبريتات) الموجودة بكثرة في الرمال أو في التربة والمياه الجوفية التي تتعرض لها الكتلة الخرسانية مكونا سلفو الومينات الكالسيوم(الاترنجايت) مما يؤدي الى زيادة حجم الكتلة الخرسانية فيسبب تشقق وتلف الكتلة الخرسانية.

-*إن وجود هذا المركب في الاسمنت غير مرغوب فيه حيث أن مشاركته في إعطاء قوة للإسمنت قليلة جدا "وتتحدد في الأيام الأولى فقط بين 1-3 يوم.

-*هذا المركب يعمل كمادة مساعدة للانصهار ويسهل اتحاد الكلس مع السليكا فهو مفيد في عملية تصنيع الاسمنت لأنه يقلل من الحرارة اللازمة لتكوين الكلنكر.

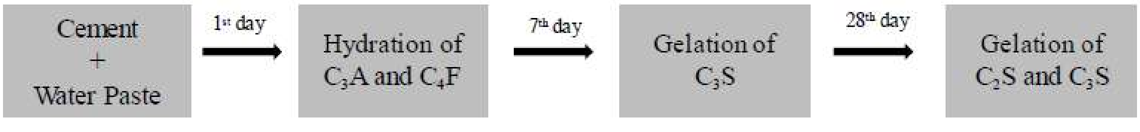
4. Hydration of Ferrite (Tetra Calcium AluminoFerrite):

4 الومنيات حديد رباعي الكالسيوم - C_4AF

يتواجد هذا المركب بكميات صغيرة في تركيب الاسمنت مقارنة مع المركبات الثلاثة الأخرى ، وهذا المركب لا يؤثر على عجينة السمنت ولكنه يتفاعل مع الجبس ليكون سلفوفرين الكالسيوم الذي يعجل بعملية الاماهة ويعمل كمادة مساعدة على الانصهار. وتتراوح نسبته بين % 7 – 12 وهو يتفاعل في الايام الاولى ويعطي حرارة عالية

$$C_4AF + 3CSH_2 + 3H \rightarrow C_6(A,F)S_3H_{32} + (A,F)H_3 + CH$$

Ferrite (Tetra Calcium AluminoFerrite) + gypsum + water → Ettringite + Ferric Aluminium



Heat of Hydration:

The reaction of cement with water is exothermic. The reaction liberates a considerable quantity of heat. This liberation of heat is called heat of hydration.

** This is clearly seen if freshly mixed cement is put in a vacuum flask and the temperature of the mass is read at intervals.

The study and control of the heat of hydration becomes important in:

1- The construction of concrete dams

2- The mass concrete constructions.

It has been observed that the temperature in the interior of large mass concrete is 50°C above the original temperature of the concrete mass at the time of placing and this high temperature is found to persist for a prolonged period. The quantity of evolved heat when the cement hydrated completely at a given temperature – Joule/gram or calorie/gram of unhydrated cement.

In general, on mixing cement with water,

1. A rapid heat evolution (ascending portion of peak A) lasting a few minutes occurs. This probably represents the heat of solution of aluminates and sulphates.
2. This initial heat evolution ceases quickly (descending portion of peak A) when the solubility of aluminates is depressed in the presence of sulphate in the solution.
3. The next heat evolution cycle, culminating in the second peak after about 4 to 8 h of hydration for most Portland cements, represents the heat of formation of ettringite (ascending portion of peak B).
4. The heat evolution period includes some heat of solution due to C_3S and heat of formation of C-S-H. The paste of a properly retarded cement will retain much of its plasticity before the commencement of this heat cycle and will stiffen and show the initial set (beginning of solidification) before reaching the apex at B, which corresponds to the final set (complete solidification and beginning of hardening).

The hydration of Portland cement involves exothermic reactions, and the hydration operation release heat which can be illustrated in Figure(2):

Compound	Heat of hydration	
	J/g	Cal/g
C_3S	502	120
C_2S	260	62
C_3A	867	207
C_4AF	419	100

Heat of hydration for pure compounds

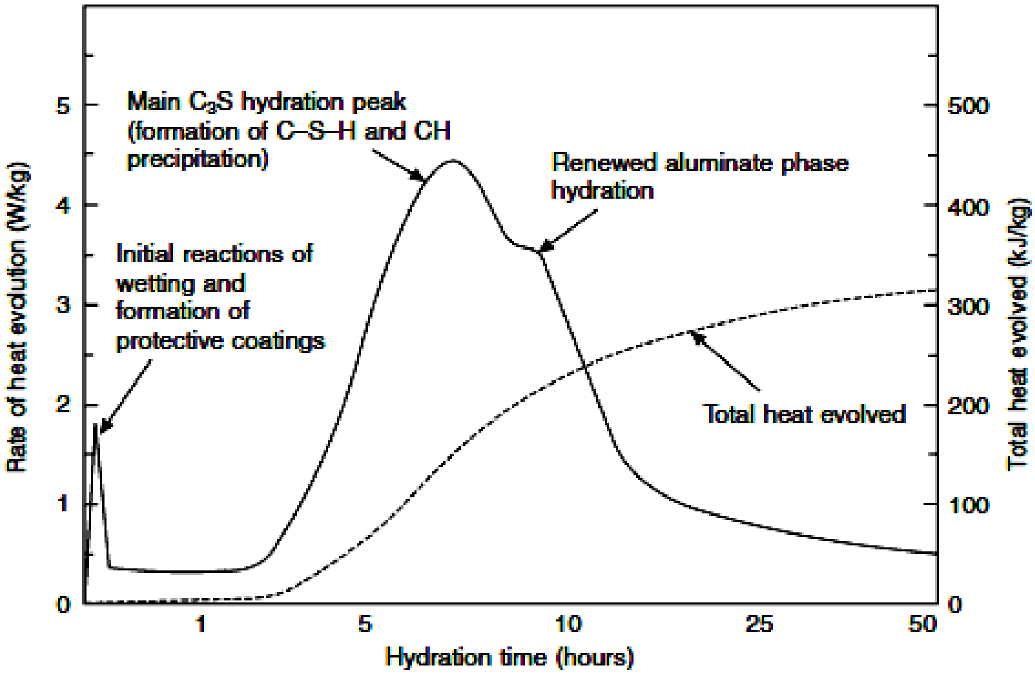
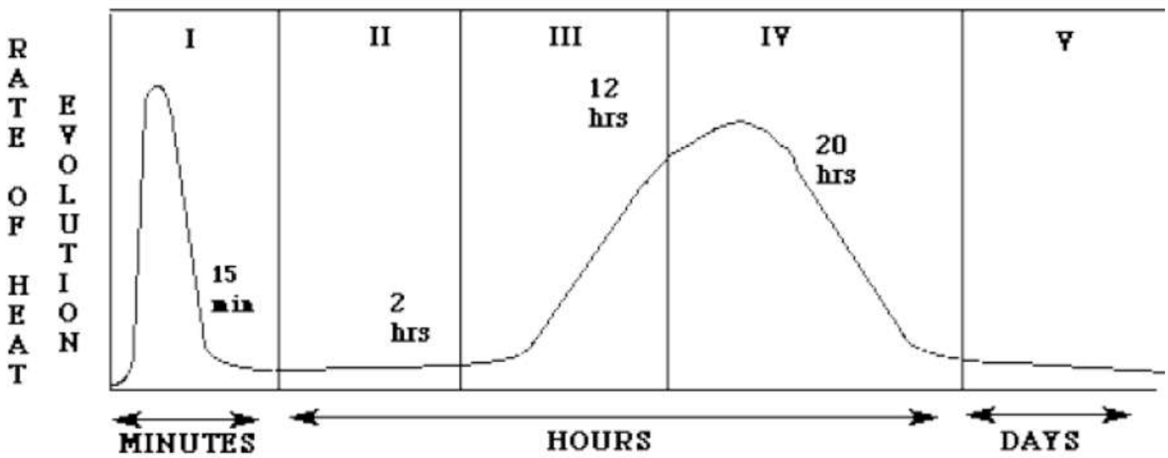


Figure (2): Heat of Hydration of a Cement Paste Determined by Conduction Calorimetry at (20°C).

The hydration of cement compounds - accompanied with heat evolution, energy of up to 120 cal/g of cement being liberated.



Rate of heat evolution during the hydration of portland cement

The actual value of the heat of hydration depends on:

1.The chemical composition of the cement :

Heat of hydration of cement = sum of the heats of hydration of the individual compounds when hydrated separately. The contribution of individual compounds to the total heat of hydration of cement can be measured from the following equation:

Heat of hydration of 1 g of cement =
$$136(C_3S) + 62(C_2S) + 200(C_3A+)\ 30(C_4AF)$$

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

2. Ambient temperature : Has great effect on the rate of heat evolution The rate of heat evolution increase with increase in the ambient temperature.

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

- Rapid hardening Portland cement.
- Ordinary Portland cement.
- Modified Portland cement.
- Sulphate resistant Portland cement.
- Low heat Portland cement.

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

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

The progress of hydration of cement can be determined by different means:
1- The measurement of the amount of $Ca\,(OH)_2$ in the paste resulted from the hydration of the silicates.
2- The heat evolved by hydration.
3- The specific gravity of the paste.
4- The amount of chemically combined water.

Influence of the compounds composition on properties of cement

Main compounds

C_3S and C_2S are the most important compounds responsible for strength .

C_3S: Contributes most to the strength development during the first four weeks.

C_2S: Influences the gain in strength from 4-weeks onwards.

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

C_3A: contributes to the strength of the cement paste at one to three days , and possibility longer , but may caucuses retrogression at an advanced age particularly in cements with high C_3A or (C_3A + C_4AF) content.

C_4AF: the development of strength of cement is still not clear , but there certainly is no appreciable positive contribution.

Setting

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

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

The **stages of setting** include:

- Initial setting
- Final setting

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

The two first to react are C_3A and C_3S.

The setting time of cement decreases with a rise in temperature. The importance of setting in concrete works comes from the importance to keep the fresh concrete in the plastic stage for enough time necessary to complete its mixing and placing under practical conditions. But, from the economical side, it is important that the concrete hardens at convenient period after casting.

There are four main stages during setting

First stage

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

Second stage (dormant period)

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

Third stage

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

Fourth stage

- hardening and gain of strength

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

Initial setting time – refers to the beginning of the cement paste setting.
Final setting time – refers to the beginning of hardening and gain of strength.
Iraqi Standard Specification No. 5 limits / 2017:

- 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 inter ground with too hot a clinker

- formed:
- :hemihydrates ($CaSO_4 . 0.5H_20$) – when temperature between 100-190^0 C
- or anhydrite ($CaSO_4$) - when temperature >190^0 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 $Ca(OH)_2$ liberated by the hydrolysis of C_3S to form $CaCO_3$. This precipitates and induces a rigidity of the paste.

K_2O or $Na_2O + CO_2 \rightarrow K_2CO_3$ or Na_2CO_3

K_2CO_3 or $Na_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3$

3- Activation of C_3S subjected to wet atmosphere

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

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

Soundness of cement

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

Causes of expansion

1- **Free lime CaO**

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

$CaO + H_2O \rightarrow Ca(OH)_2$

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.

-ASTM --- 6%
-IQS----5%
$MgO + H2O$----- $Mg(OH)_2$

3- Calcium sulphates (gypsum)

Gypsum added to the clinker during its grinding in order to prevent flash set, but if gypsum is present in excess of the amount that can react with C_3A during setting, unsoundness is in the form of a slow expansion will result.
There are two methods to determine the soundness of cement
a. Autoclave test
b. Le chatlier test

Fineness of cement

The last step in the manufacture of cement is the grinding of clinker mixed with gypsum. Because hydration starts at the surface of the cement particles, it is the total surface area of cement that presents the material available for hydration. Thus the rate of hydration depends on the fineness of the cement particles.

The high fineness is necessary for:
1. Rapid development of strength
2. To cover surface of the fine aggregate particles at better manner leading to better adhesion between cement mortar constituents.
3. To improve the workability of the concrete mix, but it will increase the amount of water required for the standard consistency.

The disadvantage of high fineness:

1. The cost of grinding to a higher fineness is considerable.

2. The finer the cement the more rapidly it deteriorates on exposure to the atmosphere during storage.

3. Finer cement increases the surface area of its alkalies leads to stronger reaction with alkali- reactive aggregate – cracks and deterioration of concrete.

4. Finer cement exhibits a higher shrinkage and a greater proneness to cracking.

5. An increase in fineness increases the amount of gypsum required .

There are four methods to determine the fineness of cement:

1. Sieve analysis

2. Blaine (air permeability)

3. Sedimentation principle

4. Wagner

Optimum Gypsum Content (OGC):

Optimum gypsum content is a percentage of gypsum that give higher compressive strength, low drying shrinkage and no excessive expansion in concrete volume when immersed in water, presented in the figure below.

Factors affecting in the OGC

1. C3A content: Increase C3A content need to increase OGC because higher percentage will react in short time.

2. Cement fineness : Increase in cement fineness promote to increase OGC

3. Alkali content: Increase in alkali content means increase reaction of gypsum that leads to increase OGC.

4. Curing temperature: Increase in temperature of curing cause increase the reaction of C3A with gypsum that means increase OGC.

5. Curing time: Increase in curing time promotes to increase OGC because of autogenously healing.

6. Free CaO and MgO: increase of these oxides lead to decrease in OGC.

7. Clorides: increase of clorides lead decrease in OGC.

Aggregates

Definition

Aggregates are defined as inert, granular, and inorganic materials that normally consist of stone or stone-like solids. Aggregates can be used alone (in road bases and various types of fill) or can be used with cementing materials (such as Portland cement or asphalt cement) to form composite materials or concrete.

The most popular use of aggregates is to form Portland cement concrete. Approximately 75% of the volume of Portland cement concrete is occupied by aggregate.

Fig. Coarse aggregate

fig. fine aggregate

Classification of Aggregates

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

A. In accordance with size:

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

B. In accordance with sources

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

2. By-Product Aggregates:

Comprise blast-furnace slags and cinders, fly ash, etc. Cinders are residue of coal or wood after burning.

3. Processed Aggregates:

These are heat treated, expanded materials with lightweight characteristics. Example: Perlite, burnt clays, shales, processed fly ash.

4. Colored Aggregates:

Glass, ceramics, manufactured marble for decorative and architectural purposes.

C. In accordance with unit weight

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

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

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

D. In accordance with origin:

1. Igneous rock Aggregate:
2. Sedimentary rock Aggregates:
3. Metamorphic rock Aggregate:

E.In accordance with shape

1. Particle shape (Rounded, Angular, Flaky, Elongated, Irregular)

a) Rounded Aggregate:

The roundness of aggregate is a result of abrasion of aggregate in water. This type of aggregate gives better workability because low percentage of surface area to its volume and this need low water cement ratio (w/c).

b) Angular Aggregate:

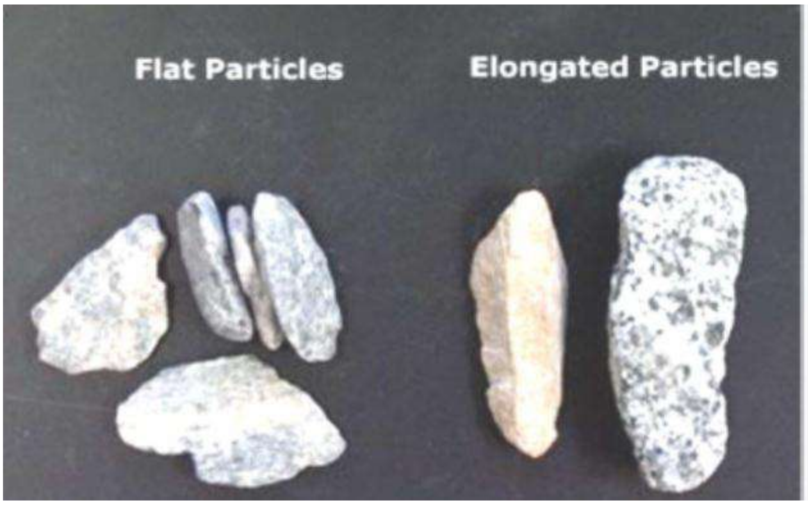
This type resulted from crushing the rock, percentage of surface area to its volume is high therefore it needs high W/C to get better workability of concrete. Percentage of voids when using this type in concrete is high compare with rounded.

c) Flaky Aggregate:

Thickness of this aggregate is little compare with its other dimensions. Particle is flaky if its thickness is less than 0.6 times the mean sieve size of the size fraction to which the particle belongs according to(B.S) Flakiness index express as a percentage of mass of flaky aggregate to the total mass of aggregate. This type has high surface area therefore it needs more water.

d) Elongated Aggregate: May lack cohesion and require increased fines aggregate which has a particle's length is more than 1.8 times the mean sieve size of the size fraction is said to be elongated. Elongation index is similar to angularity index.

e) Irregular Aggregate: Fair workability, low water demand. Irregular shape with rounded edges.



Aggregate Size

Larger size of aggregate is preferred in concrete because of the following reasons:

- It reduces the cement requirement.
- It reduces the water requirement.
- It reduces the shrinkage of concrete.

But practically, there are a number of factors which limit the use of higher size of aggregates in the concrete, such as spacing between reinforcing bars, thickness of section and concrete covers.

Angularity number

Angularity number gives a qualitative representation of shape of aggregate. In angularity number test, a quantity of single sized aggregate is filled into metal cylinder of 3 litres capacity. Then the aggregate is compacted in a standard manner and the percentage of void found out.

$$\%\ of\ Voids = \frac{\text{Bulk Density}}{Specific\ gravity} \times 100$$

- If the void content of the aggregate is 33% the angularity of such aggregate is considered 0.

- If the void is 44%, the angularity number of such aggregate is considered 11.

Importance of Angularity Number:

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

Surface Texture (smooth or rough):

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

Smooth-textured aggregates: are generally hard, dense and fine-grained aggregates. As surface smoothness increases, the surface area (contact area) decreases due to lesser irregularities, therefore these particles require quantity of cement paste for lubrication and hence less requirement of water and more compressive strength.

However, as surface smoothness increases, the bonding area with the concrete matrix reduces. Therefore, the flexural strength decreases due to poor bonding and interlocking.

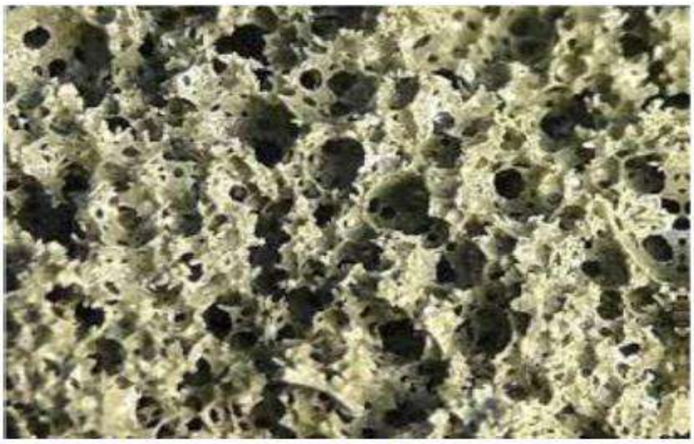
The opposite behaviour can be obtained with rough-textured aggregates.


Glassy textured aggregate


Smooth textured aggregate


Granular textured aggregate


Crystalline textured aggregate


Porous textured aggregate

Mechanical Properties of Aggregates

1. Bond of Aggregate

Bond between aggregate and cement paste is an important factor in the strength of concrete, especially the flexural strength (bending strength) is very related.

Bond is due, in part, to the interlocking of the aggregate and the paste resulting from the roughness of the surface of the aggregates. A rough surface, such as that of crushed particles, results in a better bond; better bond is also usually obtained with softer, porous and miner logically heterogeneous particles.

Because it depends on the paste strength as well as on the properties of aggregate surface, bond strength increases with the age of concrete.

2. Strength of Aggregate

It is obvious that the compressive strength of concrete cannot significantly exceed the compressive strength of aggregate contained, although it is not easy to state what is the strength of the individual particles. Indeed, the crushing strength of aggregate cannot be tested with any direct test. There are some indirect tests to inform us about the crushing strength of aggregate.

3. Other Mechanical Properties of Aggregates:

a) Impact value: Impact value of aggregates measures the toughness of particles by impact.

b) Abrasion: Abrasion of aggregates measures the resistance of aggregates against wearing. It is an important property of concrete in roads and in floor surfaces subjected to heavy traffic.

The most frequently used test method is the Los Angeles Abrasion Test.

Physical Properties of Aggregates

1. Specific Gravity

The specific gravity of an aggregate is a characteristic of the material, which needs to be determined in making calculations of mix design of concrete.

There are several types of specific gravities:

(a) **The absolute specific gravity** refers to the volume of the solid material excluding all pores.

(b) **The apparent specific gravity**: If the volume of the solid is deemed to include the impermeable pores. The apparent specific gravity is then the ratio of the mass of the aggregate to the mass of water occupying a volume equal to that of the solid including the impermeable pores (Total Volume of Solid).

Apparent Specific Gravity = A/ B-C+A

A: mass of oven- dried sample

B: the mass of the vessel full of water

C: the mass of the vessel with the sample and topped up with water.

(c) Bulk Specific Gravity

It refers to the mass of volume of aggregate, including all pores, permeable and impermeable, to the mass of an equal volume of gas free distilled water, both taken at a stated temperature.

This is the specific gravity most frequently and easily determined, and it is used for calculations of yield of concrete or of the quantity of aggregate required for a given volume of concrete. The apparent specific gravity of aggregate depends on the specific gravity of the minerals of which the aggregate is composed and also on the amount of voids. The majority of natural aggregates have a specific gravity of between 2.6 and 2.7.

2. Bulk Density (Unit Weight)

The bulk density depends on how dense the aggregate is packed. For a coarse aggregate of given specific gravity, a higher bulk density means there are fewer voids to be filled by sand, and cement. The bulk density test has been used as a basis of proportioning of mixes.

Empty space between the aggregate particles are termed VOIDS. It is the difference between the gross volume of aggregate mass and volume occupied by the particles alone.

$$\boldsymbol{Voids\ ratio} = \mathbf{1} - \frac{\text{Bulk Density}}{\boldsymbol{apparent\ specific\ gravity}\ (\boldsymbol{SSD}) \times \boldsymbol{Unit\ Weight\ of\ Water}}$$

Voids ratio indicates the volume of mortar required to fill the space between the coarse aggregate particles.

3. Absorption and Moisture Content of Aggregates

The porosity of aggregate, its permeability, and absorption influence the bonding between aggregate and cement paste, and also influence the resistance of concrete to freezing and thawing and resistance to abrasion.

The water absorption of aggregate is determined by measuring the increase in weight of an oven-dried sample when immersed in water; the surface water being removed. The ratio of the increase in weight to the weight of dry sample, expressed as a percentage is termed absorption.

The aggregates can be found in several moisture (water) contents as follows:

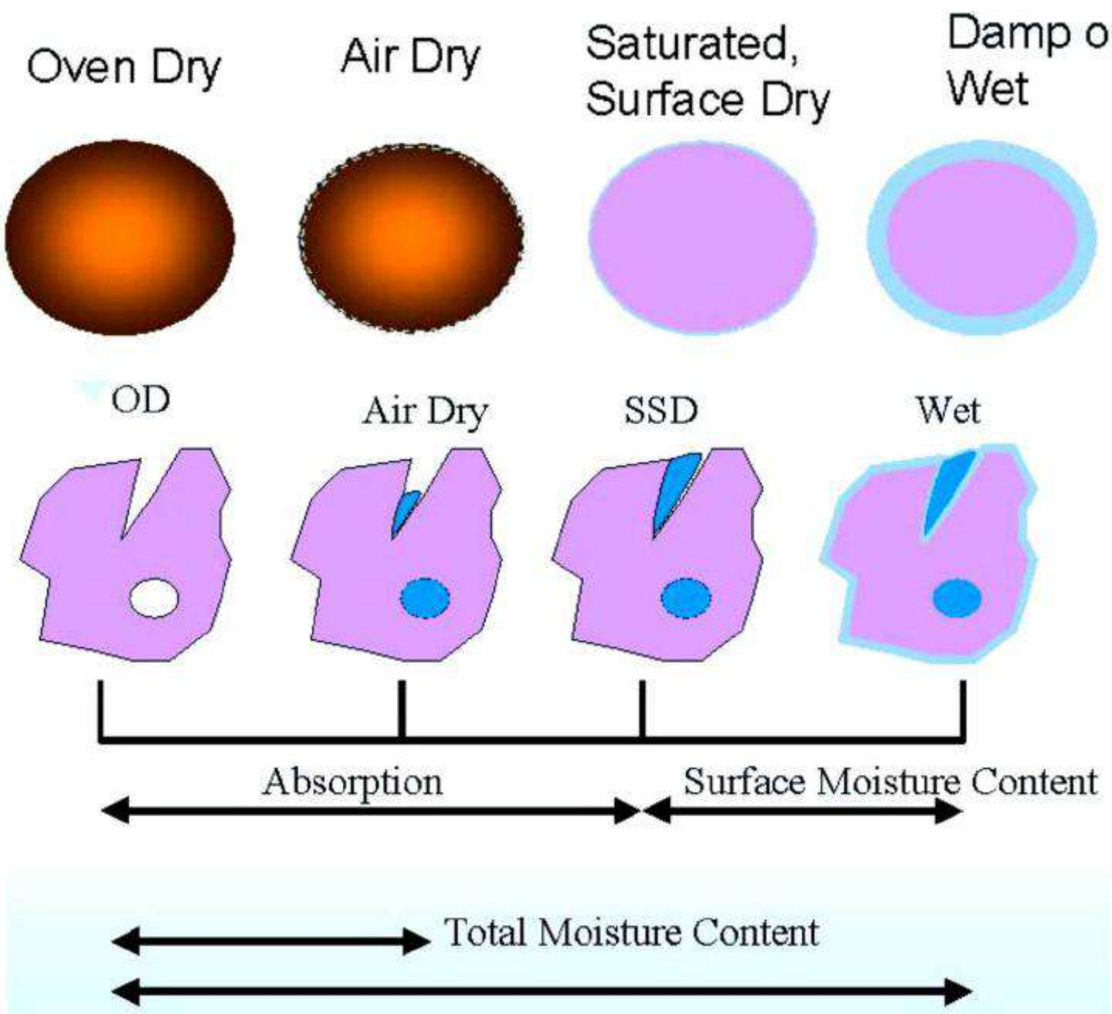
a- Oven dry condition.
b- Air-dry condition.
c- Saturated and surface dry (SSD) condition.
d- Wet (moist or damp) condition.

a) Oven-dry condition: All free moisture, whether external surface moisture or internal moisture, driven off by heat.

b) Air dry condition: No surface moisture, but some internal moisture remains.

c) Saturated-surface dry condition (SSD): Aggregates are said to be SSD when their moisture states are such that during mixing, they will neither absorb any of the mixing water added; nor will they contribute any of their contained water to the mix.

d) Damp or Wet condition: Aggregate containing moisture in excess of the SSD condition. It is called "free water". The free water, which will become part of the mixing water, is in excess of the SSD condition of the aggregate.



Notes:

・ If Total moisture content is greater than absorption, surface water presents (wet condition).

・ If Total moisture content is less than absorption, aggregate is air dry (air-dry condition).

・ In mix-design calculations, it is assumed that aggregate to be saturated surface dry (SSD).

- If aggregate is drier than SSD, it will absorb water from concrete and reduce the workability. On the other hand, if it is moist, it will contribute water in the concrete reducing the strength.

Bulking of Sand:

The volume increase of fine aggregate due to presence of moisture content is known as ***bulking***. Fine sand bulks more as compared to coarse sand. Extremely fine sand particularly the manufactured fine aggregate bulks as much as about 40% .Fine aggregate do not show any bulking when it is absolutely dry or completely saturated.

The moisture present in aggregate forms a film around each particle. These films of moisture exert a force, known as **surface tension,** on each particle. Due to this surface tension each particles gets away from each other. Because of this no direct contact is possible among individual particles and this causes bulking of the volume.

Bulking of aggregate is dependent upon two factors,

1. Percentage of moisture content
2. Particle size of fine aggregate

Bulking increases with increase in moisture content up to a certain limit and beyond that the further increase in moisture content results in decrease in volume as shown in fig below. When the fine aggregate is completely saturated it does not show any bulking. Fine sand bulks more as compared to coarse sand, i.e. percentage of bulking is indirectly proportional to the size of particle. If care is not given to the effect of bulking, in the case of volume batching, the resulting concrete is likely to be under-sanded and harsh. It will also affect the yield of concrete for a given cement content.

Determination of Bulking of Sand:

The extent of bulking can be estimated by a simple field test.

1. Fill a sample of moist fine aggregate (sand) into a measuring cylinder. Note down the level, say **h1**
2. Pour water into a measuring cylinder upto top surface of sand and completely cover the sand with water and shake it. Since the volume of the saturated sand is the same as that of the dry sand, the saturated sand completely counteract the bulking effect. Note down the level of sand, say **h2**.
3. Subtract the final level h2 from initial level h1 (i.e. **h1-h2**), which shows the bulking of sand under test.
4. Calculate percentage of bulking using formula given below.

   Percentage of bulking = **[(h1-h2)/h2]*100**

Deleterious Substances in Aggregates

a) Organic Impurities:

The organic matter found in aggregate consists of products of decay of vegetable matter. The organic impurities may interfere with the process of hydration of cement. This affects the rate of gaining strength.

b) Clay and Other Fine Materials:

Clay may be present in aggregate in the form of surface coatings which interfere with the bond between aggregate and the cement paste. This is an important problem and affects the strength and durability of concrete.
Other types of fine material that can present in aggregate are silt and crusher dust. Silt and crusher dust also adversely affect the bond between cement paste and aggregates.

c) Salt Contamination:

Aggregates obtained from the seashore contain salt and have to be washed with fresh water. The aggregate washed even with the sea water do not contain harmful quantities of salts.

If salt is not removed, it will absorb moisture from the air and cause efflorescence (white deposits on the surface of the concrete). A slight corrosion of reinforcement may also result, but this is not believed to progress to a dangerous degree, especially when the concrete is of good quality and adequate cover to reinforcement is provided.

d) Alkalinity of Aggregates:

Some reactive forms of silica may occur in some types of rocks, like siliceous limestone. The reaction takes place between the siliceous minerals in the aggregate and the alkaline hydroxides derived from the alkalis (Na_2O, K_2O) in the cement. The resulting gel tends to increase in volume in a humid medium and causes cracking of concrete. In this case, it is recommended to control the limit of alkalis in the cement.

Soundness of Aggregate

Soundness of an aggregate refers to its ability in concrete to withstand aggressive exposure, particularly due to weather.
In areas with severe or moderate winters, a major cause of aggregate deterioration in exposed concrete is freezing and thawing. If an aggregate particle absorbs so much water that its pores are nearly completely filled, it may not accommodate the expansion that occurs when water turns to ice. As ice forms, the resulting expansion pushes unfrozen water through

the aggregate pores and the resistance to this flow results in pressures that may be high enough to crack the particle. These pressures may crack the aggregate particle.

Sieve Analysis of Aggregates

Sieve analysis is the name of the operation of dividing a sample of aggregate into fractions, each consisting of particles of the same size. In practice each fraction contains particles between specific limits, these being the openings of standard test sieves. Sieves are used to be described by the size of opening for larger openings and by the number of openings for smaller sizes.

التحليل المنخلي

هو فصل المقاسات المختلفة من الركام بعضها عن بعض فى أية كمية من الركام ويكون ذلك باستخدام التحليل بالمناخل بهز الركام على مجموعة من المناخل مرتبة حسب مقاس فتحتها وموضوعة فوق بعضها البعض بحيث يكون أكبرها مقاسا من أعلى وأصغرها مقاسا من أسفل ثم وزن المحجوز على كل منخل .المنخل يعرف بمقاس فتحته أى طول ضلع الفتحة.

يتم حساب النسبة المئوية للركام المار من كل منخل وترسم بيانيا العلاقة بين مقاس فتحة المنخل والنسبة المئوية للركام المار منه ليعبر هذا الرسم عن مدى التوزيع الحجمي للركام .

Table 1—Sieves commonly used for sieve analysis of concrete aggregates

Standard sieve designation (ASTM E 11)		Nominal sieve opening	
		mm	in.
Coarse sieves			
Standard	Alternate		
75.0 mm	3 in.	75.0	3
63.0 mm	2-1/2 in.	63.0	2.5
50.0 mm	2 in.	50.0	2
37.5 mm	1-1/2 in.	37.5	1.5
25.0 mm	1 in.	25.0	1
19.0 mm	3/4 in.	19.0	0.75
12.5 mm	1/2 in.	12.5	0.5
9.5 mm	3/8 in.	9.5	0.375
Fine sieves			
4.75 mm	No. 4	4.75	0.1870
2.36 mm	No. 8	2.36	0.0937
1.18 mm	No. 16	1.18	0.0469
600 μm*	No. 30	0.60	0.0234
300 μm	No. 50	0.30	0.0117
150 μm	No. 100	0.15	0.0059

I.S. Sieve Designation	Percentage of passing by weight for grading			
	Zone-I	Zone-II	Zone-III	Zone-IV
4.75 mm	90-100	90-100	90-100	95-100
2.36 mm	60-95	75-100	85-100	95-100
1.18 mm	30-70	55-90	75-100	90-100
600 μ	15-34	35-59	60-79	80-100
300 μ	5-20	8-30	12-40	15-50
150 μ	0-10	0-10	0-10	0-15

Table 2: Grading of fine aggregates

Iraqi specification IQ.S 45/1984 classified four grading zones for fine aggregates:

Sieve size, mm	% passing (by weight)			
	Grading zone 1	Grading zone 2	Grading zone 3	Grading zone 4
9.5	100	100	100	100
4.75	90-100	90-100	90-100	95-100
2.36	60-95	75-100	85-100	95-100
1.18	30-70	55-90	75-100	90-100
0.6 (600 μm)	15-34	35-59	60-79	80-100
0.3 (300 μm)	5-20	8-30	12-40	15-50
0.15 (150 μm)	0-10	0-10	0-10	0-15

*: **A deviation of 5% is allowed within the grading limits of all sieves except sieve 0.6 mm**

Table 3: Grading of coarse aggregate

Example of Sieve Analysis

Sieve size	Wt. retained	% retained	%Accumulative retained	%Accumulative passing
10mm	0	0	0	100
5mm	6	(6/307)*100=2	2	100-2=98
2.36mm	31	10.1	12	88
1.18mm	30	9.8	22	78
0.6mm	59	19.2	41	59
0.3mm	107	34.9	76	24
0.15mm	53	17.3	93	7
0.075mm	21	6.8	---	
	Total= 307		Total=246 Fineness Modulus=2.46	

Grading Curves

Grading is the particle-size distribution of an aggregate as determined by a sieve analysis. The results of a sieve analysis can be graded much more easily if represented graphically, and for this reason grading charts are very extensively used. By using a chart, it is possible to see at a glance whether the grading of a given sample conforms to that specified or is too coarse or too fine.

In the grading chart commonly used, the ordinates represent the cumulative percentage passing and the abscissa the sieve opening plotted to a logarithmic scale.

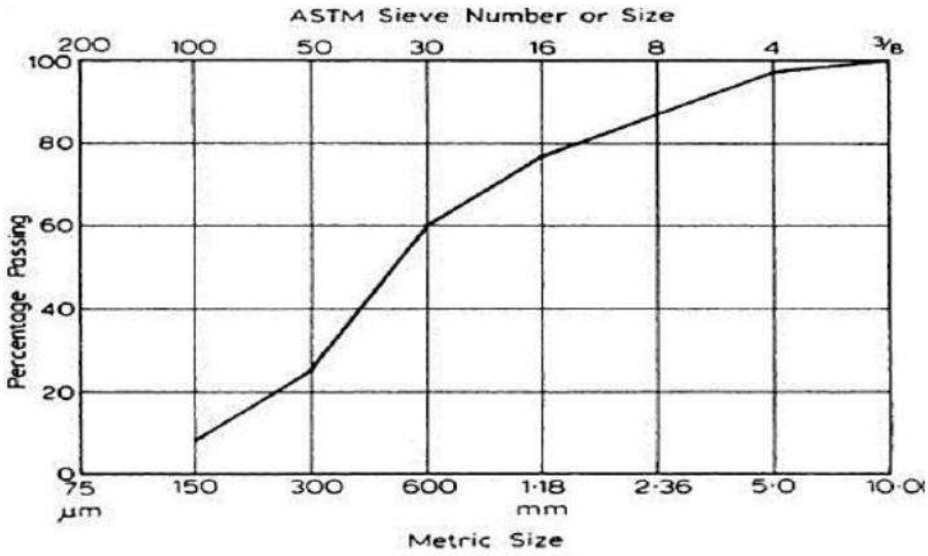


Fig. Example of a grading curve

Fineness Modulus (FM)

The fineness modulus, defined as of the sum of the cumulative percentages retained on the sieves of the standard series: 150, 300, 600 µm, 1.18, 2.36, 5.00 mm (ASTM Nos. 100, 50, 30, 16, 8, 4) and up to the largest sieve size used divided by 100. It should be remembered that, when all the particles in a sample are coarser than, say, 600 μm (No. 30 ASTM), the cumulative percentage retained on 300 μm (No. 50 ASTM) sieve should be entered as 100; the same value, of course, would be entered for 150 μm (No. 100). The value of the fineness modulus is higher the coarser the aggregate (see column (5). The fineness modulus can be looked upon as a weighted average size of a sieve on which the material is retained. The fineness modulus gives an indication of the probable behaviour of a concrete mix made with aggregate having a certain grading, and the use of the fineness modulus in assessment of aggregates and in mix proportioning has many supporters.

Limits for FM

Sand	FM
Fine Sand	2.2 – 2.6
Medium Sand	2.6 – 2.9
Coarse Sand	2.9 – 3.2

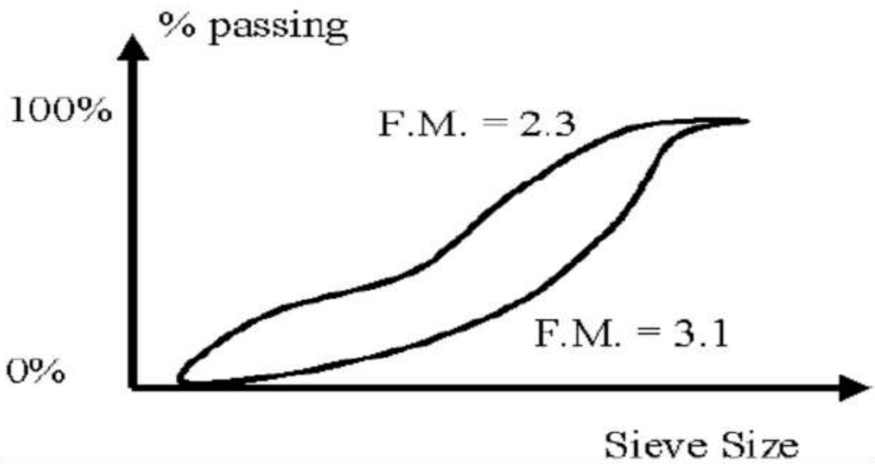


Table 5-4. Determination of Fineness Modulus of Fine Aggregates

Sieve size		Percentage of individual fraction retained, by mass	Percentage passing, by mass	Cumulative percentage retained, by mass
9.5 mm	(⅜ in.)	0	100	0
4.75 mm	(No. 4)	2	98	2
2.36 mm	(No. 8)	13	85	15
1.18 mm	(No. 16)	20	65	35
600 µm	(No. 30)	20	45	55
300 µm	(No. 50)	24	21	79
150 µm	(No. 100)	18	3	97
	Pan	3	0	—
Total		100		283

Fineness modulus
= 283 ÷ 100 = 2.83

Maximum Aggregate Size (MSA)

- It is the smallest sieve opening through which the entire sample passes (or in practice only 5% retained on this sieve.
- The largest size particle presents significantly to affect concrete properties. It affects the paste requirements. The higher MSA, the lower the paste requirements for the mix. Aggregate size affects the following concrete properties: water demand, cement content, micro-cracking (strength).

المقاس الأقصى للركام Maximum aggregate size
هومقاس اصغر فتحة منخل تسمح لمرور 95 100 % - من الركام الخشن

المساحة السطحية لحبيبات الركام

احد العوامل الرئيسية التي تتحكم في جودة الخرسانة نظرا لان مقاومة الخرسانة للأحمال تتوقف على مقاومة التماسك بين حبيبات الركام.

أذا استعمل الركام الكبير فقط مع عجينة الاسمنت يكون الناتج خرسانة ضعيفة لان المساحة النوعية لسطح الركام الكبير صغيرة وعلى ذلك يكون التماسك وترابط حبيبات الركام على مساحة صغيرة وبالتالي مقاومة ضعيفة للأحمال.

اما أذا استعمل الركام الصغير فقط مع عجينة الاسمنت يكون الناتج خرسانة ضعيفة المقاومة لان المساحة النوعية لسطح الركام الصغير كبيرة فلا تكفى حبيبات الركام عجينة الاسمنت الموجودة بقيمة محددة للالتصاق التام لجميع حبيبات الركام بالتالي تضعف المقاومة للأحمال.

يلاحظ ضعف مقاومة الخرسانة المصنوعة من الركام الكبير ناتج من تواجد الفراغات بالخرسانة نتيجة عدم امكان الرص التام وعدم وجود حبيبات صغيرة لملىء الفراغات بين حبيبات الركام الكبير اما ضعف مقاومة الخرسانة المصنوعة من ركام صغير فهو ناتج عن كثرة ماء اللازم للخلط لإعطاء خرسانة قابلة للتشغيل و ينتج عن ذلك زيادة الماء الحر الذى يتبخر مسببا فراغات المساحة السطحية للركام الخليط تكون مناسبة لأحداث تماسك بين الحبيبات ويحقق المقاومة المطلوبة لخرسانة الاعمال الانشائية.

Grading Requirements

The purpose of sieve analysis is to determine whether or not a particular grading is suitable. The related problem of grading is the combining of fine and coarse aggregates so as to produce desired grading. The main factors governing the desired aggregate grading are:

1. Surface area of the aggregate, which determines the amount of water necessary to wet all the solids.
2. Relative volume occupied by the aggregate.
3. Workability of the mix.
4. Tendency to segregation

The grading of aggregate is a major factor in the workability of a concrete mix. Workability, affects the water and cement requirements, controls segregation, has some effect on bleeding, and influence the placing and finishing of the concrete. These factors represent the important characteristics of fresh concrete and affect also the properties in the hardened state: strength, shrinkage and durability.
It also must be remembered that far more important than devising a good grading is ensuring that the grading is kept constant; otherwise variable workability results and variable strength is obtained.

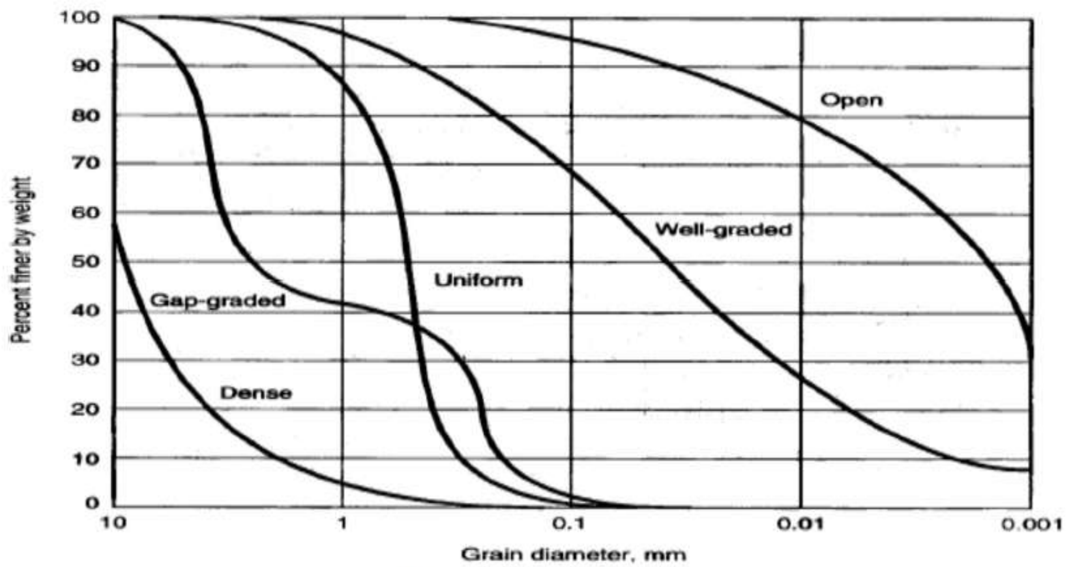
Types of Aggregate Gradation

Gap grading is a grading in which one or more intermediate size fractions are omitted.

Well Graded means sizes within the entire range are in approximately equal amounts (friction at many points, excellent interlocking, very few voids).

Uniform gradation means a large percentage of the particles are of approximately the same size (poor interlocking, high percentage of voids, friction at few points of contact).

Combined gradation means fine and coarse aggregates are combined (friction at many points, good interlocking, few voids, economical).

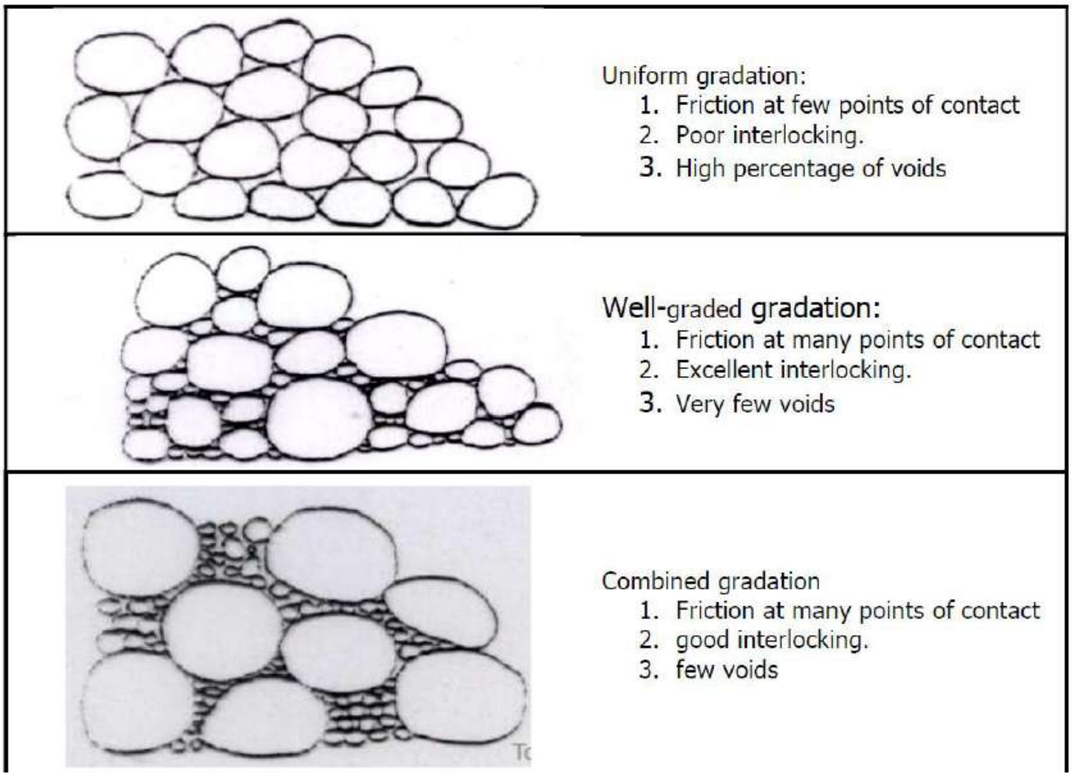


Types of gradation

Significance of Gradation

Gradation of aggregate affects the following concrete properties

- Economy
- Consistency
- Strength
- Shrinkage
- Finish ability



.

Fig : Types of grading

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:

1– Relative strength of the cement paste

2– Cement-aggregate bond
3– 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%).
• **Example**: Aggregate size number 7 has a maximum size of 19 mm, and a nominal maximum size of 12.5 mm.

• The maximum size of aggregate that must be used generally depends on the following:
1– Size and shape of the concrete member
2– The amount and distribution of reinforcing steel

• **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

Table 2—Ranges in physical properties for normal-weight aggregates used in concrete

Property		Typical ranges
Fineness modulus of fine aggregate (defined in the following)		2.0 to 3.3
Nominal maximum size of coarse aggregate		9.5 to 37.5 mm (3/8 to 1-1/2 in.)
Absorption		0.5 to 4%
Bulk specific gravity (relative density)		2.30 to 2.90
Dry-rodded bulk density* of coarse aggregate		1280 to 1920 kg/m^3 (80 to 120 lb/ft^3)
Surface moisture content	Coarse aggregate	0 to 2%
	Fine aggregate	0 to 10%

*Previously dry-rodded unit weight.

- **Gap grading can be defined as a grading in which one or more intermediate size fractions are omitted.**

1. The term *continuously graded* is used to describe conventional grading when it is necessary to distinguish it from gap grading.

2. Gap grading is represented by horizontal line over the range of size omitted.

3. Concrete mix with gap grading aggregate gives higher workability than concrete with continuous grading for the same aggregate/ cement ratio or w/c ratio.

4. However, in the more workable range of mixes, Gap grading aggregate showed greater segregation.

5. Gap grading aggregate is recommended mainly for mixes of relatively low workability such mixes respond well to vibration

6. Good control and, above all, care in handling, so as to avoid segregation, are essential.

7. For instance, the top grading curve of Fig. 3.9 shows that no particles of size between 10.0 and 2.36 mm sieve are present.

Admixtures for Concrete

Definition

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

The major reasons for using admixtures are:

1. To reduce the cost of concrete construction.
2. To achieve certain properties in concrete more effectively than by other means.
3. To maintain the quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather conditions.
4. To overcome certain emergencies during concreting operations.
5. Increase workability without increasing water content or to decrease water content at the same workability.

The effectiveness of an admixture depends upon several factors such as type, brand, amount of cementing materials; water content; aggregate shape, gradation, and proportions; mixing time; slump; and temperature of the concrete.

الإضافات Admixtures

هي مواد(غير الركام والإسمنت والماء)تضاف إلى الخلطة الخرسانية أثناء عملية الخلط بكميات صغيرة جداً بغرض إعطاء الخرسانة الطازجة أو الخرسانة المتصلبة خواص معينة مطلوبة مثل:-

- 1- تحسين قابلية تشغيل Workability الخرسانة الطرية . Fresh Concrete
- 2- تعجيل عملية التجمد والتصلب للحصول على مقاومة عالية في الأوقات المبكرة.
- 3- إبطاء عملية التجمد في الأجواء الحارة.
- 4- تقليل الحرارة المنبعثة من عملية الاماهة.
- 5--تقليل النضح. Bleeding
- 6- تقليل أو معادلة الانكماش Shrinkage الحاصل أثناء التجمد والتصلب.
- 7- تحسين مقاومة التآكل.
- 8- تقليل الماء اللازم لعملية الخلط.
- 9- تحسين المتانة . Durability
- 10- تقليل نفاذية Permeability الخرسانة للسوائل.
- 11- منع صدأ حديد التسليح المغمور في الخرسانة.
- 12تقليل التمدد الناتج عن التفاعل بين القلوياتAlkalis الموجودة في الاسمنت وبعض أنواع السليكا الفعالة في الركام.
- 13زيادة قوة الربط بين الخرسانة وحديد التسليح.
- 14إعطاء لون للخرسانة للاستفادة منها للأغراض المعمارية.
- 15تقليل كلفة الخرسانة.
- 16إنتاج أنواع من الخرسانة الخفيفة الوزن.

There are two general groupings of admixtures' namely:

- Chemical admixtures.
- Mineral admixtures.

First: Chemical Admixtures

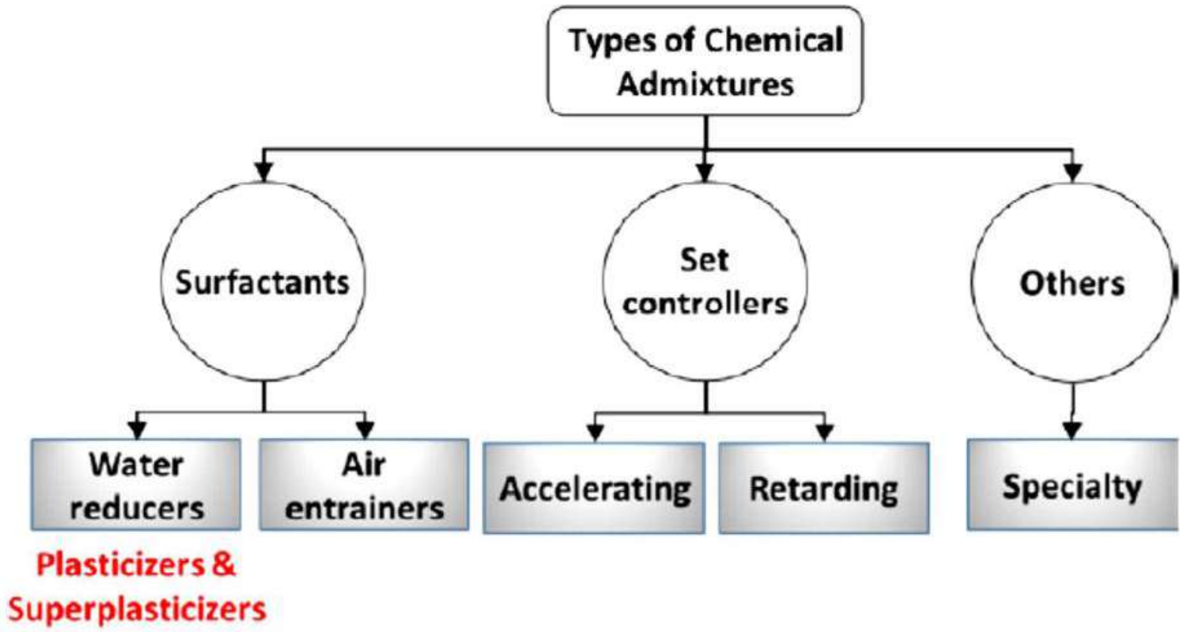
Definition

They are water soluble compounds added primarily to control setting and early hardening of fresh concrete or to reduce the water requirements.

Therefore, the chemical admixtures include:

1. Air entraining admixtures.
2. Water reducing admixtures.
3. Retarding admixtures.
4. Accelerating admixtures.
5. Specialty admixtures.

Hydration-control admixtures, corrosion inhibitors, shrinkage reducers, alkali-silica reactivity inhibitors, coloring admixtures, miscellaneous admixtures such as workability, bonding, damp-proofing, permeability reducing, grouting, gas-forming, anti-washout, foaming, and pumping admixtures.



1. Air-Entraining Admixtures.

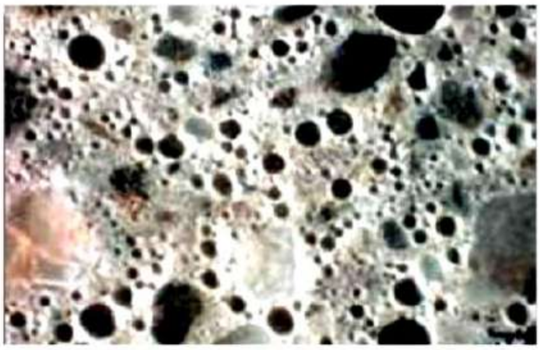
Air-entraining admixtures are used to purposely introduce and stabilize microscopic air bubbles in concrete (air bubbles predominately between 0.25—1 mm diameter). Air entrainment will improve the durability of concrete exposed to cycles of freezing and thawing.

Furthermore, the workability of fresh concrete is improved significantly, and segregation and bleeding are reduced or eliminated.

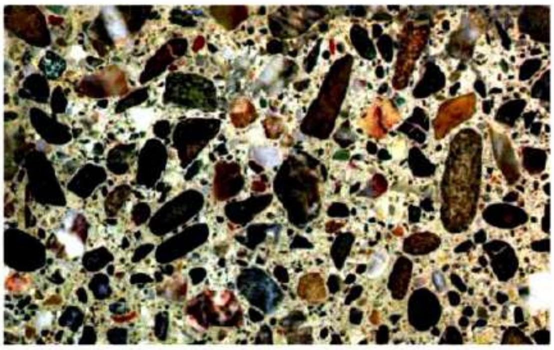
a. The Air-Void System

As un-reacted water freezes it expands 9 % by volume on phase change. This internal volume expansion causes internal stresses in the matrix. It can generate cracks in the concrete, which may allow water to infiltrate and the process can get progressively worse. It can lead to significant degradation of the concrete.

Further, the formation of ice in the pore spaces generates pressure on any remaining unfrozen water. Introducing a large quantity of air bubbles provides a place for this water to move in to relieving the internal pressure.



Air-Entrained concrete



Non Air-Entrained concrete

The air void parameters that need to be determined for the concrete are:

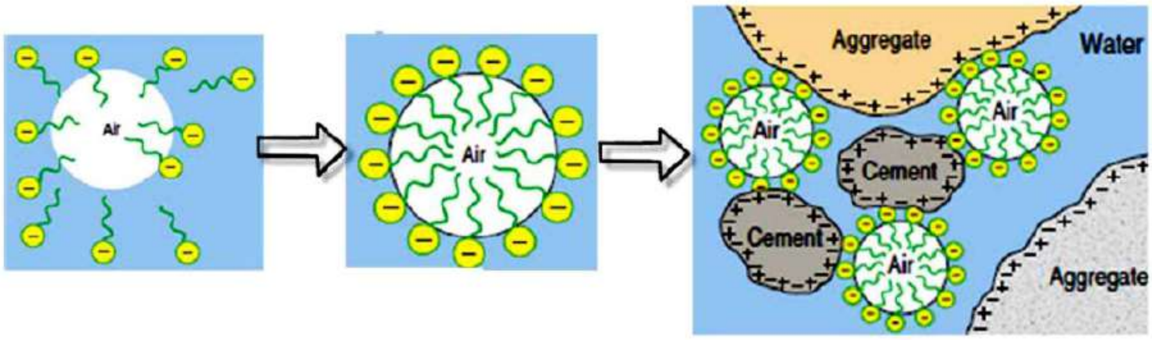
1- Total Entrained Air;

2- Spacing Factor distance between voids (not more than 200 micron =0.2mm).

Entrapped air is different from **entrained** air. Entrapped air consists of irregular voids that are produced through the compaction process. Some amount of entrapped air is always present in concrete, and the mix design codes generally stipulate the assumption of the amount of entrapped air based on the coarse aggregate size in concrete. In general, about 1 – 2% of entrapped air is present inside concrete. Entrained air, on the other hand, is generated using the admixture, and consists of small and spherical voids.

b. Air Entraining Materials

What is needed is an agent that causes the water to foam into a very small matrix of very small bubbles. The admixtures are of the same family as household detergents, but these do not generate small enough bubbles and are not stable enough. Air entraining agents contain surface-active agents or surfactants. These lower the water surface tension so bubbles can form, and stabilize the bubbles once they are formed.



c. Effect of Air on Other Concrete Properties

Air entrainment will affect directly the following three properties of concrete:
1. – Increased resistance to freezing and thawing.
2. – Improvement in workability and cohesiveness of fresh concrete.
3. – Reduction in strength.

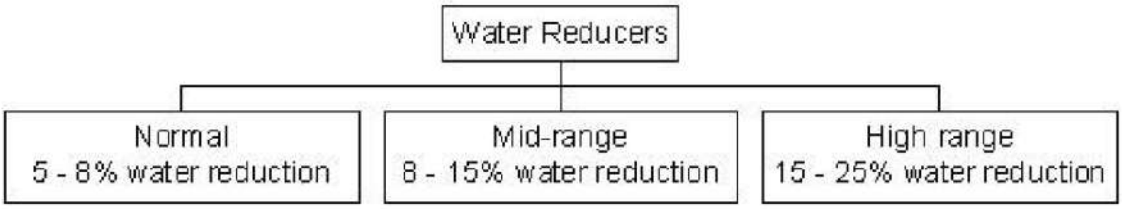
Air entrainment will affect the properties in following ways:
1. – Reduces the tendencies of segregation and bleeding.
2. In addition, the lower w/c ratio that can be used the better compaction characteristics results, which give more impermeable concrete and a better overall resistance to aggressive agents (i.e. sulfates).

2. Water-Reducing Admixtures

Water-reducing admixtures are used to
(1) reduce the quantity of mixing water required to produce concrete of a certain slump,
(2) reduce water-cement ratio,
(3) reduce cement content,
(4) improve durability,
(5) improve water tightness, or
(6) increase slump.

Various types of Water Reducers can reduce the water content by approximately 5% to 25%.

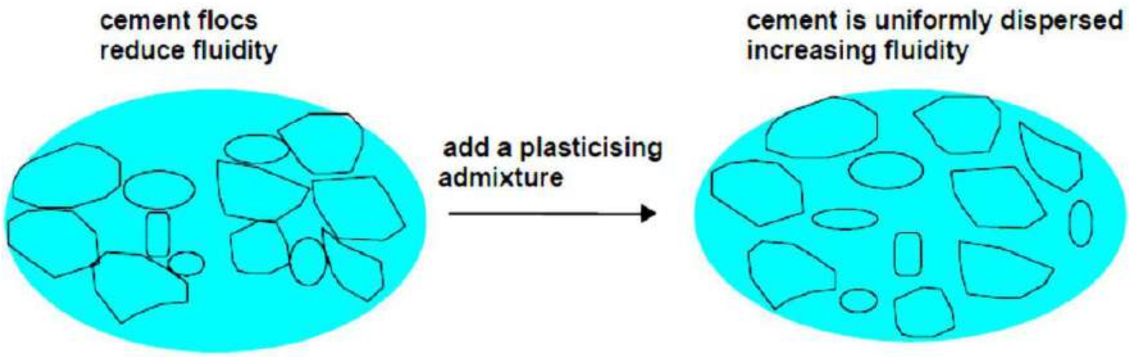
Adding a water-reducing admixture to concrete without reducing the water content can produce a mixture with a higher slump. The rate of slump loss, however, is not reduced and in most cases is increased. Rapid slump loss results in reduced workability and less time to place concrete.



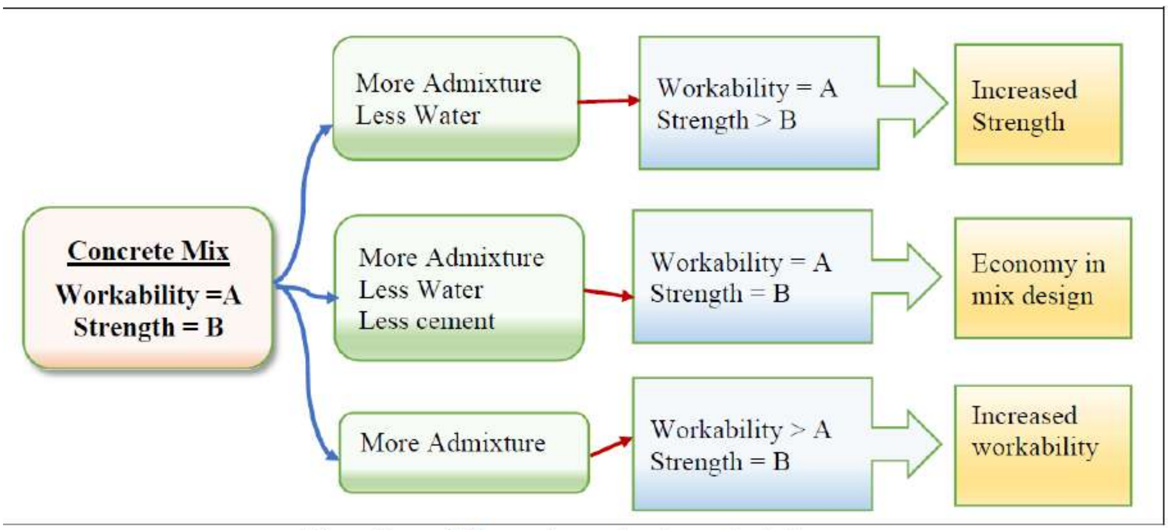
An increase in strength is generally obtained with water-reducing admixtures as the water-cement ratio is reduced.

It can be said that Water Reducers can be used in three ways:

1. For a given workability, they can reduce the water demand, thus resulting in higher strength and durability.
2. For a given w/c and strength, they can increase the workability.
3. For a given w/c, strength and workability, the quantity of cement can be reduced.



This effect of water-reducing admixtures on concrete mixtures can be utilized in three ways as shown in Figure below:



Function of the water reducing admixtures.

High-Range Water-Reducing (Super-plasticizers) - HRWR

Super-plasticizers, also called High Range Water-Reducing Admixtures (HRWR) because of their ability to reduce three to four times the mixing water in a given concrete mixture compared to normal water-reducing admixtures, were developed in the 1970s and have found wide .acceptance in the concrete construction industry.

Super-plasticizer materials

There are four types of super plasticizers that are generally used for concrete as given below:

1. Sulphonated melamine formaldehyde condensates – It is suitable in low temperature areas, dosage: 0.5 - 3% by weight of cement.
2. Sulphonated naphthalene formaldehyde condensates – It is more suitable in high temperature areas, dosage: 0.5 - 3% by weight of cement.
3. Modified Ligno sulphates – It is suitable for Indian conditions where temperature variation is high, dosage not more than 0.25% by weight of cement.
4. Carboxylated admixture – It is suitable where workability is required to be retained for large duration.

The advantages of Super-plasticizers are:

1– Significant water reduction.
2– Reduced cement contents.
3– Reduce water requirement by 12-30%.
4– Increased workability of concrete.
5– Reduced effort required for placement.
6– More rapid rate of early strength development.
7– Increased long-term strength.
8– Reduced permeability of concrete.

The disadvantages of Super-plasticizers are:

– Additional admixture cost (the concrete in-place cost may be reduced)
– Slump loss greater than conventional concrete
– Less responsive with some cement

-

إضافات تخفيض الماء (الملدنات والملدنات الفائقة Plasticizers and Supper plasticizers)

وهذه الإضافات هي أهم وأكثر أنواع الإضافات استخداما وشيوعا في مجال الخرسانة وهى تختص بتقليل ماء الخلط بدرجات متفاوتة.

توجد الملدنات و الملدنات الفائقة عموما في صورة سائلة وتضاف إلى الخلطة الخرسانية بنسبة تتراوح من 1 % إلى 3 % من وزن الإسمنت وهى أكثر وأهم أنواع الإضافات استخداما وشيوعا . وقد وجد أن نسبة 3 % من الملدنات الفائقة تعطى أفضل النتائج.

وظيفة الملدنات

- 1- تحسين خواص الخرسانة الطازجة وذلك بزيادة القابلية للتشغيل وزيادة السيولة مع ثبات نسبة الماء الى الاسمنت w/c
- 2- الحصول على خرسانة ذاتية الرص.
- 3- تحسين خواص الخرسانة المتصلدة وذلك بتخفيض نسبة(م/س)في الخلطة مع ثبات درجة القابلية للتشغيل وبالتالي الحصول على خرسانة عالية المقاومة.
- 4- الحصول على خرسانة ذات مقاومة مبكرة عالية.
- 5- الحصول على خرسانة عالية الأداء قليلة النفاذية.
- 6- الحصول على خرسانة بدون انفصال حبيبي أو نضح.

كيف تعمل الملدنات

ان كيفية عمل الملدنات أو الملدنات الفائقة في تسبيل الخرسانة يأخذ واحدا "أو أكثر من الصور الآتية-:

1 - تشتيت حبيبات الإسمنت المتكتلة وإطلاق المياه المحبوسة بينها.
- 2- إحداث التنافر الكهروستاتيكي بين الجزيئات.
- 3- العمل على تشحيم الطبقة الرقيقة بين حبيبات الإسمنت.
- 4- تأجيل عملية الإماهة السطحية لحبيبات الإسمنت مع ترك المزيد من المياه لتسييل الإسمنت.

إن جزئيات الإسمنت البورتلاندي العادي تتميز بميلها الشديد للتكتل عندما تخلط مع الماء و هذا الميل هو حصيلة لتفاعلات داخلية متنوعة. ودور الملدنات أو الملدنات الفائقة هنا هو العمل على فصل حبيبات الإسمنت المتكتلة عن بعضها ومن ثم الحصول على توزيع متجانس للمياه واتصال مثالي بين المياه وحبيبات الإسمنت.

Accelerators materials

Most accelerators are based on one of the following chemicals:

1. Soluble inorganic salts (CaCl, carbonates, aluminates, fluorides, and ferric salts).
2. Soluble organic compounds (triethanolamine, calcium formate, calcium acetate).

Calcium chloride is the most popular choice due to low cost and high rate of acceleration for a given dosage.

The purposes of using accelerators and the advantages resulting from the use of accelerators are many, among them are:

1– Allow an earlier finishing of the concrete surfaces,
2– Earlier removal of forms
3– Reduction of the required period of curing and protection
4– Earlier placement in service of a structure or a repair.
5– Partial or complete compensation for the effects of low temperatures on strength development.
6– Reduced bleeding and segregation and increase density of concrete.

Precautions of using accelerators

1- High dosage rates or, occasionally, normal dosage rates with high cement content mixes may cause rapid stiffening and considerable heat evolution with consequent risk of thermal and shrinkage cracking. Calcium chloride in particular should be used with care in hot weather.
2- Calcium chloride or admixtures containing calcium chloride are restricted in structural concrete which contains embedded metal.

Retarding admixtures.

Retarding admixtures are used where setting time of concrete need to be delayed. Retarder delays the hydration process but doesn't affect the eventual process. Initial setting time can be delayed by more than 3 hours. The main application of retarding admixtures is in controlling the setting time of concrete.
The retarders slow the rate of early hydration of C_3S by extending the length of the dormant period. They also tend to retard the hydration of C_3A phases.

The main purposes of retarders are:

1.To offset the accelerating effect of high ambient temperature (hot weather) and thereby lowering the maximum temperature to a level where thermal cracks give less problems.
2. To keep the concrete workable throughout the entire transport, placing and finishing periods.
Particularly important when transporting concrete over large distances.
3. To prevent setting of the concrete in the truck in case of delay.

Retarder Materials

1. salts and derivatives of lignosulfonates.
2. salts and derivatives of hydroxyl carboxylic acids.
3. sugars and their derivatives (a bag of sugar mixed in a truck of concrete can stop the set in case of emergency).
4. inorganic salts.
Note: 1&2 are also water reducers.

General Precautions in use of admixtures:

Admixtures are required to conform to relevant specifications (such as ASTM, BS, EN), where applicable. Technical data should include:
a. Main effect of admixture.
b. Any additional influences admixture may have.
c. Physical properties of the material.
d. Concentration of active ingredient.
e. Presence of any potentially detrimental substances such as chlorides, sulphates etc.

f. Potential occupational hazards for users.
g. Conditions for storage and shelf life.
h. Instructions for preparation of admixture and procedures for introducing it into the concrete mix.
i. recommended dosage under identified conditions, max permissible dosage, and effects of over-dosage.

Second: Mineral Admixtures

Mineral Admixtures

Mineral admixtures (Also called 'Supplementary Cementing Materials) are inorganic materials that also have pozzolanic properties. Mineral admixtures are very fine-grained materials which added to the concrete mix to improve the properties of concrete and make it more economical, or
as a replacement for Portland cement (blended cements). The designation pozzolana is derived from one of the primary deposits of volcanic ash used by the Romans.

It should be said that most of the mineral admixtures have lesser specific gravity than the other constituents of concrete, therefore more volume is expected when one of these mineral admixtures replaces OPC by mass.
Mineral admixtures are added to concrete in different amounts in order to:
1- Enhance the workability of fresh concrete;
2- Improve resistance of concrete to thermal cracking,
3- Resist alkali-aggregate expansion, and sulfate attack;
4- Enable a reduction in cement content."

The American Concrete Institute (ACI) defines pozzolans as "a siliceous or siliceous and aluminous material that in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically reacts with calcium hydroxide at ordinary temperatures to form compounds having cementitious properties."
Commonly used mineral admixtures are:
1. Ground granulated blast furnace slag (GGBFS)
2. Type F fly ash (F-FA),
3. C-FA: Type C fly ash (C-FA),
4. SF: Silica fume (SF)
5. Metakaolin (MK)
6. Glass powder (GP)
7. Rice husk ash (RHA)

-إضافات لمنع نفاذ الماء بالخرسانة Permeability_- Reducing Admixture .
الهدف منها
تساعد على مقاومة نفاذ الماء إلى الخرسانة ولكنها لا تمنع نفاذ الماء تماما .وللوصول إلى درجة عالية من مقاومة النفاذية ينبغي العناية بتصميم الخلطة الخرسانية ثم العناية بعمليتي الرص والمعالجة .ويمكن تحسين نفاذية الخرسانة بإحدى المحاور التالية:-

أ -اضافات صادة للماء Water Proofing Agents

وهى تعمل على منع الخرسانة من امتصاص ماء المطر والمياه السطحية الملامسة ومن امثلتها زيوت البترول والشمع wax وتضاف بنسبة تتراوح من ٠,١ % إلى ٠,٤ % من وزن الإسمنت .وتستخدم المواد البوليميرية أيضا لهذا الغرض وذلك في صورة دهانات لأسطح الخرسانة لسد الفجوات الهوائية والشروخ الشعرية الموجودة بالسطح.

ب -استعمال الملدنات الفائقة Super plasticizers

وهى تفيد هنا بطريقة غير مباشرة حيث أنها تعمل على تقليل ماء الخلط وبالتالي الحصول على أقل نسبة فراغات ممكنة بالخلطة ومن ثم تتحسن منفذية الخرسانة.

ج -استعمال مواد بوزولانية مالئة للفراغات(Pozzolanic Materials (Filling Effect

والمواد البوزولانية هي المواد التي تتفاعل مع هيدروكسيد الكالسيوم الحر الناتج من تفاعل الإسمنت مع الماء مكونة مركبات غير قابلة للذوبان مثل سيليكات وألومنيات الكالسيوم والتي تعمل على سد الفجوات الداخلية والمسام الشعرية

ومن أمثلتها مادة غبار السيليكا Silica Fume وهى مادة تتكون من حبيبات دقيقة جدا مساحتها السطحية حوالى أربعة إلى خمسة أمثال المساحة السطحية للإسمنت وهى ناتج ثانوي Byproduct في صناعة سبائك السيليكون والفيروسليكون. وتتفاعل مادة غبار السيليكا مع هيدروكسيد الكالسيوم مكونة سيليكات الكالسيوم المماهة والتي لا تذوب فتؤدي إلى تقليل الفجوات الداخلية والمسام الشعرية. -

اضافات لمنع اجتراف الاسمنت بفعل Anti- wash out admixture

عند صب الخرسانة تحت الماء يعمل الماء على إجتراف الإسمنت من الخرسانة وينتج عن ذلك نقص في مقاومتها و تعكر في المياه المحيطة بها .ولهذا السبب يستخدم هذا النوع من الإضافات التي تعتبر من أحدث أنواع الإضافات الموجودة في السوق حاليا.

تعمل هذه الإضافات على تكوين جل في الماء المحيط بحبيبات الإسمنت فتحميه من الإجتراف بفعل الماء كما تعمل على زيادة اللزوجة و التماسك بين جزئيات الخرسانة و تحسن من مقاومتها للانفصال.

ويستخدم هذا النوع من الإضافات أيضا في إنتاج الخرسانة عالية السيولة أو الخرسانة ذاتية الرص حيث تقوم هذه الإضافات بمقاومة الانفصال الحبيبي وزيادة التماسك للخرسانة .وتتكون هذه الإضافات من بوليمرات أو مركبات سلولوزية على هيئة بودرة قابلة للذوبان في الماء وتضاف إلى الخلطة بنسبة تقريبية ١ % من وزن الإسمنت.

تؤدى هذه الإضافات إلى نقص مقاومة الضغط للخرسانة المصبوبة تحت الماء بنسبة قد تصل إلى 20 % إذا ما قورنت بمقاومة الضغط للخرسانة المماثلة و المصبوبة في الهواء

Fresh Concrete

The potential strength and durability of concrete of a given mix proportion is very dependent on the degree of its compaction. that the consistency of the mix (consistency: ability to flow) be such that the concrete can be transported, placed, and finished sufficiently early and easily enough to attain the expected strength and durability without segregation or bleeding.

For fresh concrete to be acceptable, it should:
1. Be easily mixed and transported.
2. Be uniform throughout a given batch and between batches.
3. Be of a consistency so that it can fill completely the forms for which it was designed.
4. Have the ability to be compacted without excessive loss of energy.
5. Not segregate and bleeding during placing and consolidation.
6. Have good finishing characteristics.

Workability

Definition of Workability

1- The amount of useful internal work necessary to produce full compaction without occurrence of the known concrete problems. The useful internal work is the work or energy required to overcome the internal friction between the individual particles in the concrete.
In practice, however, additional energy is required to overcome the surface friction between concrete and the framework or the reinforcement. Thus, in practice, it is difficult to measure the workability as defined above, and what we measure is workability which is applicable to particular method adopted.
2- This term is defined in ASTM C 125 as the property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity. The term manipulate includes the operations of placing, compacting and finishing the concrete.

Factors Affecting Workability

1. Water Content of the Mix. This is the most important fact for governing workability of concrete. A group of particles requires a certain amount of water. Water is absorbed on the particle surface, in the volumes between particles, and provides "lubrication" to help the particles move past one another more easily. Therefore, finer particles

require more water. Side-effects of increased water are loss of strength and possible segregation.

2. Influence of Aggregate: Mix Proportions. Increasing the proportion of aggregates relative to the cement will decrease the workability of the concrete. Also, any additional fines will require more cement in the mix. An "over sanded" mix will be permeable and less economical. A concrete deficient of fines will be difficult to finish and prone to segregation.

3. Aggregate Properties. The ratio of coarse/fine aggregate is not the only factor affecting workability. The gradation and particle size of sands are important. Shape and texture of aggregate will also affect workability.

Spherical shaped particles will not have the interaction problems associated with more angular particles. Also, spherical shapes have a low surface/volume ratio, therefore, less cement will be required to coat each particle and more will be available to contribute to the workability of the concrete.

Aggregate which is porous will absorb more water leaving less to provide workability. It is important to distinguish between total water content, which includes absorbed water, and free water which is available for improving workability.

Use of larger maximum size of aggregate gives less surface area to be wetted and more water in medium, and hence improvement in workability.

4. Time and Temperature. In general, increasing temperature will cause an increase in the rate of hydration and evaporation. Both of these effects lead to a loss of workability.

5. Loss of Workability. Workability will decrease with time due to several factors; continued slow hydration of C3S and C3A during dormant period, loss of water through evaporation and absorption, increased particle interaction due to the formation of hydration products on the particle surface. Loss of workability is measured as "slump loss" with time. Due to absorption of water by cement (and aggregates if absorbent) workability may decrease rapidly after mixing.

6. Cement Characteristics. Cement characteristics are less important than aggregate properties in determining workability. However, the increased fineness of rapid-hardening cements will result in rapid hydration and increased water requirements, both of which reduce workability.

7. Admixtures. In general, air-entraining, water-reducing, and set-retarding admixtures will all improve workability. However, some chemical admixtures will react differently with cements and aggregates and may result in reduced workability.

Measurement of Workability

Unfortunately, there is no accepted test, which measure directly the workability. There are numerous attempts to correlate workability with some easily determinable physical measurements, but none of these is fully satisfactory, although they may provide useful information within a range of variation in workability.

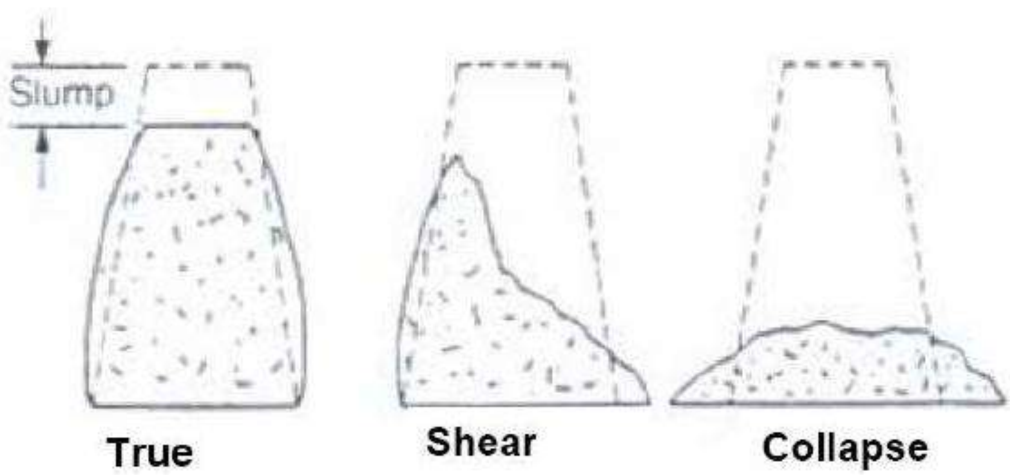
Different empirical measurements of workability have been developed over the years. None of these tests measure workability in terms of the fundamental properties of concrete.

However, the following tests have been developed:

1. **Subjective Assessment.** The oldest way of measuring workability based on the judgement and experience of the engineer. Unfortunately, different people see things, in this case concrete, differently.

2. **Slump Test.** The oldest, most widely used test for determining workability. The device is a hollow cone-shaped mold. The mold is filled in three layers of each volume. Each layer is rodded with a 16mm steel rod 25 times. The mold is then lifted away and the change in the height of the concrete is measured against the mold. The slump test is a measure of the resistance of concrete to flow under its own weight. There are three classifications of slump; "true" slump, shear slump, and collapse slump. Slump test gives good results for rich mixes.

True slump is a general reduction in height of the mass without any breaking up. Shear slump indicates a lack of cohesion, tends to occur in harsh mixes. This type of result implies the concrete is not suitable for placement. Collapse slump generally indicates a very wet mix.



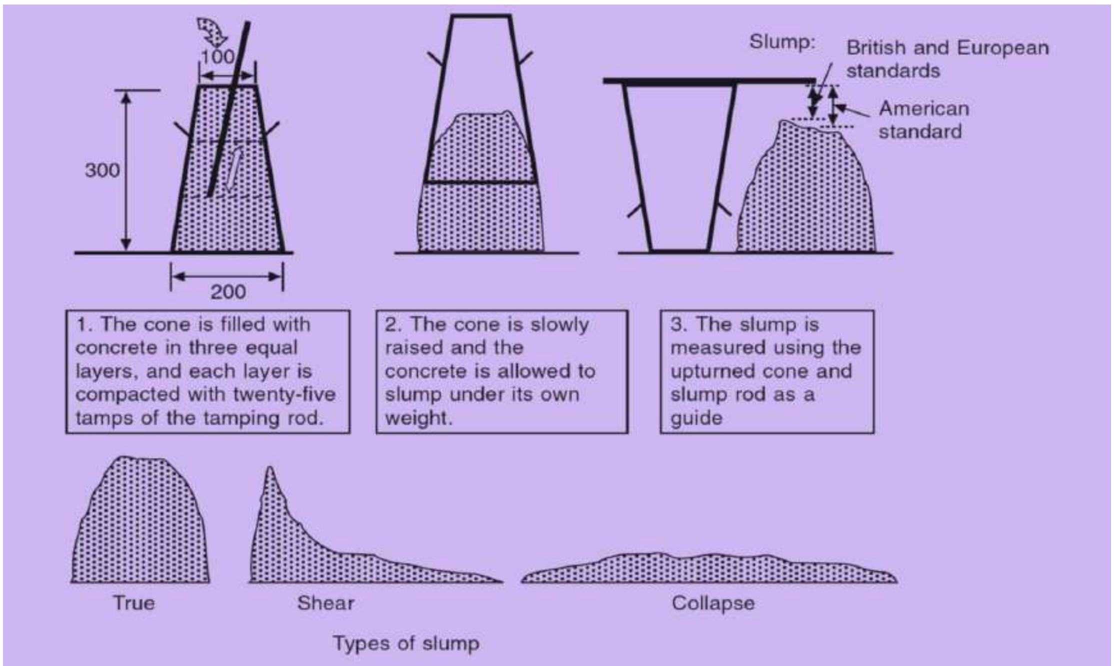
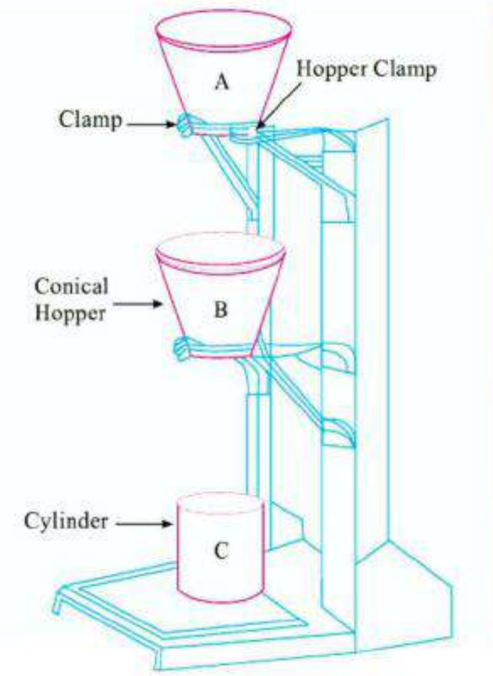


Figure 1.1 The slump test (BS 1881 Part 102: 1983; BS EN 12350-2: 2000; ASTM C 143-90a).

3. Compacting Factor Test. Concrete strength is proportional to its relative density. A test to determine the compaction factor was developed in 1947. It involves dropping a volume of concrete from one hopper to another and measuring the volume of concrete in the final hopper to that of a fully compacted volume. This test is difficult to run in the field and is not practical for large aggregates (over 1 in.). Compacting factor test is used for low workable concretes.



Compacting Factor Apparatus

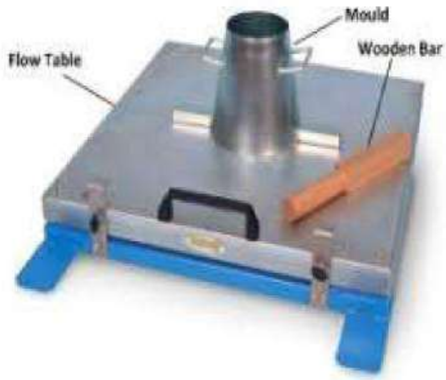
Workability	Flow (mm)	Compacting factors
Very low	0-25	0.78
Low	25-50	0.85
Medium	50-100	0.92
High	100-175	0.95

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

4. Flow Table Test. It measures a concretes ability to flow under vibration and provides information on its tendency to segregate. There are a number of tests available but none are recognized by ASTM. However, the flow table test described for mortar flows is occasionally used. It is usually used for high workable concretes.

The table top is cleaned of all gritty material and is wetted. The mold is kept on the centre of the table, firmly held and is filled in two layers.

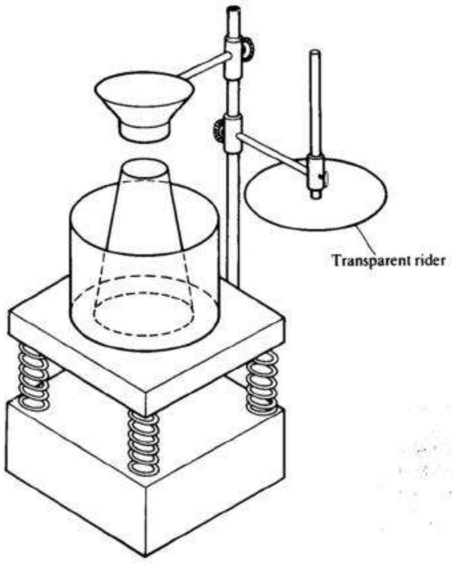
Each layer is rodded 25 times with a tamping rod 1.6 cm in diameter and 61 cm long rounded at the lower tamping end. The mold is lifted vertically upward and the concrete stands on its own without support. The table is then raised and dropped 12.5 mm 15 times in about 15 seconds. The diameter of the spread concrete is measured in about 6 directions to the nearest 5 mm and the average spread is noted. The Flow is the average diameter of the concrete.



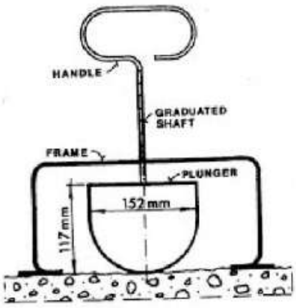
Flow Table Test

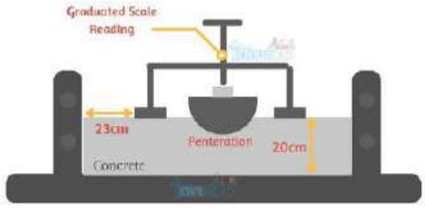
5. Remoulding Tests. It developed to measure the work required to cause concrete not only to flow but also to conform to a new shape.

1- Vebe Test - A standard slump cone is cast, the mold removed, and a transparent disk placed on top of the cone. The sample is then vibrated till the disk is completely covered with mortar. The time required for this is called the Vebe time. It is used for low workable concretes (fiber reinforced concrete).



2- Penetration Test - A measure of the penetration of some indenter into concrete. It is a practical field test. Only **the Kelly ball penetration** test is included in the ASTM Standards. **The Kelly ball** penetration test measures the penetration of a 30 lb. hemisphere into fresh concrete. This test can be performed on concrete in a buggy, open truck, or in form if they are not too narrow.





It can be compared to the slump test for a measure of concrete consistency. For a given concrete mixture, the results of the Kelly ball test can be correlated to slump. Typically, the value of slump is 1.10 to 2.00 times the Kelly ball test reading

Segregation

Segregation can be defined as separation of the constituents of a heterogeneous mixture so that their distribution is no longer uniform. Also, Segregation refers to a separation of the components of fresh concrete, resulting in a non-uniform mix. This can be seen as a separation of coarse aggregate from the mortar, caused from either the settling of heavy aggregate to the bottom or the separation of the aggregate from the mix due to improper placement.

Some factors that increase segregation are:

1. Larger maximum particle size (25mm) and proportion of the larger particles.
2. High specific gravity of coarse aggregate.
3. Decrease in the amount of fine particles.
4. Particle shape and texture.
5. Water/cement ratio.

Good handling and placement techniques are most important in prevention of segregation.

There are two forms of segregation:

1. In the first form, the coarse particles tend to separate out since they tend to settle more than fine particles.

2. The second form of segregation occurs particularly in wet mixes; it is indicated by the separation of (cement + water) from the mix.

Causes of Segregation of Concrete

1. Use of high water-cement ratio in concrete. This general happens in case of concrete mixed at site by unskilled workers.
2. Excessive vibration of concrete with mechanical needle vibrators makes heavier particles settle at bottom and lighter cement sand paste comes on top. This prohibition includes the use of a vibrator to spread a heap of concrete over a large area. This is particularly so when vibration is allowed to continue too long; with many mixes.
3. When concreting is done from height in case of underground foundations and rafts, which causes concrete to segregate.
4. Dropping concrete from a considerable height, passing along a chute, particularly with changes of direction and discharging against an obstacle.
5. The use of coarse aggregate whose specific gravity differs appreciably from that of fine aggregate would lead to increased segregation.

Prevention of Concrete Segregation

1. Wherever depth of concreting is more than 1.5 meters, it should be placed through temporary inclined chutes. The angle of inclination may be kept between 1:3 and 1:2 so that concrete from top of chutes travels smoothly to bottom.

2. The delivery end of chute should be as close as possible to the point of deposit.

3. The concrete does not have to travel too far and to be transferred directly from the wheelbarrow to the position in the form, the danger of segregation is small.

4. Concrete should always be placed direct in the position in which it is to remain and must not be allowed to flow or be worked along the form.

5. The improvement of cohesive of concrete reduces the danger of segregation. For example, entrained air in concrete controls the danger of segregation.

Bleeding of Concrete

Bleeding is defined as the appearance of water on the surface of concrete (water gain) after it has consolidated but before it is set. Since mixing water is the lightest component of the concrete, this is a special form of segregation. This is caused by the inability of the solid constituents of
the mix to hold all of the mixing water when they settle downwards. Also, it can be said that bleeding is the result of aggregates settling into the mix and releasing their mixing water.

The upper layers will become too rich in cement with a high w/c ratio causing a weak, porous structure. On the other hand, if the rising water carries with it a considerable amount of the finer cement particles a layer of scum will be formed. At the top of a slab, a porous surface will form and result with a permanently dusty surface. At the top of a lift a plane of weakness would form and the bond with the next lift would be inadequate. For this reason, scum should always be removed by brushing and washing.

Bleeding may be reduced by:

1. delaying the finishing operations until the bleeding water has evaporated.
2. Increasing cement fineness.
3. Increasing the rate of hydration (adding of calcium chloride).
4. Using air-entraining admixtures.
5. Reducing the water content.

Mixing Time

On a site, there is often a tendency to mix concrete as rapidly as possible, and therefore, it is important to know what is the minimum mixing time necessary to produce a concrete uniform in composition and as result of satisfactory strength.

For a given mixer, there exists a relation between mixing time and uniformity of the mix. It is apparent that mixing for less than 1 to l ¼ minutes produces an appreciably more variably concrete, but prolonging the mixing time beyond these values results in no significant improvement in uniformity.

Recommended minimum mixing times

Capacity of mixer (m^3)	Mixing time (Minutes)
0.8	1
1.5	1 ¼
2.3	1 ½
3.1	1 ¾
3.8	2
4.6	2 ¼
7.6	3 ¼

ACI 304-73 (reaffirmed 1983) and ASTM Standard C 94-83.

Compaction of Concrete

This is a very significant stage of concrete production. The process of compacting the concrete consists essentially of the elimination of entrapped air in concrete. It can be achieved either by ramming or by vibration. In any case, the particles are so separated that a compact mass is obtained.

The use of vibration as a mean of compaction makes it possible to use drier mixes that for a given strength concrete can be made with lower cement content. But, vibration must be applied uniformly to the entire concrete mass so that, for some parts of it will not be left without compaction while others are segregated owing to over-vibration.

The two basic methods of compaction require mixes of different workabilities: too dry mix cannot be sufficiently worked by hand; and, conversely, too wet mix should not be vibrated as segregation may result.

Curing of Concrete

Curing of Concrete is a method by which the concrete is protected against loss of moisture required for hydration and kept within the recommended temperature range. Curing will increase the strength and decrease the permeability of hardened concrete. Curing is also helps in mitigating (reduction) thermal and plastic cracks, which can severely impact durability of structures.

A curing practice involves keeping the concrete damp or moist until the hydration of concrete is complete and strength is attained. Curing of concrete should begin soon after final setting time of concrete or formwork/shuttering is removed and must continue for a reasonable period of time as per the specified standards, for the concrete to achieve its desired strength and durability.

Significance of Curing of Concrete

1. Enhance Hydration of Concrete to achieve desired Strength
2. Improved durability of concrete by reducing cracks.
3. Higher serviceability performance by increasing abrasion resistance.
4. Improved microstructure by developing better hydrate gels and solid mass.

Methods to Cure Concrete

Depending upon the site constraints, type of structure and other material parameters, different methods of curing are adopted at site. Methods of curing concrete fall into the following categories:

1. Water curing
2. Membrane Curing
3. Steam Curing
4. Internal Curing

Strength of Concrete

Strength of concrete could be defined as *the ultimate load that causes failure (or is its resistance to rupture)* and its units are force units divided by area (N/mm^2, lb/in^2).

Strength of Concrete مقاومة الخرسانة

تعتبر مقاومة الخرسانة من أهم خواصها الأخرى كالمتانة وعدم النفاذية فهي تعطي صورة شاملة عن نوعية الخرسانة

ودليل جيد لمعظم خواصها الأخرى.

إن مقاومة الخرسانة تنتج من-:

1. مقاومة الملاط Mortar
2. قوة التلاصق بين الملاط والركام الخشن.
3. مقاومة حبيبات الركام الخشن للإجهادات المسلطة.

أنواع مقاومة الخرسانة

- 1- مقاومة الضغط Compressive Strength

- 2- مقاومة الشد Tensile Strength

- 3- مقاومة الانحناء Flexural Strength

- 4- مقاومة القص Shear Strength

- 5- مقاومة التماسك Bond Strength

Fracture and failure

Concrete specimens subjected to any state of stress can support loads of up to 40–60 per cent of ultimate without any apparent signs of distress. Below this level, any sustained load results in creep strain which is proportional to the applied stress and can be defined in terms of specific creep (i.e. creep strain per unit stress). Also the concrete is below the fatigue limit. As the load is increased above this level, soft but distinct noises of internal disruption can be heard until, at about 70–90 per cent of ultimate, small fissures or cracks appear on the surface. At this stage sustained loads result in eventual failure. Towards ultimate, cracks spread and interconnect until, at ultimate load and beyond; the specimens are increasingly disrupted and eventually fractured into a large number of separate pieces. The formation and propagation of small microscopic 2-5cracks μm long (micro cracks) have long been recognized as the causes of fracture and failure of concrete and the marked non-linearity of the stress–strain curve near and beyond ultimate.

The stages of cracking (fracture) in concrete:

There appear to be at least three stages in the cracking process. In describing the cracking mechanisms, it is important to differentiate between the mode of crack initiation and how this occurs at the microscopic level, and the subsequent paths of propagation and the eventual macroscopic crack pattern at the engineering level.

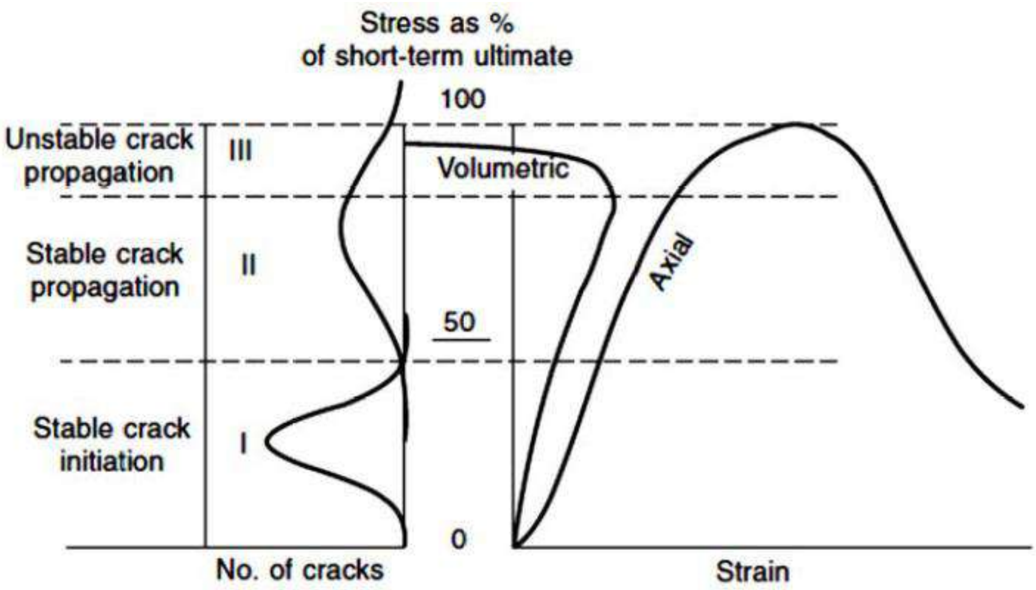
Although some discontinuities exist as a result of the compaction process of fresh concrete, the formation of small fissures or micro cracks in concrete is due primarily to the strain and stress concentrations resulting from the incompatibility of the elastic moduli of the aggregate and paste components.

Stage I: Even before loading, intrinsic volume changes in concrete due to shrinkage or thermal movements can cause strain concentrations at the aggregate–paste interface. Within this stage localized cracks are initiated at the microscopic level at isolated points throughout the specimen where the tensile strain concentration is the largest. This shows that these cracks are stable and, at this load stage, do not propagate

Stage II: As the applied load is increased beyond Stage I, initially stable cracks begin to propagate. There will not be a clear distinction between Stages I and II since stable crack initiation is likely to overlap crack propagation and there will be gradual transition from one stage to another. This is illustrated diagrammatically in Fig. 6.1. During Stage II the crack system multiplies and propagates but in a slow stable manner in the sense that, if loading is stopped and the stress level remains constant propagation ceases.

The extent of the stable crack propagation stage will depend markedly upon the applied state of stress, being very short for 'brittle' fractures under predominantly tensile stress states and longer for more 'plastic' fractures under predominantly compressive states of stress.

Stage III: This occurs when, under load, the crack system has developed to such a stage that it becomes unstable and the release of strain energy is sufficient to make the cracks self-propagate until complete disruption and failure occurs. Once Stage III is reached failure will occur whether or not the stress is increased. This stage starts at about 70–90 per cent of ultimate stress and is reflected in an overall expansion of the structure as signified by a reversal in the volume change behavior. As stated above, the load stage at which this occurs corresponds approximately to the long-term strength of concrete.



1. Compressive Strength

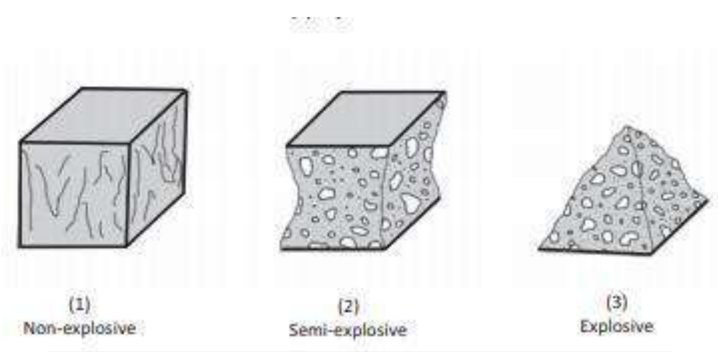
- Compressive strength of concrete specimens treated in a standard manner which includes fully compaction and wet curing for specified period give results representing the potential quality of concrete. There are three types of loading in compression test:

(a) Uniaxial loading. , (b) Biaxial loading. (c) Triaxial loading.

- Two types of compression test specimens are used: cubes (150 mm cubes or 100 mm cubes) and cylinders (150×300 mm or 100×200 mm).

- The uniaxial loading case represents the most conservative system and yields the lowest values in compression.

- Failure mechanism: There are different types of failure in uniaxial compression test as shown below for cubes and cylinders;



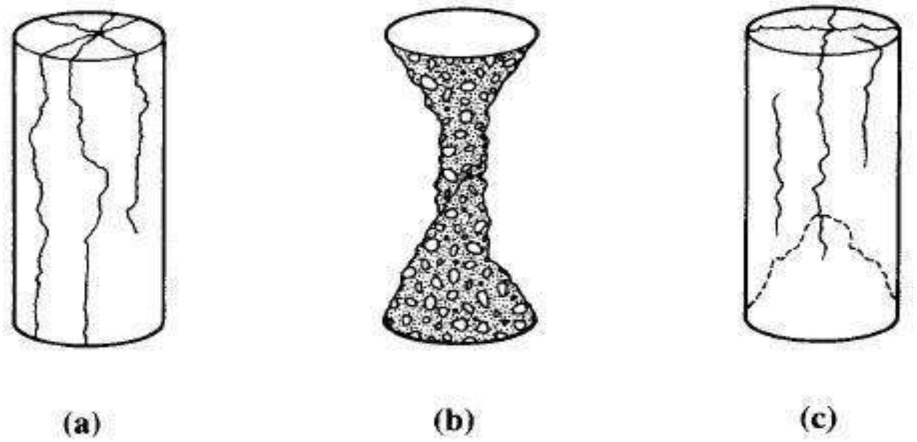
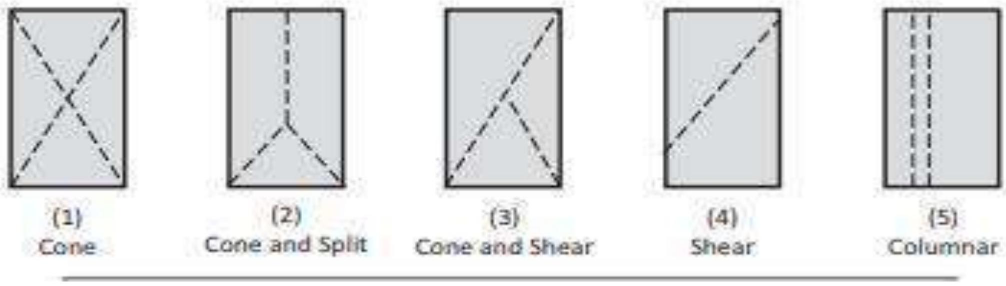


Fig. 16.2: Typical failure modes of standard test cylinders; (a) splitting, (b) shear (cone), and (c) splitting and shear (cone)



مقاومة الضغط Compressive Strength

إن مقاومة الضغط هي أهم خواص الخرسانة المتصلبة على الإطلاق وهى تعبر عن درجة جودتها وصلاحيتها ، ومقاومة الضغط هي المقاومة الأم للخرسانة حيث أن معظم الخواص والمقاومات الأخرى مثل الشد و الانحناء والقص والتماسك مع حديد التسليح تتحسن وتزيد بزيادة مقاومة الضغط والعكس صحيح . لذلك يجرى اختبار الضغط بغرض التحكم في جودة إنتاج الخرسانة في موقع المشروع.

تتراوح مقاومة الضغط بين) 35– 25 (نت / مم ^{2} للمنشآت الاعتيادية.

تتراوح مقاومة الضغط بين) 50– 40 (نت / مم ^{2} للمنشآت الخاصة.

تتراوح مقاومة الضغط بين) 60– 50 (نت / مم ^{2} للخرسانة مسبقة الجهد.

العوامل المؤثرة على مقاومة الضغط Factors affecting compressive strength

تتأثر مقاومة الضغط بعوامل عديدة ومتنوعة ويمكن تقسيمها إلى أربعة مجموعات رئيسية-:

- 1المواد المكونة ونسب الخلط.

- 2طرق صناعة الخرسانة من خلط ونقل وصب ورص.

- 3ظروف المعالجة.

- 4العمر وظروف الاختبار.

2. Tensile Strength

- Although concrete is not normally designed to resist direct tension, the knowledge of tensile strength is used to estimate the load under which cracking will developed.

- The absence of cracking is of considerable importance in maintaining the continuity of concrete structure and in many cases in the prevention of corrosion of reinforcement.

- The knowledge of tensile strength is of value in estimating the load under which cracking will develop.

- The tensile strength of concrete is very much lower than the compressive strength. This shows that concrete is more brittle and almost non-ductile.

- There are two types of tests for strength in tension: 1.direct tension test and 2. splitting tension test.

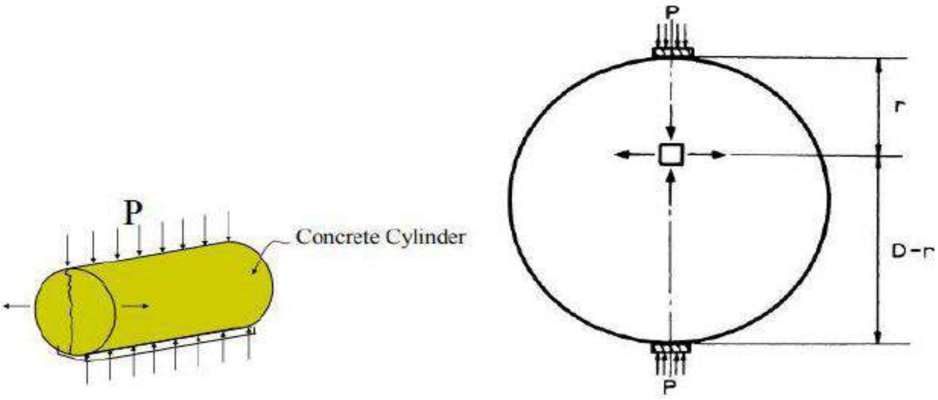
2- Splitting tension test :

In this test, a concrete cylinder, of the type used for compression tests, is placed with its axis horizontal between the platens of a testing machine, and the load is increased until failure by indirect tension in the form of splitting along the vertical diameter takes place.

However, immediately under the load, a high compressive stress would be induced and, in practice, narrow strips of a packing material, such as plywood, are interposed between the cylinder and the platens.

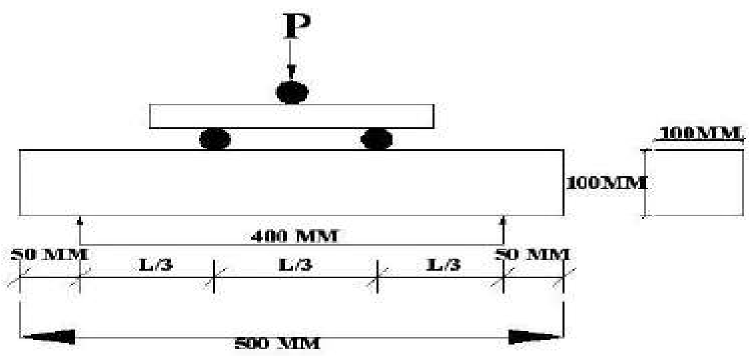
Without packing strips, the recorded strength is lower, typically by 8 %. ASTM C 496-04 prescribes plywood strips, 3 mm thick and 25 mm wide. British Standard BS EN 12390-6 : 2009 specifies hardboard strips, 4 mm thick and 15 mm wide.

The stress is expressed in terms of $2P/\pi LD$. The strength determined in the splitting test is believed to be close to the direct tensile strength of concrete, being 5 to 12 % higher.



3. Flexural strength

In these tests, a plain (unreinforced) concrete beam is subjected to flexure using symmetrical *two-point loading* until failure occurs. Because the load points are spaced at one-third of the span, the test is called a *third-point loading* test. Normal standard size of beams is 150×150×750 mm. Beams with 100×100×500 mm could be used too. Span of the beam is three times its depth. The requirements of ASTM C 78-09 are similar to those of BS EN 12390-5 : 2009.



TWO POINT LOADING SETUP IN FLEXURE TEST

- If fracture occurs within the central one-third of the beam, the modulus of rupture is calculated on the basis of ordinary elastic theory, and is thus equal to:

Flexural strength or modulus of rupture (MOR) = PL / bd^2

$$\sigma = \frac{M\,c}{I} = \frac{P\,l}{b\,d^2}$$

- If, however, fracture occurs outside the load points, say, at a distance *a* from the near support, *a* being the average distance measured on the tension surface of the beam, but not more than 5 % of the span, then the modulus of rupture is given:

Flexural strength or modulus of rupture (MOR) = 3Pa / bd^2

Where,

a = the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen

b = width of the beam (mm) , d = depth of the beam (mm) , l = span (mm) , P = max. Load (N)

Factors affecting strength of concrete:

1. Water/cement ratio:

In engineering practice, the strength of concrete at a given age and cured in water at a prescribed temperature is assumed to depend primarily on two factors only:

(a) Water/cement ratio.

(b) Degree of compaction.

When considering fully compacted concrete only: for mix proportioning purposes this is taken to mean that the hardened concrete contains about 1 % t of air voids. When concrete is fully compacted, its strength is taken to be inversely proportional to the water/cement ratio as shown in the following equation:

$$f_c = \frac{K_1}{K_2^{w/c}}$$

Where:

w/c : represents the water/cement ratio of the mix (originally taken by volume),

*K*1 and *K*2 : are empirical constants.

The general form of the strength versus water/cement ratio curve is shown in Fig. 6.1.

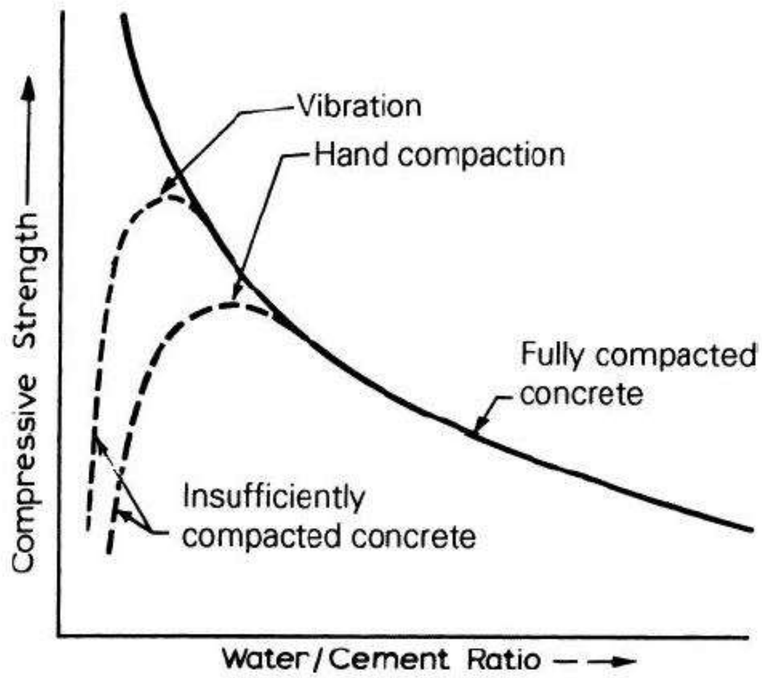


Fig. 6.1. The relation between strength and water/cement ratio of concrete

2. Effective water in the mix

-- We consider as effective that water which occupies space outside the aggregate particles when the gross volume of concrete becomes stabilized, i.e. approximately at the time of setting. Hence the terms *effective*, *free*, or *net* water/cement ratio.

-- *Generally, water in concrete consists:*

(1) Added water to the mix.

(2) Water that held by the aggregate at the time when it enters the mixers.

-- A part of the latter water is absorbed within the pore structure of the aggregate while some exists as free water on the surface of the aggregate and is therefore no different from the water added direct into the mixer.

-- Conversely, when the aggregate is not saturated and some of its pores are therefore air-filled, a part of the water added to the mix will be absorbed by the aggregate during the first half-hour or so after mixing. Under such circumstances the demarcation between absorbed and free water is a little difficult.

3. Gel/space ratio

In particular, strength at any water/cement ratio depends on:

(1) Degree of hydration of cement.

(2) Chemical and physical properties of cement;

(3) Temperature at which hydration takes place;

(4) Air content of the concrete;

(5) Formation of cracks due to bleeding

It is more correct, therefore, to relate strength to the concentration of the solid products of hydration of cement in the space available for these products.

4. Influence of aggregate/cement ratio on strength

-- There is no doubt that the aggregate/ cement ratio, is only a secondary factor in the strength of concrete but it has been found that, for a constant water/cement ratio, a leaner mix leads to a higher strength.

-- In certain cases, some water may be absorbed by the aggregate: a larger amount of aggregate absorbs a greater quantity of water, the effective water/ cement ratio being thus reduced.

-- In other cases, a higher aggregate content would lead to lower shrinkage and lower bleeding, and therefore to less damage to the bond between the aggregate and the cement paste; likewise, the thermal changes caused by the heat of hydration of cement would be smaller.

-- The total water content per cubic meter of concrete is lower in a leaner mix than in a rich one. As a result, in a leaner mix, the voids form a smaller fraction of the total volume of concrete, and it is these voids that have an adverse effect on strength.

5. Influence of properties of coarse aggregate:

-- The properties of aggregate affect the cracking load, as distinct from ultimate load, in compression and the flexural strength in the same manner that the relation between the two quantities is independent of the type of aggregate used.

-- On the other hand, the relation between the flexural and compressive strengths depends on the type of coarse aggregate because (except in high strength concrete) the properties of aggregate, especially its shape and surface texture, affect the ultimate strength in compression very much less than the strength in tension or the cracking load in compression.

-- In experimental concrete, entirely smooth coarse aggregate led to a lower compressive strength, typically by 10 % than when roughened.

-- The influence of **the type of coarse aggregate on the strength of concrete** varies in magnitude and depends on the **water/cement ratio of the mix**.:

a) For water/cement ratios below 0.4, the use of crushed aggregate has resulted in strengths up to 38 % higher than when gravel is used.

b) With an increase in the water/cement ratio to 0.5, the influence of aggregate falls off, presumably because the strength of the hydrated cement paste itself becomes paramount.

c) at a water/cement ratio of 0.65, no difference in the strengths of concretes made with crushed rock and gravel has observed.

6. Effect of age on strength:

The relation between the water/cement ratio and the strength of concrete applies to one type of cement and one age only, and also assumes wet curing conditions.

On the other hand, the strength versus gel/space ratio relationship has a more general application because the amount of gel present in the cement paste at any time is itself a function of age and type of cement. The latter relation thus allows for the fact that different

cements require a different length of time to produce the same quantity of gel.

In concrete practice, the strength of concrete is traditionally characterized by the 28-day value, and some other properties of concrete are often referred to the 28-day strength. If, for some reason, the 28-day strength is to be estimated from the strength determined at an earlier age, say 7 days, then the relation between the 28-day and the 7-day strengths has to be established experimentally for the given mix.

7- Effect of temperature on strength

- The rise in the curing temperature speeds up the chemical reactions of hydration and thus affects beneficially the early strength of concrete without any ill-effects on the later strength.

- Higher temperature during and following the initial contact between cement and water reduces the length of the dormant period so that the *overall* structure of the hydrated cement paste becomes established very early.

- Although a higher temperature during placing and setting increases the very early strength, it may adversely affect the strength from about 7 days onwards. The explanation is that:

1. a rapid initial hydration appears to form products of a poorer physical structure, probably more porous, so that a proportion of the pores will always remain unfilled. It follows from the gel/space ratio rule, that this will lead to a lower strength compared with a less porous, though slowly

hydrating, cement paste in which a high gel/space ratio will eventually be reached.

2. at the high initial rate of hydration, there is insufficient time available for the diffusion of the products of hydration away from the cement particle and for a uniform precipitation in the interstitial space (as is the case at lower temperatures). As a result, a high concentration of the products of hydration is built up in the vicinity of the hydrating particles, and this retards the subsequent hydration and adversely affects the long-term strength.

- For laboratory-made concrete, using ordinary or modified Portland cement, the optimum temperature is approximately 13 °C ; for rapid-hardening Portland cement it is about 4 °C .

- Beyond the initial period of setting and hardening the influence of temperature (within limits) accords with the maturity rule: a higher temperature accelerates the development of strength.

- The tests described so far were all made in the laboratory or under known conditions, but the behavior on site in a hot climate may not be the same. There are some additional factors acting:

- ✓ Ambient humidity,
- ✓ Direct radiation of the sun,
- ✓ Wind velocity,
- ✓ Method of curing.
- ✓ Temperature of concrete.
- ✓ Size of the member.

Bond Strength:

The bond strength can be considered from two different angles; one is the bond strength between paste and steel reinforcement and the other is the bond strength between paste and aggregate. Firstly, let us consider the bond strength between paste and steel reinforcement. Bond strength between paste and steel reinforcement is of considerable importance. A perfect bond, existing between concrete and steel reinforcement is one of the fundamental assumptions of reinforced concrete. Bond strength arises primarily from the friction and adhesion between concrete and steel. The roughness of the steel surface is also one of the factors affecting bond strength. The bond strength of concrete is a function of compressive strength and is approximately proportional to the compressive strength up to about 20 MPa. For higher strength, increase in bond strength becomes progressively smaller. The bond strength, is also a function of specific surface of gel. Cement which consists of a higher percentage of C_2S will give higher specific surface of gel, thereby giving higher bond strength. On the other hand, concrete containing more C_3S or the concrete cured at higher temperature results in smaller specific surface of gel which gives a lower bond strength. It has been already pointed out that high pressure steam cured concrete produces gel whose specific surface is about 1/20 of the specific surface of the gel produced by normal curing. Therefore, bond strength of high pressure steam cured concrete is correspondingly lower.

Curing of concrete

Curing of concrete is one of the most important factors in concrete construction as it is related to properties such as *characteristic strength*, permeability, *durability*, etc. Further, it is required to do the curing at the right time and a sufficient period of curing is very important to achieve the exact properties of concrete.

There are three main functions of curing:

1) Maintaining mixing water in concrete during the early hardening process

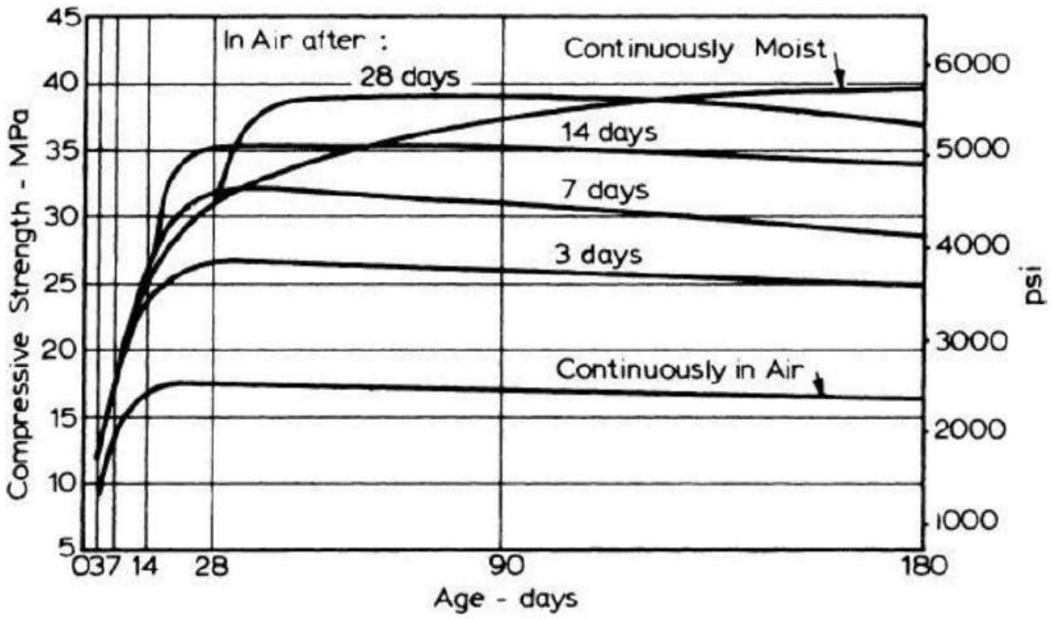
2) Reducing the loss of mixing water from the surface of the concrete

3) Accelerating strength gain using heat and additional moisture

Methods for Curing of Concrete

1. Water Curing
2. Wet Covering
3. Formwork Curing
4. Membrane Curing
5. Sheet Curing
6. Curing by Absorbing Heat
7. Hot mixing method
8. Electrical curing
9. Infra-Red Curing

10. Cover with Sand or Sawdust, Soil, etc
11. Natural Curing (Exposed concrete)



. 7.6. Influence of moist curing on the strength of concrete with a water/cement ratio of 0.50

1. Wet curing:

This method is that of providing water which can be imbibed by the concrete. This requires that the surface of the concrete is continuously in contact with water for a specified length of time, starting as soon as the surface of the concrete is no longer liable to damage.

Such conditions can be achieved by:

- Continuous spraying or flooding (ponding).
- Covering the concrete with wet sand or earth, sawdust or straw.
- Covering the concrete with periodically-wetted clean hessian (burlap) or cotton mats (thick and lapped).

2. Membrane curing:

This method of curing relies on the prevention of loss of water from the surface of the concrete, without the possibility of external water ingressing into it. This could be called a water-barrier method. The techniques used include:

- Covering the surface of the concrete with overlapping polyethylene sheeting, laid flat or with reinforced paper. The sheeting can be black, which is preferable in cold weather, or white, which has the advantage of reflection of solar radiation in hot weather. Paper with a white surface is also available. Sheeting can cause discoloration or mottling because of non-uniform condensation of water on the underside.
- Spray-applied curing compounds which form a membrane. The common ones are solutions of synthetic hydrocarbon resins in high-volatility solvents, sometimes including a fugitive bright-color dye. The dye makes obvious the areas not properly sprayed. A white or alumina pigment can be included to reduce the solar heat gain; this is very effective. Other resin solutions are available acrylic, vinyl or styrene butadiene and chlorinated rubber. Wax emulsions can also be used, but they result in a slippery finish which is not easy to remove, whereas the hydrocarbon resins have poor adhesion to concrete and are degraded by ultraviolet light; both these features are desirable.

Figure 15-7. Polyethylene film is an effective moisture barrier for curing concrete and easily applied to complex as well as simple shapes. To minimize discoloration, the film should be kept as flat as possible on the concrete surface.

American method of concrete mix design:

هذه الطريقة توفر تقديرا لنسب المواد لاستخدامها في الخلطات التجريبية عن طريق تسع خطوات مباشرة تأخذ بنظر الاعتبار خصائص المواد .

In this method, Data to be collected

1. Fineness modulus of selected F.A.

2. Unit weight of dry rodded coarse aggregate.

3. Sp. gravity of coarse and fine aggregates in SSD condition

4. Absorption characteristics of both coarse and fine aggregates.

5. Specific gravity of cement

Step 1. Choice of slump

Step 2. Choice of maximum size of aggregate

Step 3. Estimation of mixing water and air content

Step 4. Selection of water/cement ratio

Step 5. Calculation of cement content

Step 6. Estimation of coarse aggregate content

Step 7. Estimation of Fine Aggregate Content

Step 8. Adjustments for Aggregate Moisture

Step 9. Trial Batch Adjustments

Step1 : Nominal maximum size of aggregate shall not be larger than:
M.A.S = 1/5 (least dimension), or
= 3/4 (minimum spacing of reinforcement), or
= 1/3 (slab thickness)

Choose the **smallest** of them

Step 2: Select the slump
If slump is not specified, a value appropriate for the work can be selected from the Table (1) below, or from any other references.

Table (1): Recommended slumps for various types of constructions

Type of Construction	Slump (mm)	Slump (inches)
Reinforced foundation walls and footings	25 - 75	1 - 3
Plain footings, caissons and substructure walls	25 - 75	1 - 3
Beams and reinforced walls	25 - 100	1 - 4
Building columns	25 - 100	1 - 4
Pavements and slabs	25 - 75	1 - 3
Mass concrete	25 - 50	1 - 2

Step 3: Estimation of mixing water and the air content.

The quantity of water per unit volume of concrete required for a given slump value depends on the maximum particle size, shape, and grading of the aggregates, as well as on the amount of entrained air. If data based on experience with the given aggregates are not available, assuming normally shaped and well-graded particles, an estimate of the mixing water, with or without air entrainment, can be obtained from **Table (2)** for the purpose of deriving the trial batches.

Table (2): Approximate Mixing Water and Air Content Requirements for Different Slumps and Maximum Aggregate Sizes.

Water kg /m^3 of concrete (كمية الماء كغم / م^3)								
	max size aggregate							
Slump(mm)	9.5	12.5	19	25	37.5	50	75	150
25-50	207	199	190	179	166	154	130	113
75-100	228	216	205	193	181	169	145	124
150-175	243	228	216	202	190	178	160	-
air cont %	3	2.5	2	1.5	1	.5	.3	.2

	Mixing Water Quantity in kg/m³ (lb/yd³) for the listed Nominal Maximum Aggregate Size							
Slump	9.5 mm (0.375 in.)	12.5 mm (0.5 in.)	19 mm (0.75 in.)	25 mm (1 in.)	37.5 mm (1.5 in.)	50 mm (2 in.)	75 mm (3 in.)	100 mm (4 in.)
Non-Air-Entrained								
25 - 50 (1 - 2)	207 (350)	199 (335)	190 (315)	179 (300)	166 (275)	154 (260)	130 (220)	113 (190)
75 - 100 (3 - 4)	228 (385)	216 (365)	205 (340)	193 (325)	181 (300)	169 (285)	145 (245)	124 (210)
150 - 175 (6 - 7)	243 (410)	228 (385)	216 (360)	202 (340)	190 (315)	178 (300)	160 (270)	-
Typical entrapped air (percent)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-Entrained								
25 - 50 (1 - 2)	181 (305)	175 (295)	168 (280)	160 (270)	148 (250)	142 (240)	122 (205)	107 (180)
75 - 100 (3 - 4)	202 (340)	193 (325)	184 (305)	175 (295)	165 (275)	157 (265)	133 (225)	119 (200)
150 - 175 (6 - 7)	216 (365)	205 (345)	197 (325)	184 (310)	174 (290)	166 (280)	154 (260)	-
Recommended Air Content (percent)								
Mild Exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate Exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Severe Exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Step 4. Selection of water/cement ratio.

The required water/cement ratio is determined by strength, durability and finish ability. The appropriate value is chosen from prior testing of a given system of cement and aggregate or a value is chosen from Table 2 and/or Table 3.

Table 3: Water-Cement Ratio and Compressive Strength Relationship

28-Day Compressive Strength in MPa (psi)	Water-cement ratio by weight	
	Non-Air-Entrained	Air-Entrained
41.4 (6000)	0.41	-
34.5 (5000)	0.48	0.40
27.6 (4000)	0.57	0.48
20.7 (3000)	0.68	0.59
13.8 (2000)	0.82	0.74

Table 4. Maximum permissible water/cement ratios for concrete in severe exposures

Type of Structure	Structure wet continuously or fequently exposed to freezing & thawing*	Structure exposed to seawater
Thin sections (railings, curbs, sills, ledges, ornamental work) & sections with less than 1-inch cover over steel	0.45	0.40
All other structures	0.50	0.45

Step 5. Calculation of cement content.

The amount of cement is fixed by the determinations made in Steps 3 and 4 above.

Weight of cement = weight of water / w/c

Step 6. Estimation of coarse aggregate content.

The most economical concrete will have as much as possible space occupied by CA since it will require no cement in the space filled by CA.

Table(5) : Volume of Coarse Aggregate per Unit Volume for Different Fine aggregate Fineness Moduli

Volume of coarse aggregate per unit of volume				
Nominal max size of aggregate (mm)	Fineness modulus of fine aggregate معامل النعومة للركام الناعم			
	2.4	2.6	2.8	3
9	0.50	0.48	0.46	0.44
12.5	0.59	0.75	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Step7. Estimation of Fine Aggregate Content.

At the completion of Step 7, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity can be determined by difference if the "absolute volume" displaced by the known ingredients-, (i.e., water, air, cement, and coarse aggregate), is subtracted from the unit volume of concrete to obtain the required volume of fine aggregate. Then, once the volumes are known the weights of each ingredient can be calculated from the specific gravities.

يوجد طريقتين لتقدير محتوى الركام الناعم:

طريقة الوزن:- Weight method

اذا كان وزن الخرسانة" معلوم كثافتها "فأن الوزن المطلوب من الركام الناعم يمثل الفرق بين وزن الخرسانة والوزن الكلي لبقية مكونات الخرسانة(الحصى والاسمنت والماء .)اما اذا كان وزن الخرسانة غير معلوم فيمكن تقديرها من الجدول التالي:

ت	المقاس الاقصى للركام (مم)	التقدير الاولي لوزن الخرسانة كغم/م^3	
		الخرسانة الاعتيادية	الخرسانة الحاوية على الهواء المقصود
1	10	2285	2190
2	12.5	2315	2235
3	20	2355	2280
4	25	2375	2315
5	40	2420	2355
6	50	2445	2375
7	70	2465	2400
8	150	2506	2435

طريقة الحجم المطلق Absolute volume method :

هذه الطريقة ا كثر دقة من طريقة الوزن وتستند على الحجوم المزاحة من قبل مكونات الخرسانة (الماء والهواء والاسمنت والركام الخشن) حيث تطرح هذه الحجوم للخرسانة من وحدة الحجم للخرسانة للحصول على الحجم المطلوب للركام الناعم حيث ان الحجم المشغول في الخرسانة لأي من مكوناتها يساوي وزن المادة مقسوماً على كثافتها

$$\text{Absolute Volume} = \frac{\text{Cement weight}}{\text{Cement SG}} + \frac{\text{Sand weight}}{\text{Sand SG}} + \frac{\text{Gravel weight}}{\text{Gravel SG}} + \frac{\text{Water weight}}{\text{Water SG}} = 1000\ \text{Liters}$$

$$\text{Sand volume} = 1 - \left[\frac{\text{Cement weight}}{\text{Cement SG}} + \frac{\text{Gravel weight}}{\text{Gravel SG}} + \frac{\text{Water weight}}{\text{Water SG}} + \text{Air volume}\right]$$

علماً بأن واحد متر مكعب من الخرسانة = 1000 لتر

Step 8. Adjustments for Aggregate Moisture.

As explained previously

Step 9. Trial Batch Adjustments.

The ACI method is written on the basis that a trial batch of concrete will be prepared in the laboratory, and adjusted to give the desired slump, freedom from segregation, finish ability, unit weight, air content and strength.

Concrete Mix Design

Introduction:

The required properties of hardened concrete are specified by the designer of the structure and the properties of fresh concrete are governed by the type of construction and by the techniques of placing and transporting. These two sets of requirements are the main factors that determine the composition of the mix, also taking account of the construction experience on site.

Definition:

Mix design can be defined as the processes of selecting suitable ingredients and determining their relative quantities, with the purpose of producing an economical concrete that has certain minimum properties, notably workability, strength, and durability.

Mixture proportioning: is to determine the most economical and practical combination of readily available materials to produce a concrete that will satisfy the performance requirements under particular conditions of use.

Factors to be Considered Mix Proportioning:

1・ Required workability (Cohesiveness, slump) based on placement conditions.

2・ Strength and durability.

3・ Appearance.

4・ Economy.

5・ Minimize the amount of cement, Minimize w/c ratio.

6・ Minimum amount of water, to reduce cement content.

Advantages of low water/cement ratio:

1・ Increased strength. 2・ Lower permeability.

3・ Increased resistance to weathering.

4・ Better bond between concrete and reinforcement.

5・ Reduced drying shrinkage and cracking.

6・ Less volume change from wetting and drying.

Basic data required for mix proportioning.

The following basic data is required for concrete mix proportioning:

(i) Grade designation: It gives characteristic compressive strength of concrete. The target mean strength of concrete is fixed by adding a suitable margin to the characteristic strength depending upon the quality control to be envisaged.

(ii) Type of cement: The type and grade of cement mainly influences the rate of development of compressive strength of concrete.

(iii) Maximum nominal size of aggregate: The maximum nominal size of the aggregate to be used in concrete is governed by the size of the section to be concreted and spacing of the reinforcement.

(iv) Maximum water-cement ratio: The maximum water cement ratio to be used for a particular work is governed by the desired strength and limited by the durability requirements.

(v) Minimum cement content: The minimum cement content to be used is governed by the respective environmental exposure conditions.

(vi) Workability: The desired workability for a particular job depends upon the shape and size of section to be concreted, denseness of reinforcement, and method of transportation, placing and compaction of concrete.

(vii) Exposure conditions: The anticipated environmental exposure conditions in which the structure is intended to serve during its service span defines the durability requirements.

(viii) Type and properties of aggregate: It influences the workability and strength of concrete. The relative proportions of coarse and fine aggregate are determined from the characteristics of the aggregates such as grading, shape, size and surface texture.

(ix) Method of transporting and placing: It influences workability of the mix.

(x) Use of admixtures: Admixtures are used to enhance and modify one or more properties of concrete in fresh as well as hardened state.

Compressive Strength Grading and Classes

Grade of Concrete is the classification of concrete according to its compressive strength.

There are different grades of concrete are given as M10, M15, M20, M25, M30, M35 and M40.

The letter "M" denotes Mix design with proportion of materials like Cement: Fine Aggregate: Coarse Aggregate.

Nominal Grades

Grade of Concrete	Mix Ratio	Compressive Strength in N/mm2 or MPa	Compressive Strength in Psi
M5	1 : 5 : 10	5 MPa	725 psi
M7.5	1 : 4 : 8	7.5 MPa	1087 psi
M10	1 : 3 : 6	10 MPa	1450 psi
M15	1 : 2 : 4	15 MPa	2175 psi
M20	1 : 1.5 : 3	20 MPa	2900 psi

2. Standard Grades

M25	1 : 1 : 2	25 MPa	3625 psi
M30	Design Mix	30 MPa	4350 psi
M35	Design Mix	35 MPa	5075 psi
M40	Design Mix	40 MPa	5800 psi
M45	Design Mix	45 MPa	6525 psi

3. High Strength Grades

M50	Design Mix	50 MPa	7250 psi
M55	Design Mix	55 MPa	7975 psi
M60	Design Mix	60 MPa	8700 psi
M65	Design Mix	65 MPa	9425 psi
M70	Design Mix	70 MPa	10150 psi
M80	Design Mix	80 MPa	11600 psi
M90	Design Mix	90 MPa	13050 psi
M100	Design Mix	100 MPa	14500 psi
M150	Design Mix	150 MPa	21750 psi
M200	Design Mix	200 MPa	29000 psi

Component of concrete

Up to 8% Air

7-15% Cement

60-75% Aggregates

(Coarse and Fine)

14-21% Water

Characteristic Strength and Target Mean Strength

(a) Mean strength:

This is the average strength obtained by dividing the sum of strength of all the cubes by the number of cubes.

$$\bar{x} = \frac{\Sigma x}{n}$$

where $\bar{x}$ = mean strength

Σx = sum of the strength of cubes

n = number of cubes.

(b) Variance: This is the measure of variability or difference between any single observed data from the mean strength.

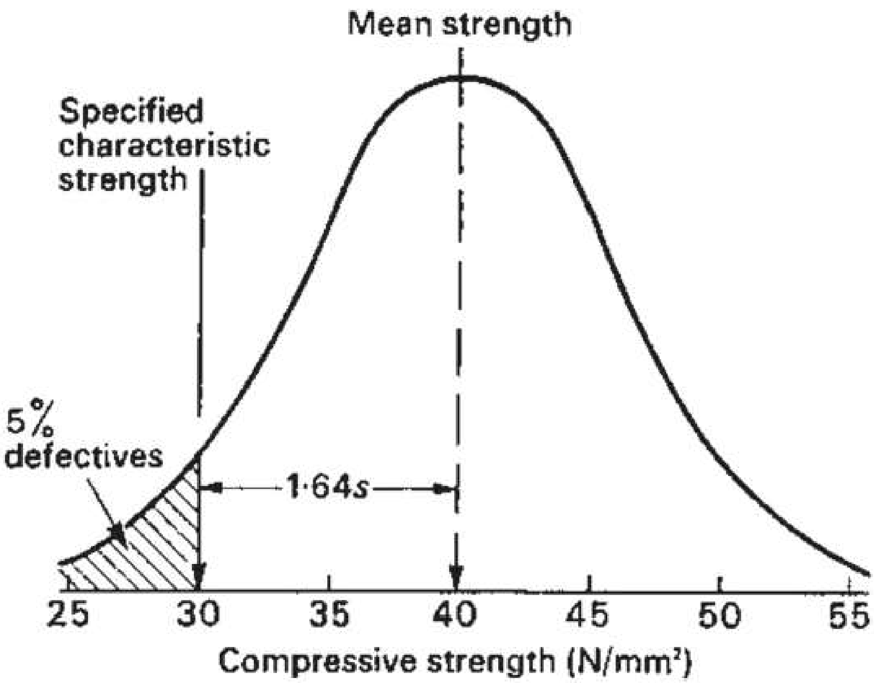


Figure: Normal distribution of concrete strengths

This normal distribution curve is symmetrical about its mean, has a precise mathematical equation and is completely specified by two parameters, its mean "m" and its standard deviation "s". Concrete cube strengths follow the normal distribution. There is therefore always the probability that a result will be obtained less than the specified strength.

(c) Standard deviation: The standard deviation is a measure of the variability calculated from the equation:

$$s = \sqrt{\frac{(x - \bar{x})^2}{n - 1}}$$

x = individual test result.
$\bar{x}$ = average strength results.
n = number of results.

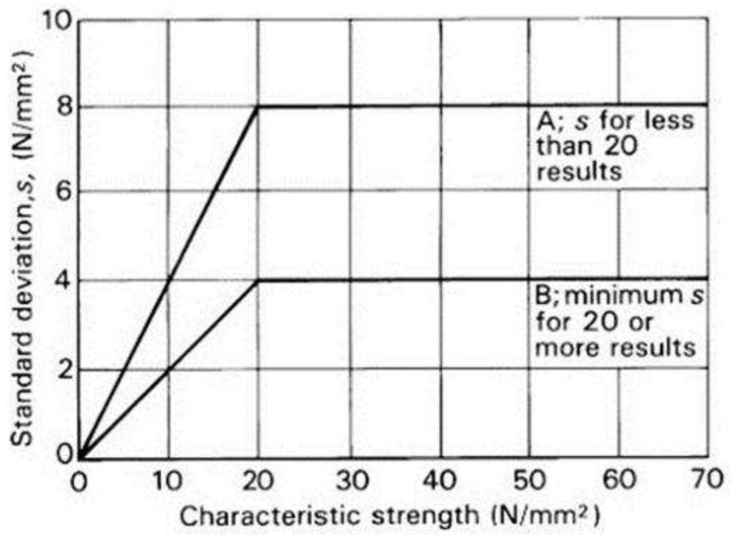


Figure A. Relationship between standard deviation and characteristic strength.

(d) Coefficient of variation: It is an alternative method of expressing the variation of results.

It is a non-dimensional measure of variation obtained by dividing the standard deviation by the arithmetic mean and is expressed as:

$$V\ \% = \frac{S}{\bar{x}} * 100$$

Target Mean Strength

The producer of concrete should design the concrete mix using a higher strength than that of the characteristic strength by a certain Margin (risk factor), in order to ensure satisfying the quality criteria set by the client. This higher strength is called Target Mean Strength.

Target mean strength = specified characteristic strength + Margin

Target mean strength = $\boldsymbol{fm}$

Specified characteristic strength = $\boldsymbol{fc}$

Margin = $\boldsymbol{k.\ s}$

$\boldsymbol{fm} = \boldsymbol{fc} + \boldsymbol{k.\ s}$

The constant **k** is derived from the mathematics of the normal distribution and increases as the proportion of defectives is decreased, thus:

k for 10% defectives = 1.28

k for 5% defectives = 1.65

k for 2.5% defectives = 1.96

k for 1% defectives = 2.33

S is the standard deviation

S = 8.0 (for less than 40 results)

S = 4.0 (for 40 results and more)

Methods of Concrete Mix

(a) Arbitrary proportion (Trial and adjustment method of mix design).
(b) Fineness modulus method
(c) Maximum density method
(d) Surface area method
(e) High strength concrete mix design
(f) Mix design based on flexural strength
(g) Road note No. 4 (Grading Curve method)
(h) ACI Committee 211 method
(i) DOE method (British method)
(j) Mix design for pumpable concrete

1. British Method of Concrete Mix Design (DoE Method)

The following are the steps involved in DOE method:

Step 1: Find Target Mean Strength

Find the target mean strength as explained before.

Step 2 : Checking the maximum size of aggregate

M.A.S = 1/5 (least dimension), or

= 3/4 (minimum spacing of reinforcement), or

= 2/3 (slab thickness)

choose the **smallest** of them

Step 3: Checking (Calculation) of Water/Cement Ratio

(a) From Table (1), knowing age of concrete, type of cement and aggregate, the approximate Compressive Strength (made with a free water/cement ratio of 0.5) is obtained.

(b) This value of Compressive Strength is projected on Figure (1) and a new curve is drawn parallel to the existing curves, this curve will be used in calculating the free water/cement ratio.

(c) From Figure (1), the free w/c ratio is fixed, and this value is compared with the given w/c ratio, choosing the **smaller** one of them

Table (1) : Approximate Compressive strength of concrete made with a free water / cement ratio of 0.5 according to the British method /1988

Type of Cement	*Type of C.A*	*Compressive Strength at the age (cube) of days MPa*			
		3	*7*	*28*	*91*
Ordinary Portland cement (Type I) Sulphate Resisting Cement (Type V)	uncrushed	22	30	42	49
	Crushed	27	36	49	56
Rapid-Hardening Portland Cement (Type III)	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Step 4 : Calculating of the free water in the mix

Knowing the workability (slump) of the concrete, the type and maximum size of aggregate, Table (2) gives the quantity of free water content to give different levels of workability.

step 5 : Checking and calculating of the cement content

cement content = water / w/c

This value of cement content is compared with the given value,

choosing the **larger** one of them.

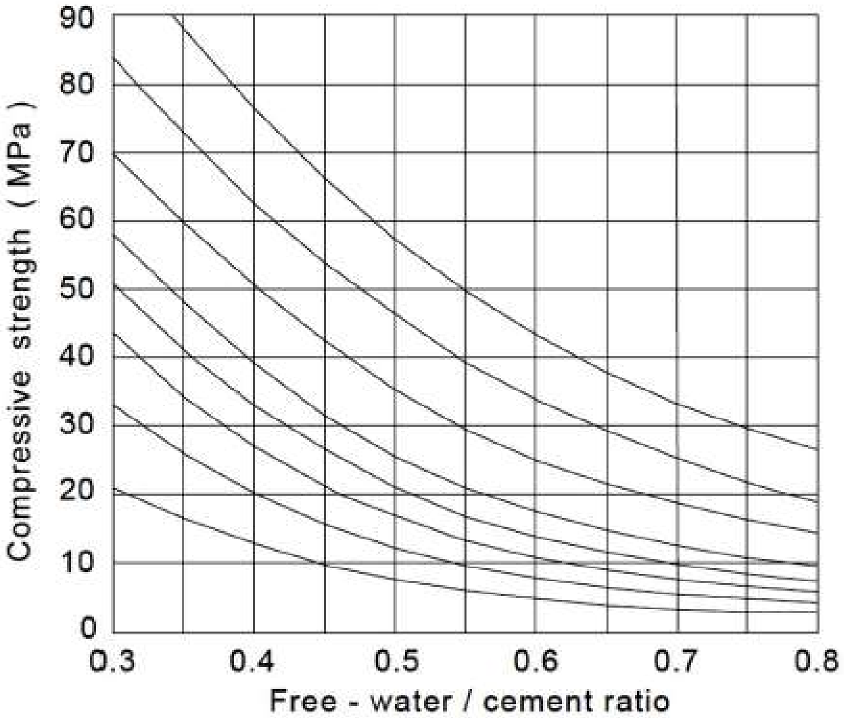


Figure 1 Relation between compressive strength and free-water/cement ratio

Table (2) Approximate Free water Contents required to give various levels of workability according to the British Method

Aggregate		*Water Content kg/m³ for:*			
Max-size mm	*Type*	*Slump 0–10*	*10–30*	*30–60*	*60–180*
		Vebe > 12 seconds	*6–12*	*3–6*	*0–3*
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	crushed	155	175	190	205

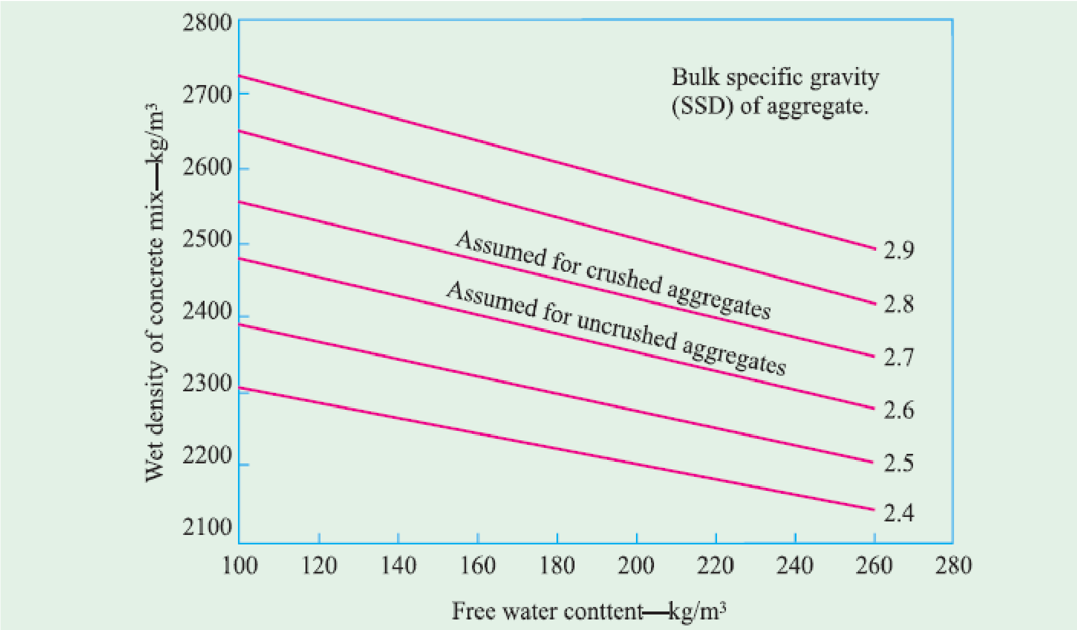
Step 6 : Determination of the total content of aggregate

Knowing the specific gravity of aggregate, Figure (2) gives the wet density (fresh weight) for fully compacted concrete is estimated

Total content of aggregate

= wet density of concrete - (free water + cement)

Figure(2): Estimated wet density of fully compacted concrete



Step 7: Calculating of fine and coarse aggregate :

Knowing the workability and M.A.S. of aggregate as well as sand zone number, Figure (3) gives the percentage of fine aggregate, as follows:

figure (3a) for M.A.S. = 10mm

figure (3b) for M.A.S. = 20 mm

Figure (3c) for M.A.S. = 40 mm, There for

Sand content = total aggregate content × percentage of fine aggregate

Gravel content = total aggregate content - sand content

Step 8 : Adjustments for Aggregate Weights and Water Content.

Figure (3a) : Recommended properties o fine aggregate according to percentage passing 600µm sieve (Dmax 10 mm)

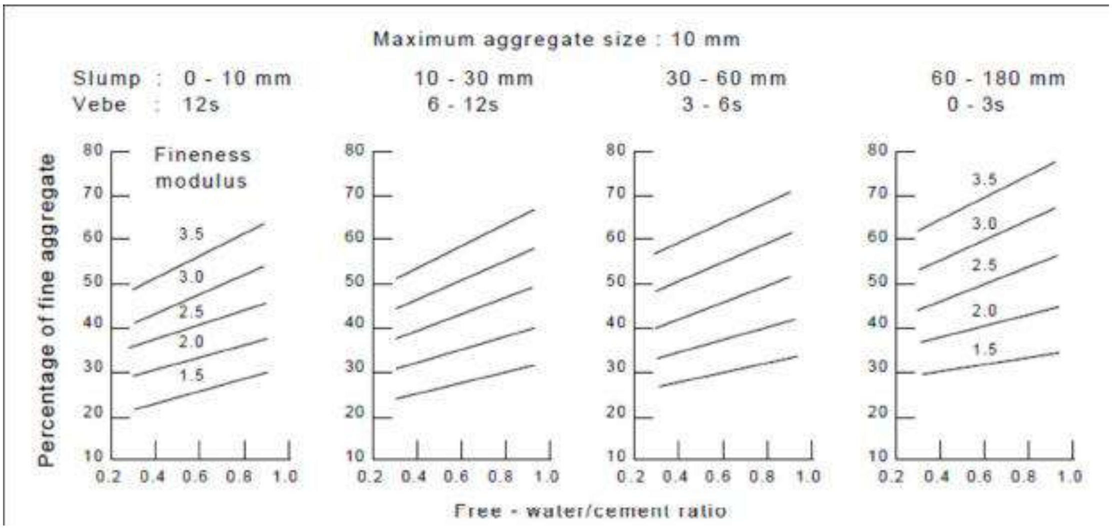


Figure (3b) : Recommended properties o fine aggregate according to percentage passing 600µm sieve (Dmax 20 mm)

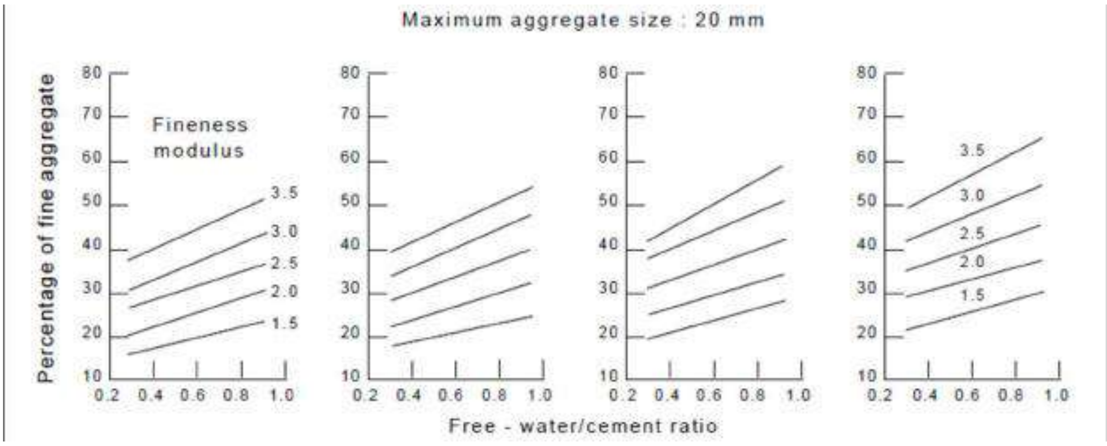
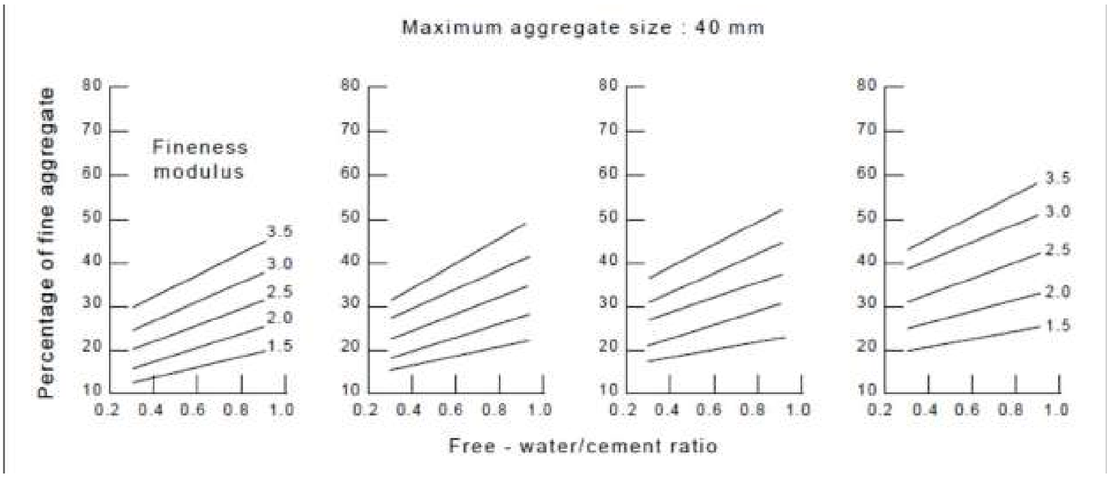


Figure (3c) : Recommended properties o fine aggregate according to percentage passing 600µm sieve (Dmax 40 mm)



Example 1

Design a concrete mix to obtain a characteristic compressive strength (fc) = 30 N/mm^2 at 28 days, with a 2.5% defective rate (k = 1.96), assume that less than 20 previous results are available for calculating the standard deviation. The design requirements are as follows:

- Slump required = 10–30 mm.
- the Maximum aggregate size, MSA = 20 mm (uncrushed),
- Fine aggregate: Fineness modulus, FM =2.5.
- Portland cement class = 42.5.
- maximum free-w/c ratio = 0.55,
- minimum cement content = 290 kg/m^3,
- maximum cement content = not specified.

Both aggregates (sand and gravel) are wet (damp), surface water is 2% for sand and 1.1% for gravel.

What are the proportions to produce trial mix of 0.05 m^3 concrete?

What are the proportions to produce 25 m^3 concrete?

Step 1: Find Target Mean Strength

Find the target mean strength.

Target mean strength = $\boldsymbol{fm}$

Specified characteristic strength = $\boldsymbol{fc}$, Margin = $\boldsymbol{k.s}$

From Figure A. the standard deviation is 8 MPa

$$fm = fc + k.s$$

$$fm = 30 + 1.96 \times 8 = 45.7\ MPa$$

Step 2: Calculation of Water/Cement Ratio

From Table 1 the compressive strength for w/c =0.50 is 42MPa. From Figure 1 the w/c for compressive strength of 45.7 MPa is 0.47.

Step 03: Calculation of free Water Content

From Table 2, for 10-30mm level of workability, uncrushed aggregates and maximum aggregate size of 20mm the water content is 160 kg/m^3 concrete.

Step 04: Calculation of cement Content

$$^{w}/_{c} = \frac{w}{c}\quad , \text{cement content, c} = \frac{160}{0.47} = 340\frac{kg}{m^3}concrete$$

Step 05: Weight of Total Aggregate

From Figure 2 for free water content of 160 kg/m^3, Specific gravity of Uncrushed aggregates:

=2.6 (assumed), the wet density of concrete = 2400 kg/m^3. Therefore, the total aggregate content is

Total aggregate content = Wet density of 1m^3 concrete – water content – cement content

= 2400 – 160 – 340 = 1900 kg/m^3

Step 06: Weight of Fine Aggregate

From Figure 3. The workability level =10-30 mm, FM = 2.5,

w/c = 0.47, MSA = 20mm the percentage of fine aggregates = 32%.

Fine aggregate content = 1900×0.32 = 608 kg/m^3 concrete

Coarse aggregate content = 1900 – 608 = 1292 kg/m^3 concrete

Step 7 : adjustment for fine and coarse aggregate

Both aggregate are wet

weight of surface water on sand = 608 × 0.02 = 12.16 Kg

weight of surface water on gravel = 1292 ×0.011 = 14.212 Kg

The net weight of mixing water = 160 - 12.16 - 14.212 = 133.628 Kg

weight of saturated sand = 608 + 12.16 = 620.16 Kg

weight of saturated gravel = 1292 + 14.212 = 1306.212 Kg

water cement ratio w/c = 133.628 / 340 = 0.393

	cement Kg	water Kg	fine aggregate Kg	coarse aggregate Kg	
for I m^3	340	133.628	620.16	1306.212	
for 0.05 m^3	17	6.6814	31.00	65.31	
for 25 m^3	8500	3340.7	15504	32655.3	
mix =	1		1.824	3.8418	w/c =0.393

1 : 1.824 : 3.842

Concrete Mix Design

Introduction:

The required properties of hardened concrete are specified by the designer of the structure and the properties of fresh concrete are governed by the type of construction and by the techniques of placing and transporting. These two sets of requirements are the main factors that determine the composition of the mix, also taking account of the construction experience on site.

Definition:

Mix design can be defined as the processes of selecting suitable ingredients and determining their relative quantities, with the purpose of producing an economical concrete that has certain minimum properties, notably workability, strength, and durability.

Mixture proportioning: is to determine the most economical and practical combination of readily available materials to produce a concrete that will satisfy the performance requirements under particular conditions of use.

Factors to be Considered Mix Proportioning:

1 • Required workability (Cohesiveness, slump) based on placement conditions.

2 • Strength and durability.

3 • Appearance.

4 • Economy.

5 • Minimize the amount of cement, Minimize w/c ratio.

6 • Minimum amount of water, to reduce cement content.

Advantages of low water/cement ratio:

1 • Increased strength. 2 • Lower permeability.

3 • Increased resistance to weathering.

4・ Better bond between concrete and reinforcement.

5・ Reduced drying shrinkage and cracking.

6・ Less volume change from wetting and drying.

Basic data required for mix proportioning.

The following basic data is required for concrete mix proportioning:

(i) Grade designation: It gives characteristic compressive strength of concrete. The target mean strength of concrete is fixed by adding a suitable margin to the characteristic strength depending upon the quality control to be envisaged.

(ii) Type of cement: The type and grade of cement mainly influences the rate of development of compressive strength of concrete.

(iii) Maximum nominal size of aggregate: The maximum nominal size of the aggregate to be used in concrete is governed by the size of the section to be concreted and spacing of the reinforcement.

(iv) Maximum water-cement ratio: The maximum water cement ratio to be used for a particular work is governed by the desired strength and limited by the durability requirements.

(v) Minimum cement content: The minimum cement content to be used is governed by the respective environmental exposure conditions.

(vi) Workability: The desired workability for a particular job depends upon the shape and size of section to be concreted, denseness of reinforcement, and method of transportation, placing and compaction of concrete.

(vii) Exposure conditions: The anticipated environmental exposure conditions in which the structure is intended to serve during its service span defines the durability requirements.

(viii) Type and properties of aggregate: It influences the workability and strength of concrete. The relative proportions of coarse and fine aggregate are determined from the characteristics of the aggregates such as grading, shape, size and surface texture.

(ix) Method of transporting and placing: It influences workability of the mix.

(x) Use of admixtures: Admixtures are used to enhance and modify one or more properties of concrete in fresh as well as hardened state.

Compressive Strength Grading and Classes

Grade of Concrete is the classification of concrete according to its compressive strength.

There are different grades of concrete are given as M10, M15, M20, M25, M30, M35 and M40.

The letter "M" denotes Mix design with proportion of materials like Cement: Fine Aggregate: Coarse Aggregate.

Nominal Grades

Grade of Concrete	Mix Ratio	Compressive Strength in N/mm2 or MPa	Compressive Strength in Psi
M5	1 : 5 : 10	5 MPa	725 psi
M7.5	1 : 4 : 8	7.5 MPa	1087 psi
M10	1 : 3 : 6	10 MPa	1450 psi
M15	1 : 2 : 4	15 MPa	2175 psi
M20	1 : 1.5 : 3	20 MPa	2900 psi

2. Standard Grades

M25	1 : 1 : 2	25 MPa	3625 psi
M30	Design Mix	30 MPa	4350 psi
M35	Design Mix	35 MPa	5075 psi
M40	Design Mix	40 MPa	5800 psi
M45	Design Mix	45 MPa	6525 psi

3. High Strength Grades

M50	Design Mix	50 MPa	7250 psi
M55	Design Mix	55 MPa	7975 psi
M60	Design Mix	60 MPa	8700 psi
M65	Design Mix	65 MPa	9425 psi
M70	Design Mix	70 MPa	10150 psi
M80	Design Mix	80 MPa	11600 psi
M90	Design Mix	90 MPa	13050 psi
M100	Design Mix	100 MPa	14500 psi
M150	Design Mix	150 MPa	21750 psi
M200	Design Mix	200 MPa	29000 psi

Component of concrete

Up to 8% Air

7-15% Cement

60-75% Aggregates

(Coarse and Fine)

14-21% Water

Characteristic Strength and Target Mean Strength

(a) Mean strength:

This is the average strength obtained by dividing the sum of strength of all the cubes by the number of cubes.

$$\bar{x} = \frac{\Sigma x}{n}$$

where $\bar{x}$ = mean strength

Σx = sum of the strength of cubes

n = number of cubes.

(b) Variance: This is the measure of variability or difference between any single observed data from the mean strength.

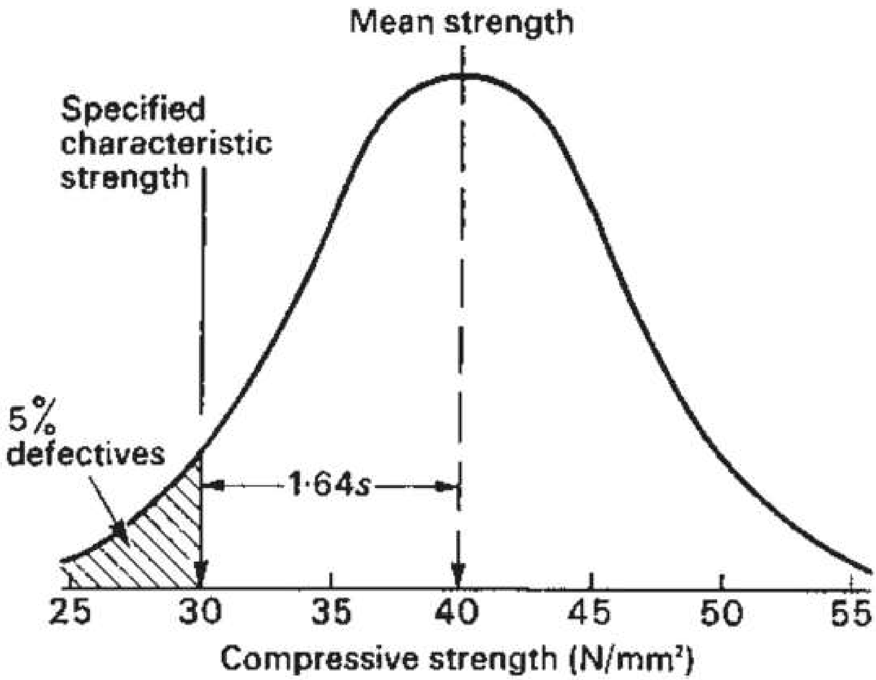


Figure: Normal distribution of concrete strengths

This normal distribution curve is symmetrical about its mean, has a precise mathematical equation and is completely specified by two parameters, its mean “m” and its standard deviation “s”. Concrete cube strengths follow the normal distribution. There is therefore always the probability that a result will be obtained less than the specified strength.

(c) Standard deviation: The standard deviation is a measure of the variability calculated from the equation:

$$s = \sqrt{\frac{(x - \bar{x})^2}{n - 1}}$$

x = individual test result.
$\bar{x}$ = average strength results.
n = number of results.

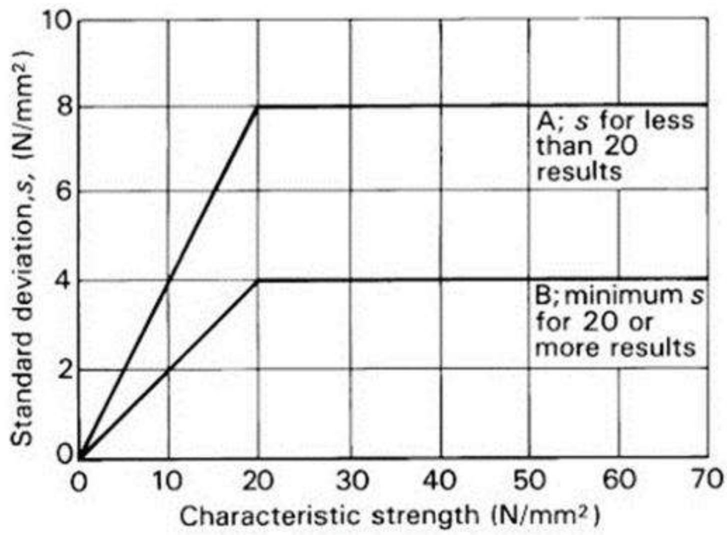


Figure A. Relationship between standard deviation and characteristic strength.

(d) Coefficient of variation: It is an alternative method of expressing the variation of results.

It is a non-dimensional measure of variation obtained by dividing the standard deviation by the arithmetic mean and is expressed as:

$$V\ \% = \frac{S}{\bar{x}} * 100$$

Target Mean Strength

The producer of concrete should design the concrete mix using a higher strength than that of the characteristic strength by a certain Margin (risk factor), in order to ensure satisfying the quality criteria set by the client. This higher strength is called Target Mean Strength.

Target mean strength = specified characteristic strength + Margin

Target mean strength = $\boldsymbol{fm}$

Specified characteristic strength = $\boldsymbol{fc}$

Margin = $\boldsymbol{k.\ s}$

$\boldsymbol{fm} = \boldsymbol{fc} + \boldsymbol{k.\ s}$

The constant **k** is derived from the mathematics of the normal distribution and increases as the proportion of defectives is decreased, thus:

k for 10% defectives = 1.28

k for 5% defectives = 1.65

k for 2.5% defectives = 1.96

k for 1% defectives = 2.33

S is the standard deviation

S = 8.0 (for less than 40 results)

S = 4.0 (for 40 results and more)

Methods of Concrete Mix

(a) Arbitrary proportion (Trial and adjustment method of mix design).
(b) Fineness modulus method
(c) Maximum density method
(d) Surface area method
(e) High strength concrete mix design
(f) Mix design based on flexural strength
(g) Road note No. 4 (Grading Curve method)
(h) ACI Committee 211 method
(i) DOE method (British method)
(j) Mix design for pumpable concrete

1. British Method of Concrete Mix Design (DoE Method)

The following are the steps involved in DOE method:

Step 1: Find Target Mean Strength

Find the target mean strength as explained before.

Step 2 : Checking the maximum size of aggregate

M.A.S = 1/5 (least dimension), or

= 3/4 (minimum spacing of reinforcement), or

= 2/3 (slab thickness)

choose the **smallest** of them

Step 3: Checking (Calculation) of Water/Cement Ratio

(a) From Table (1), knowing age of concrete, type of cement and aggregate, the approximate Compressive Strength (made with a free water/cement ratio of 0.5) is obtained.

(b) This value of Compressive Strength is projected on Figure (1) and a new curve is drawn parallel to the existing curves, this curve will be used in calculating the free water/cement ratio.

(c) From Figure (1), the free w/c ratio is fixed, and this value is compared with the given w/c ratio, choosing the **smaller** one of them

Table (1) : Approximate Compressive strength of concrete made with a free water / cement ratio of 0.5 according to the British method /1988

Type of Cement	*Type of C.A*	*Compressive Strength at the age (cube) of days MPa*			
		3	*7*	*28*	*91*
Ordinary Portland cement (Type I) Sulphate Resisting Cement (Type V)	uncrushed	22	30	42	49
	Crushed	27	36	49	56
Rapid-Hardening Portland Cement (Type III)	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Step 4 : Calculating of the free water in the mix

Knowing the workability (slump) of the concrete, the type and maximum size of aggregate, Table (2) gives the quantity of free water content to give different levels of workability.

step 5 : Checking and calculating of the cement content

cement content = water / w/c

This value of cement content is compared with the given value,

choosing the **larger** one of them.

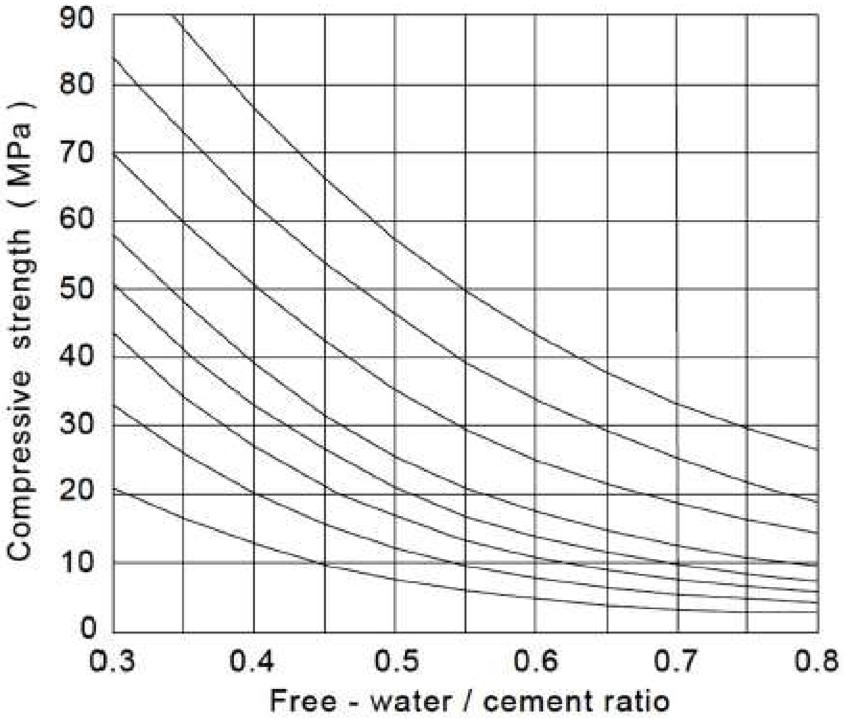


Figure 1 Relation between compressive strength and free-water/cement ratio

Table (2) Approximate Free water Contents required to give various levels of workability according to the British Method

Aggregate		*Water Content kg/m³ for:*			
Max-size mm	*Type*	*Slump 0–10*	*10–30*	*30–60*	*60–180*
		Vebe > 12 seconds	*6–12*	*3–6*	*0–3*
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	crushed	155	175	190	205

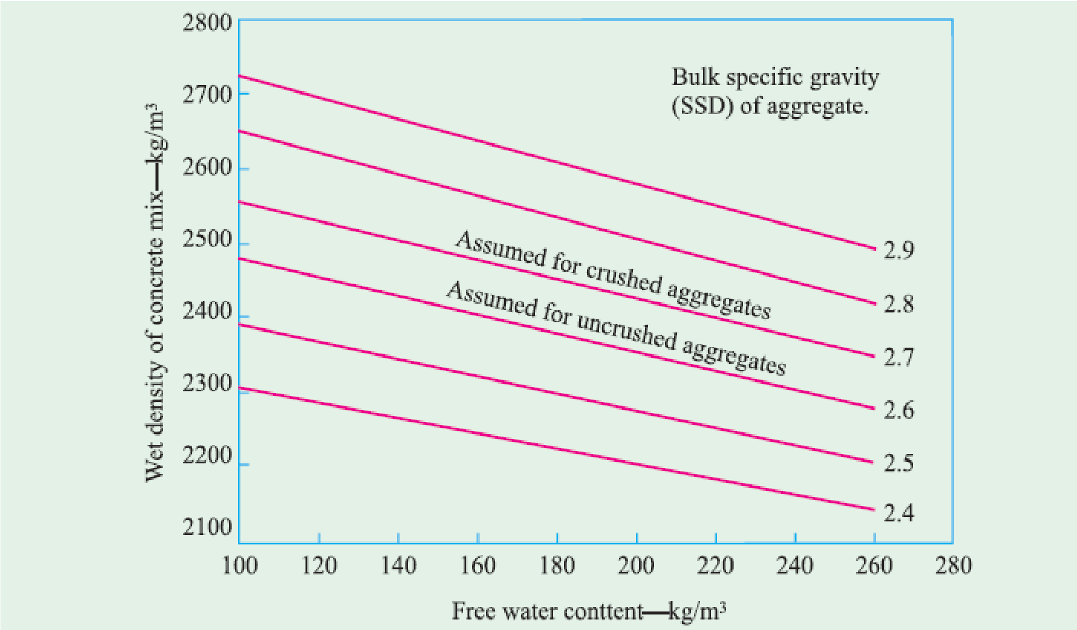
Step 6 : Determination of the total content of aggregate

Knowing the specific gravity of aggregate, Figure (2) gives the wet density (fresh weight) for fully compacted concrete is estimated

Total content of aggregate

= wet density of concrete - (free water + cement)

Figure(2): Estimated wet density of fully compacted concrete



Step 7: Calculating of fine and coarse aggregate :

Knowing the workability and M.A.S. of aggregate as well as sand zone number, Figure (3) gives the percentage of fine aggregate, as follows:

figure (3a) for M.A.S. = 10mm

figure (3b) for M.A.S. = 20 mm

Figure (3c) for M.A.S. = 40 mm, There for

Sand content = total aggregate content × percentage of fine aggregate

Gravel content = total aggregate content - sand content

Step 8 : Adjustments for Aggregate Weights and Water Content.

Figure (3a) : Recommended properties o fine aggregate according to percentage passing 600μm sieve (Dmax 10 mm)

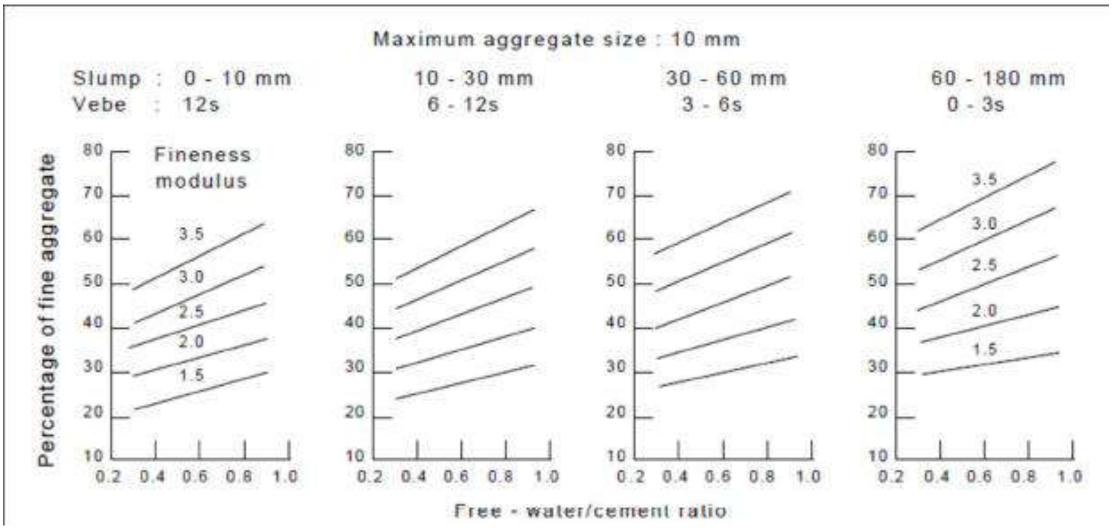


Figure (3b) : Recommended properties o fine aggregate according to percentage passing 600μm sieve (Dmax 20 mm)

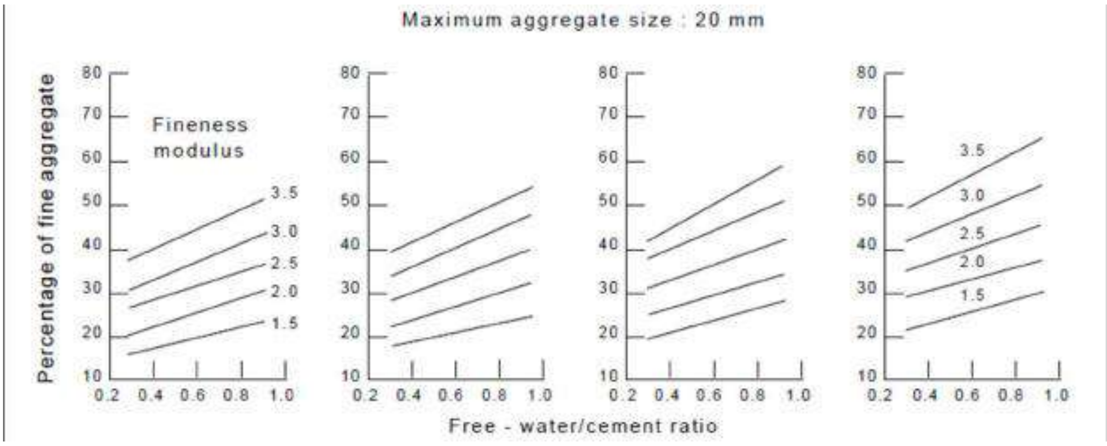
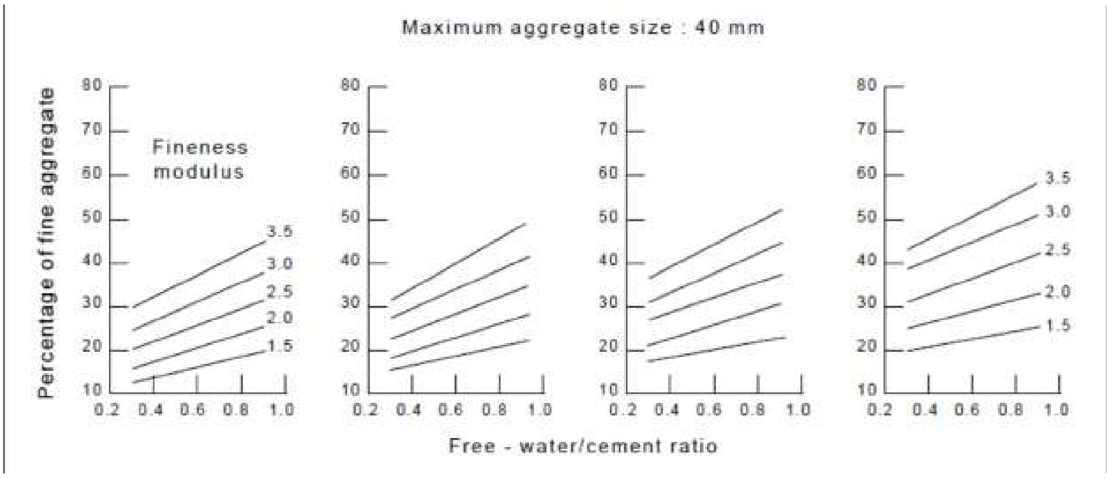


Figure (3c) : Recommended properties o fine aggregate according to percentage passing 600µm sieve (Dmax 40 mm)



Example 1

Design a concrete mix to obtain a characteristic compressive strength (fc) = 30 N/mm^2 at 28 days, with a 2.5% defective rate (k = 1.96), assume that less than 20 previous results are available for calculating the standard deviation. The design requirements are as follows:

- Slump required = 10–30 mm.
- the Maximum aggregate size, MSA = 20 mm (uncrushed),
- Fine aggregate: Fineness modulus, FM =2.5.
- Portland cement class = 42.5.
- maximum free-w/c ratio = 0.55,
- minimum cement content = 290 kg/m^3,
- maximum cement content = not specified.

Both aggregates (sand and gravel) are wet (damp), surface water is 2% for sand and 1.1% for gravel.

What are the proportions to produce trial mix of 0.05 m^3 concrete?

What are the proportions to produce 25 m^3 concrete?

Step 1: Find Target Mean Strength

Find the target mean strength.

Target mean strength = $\boldsymbol{fm}$

Specified characteristic strength = $\boldsymbol{fc}$, Margin = $\boldsymbol{k.s}$

From Figure A. the standard deviation is 8 MPa

$$\boldsymbol{fm} = \boldsymbol{fc} + \boldsymbol{k}.\,\boldsymbol{s}$$

$$\boldsymbol{fm} = \mathbf{30} + \mathbf{1.96} \times \mathbf{8} = \mathbf{45.7}\ \boldsymbol{MPa}$$

Step 2: Calculation of Water/Cement Ratio

From Table 1 the compressive strength for w/c =0.50 is 42MPa. From Figure 1 the w/c for compressive strength of 45.7 MPa is 0.47.

Step 03: Calculation of free Water Content

From Table 2, for 10-30mm level of workability, uncrushed aggregates and maximum aggregate size of 20mm the water content is 160 kg/m^3 concrete.

Step 04: Calculation of cement Content

$$\mathrm{w}/\mathrm{c} = \frac{\mathrm{w}}{\mathrm{c}} \quad \text{, cement content, c} = \frac{160}{0.47} = 340\frac{kg}{m^3}concrete$$

Step 05: Weight of Total Aggregate

From Figure 2 for free water content of 160 kg/m^3, Specific gravity of Uncrushed aggregates:

=2.6 (assumed), the wet density of concrete = 2400 kg/m^3. Therefore, the total aggregate content is

Total aggregate content = Wet density of 1m^3 concrete – water content – cement content

= 2400 – 160 – 340 = 1900 kg/m^3

Step 06: Weight of Fine Aggregate

From Figure 3. The workability level =10-30 mm, FM = 2.5,

w/c = 0.47, MSA = 20mm the percentage of fine aggregates = 32%.

Fine aggregate content = 1900×0.32 = 608 kg/m^3 concrete

Coarse aggregate content = 1900 – 608 = 1292 kg/m^3 concrete

Step 7 : adjustment for fine and coarse aggregate

Both aggregate are wet

weight of surface water on sand = 608 × 0.02 = 12.16 Kg

weight of surface water on gravel = 1292 ×0.011 = 14.212 Kg

The net weight of mixing water = 160 - 12.16 - 14.212 = 133.628 Kg

weight of saturated sand = 608 + 12.16 = 620.16 Kg

weight of saturated gravel = 1292 + 14.212 = 1306.212 Kg

water cement ratio w/c = 133.628 / 340 = 0.393

	cement Kg	water Kg	fine aggregate Kg	coarse aggregate Kg	
for I m^3	340	133.628	620.16	1306.212	
for 0.05 m^3	17	6.6814	31.00	65.31	
for 25 m^3	8500	3340.7	15504	32655.3	
mix =	1		1.824	3.8418	w/c =0.393

1 : 1.824 : 3.842

Durability of concrete:

Definition of Durability

The durability of cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment.

المتانة هي مقاومة الخرسانة للتدهور (Deterioration) سواء التدهور الناتج من عوامل خارجية أو من عوامل داخلية . العوامل الداخلية تشمل حدوث تفاعلات ضارة بين مواد الخرسانة وحدوث تغيرات حجمية بها وكذلك نفاذ السوائل فيها . أما العوامل الخارجية فتشمل ظروف التشغيل والتحميل وتأثير الجو المحيط بالمنشأ.

Types of durability conditions: **External**

Physical	**Chemical**
Freezing & Thawing	Alkali aggregate reaction
Permeability	Sulphate attack
Temperature stresses (High heat of hydration)	Chloride ingress
Delayed ettringite formation (DCF)	
Corrosion of reinforcement	

Causes:

Extreme weather conditions, Extreme temperatures, Extreme humidity, Abrasion, Electrol action, Attack by natural or industrial liquids/gases

Internal

Physical	**Chemical**
Volume changes due to different thermal properties of aggregates, and cement paste	Alkali silica reaction
Frost action	Alkali carbonate reaction
Alkali carbonate reaction	

Factors affecting durability of concrete listed below

1. High humidity and Rain
2. Ultraviolet resistance
3. Chemical Resistance

4. Seawater exposure
5. Chloride resistance and steel corrosion
6. Sulfate resistance
7. Resistance to Alkali-silica reaction (ASR)
8. Carbonation
9. Abrasion Resistance
10. Moderate to severe exposure condition for concrete
11. Resistance to freezing and Thawing
12. Cement Content
13. Aggregate quality
14. Water Quality
15. Concrete compaction
16. Placing time after batching and cold joint formation
17. Curing period
18. Permeability
19. Temperature
20. Construction defects (honeycombs, cracks, etc.)

المسامية والنفاذية والامتصاص

porosity and permeability and absorption

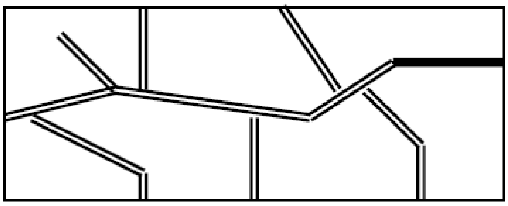
ينبغي عدم الخلط بين الامتصاص (Absorption) والنفاذية (Permeability) (والمساميةPorosity). **فالامتصاص** هو قدرة الخرسانة على سحب الماء داخل فجواتها وهو غير مرتبط بالنفاذية ويؤدى الامتصاص إلى انتفاخ الخرسانة كما يؤدى إلى تفتتها عند تعرضها لدورات التجمد والذوبان وهى مشبعة بالماء.

أما النفاذية فهي الخاصية التي بواسطتها يمكن تسرب أي سائل خلال الخرسانة . وهذه السوائل تقلل من عمر الخرسانة لأن وصول الرطوبة إلى حديد التسليح يؤدى إلى الصدأ ودخول الأحماض والأملاح يؤدى إلى تدهور الخرسانة . كما أن نفاذية الخرسانة قد تعنى في بعض الأحوال عدم أداء المنشأ لوظيفته كما في حالة الخزانات المحتوية على سوائل

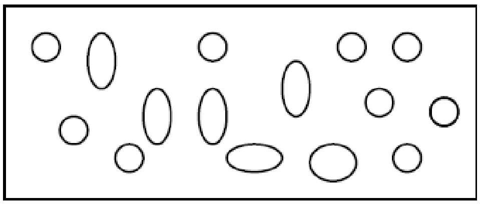
والمنشآت تحت الأرض ففي مثل هذه المنشآت تصبح عدم نفاذية الخرسانة خاصية مطلوبة وهامة كمقاومتها للأحمال وأكثر.

بينما نجد أن المسامية هي وجود مسام أو فجوات داخل المادة الصلبة وقد تكون هذه المسام متصلة عن طريق أنابيب دقيقة أو مسارات شعرية أو قد تكون هذه المسام منفصلة عن بعضها . إن التركيب الداخلي لعجينة الإسمنت يحتوى على مسام دقيقة نتيجة التفاعلات الكيميائية التي تصاحب إماهة الإسمنت والماء . إذن فالخرسانة بطبيعتها مادة مسامية ولكي تصبح الخرسانة منفذة للسوائل أو الهواء فلابد من إتصال هذه المسام على هيئة أنابيب دقيقة متقاطعة . وعلى ذلك فالمسام المحدودة العدد المعزولة عن بعضها البعض لن تؤدى إلى نفاذ الماء أو الهواء كما موضح في الشكل

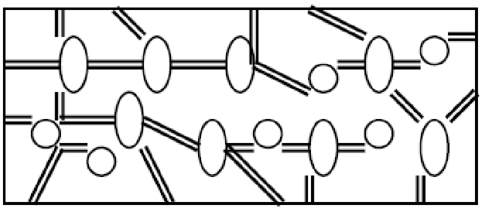
.



نفاذية عالية ومسامية منخفضة



مادة مسامية ولكن غير منفذة



مسامية عالية ونفاذية

Permeability Almost all forms of deterioration in concrete are due to ingress of water. The ways in which durability of concrete may be affected because of permeability are:

1. The chemicals in liquid form affect the concrete by penetrating it.
2. Frost action, rusting of steel, etc.

Concrete has gel pores and capillary cavities. About 1/3 of gel pores are so small that they hardly pass any water through them. The extent of capillary cavities, which depends on the w/c ratio, is the major factor contributing to permeability. The remedies are:

1. Use of puzzolanic materials.
2. Air entrainment up to 6 per cent.
3. High pressure steam curing in conjunction with silica.

Frost Action: The concrete may be affected due to being permeable or by temperature below 0°C. The mechanism of attack is attributed to the expansion of absorbed water on freezing.

Damage can also result from movement of water within concrete on cooling below 0°C. Ice builds up in large pores causing large expansion in local areas the others being dry cause disintegration. The conditions favoring frost attack are:

1. Horizontal surfaces open to sky absorbing more water in wet conditions and cooling quicker by radiation.
2. Low temperatures increasing the extent of migration of water resulting in freezing to greater depths in the concrete.
3. Repeated freezing and thawing.
4. Use of de-icing salts.

Sulphate attack: Denotes an increase in the volume of cement paste due to the chemical action between the products of hydration of cement and solutions containing sulphates. The sulphate solutions react with C_3A forming a chemical enttringite which expands and causes disruption in concrete. Sulphates occur in three form:

1. calcium sulphates
2. sodium sulphates
3. and magnesium sulphates.

Calcium has low solubility so that it does not constitute high risk. Of the remaining two magnesium sulphate has the most severe disruptive action because:

(a) the reaction product is insoluble, precipitating out of solution and leaving the way clear for further attack,

and (b) magnesium sulphate reacts with the C_3S hydrate in cement.

A common source of sulphate salts is the soil around the concrete foundation, from the water used in making concrete, and by using unwashed aggregates.

The remedy is to use blast furnaces slag cement, sulphate resisting cement, supersulphated cement, and by reducing the permeability.

Methods of Controlling Sulphate attack:

1. Use of suphate resisting cement with low C_3A content of 5%
2. Quality concrete
3. Use of air-entrainment of about 6%
4. Use pozzolana
5. High pressure steam curing

املاح الكبريتات

ان مصدر املاح الكبريتات وتأثيره على الخرسانة يأتي من مصدرين اولهما التأثير الخارجي والذي يأتي من املاح الكبريتات المتواجدة في التربة او المياه الجوفية او في ماء البحر(وفي هذه الحالة تتفاعل الكبريتات مع اسمنت متصلب ومتماسك)وثانيهما التأثير الداخلي والذي يأتي من املاح الكبريتات المتواجدة في مواد الخلط المستعملة في انتاج الخرسانة كالرمل والماء بصورة رئيسية او بكميات قليلة جدا "في الركام الخشن.
تشتمل أملاح الكبريتات الموجودة في التربة والمياه الجوفية والمواد الداخلة في الخرسانة والتي قد تسبب أضرار للخرسانة على كبريتات الكالسيوم وكبريتات الصوديوم وكبريتات المغنسيوم وكبريتات البوتاسيوم وهذه (الكبريتات باستثناء كبريتات الكالسيوم تتفاعل مع هيدروكسيد الكالسيوم $Ca(OH)_2$ (الجير الحر)الموجود داخل الخرسانة المتصلبة وينتج من هذا التفاعل كبريتات الكالسيوم (الجبس)وفق اً للمعادلة التالية:-

$$\mathbf{Ca\,(OH)_2 + Na_2\,SO_4 \,.\, 1OH_2O \rightarrow Ca\,SO_4 \,.\, 2H_2O + 2\,Na\,OH \,.\, 8H_2O}$$

فكبريتات الكالسيوم المتكونة تتفاعل بدورها مع ألومينات الكالسيوم لتشكل ألومينات الكالسيوم الكبريتية المائية أي Calcium Sulphoaluminate ويشار إليها عادة بإسم الإترنجايت Etringite))

$$4CaO \,.\, Al2O3 \,.\, 19H2O + 3(CaSO4 \,.\, 2H2O) + 16H2O \rightarrow 3\,CaO \,.\, A12O3 \,.\, 3CaSO4 \,.\, 32H2O + Ca(OH)2$$

وتسبب بلورات الإترنجايت ضغطا داخليا يؤدى الى تشرخ الخرسانة وتلفها .ويتم وقاية الخرسانة في التربة الغنية بالكبريتات وذلك بعمل طبقة من الأسفلت أو دهانها بالبيتومين أوغيرها من الطبقات العازلة على أن تكون ملتصقة تماما بسطح الخرسانة حتى لا تنفصل عنها ويمكن إستعمال الخرسانة الجيدة المخلوطة بالأسمنت البورتلاندي في التربة المحتوية على نسبة قليلة من الكبريتات .وفى حالة التربة المحتوية على نسبة كبيرة من الكبريتات فإنه من الضروري الاهتمام بتصميم الخلطة الخرسانية واستعمال الإسمنت البورتلاندي المقاوم للكبريتات.

Carbonation: Concrete is alkaline in nature and has an initial pH value of 12-13. So long as the steel reinforcement is in alkaline environment, its corrosion cannot start. However, carbon dioxide present in the atmosphere reacts with concrete in presence of water (the moist conditions). Infect, in the presence of moisture carbon dioxide changes to carbonic acid and attacks the concrete; $Ca(OH)_2$ present in concrete is converted to $CaCO_3$ causing reduction in pH of concrete. The concrete thus turns acidic. Once pH value in the concrete-cover drops below 10, the corrosion of steel reinforcement begins due to the reduction in the alkaline environment.
Because of the corrosion of steel reinforcement, its volume increases and consequently the concrete cracks and spelling takes place.

Chloride Resistance and Reinforcement Corrosion

They are interrelated and more resistant to chloride attack, more the safety against the corrosion.

Chlorides are widely available in marine environments and areas close to the sea. Therefore, there is a high chance of exposure to chlorides.

permeability of the concrete is one of the key factors that allow the transportation of chloride irons to the reinforcements. Less the permeability, lesser the risks of corrosion of reinforcements.

Further, the curing of the concrete directly affects the permeability of the concrete. Quality control and quality assurance process in the construction stage directly influence the durability of the concrete structure.

صدأ الحديدSteel Corrosion

إن صدأ حديد التسليح هو أكثر مشاكل المنشآت انتشار اً ويرجع معظم التصدع في المنشآت الخرسانية ونقص عمرها الافتراضي لصدأ الحديد . وتعتبر الخرسانة المسلحة من المواد التي تتحمل مع الزمن وتعيش طويلا ويفضلها المصممون عن كثير من أنواع المنشآت ولا يقلل من عمرها وتحملها إلا صدأ الحديد . وقد يكون الصدأ بسيط اً ويظهر في صورة تنميل خفيف - شقوق رفيعة - عند أسياخ التسليح أو بقع صدأ وقد يزيد فيؤدي إلى تساقط الخرسانة المكونة للغطاء الخرساني Spalling وقد يصل الصدأ إلى حدوث انهيار للعضو الخرساني بأكمله.

وخطورة صدأ الحديد أنه يبدأ ويستمر لمدة طويلة بدون ظهور أعراض وذلك لأن التدهور المصاحب لصدأ الحديد بطئ وقد يستمر سنين وخطورته أيضا أنه طالما بدأ فسيستمر حتى ولو أزيل مصدر الرطوبة ما لم يزال الحديد الصدئ والخرسانة المعيبة وتستبدل بخرسانة سليمة . وأي إجراء يتبع لإصلاح الوضع المتدهور لخرسانة أصابها الصدأ يعتمد كلية على الفهم السليم لأسباب حدوث الصدأ ووسائل السيطرة عليه ومنعه من الاستمرار . والحقيقة أن الرطوبة والأوكسجين هما وقود عملية الصدأ الذي يبدأ حينما تفقد الحماية التي توفرها الخرسانة للأسياخ نتيجة أسباب عديدة مثل زيادة نسبة الكلوريدات بالخلطة أو التحول الكربوني للخرسانة الخارجية أو حدوث شقوق نتيجة أسباب أخرى غير الصدأ مما يسهل وصول الرطوبة إلى الأسياخ ويبدأ الصدأ.

Alkali aggregate reaction:

Some aggregates containing particular varieties of silica may be susceptible to attack by alkalis (Na2O and K2O) originating from cement or other sources, producing an expansive reaction which can cause network of cracks and disruption of concrete by spalling. Damage to concrete will normally occur when the following are present:

Alkali aggregate reaction:

i) A high moisture level within concrete

ii) A cement with high alkali content

iii) Aggregate containing an alkali reactive constituent

EFFECTS OF ALKALI AGGREGATE REACTION