Al-Muthanna University
Engineering College
Civil Engineering Department

Concrete Technology

The 6th lecture

Properties of Aggregate

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للعام الدراسي

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Properties of Aggregate

Aggregates

Aggregates was an inert material dispersed throughout the cement paste and it is occupied at least three-quarters of the volume of concrete from 65% -75%.

Aggregates quality is of considerable importance. Not only may the aggregate limit the strength of concrete, as aggregate with undesirable properties cannot produce strong concrete, but the properties of aggregate greatly affect the durability and structural performance of concrete.

Aggregate was originally viewed as an inert material dispersed throughout the cement paste largely for economic reasons. It is possible, however, to take an opposite view and to look on aggregate as a building material connected into a cohesive whole by means of the cement paste, in a manner similar to masonry construction. In fact, aggregate is not truly inert and its physical, thermal, and sometimes also chemical properties influence the performance of concrete.
Aggregate is cheaper than cement and it is, therefore, economical to put into the mix as much of the former and as little of the latter as possible.
But economy is not the only reason for using aggregate: it confers considerable technical advantages on concrete, which has a higher volume stability and better durability than hydrated cement paste alone.

Properties of Aggregate

Effect of aggregate.

1- On fresh concrete,
such as fluidity, cohesiveness, and rheological behavior, is largely influenced by the amount, type, surface texture, and size gradation of the aggregate.

2- On hardened concrete,
in addition to reducing the cost, can reduce the shrinkage and creep of cement paste. Moreover, aggregates have a big influence on stiffness, unit weight, strength, thermal properties, bond, and wear resistance of concrete.

Properties of Aggregate

Many properties of the aggregate depend entirely on the **properties of the parent rock**, e.g. chemical and mineral composition, petrological character, specific gravity, hardness, strength, physical and chemical stability, pore structure, and colour.
On the other hand, there are some properties possessed by the aggregate but **absent in the parent rock**: particle shape and size, surface texture, and absorption. All these properties may have a considerable influence on the quality of the concrete, either fresh or in the hardened state.

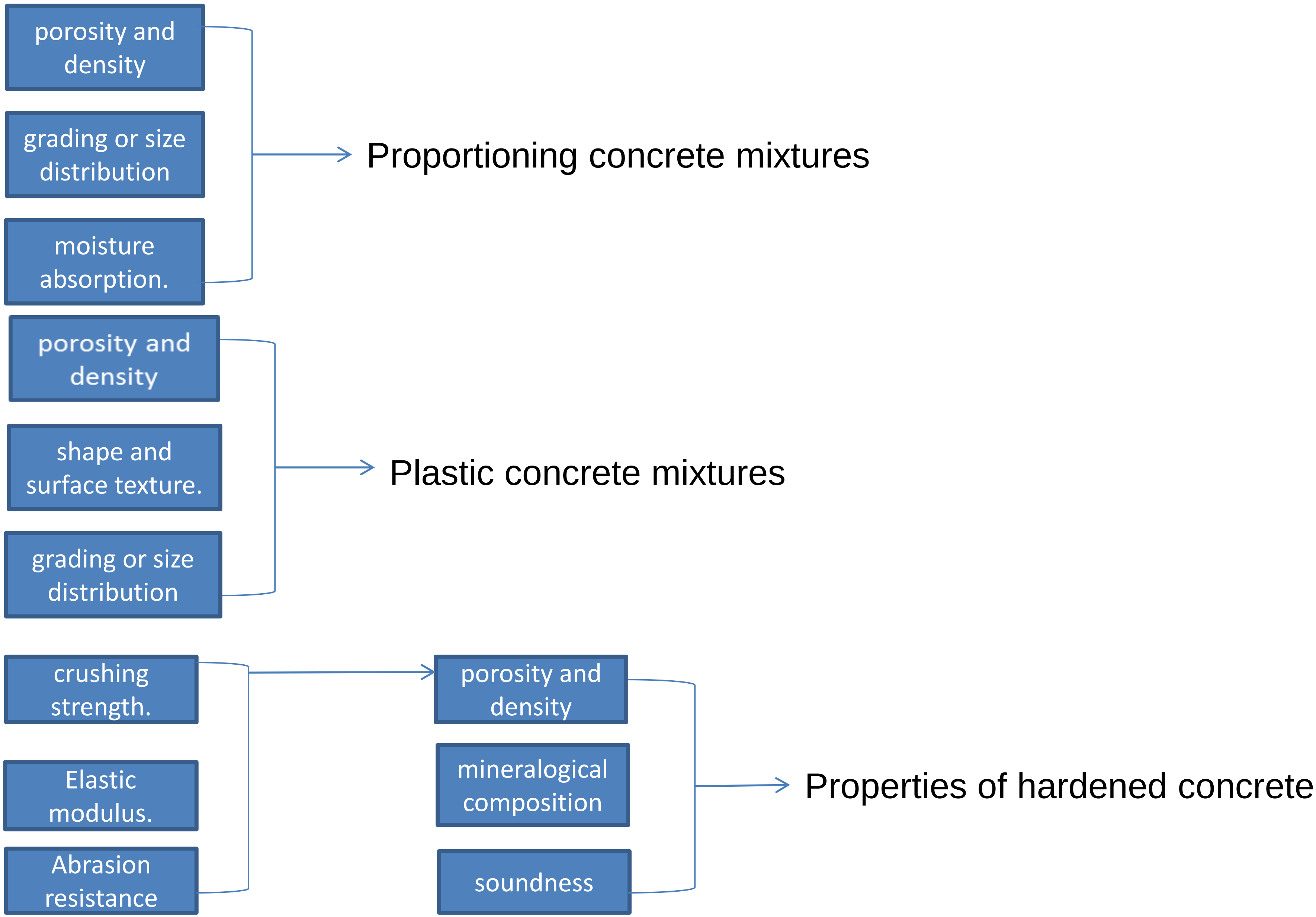
It is only reasonable to add, however, that, although these different properties of aggregate per se can be examined, it is difficult to define a good aggregate other than by saying that it is an aggregate from which good concrete (for the given conditions) can be made. While aggregate whose properties all appear satisfactory will always make good concrete, the converse is not necessarily true and this is why the criterion of performance in concrete has to be used. In particular, it has been found that aggregate may appear to be unsatisfactory on some count but no trouble need be experienced when it is used in concrete. For instance, a rock sample may disrupt on freezing but need not do so when embedded in concrete, especially when the aggregate particles are well covered by a hydrated cement paste of low permeability. However, aggregate considered poor in more than one respect is unlikely to make a satisfactory concrete, **so that tests on aggregate alone are of help in assessing its suitability for use in concrete.**

Properties of Aggregate

Aggregate characteristics that are significant for making concrete

1- porosity and density
2- grading or size distribution
3- moisture absorption.
4- shape and surface texture.
5- crushing strength.
6- Elastic modulus.
7- hardness.
8- mineralogical composition

Aggregate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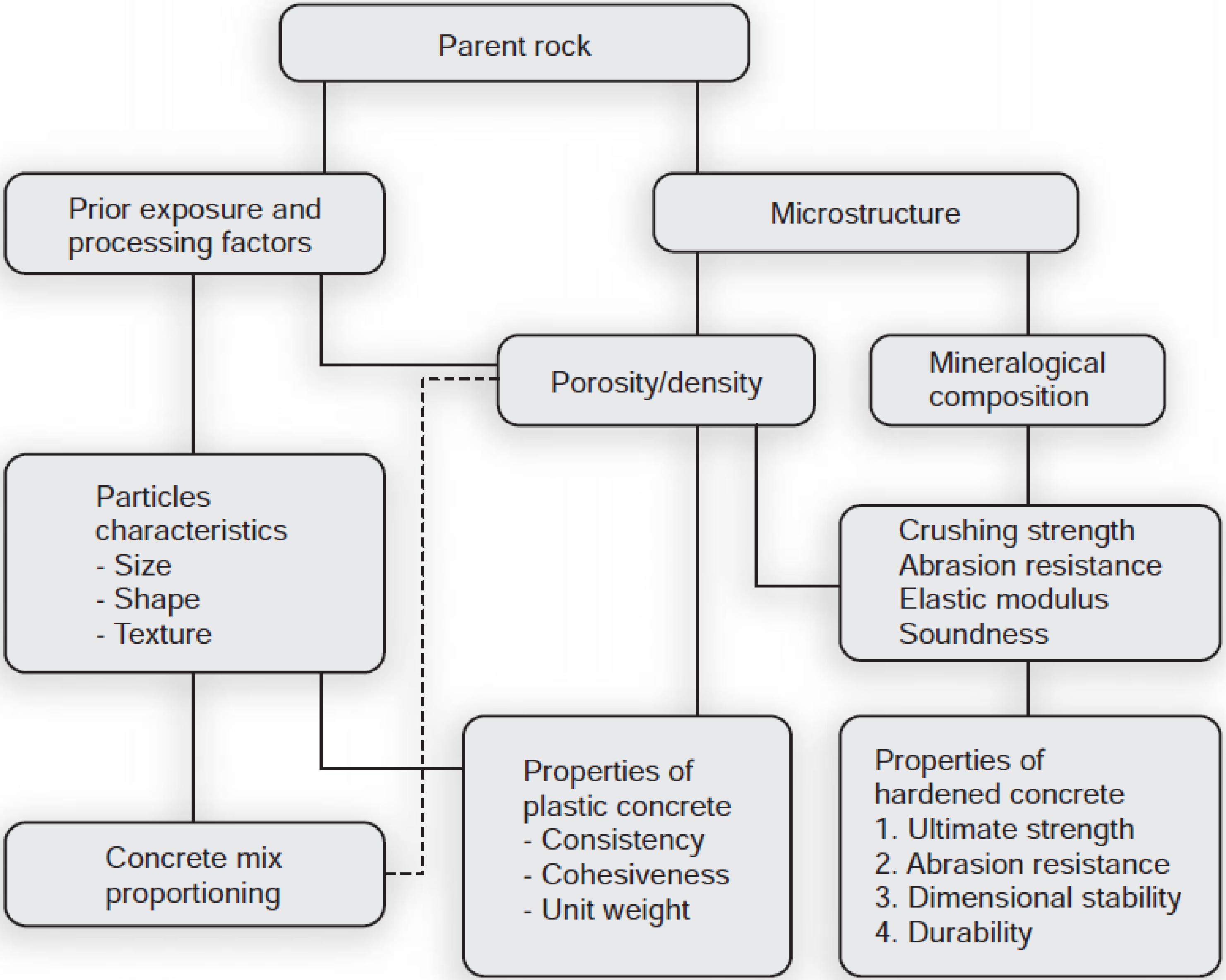
Properties of hardened concrete

Properties of Aggregate



Properties of Aggregate

Classification of aggregates.

Natural and artificial aggregates

1. Natural aggregate:

✓ **Coarse aggregate:**

The term coarse aggregate is used to describe particles **larger than 4.75** mm (retained on No. 4 sieve),

✓ **Fine aggregate:**

the term fine aggregate is used for particles **smaller than 4.75 mm**.

Typically fine aggregates contain particles in the size range 75 μm (No. 200 sieve) to 4.75 mm, and coarse aggregates from 4.75 to about 50 mm.

✓ **Silt and Clay**

Material between 60 μm and 2 μm is classified as **silt**, and particles smaller still are termed **clay**.

Most natural mineral aggregates, such as sand and gravel, have a bulk density of 1520 to 1680 kg/m^3.

Generally, the aggregates with bulk densities less than 1120 kg/m^3 are called **lightweight aggregates** and those weighing more than 2080 kg/m^3) are called **heavyweight aggregates** .

Properties of Aggregate

Classification of aggregates.

2. Artificial aggregates

Aggregate can, however, also be manufactured from industrial products: because these artificial aggregates are generally either heavier or lighter than ordinary aggregate they are considered in Chapter 13. Aggregates made from waste are referred to on p. 696.

Aggregate

Bond of aggregate.

Bond between aggregate and cement paste is an important factor in the strength of concrete, especially the flexural strength. the interlocking of the aggregate and the hydrated cement paste due to the roughness of the surface. A rougher surface, such as that of crushed particles, results in a better bond due to mechanical interlocking.

In any case, for good development of bond, it is necessary that the aggregate surface be clean and free from adhering day particles.

bond is affected by physical and chemical properties of aggregate, related to its mineralogical and chemical composition, and to the electrostatic condition of the particle surface.
bond strength increases with the age of concrete; it seems that the ratio of bond strength to the strength of the hydrated cement paste increases with age when bond is good, a crushed specimen of normal strength concrete should contain some aggregate particles broken right through.

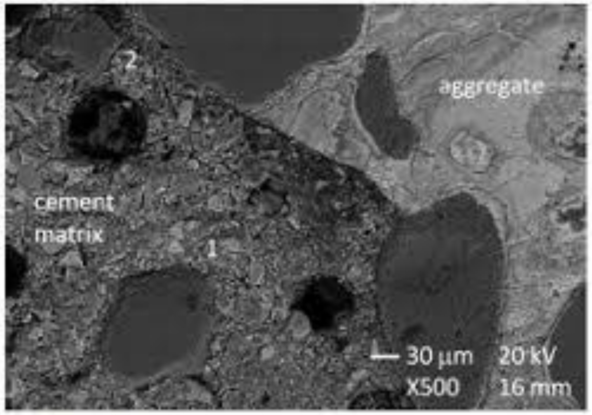


Figure 5. SEM-BSE analyses of concrete 1 (without doping).

Aggregate

Strength of aggregate

The strength of aggregate is higher than the normal range of concrete strengths because the actual stresses at the interface of individual particles within the concrete may be far in excess of the nominal compressive stress applied.

If we compare concretes made with different aggregates, we can observe that the influence of aggregate on the strength of concrete is qualitatively the same whatever the mix proportions, and is the same regardless of whether the concrete is tested in compression or in tension.3.5 It is possible that the influence of aggregate on the strength of concrete is due not only to the mechanical strength of the aggregate but also, to a considerable degree, to its absorption and bond characteristics.

the strength and elasticity of aggregate depend on its:

1- rock composition

2- texture

3- microstructure.

Thus, a low strength may be due to the weakness of constituent grains or the grains may be strong but not well knit or cemented together.

Aggregate

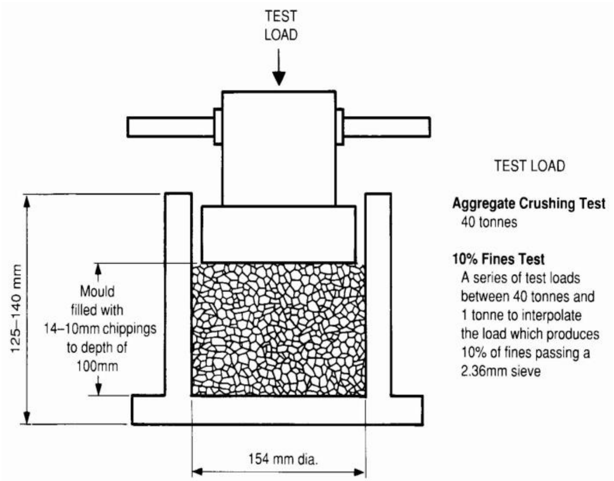
The modulus of elasticity of aggregate is rarely determined; this is, however not unimportant because the modulus of elasticity of concrete is generally higher the higher the modulus of the constituent aggregate, but depends on other factors as well. The modulus of elasticity of aggregate affects also the magnitude of creep and shrinkage that can be realized by the concrete. A large incompatibility between the moduli of elasticity of the aggregate and of the hydrated cement paste adversely affects the development of microcracking at the aggregate–matrix interface.

A good average value of the crushing strength of aggregate is about 200 MPa but many excellent aggregates range in strength down to 80 MPa .One of the highest values recorded is 530 MPa for a certain quartzite.
the modulus of elasticity of concrete is generally higher the higher the modulus of the constituent aggregate, because The modulus of elasticity of aggregate affects on the creep and shrinkage .

Aggregate

A test on the crushing properties of bulk aggregate is the so-called crushing value test of BS 812-110 : 1990 which measures resistance to crushing.
The crushing value is a useful guide when dealing with aggregates of unknown performance, particularly when lower strength may be suspected. There is no obvious physical relation between this crushing value and the compressive strength, but the results of the two tests are usually in agreement.

The ratio of mass of the material passing the smaller sieve to the total mass of the sample is called the aggregate crushing value.



Aggregate

Mechanical properties of aggregate.

toughness, which can be defined as the resistance of a sample of rock to failure by impact.

The impact is applied by a standard hammer falling 15 times under its own weight upon the aggregate in a cylindrical container. This results in fragmentation in a manner similar to that produced by the pressure of the plunger in the aggregate crushing value test.

Details of the test are prescribed in BS 812-112: 1990 (2000), and BS 882: 1992 prescribes the following maximum values: 25 percent when the aggregate is to be used in heavy duty floors; 30 per cent when the aggregate is to be used in concrete for wearing surfaces; and 45 per cent when it is to be used in other concretes.

aggregate in concrete or the strength of the concrete is not possible.

One advantage of the impact value test is that it can be performed in the field with some modifications, such as the measurement of quantities by volume rather than by mass, but the test may not be adequate for compliance purposes.

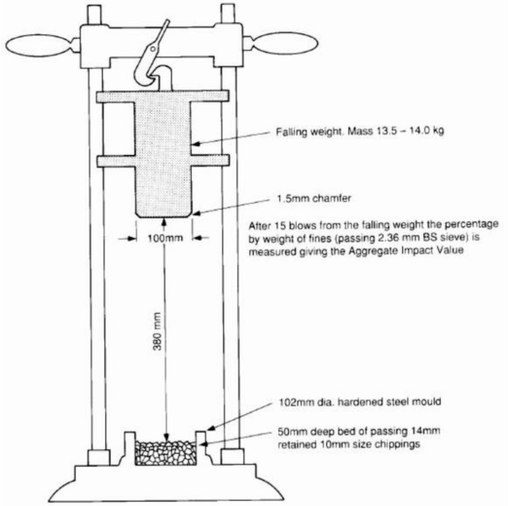


Figure 1. Apparatus for the aggregate impact test (Millard, 1993)

Aggregate

Hardness: resistance to wear is property of used in pavements concrete and in floor surfaces subjected to heavy traffic.
it is possible to cause wear of aggregate by abrasion, an abrasion value test on aggregate particles is prescribed by BS 812-113 :1990. Aggregate particles between 14.0 and 10.2 mm.
An American test ASTM C 131-06 combining attrition الاحتكاك and abrasion الكشط is the Los Angeles test. In this test,

An American test combining attrition and abrasion is the Los Angeles test; it is quite frequently used in other countries, too, because its results show good correlation not only with the actual wear of aggregate when used in concrete but also with the compressive and flexural strengths of concrete made with the given aggregate.
In this test, aggregate of specified grading is placed in a cylindrical drum, mounted horizontally, with a shelf inside. A charge of steel balls is added, and the drum is rotated a specified number of revolutions. The tumbling and dropping of the aggregate and the balls results in abrasion and attrition of the aggregate, and this is measured in the same way as in the attrition test.

Aggregate

Specific gravity

The **absolute (really)** specific gravity refers to the volume of the solid material excluding all pores, and defined as the ratio of the mass of the solid to the mass of an equal volume of distilled water.

The **apparent** specific gravity is the ratio of the mass of the aggregate dried in an oven at 100 to 110 °C for 24 hours to the mass of water occupying a volume equal to that of the solid including the impermeable pores

The apparent specific gravity is then :

$$\frac{D}{B - A + D}$$

D: is the mass of the oven-dried sample.

B: is the mass of the vessel full of water.

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

Specific gravity

Calculations with reference to concrete are generally based on the saturated and surface-dry condition of the aggregate because the water contained in all the pores in the aggregate does not take part in the chemical reactions of cement and can, therefore, be considered as part of the aggregate. Thus, if a sample of the saturated and surface-dry aggregate has a mass C, the gross apparent specific gravity is

$$\frac{C}{B - A + C}.$$

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.

Aggregate

Specific gravity

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, and the range of values is given in Table below.

Rock group	*Average specific gravity*	*Range of specific gravities*
Basalt	2.80	2.6–3.0
Flint	2.54	2.4–2.6
Granite	2.69	2.6–3.0
Gritstone	2.69	2.6–2.9
Hornfels	2.82	2.7–3.0
Limestone	2.66	2.5–2.8
Porphyry	2.73	2.6–2.9
Quartzite	2.62	2.6–2.7

Thanks For Your Listening

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Concrete Technology

The 4th lecture
Types of Cement

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Types of cement

The properties of cement change during hydration, according to the chemical composition and degree of fineness.

So, it is possible to change the proportions of the raw materials used in the formation of cement to obtain different types of it as needed. Portland cement can be divided as follows:

Table 1. Main Types of Portland Cement

item	ASTM description (American Classification)	Traditional British description B.S. (British System Classification)
1	Type I	Ordinary Portland Cement.
2	Type II	Modified Portland cement
3	Type III	Rapid-hardening Portland cement
4	Type IV	Low heat Portland cement
5	Type V	Sulfate Resistant Portland Cement
6	Type IS	blast furnace Portland cement
7	Type IP	Portland Cement Pozzolan
8	--------	White Portland Cement
9	--------	colored Portland cement

Types of Portland cement

1. Ordinary Portland cement (OPC)

- Ordinary Portland (Type I) cement is suitable for **use** in general concrete construction when there is no exposure to sulfates in the soil or groundwater.
- The limitation on the clinker composition is that not less than two-thirds of its mass consists of C3S and C2S taken together.
- the ratio of CaO to SiO_2, also by mass, be not less than 2.0, the content of MgO is limited to a maximum of 5.0 %.
- The physical and chemical requirements are shown in Tables 1 and 2 according to Iraqi Standard No. 5.

Types of Portland cement

3. Rapid hardening Portland cement (Type III)

Advantages:

- It develops resistance faster than ordinary cement, so it is called High early strength (P.C.).
- Its resistance at 3 days of age is equivalent to that of ordinary cement at the age of 7 days using the same proportion of water.
- The freezing time of this cement is the same as ordinary cement.
- The increase in resistance gain rate is obtained by increasing the C_3S compound and by finely grinding the cement clinker.
- The fineness is 3250 cm2 / g as a minimum.

Types of Portland cement

3. Rapid hardening Portland cement (R.H.P.C)

Uses of Rapid hardening Portland cement :

It is used to obtain a high early resistance, for example:

1. When the wooden block is to be raised for reuse in another place of the origin.
2. Manufacture of concrete blocks and prefabricated units so that products can be transported after a short period of pouring them.
3. In the sidewalks and places that cannot be closed for long.
4. In places that have reforms that need to be completed quickly.
5. In cold climates, to prevent freezing of water inside the capillary pores.

Types of Portland cement

4. Low heat Portland cement (L.H.P.C)

Advantages:

1. Reduces and delays heat emission of rehydration
2. Reduces concrete resistance in early times
3. Contains lower percentages of C_3S and C_3A compared to ordinary cement
4. A higher percentage of C_2S compared to ordinary cement
5. At normal temperatures, the strength of concrete is half that of concrete made of ordinary cement at the age of 7 days, and two-thirds at the age of 28 days, and equal to it at the age of 3 months.

Types of Portland cement

4. Low heat Portland cement (L.H.P.C)

Uses of low heat Portland cement :

- It is used in large concrete blocks such as dams and reservoirs, as high temperatures in large concrete blocks due to the development of heat rehydration lead to serious cracks. It is necessary to determine the rate of heat emission in this type of structure by using low temperature cement.
- In America, another type of cement is used frequently, known as **Modified cement** (Type II), and it consists of 60% of low temperature Portland cement and 40% of ordinary Portland cement and the rate of heat emission of this type of cement is slightly higher than low temperature cement. While the rate of gain resistance is the same as ordinary cement.
- It is used in structures that require that the temperature of rehydration be more than low-temperature cement or those affected by sulfates in a moderate degree.

2- Modified cement. Type II (ASTM C 150-09)

This modified cement successfully higher rate of heat development than that of low heat cement with a rate of gain of strength similar to that of ordinary Portland cement, with a heat of hydration of 290 J/g at 7 days.

Modified cement is recommended for use in structures where a moderately low heat generation is desirable or where medium sulfate attack may occur.

Types of Portland cement

5. Sulphate resisting cement (S.R.P.C)

Advantages:

1. Similar to ordinary Portland cement except that it contains a lower percentage of C_3A and C_4AF, which are the compounds most affected by sulfur salts.
2. It contains a higher percentage of silicates than ordinary cement, and in this type of cement, C_2S forms a high percentage of silicate weight.
3. Early resistance is low.
4. Its cost is higher than ordinary cement due to special requirements in installing raw materials.

In hardened cement, the effect of sulfate is of two types.

1. Aqueous calcium aluminate in its hexagonal and semi-stable form (that is, before its conversion to C_3AH_6) interacts with sulfate salts, whether in sand or in soil and ground water, leading to the formation of aqueous calcium sulfoaluminate (ettringite) and leads to an increase in the volume of the reactants up to 227% and leads to Gradual cracking.
2. The exchange between $Ca(OH)_2$ and sulfate leads to the formation of gypsum and leads to an increase in the volume of the reactants by 124% and leads to cracking and deterioration in the concrete.

Types of Portland cement

5. Portland blast furnace slag cement (S.R.P.C)

It is made by grinding ordinary cement clinker with gypsum and blast furnace slag and the percentage of added slag ranges between 25 - 60% according to the American standard ASTM C595.

Advantages:

1. Early resistance is less than ordinary cement, but in later times, equal resistance is obtained.
2. The workability of blast furnace slag cement is higher than that of ordinary Portland cement, so that the ratio of water to (cement + slag) can be reduced.
3. The rehydration temperature is lower than normal cement.
4. High sulfate resistance.

Types of Portland cement

5. Portland blast furnace slag cement (S.R.P.C)

Uses of Portland blast furnace slag cement :

1. in huge concrete blocks
2. It can be used in structures exposed to sea water
3. It is not permitted to use it when making concrete in cold climates.

Slag is industrial waste or waste produced during the manufacture of cast iron.

Types of Portland cement

6. Portland pozzolana cement

It is a mixture of portland cement and zolana.

Pozzolana: it is a wired and aluminous material that does not have binding properties by itself, but when grinded finely and in the presence of water it reacts with Ca $(OH)_2$ to form stable calcium silicate (C-S-H).

$$\text{Pozzolana} + Ca(OH)_2 \longrightarrow C_3S_2H_3$$

Types of pozzolana:

1. Natural as volcanic ash, opal rocks and flint rocks.
2. Artificial as burnt clay, rice husk ash, flesh powder ash.

Advantages and uses:

Similar to Portland cement blast furnace slag.

Types of Portland cement

7. White Portland cement (W.P.C)

Advantages:

1. Its manufacture is similar to that of ordinary Portland cement, and the raw materials used in its composition are white clay in addition to chalk limestone and limestone, which are devoid of impure materials.
2. These materials contain a small percentage of iron oxide and manganese, due to which the gray color characteristic of ordinary Portland cement.
3. Its cost is high due to the high price of raw materials.
4. It needs high temperatures due to the absence of iron, which acts as an aid for smelting.
5. Special non-iron balls to grind to prevent iron contamination.
6. Its specific weight is less than ordinary cement due to the low percentage of iron, as its specific weight ranges between 3.05 - 3.1.

Uses:

1. Covering façades as an architectural aspect
2. In mosaics and flower beds
3. Statues, fountains and antiquities restoration works

Types of Portland cement

8. Coloured Portland cement (W.P.C)

- It is prepared from adding certain types of dyes to Portland cement. When light colors are desired, pigments are added to white Portland cement in proportions ranging between 2-10% of the cement weight.
- When dark colors are desired, ordinary Portland cement is used.
- Because dyes are a non-cement material, it is preferable to use technical mixes with cement when using them.
- It is preferable not to use concrete due to the difficulty in obtaining a homogeneous color.

Other types of cement:

1. Anti-bacteria Portland cement

This cement is made by grinding Portland cement with an anti-bacteria agent and an inhibitor of micro-fermentation, where the action of bacteria appears clear in concrete floors such as food factories when organic acids interact with cement components and dissolve them, followed by fermentation by bacteria and in the presence of water.

Uses:

1. In swimming pools.
2. On the floors and walls of food factories, such as dairy and food packaging factories.

Other types of cement:

2. Super-sulphated cement

Made by grinding:

1. Slag blast furnace 80-85%.
2. Anhydrous calcium sulfate (in the form of burnt gypsum devoid of water particles) by 10-15%.
3. Ordinary cement clinker of 5%.

Advantages:

1. Its fineness is high and the specific surface area ranges between 3500 - 5000 cm2 / g
2. The initial freezing time ranges from 2.5-4 hours.
3. The final freeze time is 4.5-7 hours.
4. The rehydration temperature is lower than that of the low temperature Portland cement.

Uses:

1. in huge concrete blocks.
2. It is used in the construction of sewers and in polluted floors due to its high resistance to the high concentration of sulfates in the soil or ground water.

Other types of cement:

3. Expanding cement

There are a number of reactions that cause the expansion of the cement paste, and the occurrence of this expansion in the hardened concrete causes its cracking and damage. Hence the idea of finding a type of cement known as expansion cement by the world (H. Lossier), as its use results in a beneficial expansion in the early periods and an increase in the size of the cement paste without damaging its structure. In America, this cement is called **(Type K)**.

This cement consists of a mixture of:

1. Portland cement
2. Expanding agent
3. Stabilizer

Stabilizer: Usually using blast furnace slag, as it consumes excess calcium sulfate, conducting the expansion to its end.

Other types of cement:

3. Expanding cement

Expanding agent: It is obtained from burning a mixture of:

1. Gypsum
2. Bauxite
3. Chalk limestone

As calcium sulfate and calcium aluminate are formed in the presence of water, these compounds interact to form aqueous calcium sulfoaluminate known as Etringite, as it is accompanied by the expansion of the cement paste.

Uses:

1. It is used for the purpose of repairing exudation in the endocrine, conveying or preserving facilities such as dams, basements and reservoirs.
2. In repairing the damaged structural members due to shrinkage of other types of cement when drying out.

Other types of cement:

4. Aluminous cement

It is made from smelting limestone or chalky limestone and bauxite (stones consisting of alumina and titanium oxides and small amounts of silica) to the degree of fluidity, then grinds the clinker with a dark gray color until its smoothness reaches between 2250 - 3200 cm2 / g.

British specifications define its specifications as follows:

1. Fineness is not less than 2250 cm2 / g by Blain method
2. The time of initial freezing is not less than 2 hours and not more than 6 hours.
3. Final freezing time is no more than 2 hours after initial freezing
4. Compression strength of cement mortar.
   - ✓ 1 day = 41 MPa
   - ✓ 3 days = 48 MPa

Other types of cement:

Advantages of Aluminous cement

1. Its high resistance to sulfate effect due to the absence of Ca $(OH)_2$, it gets 80% of its final resistance at 24 hours' life while ordinary Portland cement gets most of its resistance within 28 days.
2. Great hydration temperature
3. Its high cost is due to:

   a. The high initial cost of bauxite

   b. The high heat required for combustion

   c. The high grinding cost of the hardness of the alumina cement clinker.

Other types of cement:

Uses of Aluminous cement

1. It is used as a refractory cement for lining furnaces due to the transformation of the water core to the ceramic plate at high temperatures.
2. It is not used in the construction of building structures, due to a decrease in resistance when the aqueous calcium aluminate crystals are transformed from the hexagonal and semi-stable form to the cubic and stable shape. This transformation is accompanied by a loss of cohesion and adhesion in the microstructure and an increase in the porosity of the hardened cement paste, which leads to the collapse of the structure after a period of its establishment..
3. Because of its high resistance to the effect of sulfates due to the absence of $Ca(OH)_2$, as well as the protective effect of the inert alumina gel, in addition to this cement does not attack by the CO_2 dissolved in pure water and thus it is suitable for use in the manufacture of pipes.

Thanks For Your Listening

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The Second lecture

Hydration of Portland cement

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Hydration of Portland cement

- hydration is the chemical reaction between cement grains and water, which leads to the formation of new compounds. We make cement a binder, and over time, the products of the hydration process are transformed into a solid and hard mass known as the hydrated cement paste.
- There are two ways in which compounds of the type present in cement can react with water.

1. In the first, a direct addition of some molecules of water takes place, this being a true reaction of hydration.
2. The second type of reaction with water is hydrolysis. It is convenient and usual, however, to apply the term hydration to all reactions of cement with water, i.e. to both true hydration and hydrolysis.

Hydration of Portland cement

How is silica (C_2S and C_3S) in cement chemically hydrated?

- The hydration of silica (C_2S and C_3S) is chemically very similar, and the main difference between them is only in the amount of calcium hydroxide released and the reaction is as follows:

$$2C_3S + 6H \rightarrow C_3S_2H_3 + 3CH$$

2C₃S	+	6H	→	C₃S₂H₃	+	3CH
Tricalcium silicate		**water**		**C-S-H**		**$3Ca(OH)_2$**
				hydrated calcium silicate		**calcium hydroxide**

Hydration of Portland cement

How is silica (C_2S and C_3S) in cement chemically hydrated?

- The process of reaction (**C_3S**) with water does not stop when the solution becomes saturated with calcium hydroxide, but continues and the resulting quantities of lime precipitate in the form of calcium hydroxide crystals, and the hydrated calcium silicate gel (**Calcium silicate hydrates**) remains stable when in contact with the solution saturated with lime.

$$2C_2S + 4H \rightarrow C_3S_2H_3 + CH$$

- The process of reaction (**C_2S**) is slow with water, especially in the first days after mixing cement with water, especially after 28 days, and it reaches a strength comparable to that of (**C_3S**) after about a year has passed.

➢ The calcium silicate gel resulting from the reaction is sometimes called **Tobermorite** due to the similarity of its composition to a naturally occurring mineral that bears this name.

Hydration of Portland cement

How compound (C_3A) is hydrated in cement with gypsum?

The reaction of (**C_3A**) in Portland cement is with the sulfate ion present in gypsum. This reaction can be summarized as follows:

- **C_3A + $3CSH_2$ → $C_6HS_3H_{32}$**

Calcium aluminates Gypsum ettringite ($C_3A.3CaSO_4.32H_2O$)

Sulfur calcium aluminate (**ettringite**) continues to form if the sulfate ion is present in the solution after that. In the event that the sulfate ion is depleted, the **ettringite** is transformed by its reaction with (**C_3A**) into a low sulfuric calcium sulphoaluminate called **Monosulphate**.

- **$3C_3A$ + $C_6AS_3H_{32}$ + $4H$ → $3C_4ASH_{12}$**

Monosulphate ($C_3A.CaSO_4.12H_2O$)

Hydration of Portland cement

What is the ettringite :

It is the compound resulting from the interaction of (**C_3A**) with gypsum in the presence of water and is called hydrated calcium sulphoaluminate, which is found in the form of needle crystals in early hydration stages and it contains a high percentage of sulfates and is chemically expressed ($3C_4ASH_{12}$) and the method of forming this compound is not clear. Due to the change in the percentage of components for different types of cement.

How to hydrate compound (C_4AF) in cement and in the presence of gypsum?

The hydration of the compound (C_4AF) is very similar to the hydration of the compound (C_3A), but its reaction is slower and the heat released is less. Hydration of (C_4AF) alone does not cause sudden cohesion, and gypsum slows its reaction more than it affects (C_3A).

Hydration of Portland cement

General notes about hydration of cement components:

- The final strength for the structure of hardened cement paste is due to hydrated calcium silicate, which constitute about 75% of the weight of Portland cement..
- The main hydrates of the rehydration process are:
  a. Hydrated calcium silicate.
  b. Hydrated tricalcalium aluminate.
  c. tetra-calcium iron aluminate that is hydrolysed to:
     1.Tricalcium aluminate, 2. Calcium Ferrate (**$CaO.Fe_2O_3$**) is amorphous
- The speed of chemical reactions of the main compounds varies among themselves and as follows:
  a. Aluminates: They begin to react with water first and affect the course of chemical reactions in the early times of hydration.
  b. Silicates: their influence on the reaction begins in the later stages.

Hydration of Portland cement

Rank the main cement compounds in terms of hydration temperature, from top to lowest:

1. **C_3A** **850** Joules / gm
2. **C_3S** **500** Joules / gm
3. **C_4AF** **300** Joules / gm
4. **C_2S** **250** Joules / gm

Hydration of Portland cement

What is the role of compound (C_4AF) in cement?

1. It works as an aid in fusion
2. Reacts with gypsum to form calcium sulfo-firrate
3. Its presence may accelerate the silicate hydration process

Hydration of Portland cement

What are alkalis in cement and what is their effect:

The most important of them is (**Na_2O and K_2O**) In general, the containment of alkali on the raw materials is not desirable as it impedes the process of formation of clinker, especially with regard to the formation of (**C_3S**) as it speeds up the reaction of cement compounds with water, as well as their presence leads to a reduction in strength and the appearance of unacceptable colors on the surface of concrete models, in addition to on their interaction with the outer surface with some types of gravel forming one of the components of concrete (flint stone, for example), they lead to an uneven size change.

Hydration of Portland cement

What is the effect of free calcium oxide (free lime) in cement?

The cement contains a quantity of free calcium oxide as a result of a defect in the conditions of the reaction, which crystallizes in the form of large crystals (during the burning process) where the temperature is high and under these conditions the resulting calcium oxide is inactive, but it interacts with water slowly in the solidification stage of the cement models and not In its primary and final freezing stage, where the models have not yet hardened and have elasticity and ductility, as the free calcium oxide greatly increases in size during its interaction with water, and therefore it will lead to a large internal effort, and that is accompanied by cracking and crumbling of concrete.

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

Hydration of Portland cement

What is the effect of free magnesium oxide in cement?

There is magnesium oxide in the clinker combined with **C_3S and C_2S** and in a free form. The harm of having a high percentage of magnesium oxide results from converting this oxide to magnesium hydroxide after mixing the cement with water.

This reaction is accompanied by a large increase in the volume of solids, which leads to high stresses and may crack or damage the cement or concrete.

$$MgO + H_2O \rightarrow Mg(OH)_2$$

Hydration of Portland cement

False set

It is the cohesion that occurs within a few minutes at the start of the mixing process. It differs from sudden freezing in that it is not accompanied by the release of the heat of hydration, and the cement or concrete restores its properties upon re-mixing.

the causes of false set:

1. The dryness of gypsum water: caused by high temperature during the process of grinding clinker with gypsum, where the aqueous gypsum loses part of the water crystallized into a semi-aqueous gypsum:

$$2CaSO_4.2H_2O \rightarrow 2CaSO_4.1/2H_2O + 3H_2O$$

Hydration of Portland cement

False set

2. Activation of activity (**C_3S**): due to poor cement storage, water molecules present as vapor in the atmosphere adhere to granules (**C_3S**) very quickly, causing cohesion within minutes.

3. Poor storage: The reaction of the alkali (**Na_2O and K_2O**) in the cement leads to the carbon dioxide present in the atmosphere to form the alkali carbonate (**Na_2CO_3 and K_2CO_3**). These carbonates react with the **$Ca(OH)_2$** released from the cement hydration to form calcium carbonate, which precipitates causing the cement or concrete to freeze.

$$Ca(OH)_2 + Na_2CO_3 \rightarrow 2CaCO_3 + 2NaOH$$

Soundness of cement

The soundness of cement means its resistance to the volume increase that occurs in it after hardening, and whose increase leads to damage to the cement or concrete.

The reason for the volume increase (expansion) is due to:

1. The presence of free lime (CaO) and Magnesia (MgO) present as secondary oxides in cement after its manufacture, and these two oxides interact slowly with water and result in an increase in volume, as follows:

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

$$MgO + H_2O \rightarrow Mg(OH)_2$$

Hydration of Portland cement

Soundness of cement

2. In addition to this, if the gypsum added to the clinker before the grinding process is in a greater amount than that which interacts with the compound (**C_3A**), then during freezing, the excess gypsum expands slowly due to the V.

The soundness of cement can be inferred by one of the following two methods:

1. Le Chatelier test
2. Autoclave test

Hydration of Portland cement

Fineness of cement

It is one of the important properties of cement that must be well controlled, as the hydration process begins with the surfaces of the cement grains, so the total surface area of the grains represents the material available for the rehydration process. That is, the rate of rehydration speed depends on the fineness of the cement grains, where high fineness is necessary to increase the speed of obtaining resistance.

Advantage of Fineness of cement

1. The cohesion and bonding are higher in fresh concrete.
2. Improved workability of the concrete mix.
3. If the high fineness , the less the bleeding

Hydration of Portland cement

disadvantage of Fineness of cement

1. High-fine cement undergoes partial hydration during poor storage, which leads to a loss of its cementitious properties.
2. Increasing the fineness of the cement beyond the required limit causes an increase in the surface area of the alkaline materials that the cement contains, and this results in their interaction strongly with the effective silica grains, if found in the aggregate, causing cracking and damage to the concrete, due to the occurrence of expansion in the hardened concrete. This expansion is accompanied by cracks and then the fragmentation of the concrete mass.
3. Increasing the fineness of cement causes an increase in the surface area of the compound (C_3A). This causes an increase in the amount of gypsum required to delay the reaction of this compound with water.
4. Uneconomical due to the high grinding cost.

Hydration of Portland cement

Important notes about fineness of cement:

1. Maximum cement size 0.09 mm
2. 85% to 95% of cement particles less than 0.045 mm
3. One kilogram of Portland cement contains 1 trillion granules and has a total surface area of about 300 to 400 square meters.
4. The cement particles are separated from each other by a distance of 5 to 10 microns within the limits of the practical water contents

methods of measuring the Fineness of cement:

1. The old method: sieve analysis
2. Modern methods:

   a. Wagner turbid meter method

   b. Air permeability method

   c. Blain method

Thanks For Your Listening

Al-Muthanna University
Engineering College
Civil Engineering Department

Concrete Technology

The third lecture

Hydration of Portland cement

أ.م.د حسين كريم سلطان

للعام الدراسي
2020 - 2019

Structure development in cement paste

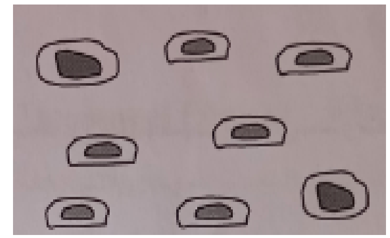
A series of developments in the structure of cement paste can be summarized in Figure 1.

1. The process begins immediately after adding water to the cement. Figure 1.A.
2. In less than 10 minutes, the water becomes highly alkaline. As the cement granules fill up, the size of the cement particles decreases and the space between the grains increases.
3. During the early stages of the hydration process, primary freezing takes place, forming weak bonds, especially as a result of hydration of C_3A, as in Figure 1.b.
4. As the hydration process progresses, this leads to the freezing or hardening of the paste, at which the granules appeared by creating voids within the structure of the paste, as in Figure 1.c.
5. The final solidification occurs when the hydrated calcium silicate is a solid structure and the space between the cement grains increases due to the decrease in the size of the particles, as shown in Figure 1.d.
6. The space between cement grains is filled with hydration products, which leads to the development of resistance and durability of cement paste, as shown in Figure 1.F.

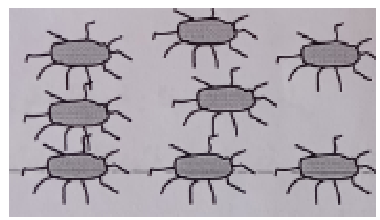
Hydration of Portland cement

Structure development in cement paste

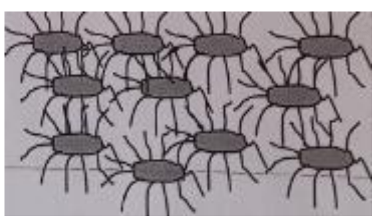
1. a



1. b



1. c



1.d

1. e

Figure 1. A series of developments in the structure of cement paste

Hydration of Portland cement

How to determine the progress of cement rehydration:

The progression of the rehydration process can be determined from:

1. The amount of calcium hydroxide obtained from hydration of the silicate.
2. The heat generated during the hydration process.
3. The specific weight of the cement paste.
4. The amount of water chemically combined with cement.
5. The amount of non-hydrated cement, by means of quantitative X-ray analysis.
6. And indirectly from hydrolysed cement paste resistance.

Hydration of Portland cement

Hydrated calcium silicate called gel. Why

Laboratory work has shown that aqueous calcium silicates are in the form of very small interlocking crystals (that cannot be seen with an ordinary microscope) and because of their precise measurement they can be described as gel.

Hydration of Portland cement

Cement hydration products.

The products of the reaction between cement and water are symbolized as hydration products, which are as follows:

First:

1. Calcium silicate hydrate C-S-H
2. Aqueous tri-calcium aluminate
3. Calcium Ferrate $CaO.Fe_2O_3$

Second: Calcium hydroxide $Ca(OH)_2$, symbolized by CH

Third: Ettringite: It is found in the form of needle crystals in the early stages of cement hydration. Its chemical composition ($C_3A.3CaSO_4.32H_2O$)

Fourth: Monosulfite: It is formed in the late stages of hydration, that is, after a few days.

Fifthly:

- some secondary compounds
- The cement is not hydrated
- Pores
  - ✓ Capillary pores
  - ✓ Gel pores

Hydration of Portland cement

Microstructure of hydrated cement pastes

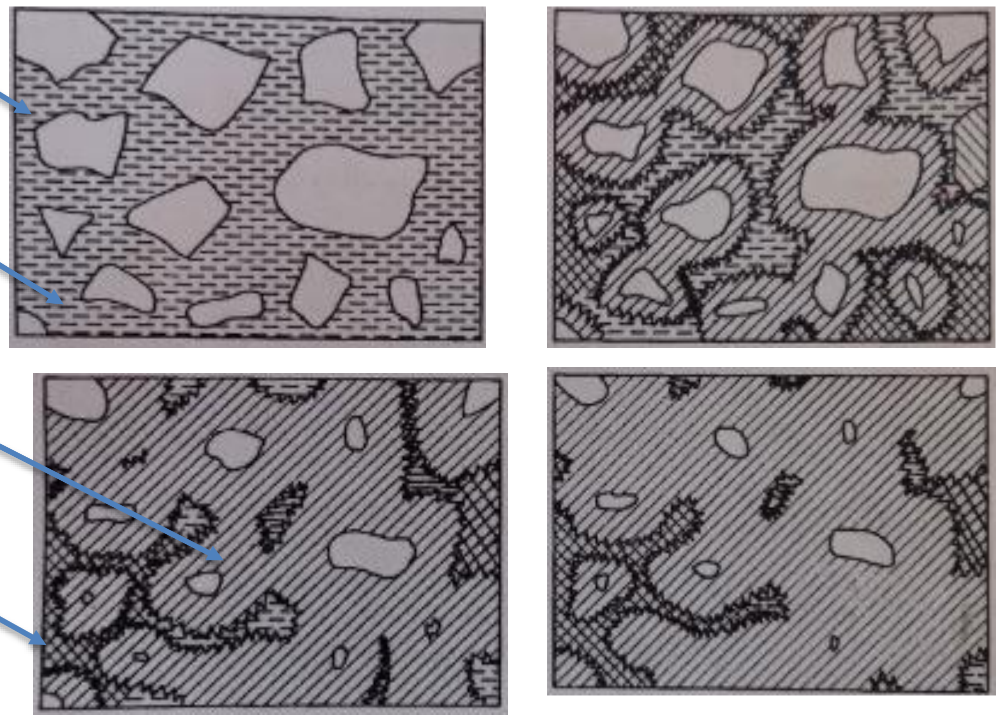
The figure below shows the structure of the cement paste

Unhydrated material

Water filled capillary pores

C-S-H

Calcium hydroxide



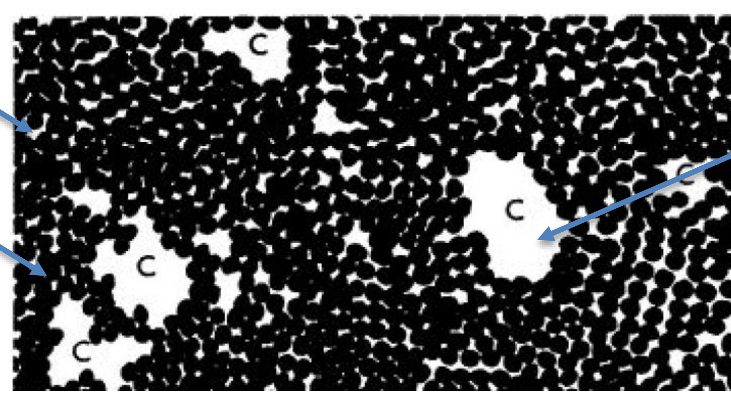
Hydration of Portland cement

Capillary pores:

It is that part of the total volume that is not filled with the products of the rehydration process and since the products of rehydration occupy more than twice the volume of gel cement alone, the size of the capillary pores decreases with the progression of the rehydration process, and the size of the capillary pores is about 1.3 microns and they form in the form of a coherent group spread throughout the cement paste and are Responsible for the permeability of the hardened cement paste. As in the figure.

the capillary porosity of the paste depends:

1. The water/cement ratio of the mix.
2. The degree of hydration, which is affected by the type of cement



Hydration of Portland cement

Explain how to prevent the presence of capillary pores interconnected with each other in the cement paste.

1. Use an appropriate water / cement ratio.

2. Sustain a wet treatment for a long and sufficient time.

Gel pores

They are pores interconnected with each other, permeating the gel particles and they can contain a large amount of evaporated water. These pores are much smaller than the capillary pores, as their diameter ranges between 15-20 inches (ankstrom A = 10^{-8} cm) and occupy about 28 per cent of the total volume of gel (solid gel + water gel).

Hydration of Portland cement

Water held in hydrated paste

- Free water: found in the capillary pores
- Chemically combined water: it forms part of the main compounds.
- Gel water is present in the gel pores: a part of it is held by the surface forces of the gel particles and is known as water adhering to the surface of the gel particles.

For research purposes, the water in the cement paste is classified into two types:

1. Evaporable water: It includes the water in the capillary pores and some of the water inside the gel pores.
2. Non-evaporable water: It includes almost all of the water that is chemically bound with cement, as well as some water that is not included in the chemical bonding, and in the cement paste completely absorbed, the non-evaporating water constitutes 23% of the weight of the non-hydrated cement.

The evaporative water can be determined from knowing the weight loss during drying of a cement paste model to the equilibrium state at 105 ° C and a vapor pressure of $8 * 10^{-3}$ mm Hg.

Hydration of Portland cement

Heat of hydration of cement

Cement hydration temperature is the amount of heat emitted when cement is completely hydrated at a certain temperature, and is measured in joules / g or kcal / g of non-hydrated cement, and the hydration process of cement compounds is accompanied by a temperature of up to 500 joules / g (120 kcal / g).

Note: The ability of concrete to conduct heat is relatively low, so it acts as an insulating material.

The process of rehydration inside large concrete blocks such as reservoirs and dams is accompanied by a large emission in temperature, and at the same time the outer surface of the concrete blocks loses some heat, so there is a severe temperature gradient between the inside and the surface of the concrete blocks, and during the subsequent cooling of the concrete blocks, stresses are generated that lead to cracks. Serious.

Hydration of Portland cement

Practical measures to reduce the temperature of rehydration when pouring concrete with a large mass in hot weather:

There are two methods to reduce the high rehydration temperature:

1. Pre cooling by cooling the gravel by spraying it with cold water or using crushed ice with mixing water.
2. Post cooling by creating a network of fine water pipes inside the concrete to cool it after pouring.

When is a high emission of rehydration heat useful, explain this and state the reason.

High temperature emission is beneficial in cold weather as it prevents water freezing inside the capillary pores of freshly poured concrete.

Hydration of Portland cement

Factors affecting cement hydration

1. The chemical composition of cement: the different compounds of cement have different speeds in the early stages of hydration. The rate of heat emission speed and total heat depends on the cement compounds. The rate of heat generation speed can be reduced in the early times by reducing the percentage of the most rapid hydration compounds, which are C_3S and C_3A.
2. The ambient temperature will have a great influence on the rate of heat emission, as increasing it increases the heat emitted.
3. Type of cement: the rate of heat emission rate of different types of cement gradually decreases with the following types.

   a. Fast hardening portland cement.

   b. Ordinary Portland cement

   c. Modified Portland cement

   d. Sulfate-resistant Portland cement

   e. Low-temperature Portland cement.
4. Fineness of cement: with its increase, the speed of chemical reactions increases, i.e. the speed of heat emission, but the total amount of heat is not affected.
5. The amount of cement in the mixture: It affects the increase in the overall heat generated, so it is possible to change the amount of cement in the mixture for the purpose of controlling the hydration temperature.

Hydration of Portland cement

Influence of the compound composition on properties of cement

The main compounds C_3S and C_2S are the most important compounds responsible for resistance.

- C_3S: Participates to a greater degree in the development of resistance during the first 4 weeks.
- C_2S: affects the acquisition of resistance after the first four weeks and at the age of about one year.
- C_3A: contributes to the development of resistance in 1 - 3 days
- C_4AF: Its role in developing the resistance has not been clarified yet.

Volume of products of hydration

The volume of rehydration outcomes consists of:

1. The gel particles are the solid products
2. The pores of the gel represent the water of the gel (the two particles and the pores make up the total volume of the gel).
3. Capillary pores
4. Unsolved cement (size depends on w / c and curing conditions).

Hydration of Portland cement

In order to calculate the rehydration output of cement, the following information must be known:

1. Dry cement specific weight = 3.15
2. Combined water (not evaporative) = 23% of dry cement weight.
3. The volume of solid products, which occupies a volume less than the sum of the two volumes of dry cement and non-evaporation water, by 0.254 of the latter's volume.
4. Gel water (gel pores) = 28% of the total volume of the gel.
5. The size of the capillary pores = the original volume of water and cement - (the total volume of hydrated + non-hydrated cement).
6. The size of the capillaries containing the water = the original volume of water - the total water.
7. Total water = gel water + non-evaporation water.

Portland cement

Vol. of (1 mm) hydration product = 2.1 liter from total vol.

Vol. of cement = wt. of cement / specific gravity of cement (3.15).

Vol. of non-evaporable water = 0.23X wt. of dry cement .

Vol. of product hydration = vol. of hydrated cement + vol. of non-evaporable water – 0.254 vol. of non-evaporable water .

Gel pores (empty or water) = 0.28 X total vol. of gel .

Total vol. gel = vol. of product hydration + vol. of gel water.

Vol. of Capillary pores = total vol. – total gel vol. – vol. of cement unhydrated.

- **For full hydration (w/c > 0.42) .**

1. Vol. of Capillary pores = total vol. (vol. of cement + vol. of water) – vol. of total gel .
2. Vol. of Capillary pores saturated = vol. of water – (vol. of non-evaporable water + gel water)
3. Vol. of empty Capillary pores = Vol. of Capillary pores - Vol. of Capillary pores saturated .

Portland cement

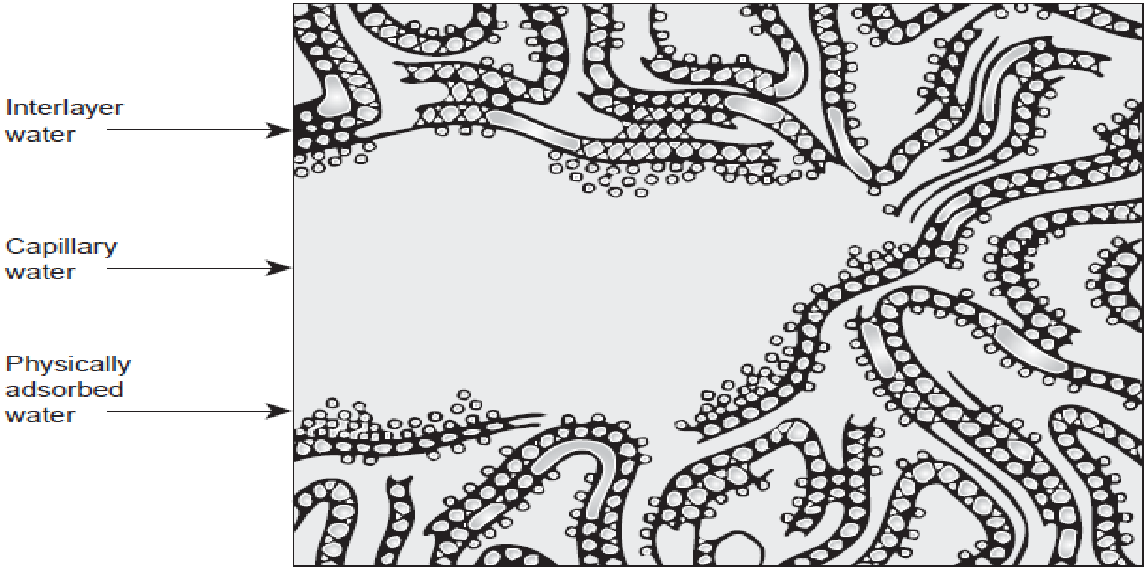


Figure shown the types of water

The non-evaporable water is about 18 % by mass of the anhydrous material; this proportion rises to about 23 %in fully hydrated cement.

Portland cement

Example 1: A quantity of cement weighing (x) was mixed with a quantity of water weighing (m). Calculate the volumes of rehydration products and pores (capillary pores and gel pores) for this mixture after the entire amount of cement reacted if you know that the specific weight of the cement is 3.15.

The solution:

Volume (x) = volume of dry cement in the mixture

Weight (x) = volume of absolute cement = x / 3.15 = 0.317 x ……….x: in grams

Volume (m) The volume of water in the mixture, Weight (m) = m / 1 = m.

Since Portland cement consumes 23% of its weight as water in the entire hydration process, and the solids resulting from the rehydration process are of a total volume less than the sum of the two volumes of cement and water reacting by 25.4% of the volume of reactive water, in other words the volume of solid rehydration compounds (volume) y)) is:

Volume (y) = 0.317x + 0.23x (1 - 0.254) = 0.489x

Among the solids, pores known as gel pores with a volume of (volume (g)) which is 28% of the total gel volume (solids + gel pores) are formed.

Volume (g) / (Volume (p g) + 0.489x) = 0.28

Volume (p g) = 0.19 x.

The remainder of the volume is the size of empty or water-filled capillaries (volume (p c))

Volume (p c) = 0.317x + m - (0.489x + 0.19x) = m - 0.36x.

Portland cement

Example 2: If we assume that the rehydration process takes place inside a tightly closed test tube, as shown in Figure 8, and there is no transfer of water to and from the cement paste, then calculate the rehydration products of a mixture that includes 100 g of cement and 42 liters of water.

The solution:

Gel particle size (solid product) = volume (g)

Volume (g) = 0.317x + 0.23x (1 - 0.254) = 0.489x = 0.317 * 100 + 0.23 * 100 (1-0.254) = 48.9 ml

.

Gel pore size (gel water) = volume (mg)

Volume (g) / (Volume (p g) + 0.489x) = 0.28

Volume (p g) = 19 ml

The total volume of gel (volume of hydrated cement) = volume (Y) + volume (p g) = 48.9 + 19 = 67.9 ml

, which is more than twice the volume of dry cement.

The volume of capillary pores = (volume of original mixing water + volume of dry cement) - total volume of gel = (42 + 31.8) -67.9 = 5.9 ml (decrease in volume represents the free capillary pores dispersed through the cement paste)

Since total water = gel water + non-evaporating water = 19 + 0.23 * 100 = 42 ml

Volume of capillary containing water = mixing water - total water = 42-42 = 0.0

Then we note that there is no non-hydrated cement

So the ratio of water / cement = **0.42**, and this ratio achieves total hydration

If the water / cement ratio is less than 0.42, it will be insufficient to complete the hydration process of all cement.

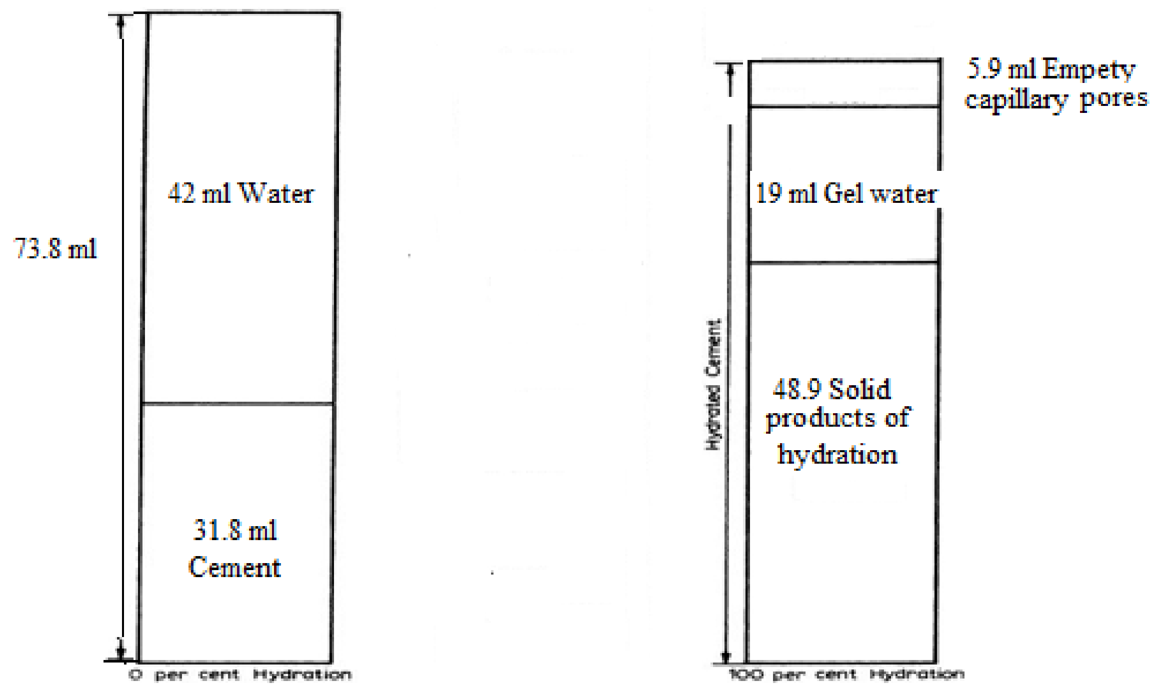
Portland cement

In the previous example, a quantity of cement of 100 grams (31.8 ml) occupies 67.9 ml after completing the rehydration. If we consider that the rehydration process of cement paste is treated under water, meaning that the capillary pores absorb water from the outside. In order not to keep the cement non-hydrated and to prevent the presence of capillaries. The original mixing water should be:

67.9 -31.8 = 36.1 ml

That is, the ratio of water / cement weight w / c = 100 / 36.1 = 0.36 and there are research indicating that this ratio = approximately 0.38 weight.

So w / c greater or equal to 0.38 achieves total hvdration.



➢**Example 3\ Calculated the hydration of products for 100 g of cement and 42 ml of water, there is no water transfer to and from the cement paste .**

solution

w/c =42/100=0.42 , cement vol.= 100/3.15= 31.8 ml

vol. of non-evaporable water = 100X 0.23= 23 ml

Vol. of product hydration = vol. of hydrated cement + vol. of non-evaporable water – 0.254 vol. of non-evaporable water = 31.8 +23 – 0.254 X23= 48.9 ml

Gel water(wg) = 0.28 X total vol. of gel

wg =0.28X (48.9 +wg) =19 ml

Total vol. of gel = 48.9+19= 67.9ml

Vol. of Capillary pores = total vol. (vol. of cement + vol. of water) – vol. of total gel = (31.8+42) -67.9=5.9 ml

2- Vol. of saturated capillary pores = vol. of water – (vol. of non-evaporable water + gel water) = 42-(23+19)=0 No saturated capillary pores.

If there is water form out side the capillary pores full with water.

Example 4: Calculate the rehydration products of a mixture consisting of 100 grams of cement and 30 grams of water, given that there is no transfer of water to and from the cement paste. What would happen if the water was supplied from the outside?

The solution:

In the first example, we knew w / c = 0.42 that achieved total hydration

In this example (w / c = 30/100 = 0.3) it is less than 0.42

So water is not sufficient to hydrate all the cement.

So suppose it is sufficient to dehydrate (A) a cloud of cement

We find the size of the gel particles:

$A / 3.15 + 0.23 * A (1 - 0.254) = 0.489A$

Since the volume of gel water is equal to:

$wg = 0.28 (0.489A + wg)$ 1

$30 = 0.23A + wg$ …………… ..2

From (1) $wg = 0.19 A$

Sub. In equ. (2)

$30 = 0.23A + 0.19A$ ……………… $A = 71.5$ gm

It is approximately equal to the volume of cement $A = 71.5 / 3.15 = 22.7$ ml

Portland cement

wg = 0.19 * 71.5 = 13.5 gm ……… ..wg = 13.5 ml.

So the volume of non-hydrated cement (100 / 3.15 - 22.7 = 9.1 ml)

The total volume of the hydrated cement (0.489 * 71.5 + 13.5 = 48.5 ml)

The size of empty or full capillary pores

(31.8 + 30) - (48.5 + 9.1) = 4.2 ml

If the water is supplied from the outside, then some dry cement, symbolized by (y), will be able to hydrate so that the products of rehydration occupy 4.2 ml in addition to the initial volume. It was found that 22.7 ml of cement fill up to 48.5 ml, meaning that the products of rehydration per liter of cement are occupied (48.5 / 22.7 = 2.13 ml) in addition to the initial volume of cement that will be filled with hydration of y milliliter of cement.

(y + 4.2) / y = 2.13 ……………… .y = 3.7 ml

The volume of cement that is still not hydrated is equal to 31.8 - (22.7 + 3.7) = 5.4 ml.

Weight of non-hydrated cement 5.4 * 3.15 = 17 gm.

In other words, 17% of the weight of the original cement is not hydrolysed and will not be able to hydrate because the gel has filled all the pores, meaning that the ratio of the volume of the hydrated cement to the total volume of cement and capillary pores is 1.

❖**Example** 5/ Find the products of hydration for 140 g of cement and 47 ml of water no water supply from out side.

Solution

w/c = 47/140=0.34 , less than 0.42 the hydration not completed .

Therefor no Know the vol. of hydrated cement because there is unhydrated cement . Let us the hydrated cement (y) .

Vol. of product hydration = vol. of hydrated cement + vol. of non-evaporable water – 0.254 vol. of non-evaporable water .

= y /3.15 +0.23 y - (0.254X0.23y) = 0.489 y.

Wg= 0.28 (0.489y+wg) ………..(1)

47 = wg+0.23y……………(2)

Solved 1,2 …………….. Y= 111.7g

Vol. of hydrated cement = 111.7/ 3.15 = 35.46 ml

Vol. of product hydration = 0.489 X111.7=54.62 ml

Home Work

❖**Example** 6/ Find the products of hydration for 200 g of cement and 62 ml of water ,what happens if water is supplied from outside?

Example 7: Calculate the rehydration products of a sample of cement of 126 g and w / c = 0.475 placed in a tightly closed test tube.

The solution:

The mixing ratios can be seen in Figure 10, but in reality the water and cement are mixed with each other and the water forms capillary pores between the hydrolysed cement grains.

w / c = 0.475> 0.42

Water is sufficient to hydrate the cement

The volume of water equals (0.475 * 126 = 60 ml)

When the cement is completely hydrated, the volume of non-evaporating water is 0.23 * 126 = 29 ml

The volume of the solid is 126 / 3.15 +29 - (0.254 * 29) = 61.6

Gel pores equal to (wg) = 0.28 (61.6 + wg) ... wg = 24 ml

The total volume of the hydrolyzed cement is 61.6 + 24 = 85.6 ml

Total capillary pore volume is 126 / 3.15 +60 -85.6 = 14.4 milliliters

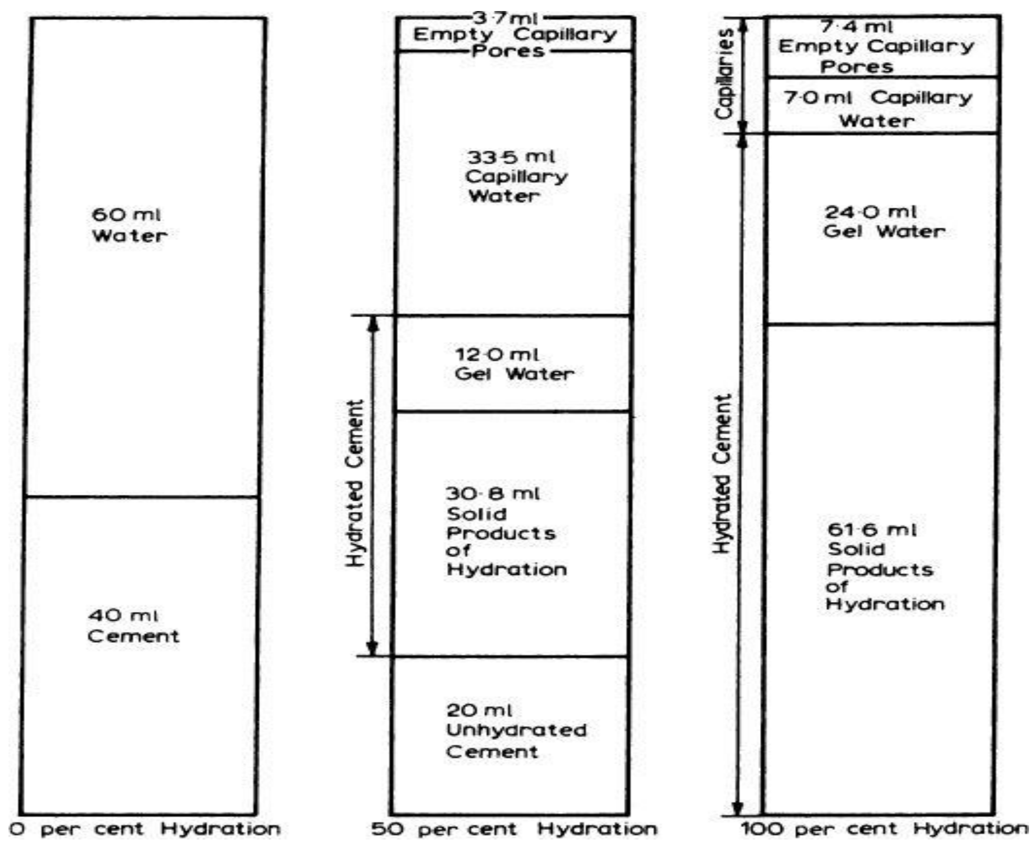
The volume of capillary pores filled with water is 60- (24 + 0.23 * 126) = 7 ml

The volume of Empty Pores 14.4 - 7 = 7.4 ml

If the cement paste is treated under water in this case, the capillary pores will be filled by absorbing water from the outside, and the gel / vacuum ratio in this case is equal to:

Gel space ratio (gel volume / void) = 85.6 / (14.4 + 85.6) = 0.856.

Portland cement



➢Volumes of products of hydration :

The gross space available for the products of hydration consists of the absolute volume of the dry cement together with the volume of water added to the mix.

If the w/c (water-cement ratio) less than 0.42 ,the water inadequate for full hydration 100% , thus some of cement unhydrated.

Thanks For Your Listening

بسم الله الرحمن الرحيم

قَالُوا۟ سُبْحَـٰنَكَ لَا عِلْمَ لَنَآ إِلَّا مَا عَلَّمْتَنَآ

إِنَّكَ أَنتَ ٱلْعَلِيمُ ٱلْحَكِيمُ

(سورة البقرة: الاية 32)

Al-Muthanna University
Engineering College
Civil Engineering Department

Concrete Technology

Second class - First Course Lectures (2020 – 2021)

By

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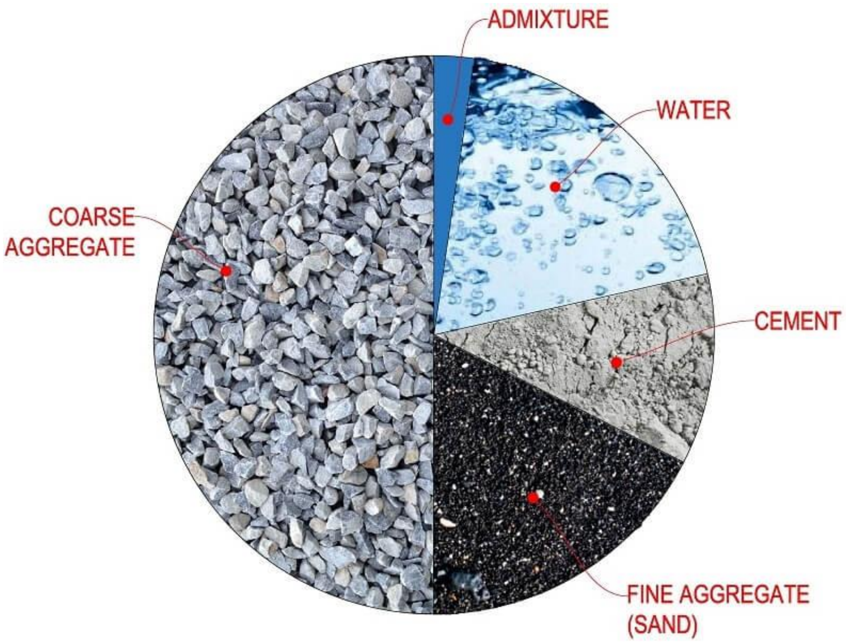
المحاضرة الاولى

صناعة الاسمنت البورتلاندي

Manufacture of Portland cement

Concrete Technology

CONTENTS



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1. Properties of concrete , Fifth Edition , A. M. Neville,
2. Concrete Microstructure, Properties, and Materials, Mehta

Portland cement

- Cement: It is a soft, dark-colored material that possesses cohesive and adhesive properties with the presence of water, which makes it able to bind the components of concrete to each other and cohesion with reinforcing bars. Cement consists of three basic raw materials, which are **calcium carbonate** found in limestone, **silica and alumina** (aluminum oxide) present. In clay and sand.
- For constructional purposes, the meaning of the term ‘cement’ is restricted to the bonding materials used with stones, sand, bricks, building blocks, etc.

Portland cement used in concrete is divided into:

- Portland cement of all kinds
- Other types of non-Portland cement.

Portland cement

<u>When was cement used and why is the Portland cement widely used so named:</u>

In the year 1290 AD, a mixture of soft volcanic stones with sand grains was made with limestone, which was the beginning of the idea of making cement. In the year 1700 AD, studies and researches were made on the components of this mixture and the interactions that took place in it, and compared with studies of other mixtures and developed.

In the year 1824 AD, the English scientist Joseph Aspdin made a cement mixture with the limestone with which the roads were paved and mixed it with the clay soil and was ground and added water to it, then he burned the dough in ovens to produce solid black pieces and then he grinded it and produced a grayish-green powder. By mixing it with water, it gave a cohesive hydraulic properties to the degree of hardness, and the color became similar to stones on a British island called Portland. That is why the gray cement resulting from the mixture was called Portland, and the word cement means adhesives.

Manufacture of Portland cement

The raw materials used in the manufacture of cement are:

Raw materials:

1. Lime materials such as
   a. Limestone or,
   b. chalky stone
   It is a source of lime.
2. Clay materials such as
   a. Shale
   b. Clay
   It is a source of silica and alumina.

- The main raw materials may suffer from a deficiency or an increase in one or more of the main compounds. In this case, materials with an appropriate composition must be added to adjust the proportions of the raw mixture.
- Most of the natural deposits (mud and rocks) contain other compounds such as iron or manganese, alkalis, phosphates, and others. Some of these materials are useful, others harmful, and each according to its percentage.

Manufacture of Portland cement

Mechanism of cement manufacturing:

In general, the manufacture of cement goes through the following processes:

1. Extracting and bringing limestone from quarries to the factory
2. Transferring rocks by truck to the stone crusher for crushing
3. Mixing well-mixed lime products with clay or other materials
4. Milling of materials in raw materials mills and ultimately adjusting mixing ratios
5. The materials are burned to form a clinker at a temperature of 1300 - 1500 ° C in an oven.
6. Cool and store the clinker in the clinker store,
7. Grinding clinker in factories, adding 2-3 percent of gypsum to it to get cement
8. Move the crushed cement, in 50 kg bags or truck silo, to a special silo for packaging and marketing.

Manufacture of Portland cement

Methods of manufacturing of portland cement:

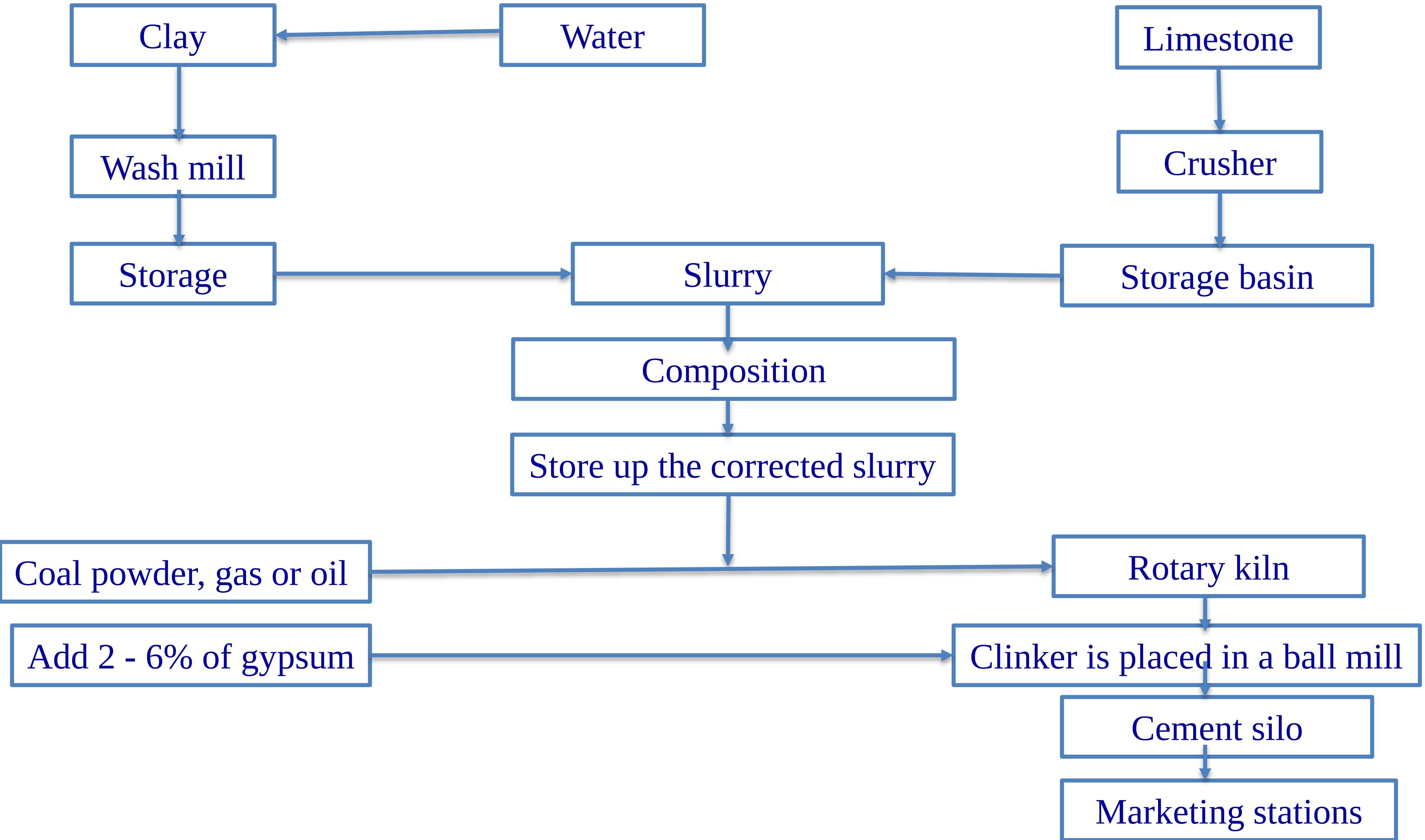
There are three methods of manufacturing Portland cement namely:

1. Wet process
2. Dry process
3. Semi dry process

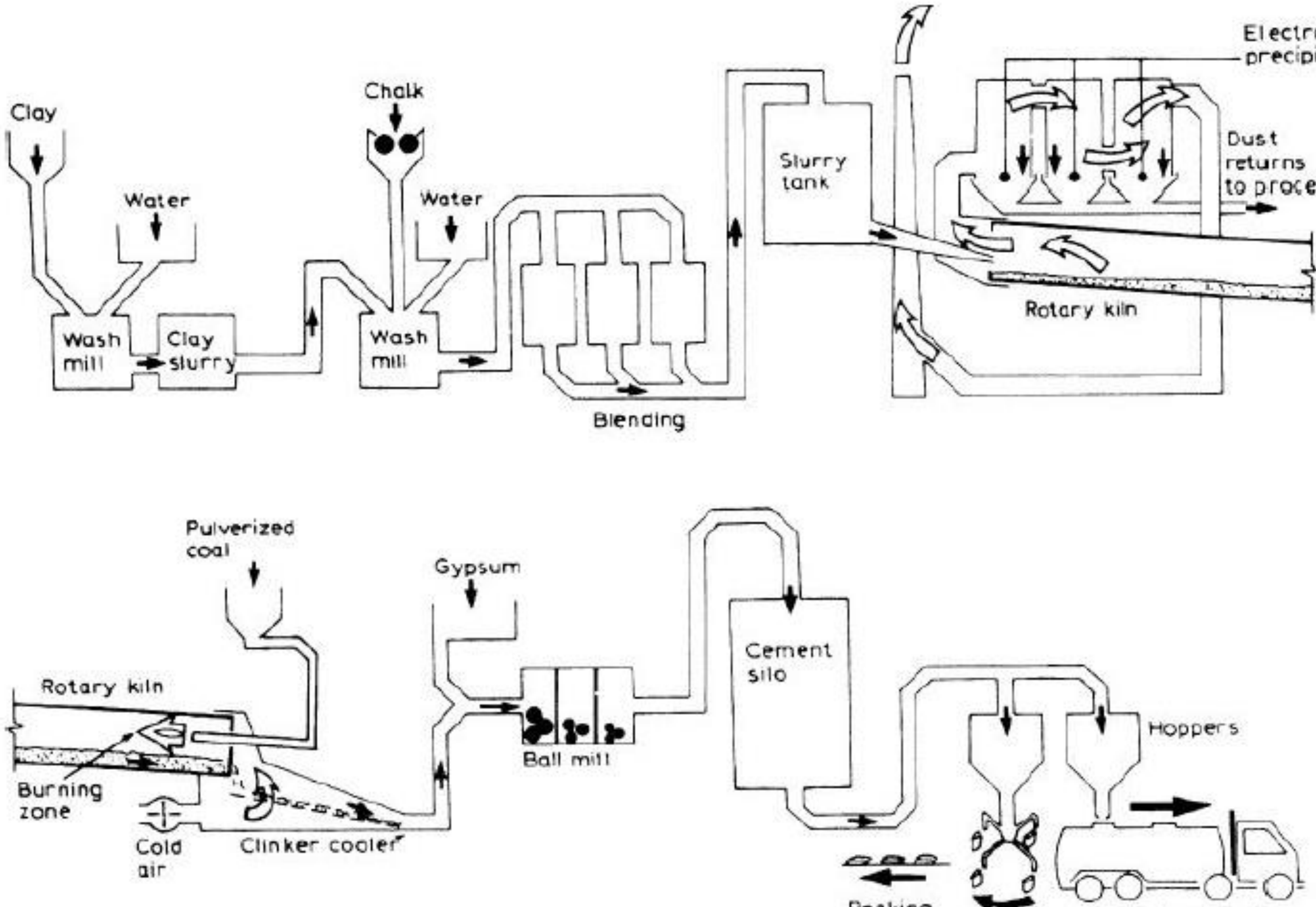
Each method has a specific working mechanism, as shown below.

Manufacture of Portland cement

1. Wet process



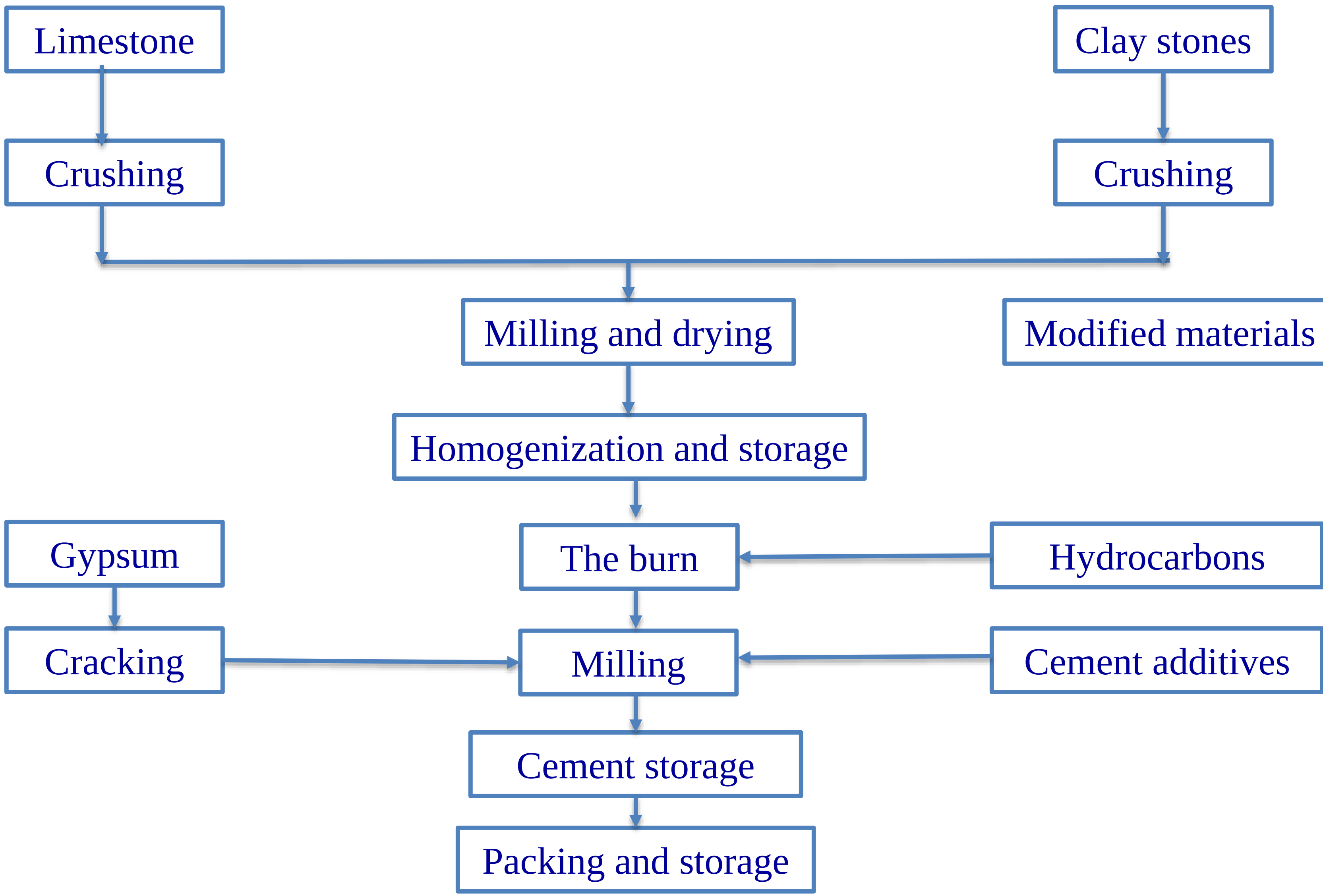
Portland cement



(a) Wet process

Manufacture of Portland cement

2. Dry process



Portland cement

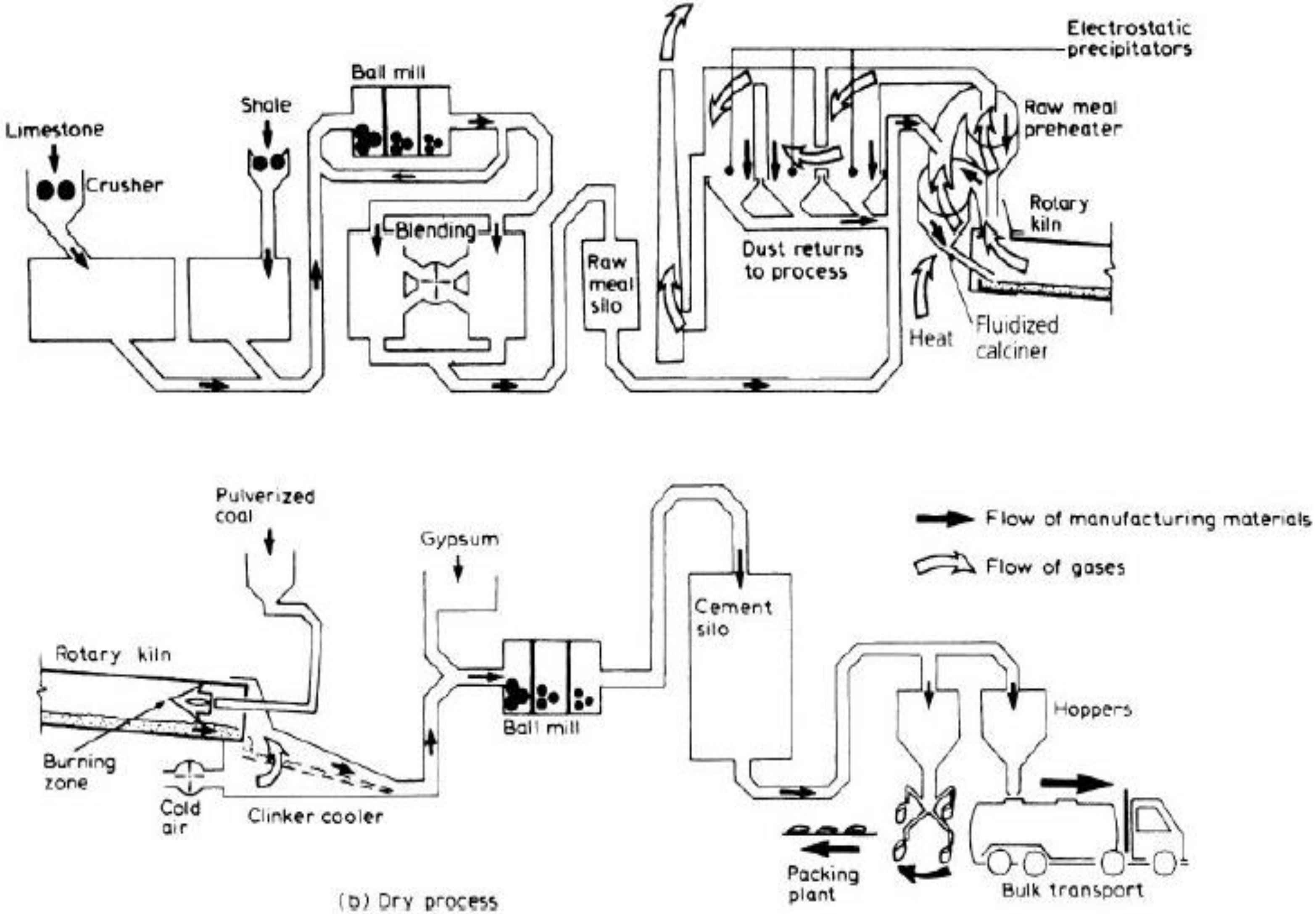


Fig. 1.1. Diagrammatic representation of: (*a*) the wet process and (*b*) the dry process of manufacture of cement

A comparison between wet and dry process of manufacturing of cement:

item	Wet process	Dry process
1	In this method, the raw materials are ground and mixed with the presence of water	In this method the raw materials are ground and mixed in their dry state
2	This method is used when the moisture content of the raw materials is high	This method is used when the raw materials are too hard to disintegrate with water
3	This method is used in countries with cold and hot climates	This method is used in countries with cold climates for fear of water freezing in the mixture, as well as in the event that the water needed for the mixing process is scarce.
4	Water added to crushed and ground raw materials leads to the formation of a slurry containing 2% of fines greater than 60 microns.	Water added to crushed and crushed raw materials creates solid balls about 15 mm in diameter
5	The water content in the slurry is about 35 - 50% of the mixture.	The water content in the solids is 12% of the raw particle weight
6	Due to the water content in the mortar, the kiln in this method is larger than the kiln in the dry method	The oven is smaller compared to the wet method
7	The amount of fuel needed to remove moisture from the slurry is greater compared to the dry method	The amount of fuel needed to remove moisture from solid bodies is less compared to the wet method
8	This method is expensive compared to the dry method	This method is more economical compared to the wet method, especially when the materials are dry
9	Ease of obtaining a homogeneous mixture	Difficulty obtaining a homogeneous mixture

Portland cement

Raw materials

Rotary kiln

Clinker

Portland cement

What depends on choosing the appropriate cement manufacturing method

- **Choosing the appropriate cement manufacturing method depends on:**

1. The percentage of moisture in the raw materials
2. The type of weather is cold or dry
3. Availability of necessary water during the manufacture of cement

Portland cement

Important notes on cement industry:

1. The kiln used in the cement industry is called the **rotary kiln**, which is a large metal cylinder with a diameter of about 5 meters and a length of about 150 meters. It is lined from the inside with fire bricks and rotates slowly around its axis, which tilts slightly from the horizon, as oil or natural gas is pumped from the lower end of the kiln. Its temperature is between 1400 - 1500 ° C, as shown in Figure 4.
2. During the movement of the **slurry** inside the furnace, a gradual rise in temperature is encountered. At first the water is expelled from the slurry and carbon dioxide is generated. Then the dry matter suffers a series of chemical reactions where 20-30% of the dry matter is transformed in the lower regions of the oven with temperatures High into a liquid, which leads to the reunion of lime, silica and alumina to form new compounds.
3. After completing the reactions, an material known as **clinker** is formed in the form of balls with a diameter of 3 to 25 mm. The clinker is then passed through special coolers called clinker coolers.
4. Gypsum ($CaSO_4.2H_2O$) is added to the cooled clinker with a bright black color and grinded finely to prevent the occurrence of **flash setting** of the cement while adding water to it.
5. It is possible to produce 700 tons of cement per day in the rotary kiln.
6. The term **slurry** is a soft-consistency dough that contains 35 - 50% water and solid particles larger than a standard 90 micron sieve, and the percentage is 2%.

Portland cement

Figure 4. Rotary kiln used in manufacturing of cement

Portland cement

What is meant by Flash Setting?

It is the freezing occurring in cement and is caused by the high speed of the initial hydration of the compound (C_3A) present in the clinker in addition to the formation of the stable aqueous calcium aluminate (C_4AH_8) on the surface of cement grains, which impedes the free flow of the cement paste, and this freezing leads to a reduction or weakness in the resistance of the cement paste. The phenomenon is clear in the types of cement that contain a large proportion of the compound (C_3A) compared with the types that contain a small percentage of it.

Portland cement

The chemical composition of Portland cement

The raw materials used in the manufacture of cement consist mainly of:

1. Lime (CaO)
2. Silica (Sio_2)
3. Alumina (Al_2O_3)
4. Iron oxide (Fe_2O_3)

These compounds interact with each other inside the oven at very high temperatures. The clinker is formed and as a result the clinker contains four main compounds:

1. Tri-calcium silicate with the chemical composition ($3CaO.Sio_2$) and the abbreviated symbol (S_3C).
2. Di-calcium silicate with the chemical structure ($2CaO.Sio_2$) and the abbreviated symbol (C_2S).
3. Tri-calcium aluminate has the chemical composition ($3CaO. Al_2O_3$) and its abbreviation (C_3A).
4. Tetra-calcium Alumina ferrite with the chemical composition ($4CaO, Al_2O_3, Fe_2O_3$) and the abbreviated symbol (C_4AF).

- CaO = C, SiO_2 = S, Al_2O_3= A, Fe_2O_3= F, H2O = H

Portland cement

What are the main compounds of Portland cement and what is the function of each compound? Explain:

The main compounds of Portland cement are:

1. Tri-calcium silicate (C_3S) with a ratio of 45 - 55%, which is responsible for giving strength to concrete during the first 28 days.
2. Dicalcium silicate (C_2S), with a ratio of 15-25%, which is responsible for the self-healing phenomenon, as it closes the capillary cracks in the mortar and in the concrete, as well as the tensile strength of the concrete.
3. Tri-calcium aluminate (C_3A), ranging from 12-15%, reacts quickly when mixing and emits high heat, so it gives concrete its strength in the first day, but it does not affect the final strength of the concrete.
4. Tetra-calcium Alumina ferrite (C_4AF) and its percentage ranges from 12-7%. It reacts in the first days and gives high heat, but it is slower than the calcium trialuminate.
5. In addition to the previous main components, cement contains secondary compounds in the form of oxides such as potassium oxides, sodium, magnesium, titanium and sulfur dioxide. These compounds make up a small proportion of cement weight.

Portland cement

How to calculate the percentage of main compounds in Portland cement after obtaining the percentage of oxides from chemical analysis:

It can be calculated with (Bogue's) equations assuming.

1. The reactions have reached a state of chemical equilibrium.
2. Products of chemical equilibrium are fully crystalline.

$C_3S = 4.07\ (CaO) - 7.6\ (SiO_2) - 6.72\ (Al_2O_3) - 1.43\ (Fe_2O_3) - 2.85\ (SO_3)$

$C_2S = 2.87\ (SiO_2) - 0.754\ (C_3S)$

$C_3A = 2.65\ (Al_2O_3) - 1.69\ (Fe_2O_3)$

$C_4AF = 3.04\ (Fe_2O_3)$

What is the modern method for finding the quantity of the main compounds present in cement:

The modern method is called X-Ray Diffractions.

Portland cement

Example / Calculate the proportions of the main compounds for a sample of cement if you know that the proportions of oxides are:

CaO = 63.33, SiO_2 = 21.73, Al_2O_3 = 5.73, Fe_2O_3 = 2.63, SO_3 = 1.73

$C_3S = 4.07\,(CaO) - 7.6\,(SiO_2) - 6.72\,(Al_2O_3) - 1.43\,(Fe_2O_3) - 2.85\,(SO_3)$

$C_2S = 2.87\,(SiO_2) - 0.754\,(C_3S)$

$C_3A = 2.65\,(Al_2O_3) - 1.69\,(Fe_2O_3)$

$C_4AF = 3.04\,(Fe_2O_3)$

$C_3S = 4.07\,(63.33) - 7.6\,(21.73) - 6.72\,(5.73) - 1.43\,(2.63) - 2.85\,(1.73) = 45.53\%$

$C_2S = 2.87\,(21.73) - 0.754\,(45.53) = 21.15\%$

$C_3A = 2.65\,(5.73) - 1.69\,(2.63) = 10.73\%$

$C_4AF = 3.04\,(2.63) = 8.0\%$.

Portland cement

Four compounds are usually regarded as the major constituents of cement: they are listed in Table 1.1, together with their abbreviated symbols.

Table 1.1. Main compounds of Portland cement

Name of Compounds	Oxide Composition	Abbreviation
Tricalcium Silicate	$3CaO.\ SiO_2$	C_3S
Dicalcium Silicate	$2CaO.\ SiO_2$	C_2S
Tricalcium Aluminate	$3CaO.Al_2O_3$	C_3A
Tetracalcium Alumina ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

Portland cement

- A general idea of the composition of cement can be obtained from Table 1.2, which gives the oxide composition limits of Portland cements.

Table 1.2. Usual composition limits of Portland cement

Oxide	Content (percent)
Lime CaO	60 - 67
Silica SiO_2	17 - 25
Alumina Al_2O_3	3.0 – 8.0
Ferric Oxide Fe_2O_3	0.5 – 6.0
Magnesia MgO	0.5 – 4.0
Alkalis (as Na_2O)	0.3 – 1.2
Sulfuric Anhydride SO_3	2.0 – 3.5

Portland cement

- Table 1.3 gives the oxide composition of a typical cement of the 1960s and the calculated compound composition, obtained by means of Bogue's equations.

Table 1.3. Oxide and compound Compositions of a typical Portland cement of the 1960s

Typical oxide composition percent		Hence, calculated compound composition (using Bogue's equations), percent	
CaO	63	C_3A	10.8
SiO_2	20	C_3S	54.1
Al_2O_3	6	C_2S	16.6
Fe_2O_3	3	C_4AF	9.1
MgO	1.5	Minor compounds	--
SO_3	2		
K_2O + Na_2O	1		
Others	1		
loss on ignition	2		
Insoluble residue	0.5		

Portland cement

- Some data of Czernin's are given in Table 1.4; column (1) shows the composition of a fairly typical rapid hardening cement. If the lime content is decreased by 3 percent, with corresponding increases in the other oxides (column (2)), a considerable change in the C_3S: C_2S ratio results.
- Column (3) shows a change of 1.5 per cent in the alumina and iron contents compared with the cement of column (1).
- Within the usual range of ordinary and rapid-hardening Portland cements the sum of the contents of the two silicates varies only within narrow limits, so that the variation in composition depends largely on the ratio of CaO to SiO_2 in the raw materials.

Table 1.4. Influence of Change in Oxide Composition on the Compound Composition

	Percentage in cement No.		
	1	2	3
oxide			
CaO	66.0	63.0	66.0
SiO_2	20.0	22.0	20.0
Al_2O_3	7.0	7.7	5.5
Fe_2O_3	3.0	3.3	4.5
others	4.0	4.0	4.0
compound			
C_3S	65	33	73
C_2S	8	38	2
C_3A	14	15	7
C_4AF	9	10	14

Portland cement

What are the secondary oxides present in cement and what is their source:

The secondary oxides in cement are:

1. SO_3 comes from gypsum added when grinding clinker, as well as a percentage of it from fuel combustion inside the rotary kiln.
2. Free calcium oxide (CaO) is one of the raw materials that contain a high percentage of this oxide.
3. Magnesium Oxide (MgO) from the magnesium carbonate found in limestone.
4. The alkalis oxides (K_2O, Na_2O) are impurities present in the raw materials.
5. Titanium Oxide (TiO_2) is an impurity found in clay.
6. Phosphorous pentoxide (P_2O_3) is an impurity present in limestone.
7. Water (H_2O) from the vapor in the atmosphere.

Portland cement

Alkalis (K2O, Na2O) are important compounds in cement.

Because these alkalis interact with some of the active silica fractions found in the aggregate (sand) within the hardened concrete, and the products of this reaction lead to an increase in the volume of concrete, causing cracking and damage to the concrete. In addition, the cement containing a high percentage of alkali affects the time required to solidify the cement.

What are the limits of oxides involved in the composition of cement

The limits of oxides used in the formation of cement are as shown in the table below:

Oxides	content%
CaO	67 – 60
SiO_2	25 – 17
Al_2O_3	8 – 3
Fe_2O_3	6 – 0.5
MgO	4 – 0.1
Alkalis	1.3 – 0.2
SO_3	3 - 1

Portland cement

Rank the main compounds in Portland cement in sequence in terms of:

1. The speed of its interaction with water
2. Its strength

The arrangement of these compounds in terms of:

First: the speed of its reaction with water:

1. C_3A High Speed
2. C_4AF is very fast (a few minutes)
3. C_3S Fast (days)
4. C_2S is slow (weeks)

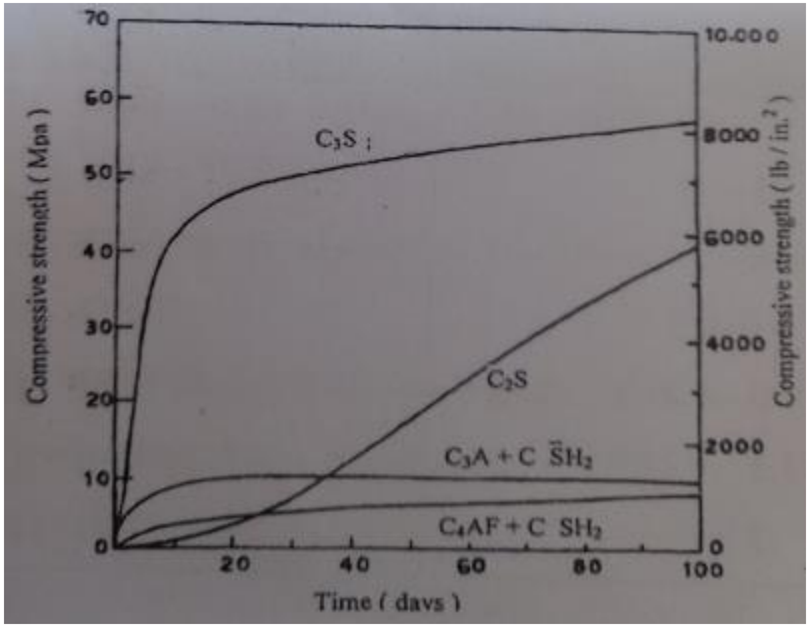
Second: Strength:

1. C_3S a few tens of N / mm2
2. C_2S a few tens of N / mm2
3. C_3A a few N / mm2
4. C_4AF a few N / mm2

Portland cement

Draw a figure of the evolution of compressive strength with age for each of the main cement compounds (C_3S, C_2S, C_3A, C_4AF).

The figure below shows the velocity of strength development for each of the major cement compounds.



Portland cement

Why is C_3A undesirable in cement.

This compound is not desirable in cement for the following reasons:

1. Its interaction with sulphates, whether internal or external, forming Ettringite (aqueous calcium aluminate sulfo), these compounds are transformed from one form to another, and this results in an increase in the volume, which leads to a weakening of the bonding in them and thus a decrease in the strength of cement or concrete. It results in an increase in volume that damages the concrete.
2. Its very rapid reaction with water leads to a rapid cohesion (flash setting), which requires adding gypsum to the clinker when grinding to slow the reaction.
3. Its hydration temperature is very high and its release speed is also high, especially in the first days after mixing cement with water.
4. Its effect on concrete strength is small, not exceeding a few Newton / mm2, and it is determined in the first days only.

Portland cement

Loss on Ignition L.O.I

It is a loss in the weight of a cement model after heating to the red temperature or to 1000 ° C, and it is expressed as:

- Carbonation amount
- Hydration process of free lime and free magnesia due to cement storage for a long time or exposure to weather conditions.

A small part of the loss during ignition is caused by the loss of water entering the composition of the gypsum. Iraqi Standard No. 5 for Portland cement specified the percentage of loss during ignition at 4% by weight as a maximum.

Portland cement

What is carbonation and what is its effect on the properties of concrete:

The refining process is the reaction of the CO_2 gas present in the atmosphere and in the presence of moisture with the hydration compounds of cement, mainly the fluorescence, where calcium carbonate is formed in a white powder. Figure No. 2 as shown by the following equation:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$

Nora calcium carbonate

The carbonization of concrete begins on the outside and gradually penetrates inside.

The carbonization speed depends on:

1. Concentration of CO_2 in the atmosphere.
2. Availability of moisture in concrete
3. The relative humidity of the surrounding medium.
4. Size models.

Portland cement

Carbonization effect on concrete:

1. Increase the density of concrete and its compressive strength (temporarily) and reduce its porosity, as a result of calcium carbonate curling in the concrete pores.
2. The carbonization process gradually reduces the alkalis of concrete and thus negatively affects the protection that concrete provides to iron from rust.

Portland cement

Insoluble Residue IR

It is that part of the cement form insoluble in acid hydrochloride HCL and mainly originates from unreacted silica to form cement compounds dissolved in this acid, so it expresses:

- How complete the chemical reactions are inside the oven.

Iraqi Standard No. 5 specified the percentage of insoluble residues at 1.5% of the cement weight as a maximum.

Thanks For Your Listening

Al-Muthanna University
Engineering College
Civil Engineering Department

Concrete Technology

The 5th lecture

Physical properties of cement

أ.م.د حسين كريم سلطان

للعام الدراسي
2020 - 2019

Physical properties of Portland cement

المواصفات القياسية العراقية الخاصة بالاسمنت البورتلاندي (م.ق.ع.5/1984)

اولا: المتطلبات الفيزيائية

جدول 1. المتطلبات الفيزيائية

ت	الفحص	نوع الاسمنت					
		اعتيادي	معتدل	سريع التصلب	واطئ الحرارة	مقاوم	ابيض
1	النعومة لا تقل على (م2/كغم)	230	250	320	320	250	230
2	وقت التماسك ▪ الابتدائي لا يقل على (دقيقة) ▪ النهائي لا يزيد على (ساعة)	 45 10	 45 10	 45 10	 45 10	 45 10	 45 10
3	السلامة: الاستطالة لا تزيد على (%)	0.8	0.8	0.8	0.8	0.8	0.8
4	تحمل الضغط لا يقل على (ميكانيوتن/م^2): ▪ بعمر يوم واحد ▪ بعمر 3 ايام ▪ بعمر 7 ايام ▪ بعمر 28 يوم	 - 15 23 -	 - 15 23 -	 11 21 28 -	 - 10 - 28	 - 15 23 -	 - 15 23 -
5	تحمل الشد (اختياري) (ميكانيوتن/م^2)	-	-	2.1	-	-	-
6	درجة البياض	-	-	-	-	-	78

Portland cement

ثانيا: المتطلبات الكيميائية

جدول 2. المتطلبات الكيميائية

ت	الفحص	نوع الاسمنت					
		اعتيادي	معتدل	سريع التصلب	واطئ الحرارة	مقاوم	ابيض
1	SiO_2 لا يقل على (%)	-	21	-	-	-	-
2	Al_2O_3 لا يقل على (%)	-	6	-	-	-	-
3	Fe_2O_3 لا يزيد على (%)	-	6	-	6.5	-	-
4	عامل الاشباع الجيري	1.02 – 0.66			0.88 – 0.66	1.02 – 0.66	
5	MgO لا يزيد عن (%)	5	5	5	5	5	5
6	محتوى SO_3 لا يزيد على عندما تكون نسبة C_3A • اقل من 5% • اكثر من 5%	 2.5 2.8	 2.5 2.8	 3 3.5	 2.5 3	 2.5 2.5	 2.5 3
7	الفقدان لا يزيد على (%)	4	4	4	4	4	4
8	المواد غير القابلة للذوبان لا يزيد على (%)	1.5	1.5	1.5	1.5	1.5	1.5
9	C_3S لا يزيد على (%)	-	-	-	35	-	-
10	C_2S لا يقل على (%)	-	-	-	40	-	-
11	C_3A لا يزيد على (%)	-	8	15	7	3.5	-
12	نسبة Al_2O_3 / Fe_2O_3 لا تقل على (%)	-	-	-	-	-	8

الرفض: يمكن رفض العبوات التي يختلف وزنها بنسبة تزيد على 3% من الوزن المؤشر عليها وفي حالة كون معدل وزن 50 عبوة منتقاة بصورة عشوائية من ارسالية اقل من الوزن المؤشر على العبوات فيمكن رفض الارسالية.

النمذجة الخاصة بالاسمنت البورتلاندي بموجب المواصفة القياسية العراقية رقم 5 لسنة 1984

الفحوص	النمذجة
المتطلبات الفيزيائية: 1. النعومة بطريقة بلين 2. وقت التماسك الابتدائي والنهائي (فيكات) 3. الثبات (اوتوكليف) 4. مقاومة الانضغاط بعمر: ✓ يوم واحد (الاسمنت سريع التصلد) ✓ ثلاثة ايام (لانواع الاسمنت البورتلاندي) ✓ سبعة ايام (لانواع الاسمنت البورتلاندي عدا الاسمنت واطئ الحرارة) ✓ 28 يوم (للاسمنت واطئ الحرارة) 5. مقاومة الشد بعمر يوم واحد 6. درجة البياض. **المتطلبات الكيميائية:** محتوى SiO_2 محتوى Al_2O_3 محتوى Fe_2O_3 عامل الاشباع الجيري محتوى MgO محتوى SO_3 محتوى C_3S محتوى C_2S الفقدان بالحرق المواد غير القابلة للذوبان محتوى اوكسيد الالمنيوم – الحديديك.	1. لاتقل كتلة النموذج المأخوذ من الارسالية عن 7 كغم (في حالتي الاسمنت المعبأ او الاسمنت الفل) ويمثل الارسالية تمثيلا صحيحا. 2. يتألف النموذج من خليط ل (12) نموذجا ثانويا متساويا مأخوذة من محلات مختلفة وموزعة توزيعا منتظما خلال الارسالية ولا يؤخذ اكثر من نموذج ثانوي واحد من اي عبوة من عبوات الارسالية. 3. في حالة كون الارسالية تتكون من 12 عبوة او اقل فيؤخذ نموذج ثانوي واحد وتخلط جميعها مكونة النموذج المطلوب 4. في حالة كون الارسالية سمنتا فل فيؤخذ من وعاء الفل او الاوعية اثناء عملية الملئ او التفريغ.

Physical properties of Portland cement

Question 1: The table below shows the chemical composition of five types of Portland cement, which are normal, fast hardening, resistant to sulfur salts, low temperature and white. Determine the following:

1. The quality of each cement according to the proportions of the compounds in it
2. Any of these types can be used as a substitute for the resistant to sulfur salts if it is not available.

compounds	Cement a	Cement b	Cement c	Cement d	Cement e
C_3S	57.5	55.9	43	45.3	29.7
C_2S	15.9	23.8	25	26.9	41.9
C_3A	8.5	13	9.4	2	2.1
C_4AF	6.8	1	10	16.9	18

Physical properties of Portland cement

The solution:

1. The types of cement are:

   Cement A: Fast curing Portland cement for high C_3S and low C_2S.

   Cement B: Portland white with low C_4AF.

   Cement C: Ordinary Portland.

   Cement D: Portland cement that is resistant to sulfur salts with low C_3A content.

   Cement E: Portland low heat due to low C_3S and C_3A ratios.

2. The type (low temperature) can be used instead of resistant to sulfur salts because the percentage of C_3A in it is less than the upper limit set by international standards.

Physical properties of Portland cement

Question 2: After conducting the chemical analysis of a sample of cement, the percentage of oxides in it was as follows:

SO_3 = 1.73%, Fe_2O_3 = 2.63%, Al_2O_3 = 5.73%, SiO_2 = 21.73%, CaO = 63.33%

Using Pogue equations, determine the type of this Portland cement based on the proportions of the main compounds and its resistance to sulfur salts if its fineness is 2750 cm2 / g.

$C_3S = 4.07\,(CaO) - 7.6\,(SiO_2) - 6.72\,(Al_2O_3) - 1.43\,(Fe_2O_3) - 2.85\,(SO_3)$

$C_2S = 2.87\,(SiO_2) - 0.754\,(C_3S)$

$C_3A = 2.65\,(Al_2O_3) - 1.69\,(Fe_2O_3)$

$C_4AF = 3.04\,(Fe_2O_3)$

$C_3S = 4.07\,(63.33) - 7.6\,(21.73) - 6.72\,(5.73) - 1.43\,(2.63) - 2.85\,(1.73) = 45.53\%$

$C_2S = 2.87\,(21.73) - 0.754\,(45.53) = 21.15\%$

$C_3A = 2.65\,(5.73) - 1.69\,(2.63) = 10.73\%$

$C_4AF = 3.04\,(2.63) = 8.0\%$.

Physical properties of Portland cement

False set

It is the cohesion that occurs within a few minutes at the start of the mixing process. It differs from sudden freezing in that it is not accompanied by the release of the heat of hydration, and the cement or concrete restores its properties upon re-mixing.

the causes of false set:

1. The dryness of gypsum water: caused by high temperature during the process of grinding clinker with gypsum, where the aqueous gypsum loses part of the water crystallized into a semi-aqueous gypsum:

$$2CaSO_4.2H_2O \rightarrow 2CaSO_4.1/2H_2O + 3H_2O$$

Physical properties of Portland cement

False set

2. Activation of activity (**C_3S**): due to poor cement storage, water molecules present as vapor in the atmosphere adhere to granules (**C_3S**) very quickly, causing cohesion within minutes.

3. Poor storage: The reaction of the alkali (**Na_2O and K_2O**) in the cement leads to the carbon dioxide present in the atmosphere to form the alkali carbonate (**Na_2CO_3 and K_2CO_3**). These carbonates react with the **$Ca(OH)_2$** released from the cement hydration to form calcium carbonate, which precipitates causing the cement or concrete to freeze.

$$Ca(OH)_2 + Na_2CO_3 \rightarrow 2CaCO_3 + 2NaOH$$

Physical properties of Portland cement

Soundness of cement

The soundness of cement means its resistance to the volume increase that occurs in it after hardening, and whose increase leads to damage to the cement or concrete.

The reason for the volume increase (expansion) is due to:

1. The presence of free lime (CaO) and Magnesia (MgO) present as secondary oxides in cement after its manufacture, and these two oxides interact slowly with water and result in an increase in volume, as follows:

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

$$MgO + H_2O \rightarrow Mg(OH)_2$$

Physical properties of Portland cement

Soundness of cement

2. In addition to this, if the gypsum added to the clinker before the grinding process is in a greater amount than that which interacts with the compound (**C_3A**), then during freezing, the excess gypsum expands slowly due to the V.

The soundness of cement can be inferred by one of the following two methods:

1. Le Chatelier test
2. Autoclave test

Physical properties of Portland cement

Fineness of cement

It is one of the important properties of cement that must be well controlled, as the hydration process begins with the surfaces of the cement grains, so the total surface area of the grains represents the material available for the rehydration process. That is, the rate of rehydration speed depends on the fineness of the cement grains, where high fineness is necessary to increase the speed of obtaining resistance.

Advantage of Fineness of cement

1. The cohesion and bonding are higher in fresh concrete.
2. Improved workability of the concrete mix.
3. If the high fineness , the less the bleeding

Physical properties of Portland cement

disadvantage of Fineness of cement

1. High-fine cement undergoes partial hydration during poor storage, which leads to a loss of its cementitious properties.
2. Increasing the fineness of the cement beyond the required limit causes an increase in the surface area of the alkaline materials that the cement contains, and this results in their interaction strongly with the effective silica grains, if found in the aggregate, causing cracking and damage to the concrete, due to the occurrence of expansion in the hardened concrete. This expansion is accompanied by cracks and then the fragmentation of the concrete mass.
3. Increasing the fineness of cement causes an increase in the surface area of the compound (C_3A). This causes an increase in the amount of gypsum required to delay the reaction of this compound with water.
4. Uneconomical due to the high grinding cost.

Physical properties of Portland cement

Important notes about fineness of cement:

1. Maximum cement size 0.09 mm
2. 85% to 95% of cement particles less than 0.045 mm
3. One kilogram of Portland cement contains 1 trillion granules and has a total surface area of about 300 to 400 square meters.
4. The cement particles are separated from each other by a distance of 5 to 10 microns within the limits of the practical water contents

methods of measuring the Fineness of cement:

1. The old method: sieve analysis
2. Modern methods:
   a. Wagner turbid meter method
   b. Air permeability method
   c. Blain method

Physical properties of Portland cement

Heat of hydration of cement

Cement hydration temperature is the amount of heat emitted when cement is completely hydrated at a certain temperature, and is measured in joules / g or kcal / g of non-hydrated cement, and the hydration process of cement compounds is accompanied by a temperature of up to 500 joules / g (120 kcal / g).

Note: The ability of concrete to conduct heat is relatively low, so it acts as an insulating material.

The process of rehydration inside large concrete blocks such as reservoirs and dams is accompanied by a large emission in temperature, and at the same time the outer surface of the concrete blocks loses some heat, so there is a severe temperature gradient between the inside and the surface of the concrete blocks, and during the subsequent cooling of the concrete blocks, stresses are generated that lead to cracks. Serious.

Physical properties of Portland cement

Practical measures to reduce the temperature of rehydration when pouring concrete with a large mass in hot weather:

There are two methods to reduce the high rehydration temperature:

1. Pre cooling by cooling the gravel by spraying it with cold water or using crushed ice with mixing water.
2. Post cooling by creating a network of fine water pipes inside the concrete to cool it after pouring.

When is a high emission of rehydration heat useful, explain this and state the reason.

High temperature emission is beneficial in cold weather as it prevents water freezing inside the capillary pores of freshly poured concrete.

Physical properties of Portland cement

Factors affecting cement hydration

1. The chemical composition of cement: the different compounds of cement have different speeds in the early stages of hydration. The rate of heat emission speed and total heat depends on the cement compounds. The rate of heat generation speed can be reduced in the early times by reducing the percentage of the most rapid hydration compounds, which are C_3S and C_3A.
2. The ambient temperature will have a great influence on the rate of heat emission, as increasing it increases the heat emitted.
3. Type of cement: the rate of heat emission rate of different types of cement gradually decreases with the following types.

   a. Fast hardening Portland cement.

   b. Ordinary Portland cement

   c. Modified Portland cement

   d. Sulfate-resistant Portland cement

   e. Low-temperature Portland cement.
4. Fineness of cement: with its increase, the speed of chemical reactions increases, i.e. the speed of heat emission, but the total amount of heat is not affected.
5. The amount of cement in the mixture: It affects the increase in the overall heat generated, so it is possible to change the amount of cement in the mixture for the purpose of controlling the hydration temperature.

Physical properties of Portland cement

Influence of the compound composition on properties of cement

The main compounds C_3S and C_2S are the most important compounds responsible for resistance.

- C_3S: Participates to a greater degree in the development of resistance during the first 4 weeks.
- C_2S: affects the acquisition of resistance after the first four weeks and at the age of about one year.
- C_3A: contributes to the development of resistance in 1 - 3 days
- C_4AF: Its role in developing the resistance has not been clarified yet.

Volume of products of hydration

The volume of rehydration outcomes consists of:

1. The gel particles are the solid products
2. The pores of the gel represent the water of the gel (the two particles and the pores make up the total volume of the gel).
3. Capillary pores
4. Unsolved cement (size depends on w / c and curing conditions).

Physical properties of Portland cement

In order to calculate the rehydration output of cement, the following information must be known:

1. Dry cement specific weight = 3.15
2. Combined water (not evaporative) = 23% of dry cement weight.
3. The volume of solid products, which occupies a volume less than the sum of the two volumes of dry cement and non-evaporation water, by 0.254 of the latter's volume.
4. Gel water (gel pores) = 28% of the total volume of the gel.
5. The size of the capillary pores = the original volume of water and cement - (the total volume of hydrated + non-hydrated cement).
6. The size of the capillaries containing the water = the original volume of water - the total water.
7. Total water = gel water + non-evaporation water.

Portland cement

Vol. of (1 mm) hydration product = 2.1 liter from total vol.

Vol. of cement = wt. of cement / specific gravity of cement (3.15).

Vol. of non-evaporable water = 0.23X wt. of dry cement .

Vol. of product hydration = vol. of hydrated cement + vol. of non-evaporable water – 0.254 vol. of non-evaporable water

= vol. of hydrated cement + vol. of non-evaporable water (1 – 0.254).

Gel pores (empty or water) = 0.28 * total vol. of gel .

Total vol. gel = vol. of product hydration + vol. of gel water.

Vol. of Capillary pores = total vol. – total gel vol. – vol. of cement unhydrated.

➢ **For full hydration (w/c > 0.42) .**

1. Vol. of Capillary pores = total vol. (vol. of cement + vol. of water) – vol. of total gel .
2. Vol. of Capillary pores saturated = vol. of water – (vol. of non-evaporable water + gel water)
3. Vol. of empty Capillary pores = Vol. of Capillary pores - Vol. of Capillary pores saturated .

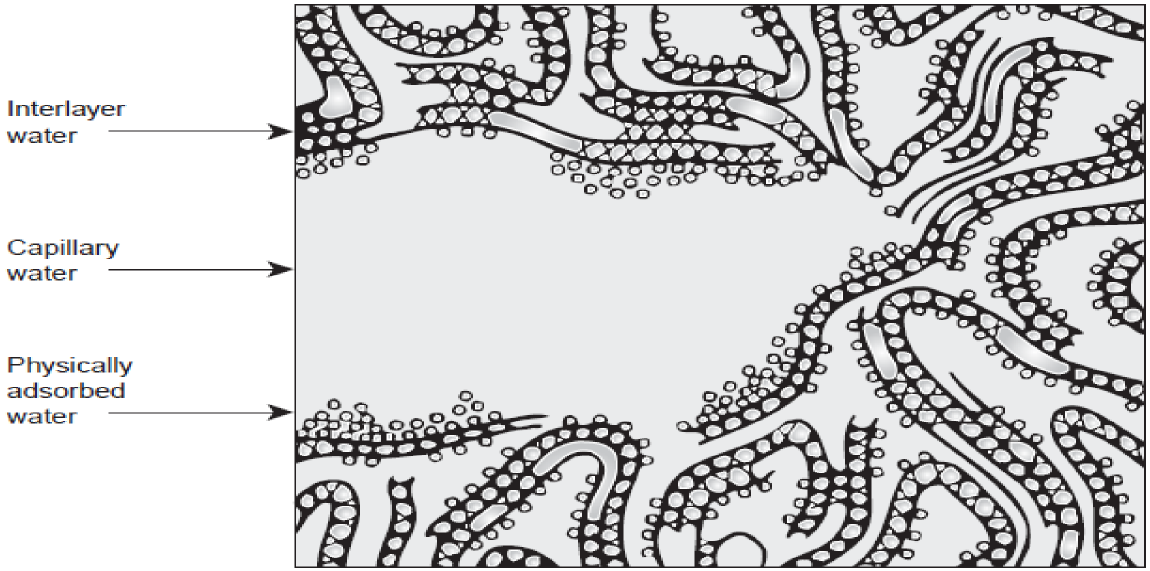


Figure shown the types of water

The non-evaporable water is about 18 % by mass of the anhydrous material; this proportion rises to about 23 %in fully hydrated cement.

Portland cement

Example 1: A quantity of cement weighing (x) was mixed with a quantity of water weighing (m). Calculate the volumes of rehydration products and pores (capillary pores and gel pores) for this mixture after the entire amount of cement reacted if you know that the specific weight of the cement is 3.15.

The solution:

Volume (x) = volume of dry cement in the mixture

Weight (x) = volume of absolute cement = x / 3.15 = 0.317 x ……….x: in grams

Volume (m) The volume of water in the mixture, Weight (m) = m / 1 = m.

Since Portland cement consumes 23% of its weight as water in the entire hydration process, and the solids resulting from the rehydration process are of a total volume less than the sum of the two volumes of cement and water reacting by 25.4% of the volume of reactive water, in other words the volume of solid rehydration compounds (volume) y)) is:

Volume (y) = 0.317x + 0.23x (1 - 0.254) = 0.489x

Among the solids, pores known as gel pores with a volume of (volume (g)) which is 28% of the total gel volume (solids + gel pores) are formed.

Volume (g) / (Volume (p g) + 0.489x) = 0.28

Volume (p g) = 0.19 x.

The remainder of the volume is the size of empty or water-filled capillaries (volume (p c))

Volume (p c) = 0.317x + m - (0.489x + 0.19x) = m - 0.36x.

Example 2: If we assume that the rehydration process takes place inside a tightly closed test tube, as shown in Figure 8, and there is no transfer of water to and from the cement paste, then calculate the rehydration products of a mixture that includes 100 g of cement and 42 liters of water.

The solution:

Gel particle size (solid product) = volume (g)

Volume (g) = 0.317x + 0.23x (1 - 0.254) = 0.489x = 0.317 * 100 + 0.23 * 100 (1-0.254) = 48.9 ml

.

Gel pore size (gel water) = volume (mg)

Volume (g) / (Volume (p g) + 0.489x) = 0.28

Volume (p g) = 19 ml

The total volume of gel (volume of hydrated cement) = volume (Y) + volume (p g) = 48.9 + 19 = 67.9 ml

, which is more than twice the volume of dry cement.

The volume of capillary pores = (volume of original mixing water + volume of dry cement) - total volume of gel = (42 + 31.8) -67.9 = 5.9 ml (decrease in volume represents the free capillary pores dispersed through the cement paste)

Since total water = gel water + non-evaporating water = 19 + 0.23 * 100 = 42 ml

Volume of capillary containing water = mixing water - total water = 42-42 = 0.0

Then we note that there is no non-hydrated cement

So the ratio of water / cement = **0.42**, and this ratio achieves total hydration

If the water / cement ratio is less than 0.42, it will be insufficient to complete the hydration process of all cement.

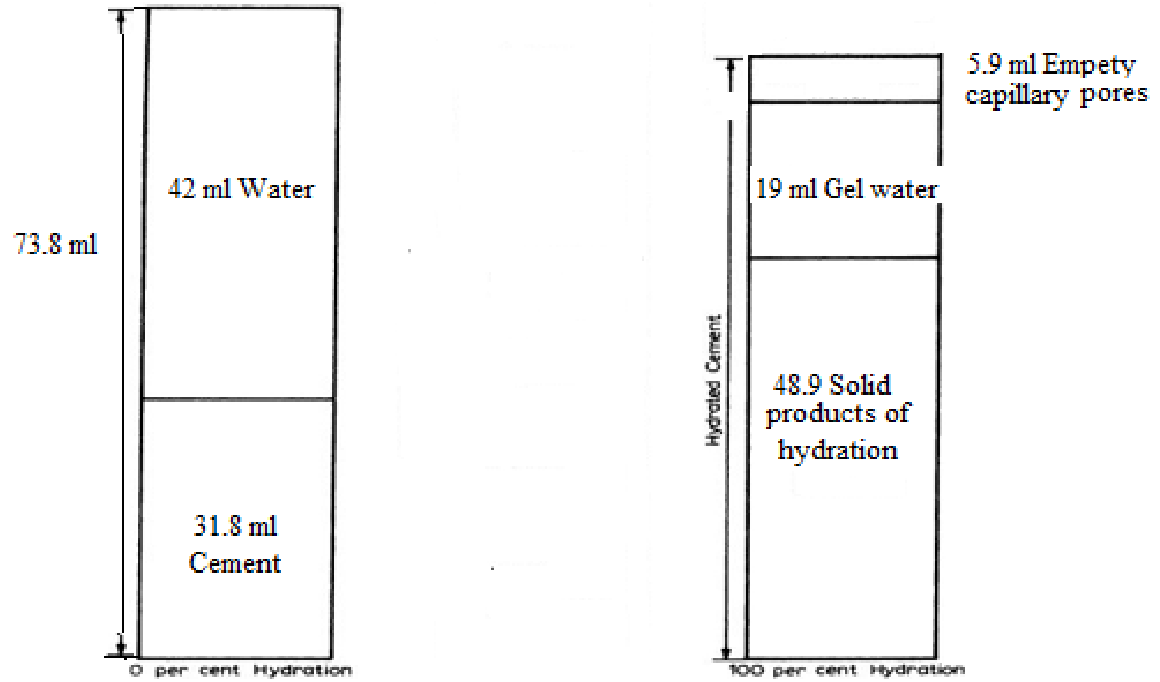
Portland cement

In the previous example, a quantity of cement of 100 grams (31.8 ml) occupies 67.9 ml after completing the rehydration. If we consider that the rehydration process of cement paste is treated under water, meaning that the capillary pores absorb water from the outside. In order not to keep the cement non-hydrated and to prevent the presence of capillaries. The original mixing water should be:

67.9 -31.8 = 36.1 ml

That is, the ratio of water / cement weight w / c = 100 / 36.1 = 0.36 and there are research indicating that this ratio = approximately 0.38 weight.

So w / c greater or equal to 0.38 achieves total hvdration.



Portland cement

➢**Example 3\ Calculated the hydration of products for 100 g of cement and 42 ml of water, there is no water transfer to and from the cement paste .**

<u>solution</u>

w/c =42/100=0.42 , cement vol.= 100/3.15= 31.8 ml

vol. of non-evaporable water = 100X 0.23= 23 ml

Vol. of product hydration = vol. of hydrated cement + vol. of non-evaporable water – 0.254 vol. of non-evaporable water = 31.8 +23 – 0.254 X23= 48.9 ml

Gel water(wg) = 0.28 X total vol. of gel

wg =0.28* (48.9 +wg) ….wg= 13.592 +0.28 wg…0.72wg=13.592…wg=19 ml

Total vol. of gel = 48.9+19= 67.9ml

Vol. of Capillary pores = total vol. (vol. of cement + vol. of water) – vol. of total gel = (31.8+42) -67.9=5.9 ml

2- Vol. of saturated capillary pores = vol. of water – (vol. of non-evaporable water + gel water) = 42-(23+19)=0 No saturated capillary pores.

If there is water form out side the capillary pores full with water.

Example 4: Calculate the rehydration products of a mixture consisting of 100 grams of cement and 30 grams of water, given that there is no transfer of water to and from the cement paste. What would happen if the water was supplied from the outside?

The solution:

In the first example, we knew w / c = 0.42 that achieved total hydration

In this example (w / c = 30/100 = 0.3) it is less than 0.42

So water is not sufficient to hydrate all the cement.

So suppose it is sufficient to dehydrate (A) a cloud of cement

We find the size of the gel particles:

$A / 3.15 + 0.23 * A (1 - 0.254) = 0.489A$

Since the volume of gel water is equal to:

$wg = 0.28 (0.489A + wg)$ 1

$30 = 0.23A + wg$ …………… ..2

From (1) $wg = 0.19 A$

Sub. In equ. (2)

$30 = 0.23A + 0.19A$ ……………… $A = 71.5$ gm

It is approximately equal to the volume of cement $A = 71.5 / 3.15 = 22.7$ ml

Portland cement

wg = 0.19 * 71.5 = 13.5 gm ……… ..wg = 13.5 ml.

So the volume of non-hydrated cement (100 / 3.15 - 22.7 = 9.1 ml)

The total volume of the hydrated cement (0.489 * 71.5 + 13.5 = 48.5 ml)

The size of empty or full capillary pores

(31.8 + 30) - (48.5 + 9.1) = 4.2 ml

If the water is supplied from the outside, then some dry cement, symbolized by (y), will be able to hydrate so that the products of rehydration occupy 4.2 ml in addition to the initial volume. It was found that 22.7 ml of cement fill up to 48.5 ml, meaning that the products of rehydration per liter of cement are occupied (48.5 / 22.7 = 2.13 ml) in addition to the initial volume of cement that will be filled with hydration of y milliliter of cement.

(y + 4.2) / y = 2.13 ……………… .y = 3.7 ml

The volume of cement that is still not hydrated is equal to 31.8 - (22.7 + 3.7) = 5.4 ml.

Weight of non-hydrated cement 5.4 * 3.15 = 17 gm.

In other words, 17% of the weight of the original cement is not hydrolysed and will not be able to hydrate because the gel has filled all the pores, meaning that the ratio of the volume of the hydrated cement to the total volume of cement and capillary pores is 1.

❖**Example** 5/ Find the products of hydration for 140 g of cement and 47 ml of water no water supply from out side.

Solution

w/c = 47/140=0.34 , less than 0.42 the hydration not completed .

Therefor no Know the vol. of hydrated cement because there is unhydrated cement . Let us the hydrated cement (y) .

Vol. of product hydration = vol. of hydrated cement + vol. of non-evaporable water – 0.254 vol. of non-evaporable water .

= y /3.15 +0.23 y - (0.254X0.23y) = 0.489 y.

Wg= 0.28 (0.489y+wg) ………..(1)

47 = wg+0.23y……………(2)

Solved 1,2 …………….. Y= 111.7g

Vol. of hydrated cement = 111.7/ 3.15 = 35.46 ml

Vol. of product hydration = 0.489 X111.7=54.62 ml

Home Work

❖**Example** 6/ Find the products of hydration for 200 g of cement and 62 ml of water ,what happens if water is supplied from outside?

Portland cement

Example 7: Calculate the rehydration products of a sample of cement of 126 g and w / c = 0.475 placed in a tightly closed test tube.

The solution:

The mixing ratios can be seen in Figure 10, but in reality the water and cement are mixed with eacl other and the water forms capillary pores between the hydrolysed cement grains.

w / c = 0.475> 0.42

Water is sufficient to hydrate the cement

The volume of water equals (0.475 * 126 = 60 ml)

When the cement is completely hydrated, the volume of non-evaporating water is 0.23*126 = 29 m

The volume of the solid is 126 / 3.15 +29 - (0.254 * 29) = 61.6

Gel pores equal to (wg) = 0.28 (61.6 + wg) ... wg = 24 ml

The total volume of the hydrolyzed cement is 61.6 + 24 = 85.6 ml

Total capillary pore volume is 126 / 3.15 +60 -85.6 = 14.4 milliliters

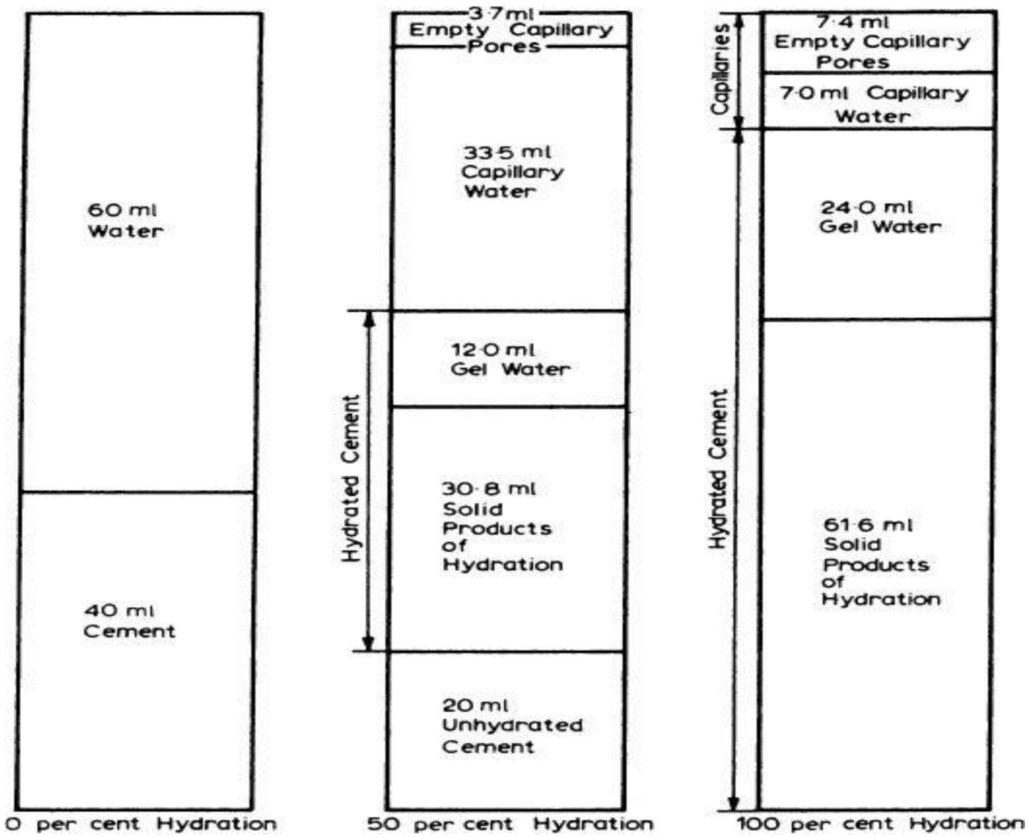
The volume of capillary pores filled with water is 60- (24 + 0.23 * 126) = 7 ml

The volume of Empty Pores 14.4 - 7 = 7.4 ml

If the cement paste is treated under water in this case, the capillary pores will be filled by absorbin water from the outside, and the gel / vacuum ratio in this case is equal to:

Gel space ratio (gel volume / void) = 85.6 / (14.4 + 85.6) = 0.856.

Portland cement



➢**Volumes of products of hydration :**

The gross space available for the products of hydration consists of the absolute volume of the dry cement together with the volume of water added to the mix.

If the w/c (water-cement ratio) less than 0.42 ,the water inadequate for full hydration 100% , thus some of cement unhydrated.

Thanks For Your Listening

Al-Muthanna University
Engineering College
Civil Engineering Department

Concrete Technology

The 7th lecture
Properties of Aggregate

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2020 - 2019

Aggregate

Properties of aggregates.

Porosity and absorption of aggregate.

- Since aggregate represents some three-quarters of the volume of concrete, it is clear that the porosity of aggregate contributes to the overall porosity of concrete.
- The porosity of aggregate, its the internal pores in the aggregate particles and refer to permeability,
- The apparent specific gravity of aggregate also depends on its porosity.

- The porosity of aggregate, its permeability, and absorption influence on:
  1- the bond between aggregates and the hydrated cement paste.
  2- the resistance of concrete to freezing and thawing.
  3- its chemical stability and resistance to abrasion.

- water can enter the pores, the amount and rate of penetration depending on their size, continuity and total volume of pores.

Aggregate

Porosity and absorption of aggregate.

1. When all the pores in the aggregate are full, it is said to be **saturated and surface-dry.**
2. If aggregate in this condition is allowed to stand free in dry air, e.g. in the laboratory, some of the water contained in the pores will evaporate and the aggregate will be less than saturated, i.e. **air-dry**.
3. Prolonged drying in an oven would reduce the moisture content of the aggregate still further until, when no moisture whatever is left, the aggregate is said to be bone-dry **(oven dry).**
4. The water absorption of aggregate is determined by measuring the increase in mass of an oven-dried sample when immersed in water for 24 hours (the surface water being removed). The ratio of the increase in mass to the mass of the dry sample, expressed as a percentage, is termed **absorption**. Standard procedures are prescribed in BS 812-2: 1995.

✓ Although there is no clear-cut relation between the strength of concrete and the water absorption of aggregate used, the pores at the surface of the particle affect the bond between the aggregate and the cement paste, and may thus exert some influence on the strength of concrete.

Aggregate

Properties of aggregates.

1- **Moisture content (MC)**, defines as the amount of water in the pores and on the surface of the aggregate. The surface moisture is expressed as a percentage of the mass of the saturated and surface-dry aggregate, and is termed moisture content.

✓ There are four moisture conditions, as demonstrated in Figure.

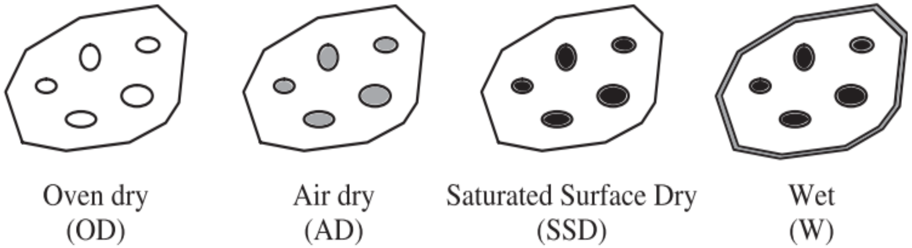


Figure. Aggregate in various moisture states

Aggregate

Properties of aggregates.

1- **Moisture content (MC),**

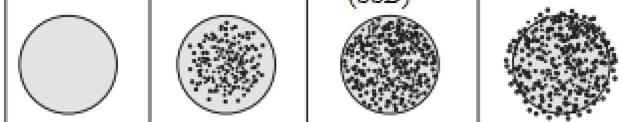
a. **Oven dry (OD):** is obtained by keeping the aggregate in oven at a temperature of 110 C long enough to drive all water out from internal pores and reach a constant weight.

b. **Air dry (AD):** This condition is obtained by keeping the aggregate at ambient temperature and ambient humidity.

c. **Saturated surface dry (SSD):** the pores of the aggregate are fully filled with water and the surface is dry.

d. **Wet (W):** The pores of the aggregate are fully filled with water and the surface of the aggregate has a film of water

State	Oven dry (OD)	Air dry (AD)	Saturated, surface dry (SSD)	Damp or wet (W)
Total moisture	None	Less than potential absorption	Equal to potential absorption	Greater than absorption



Moisture conditions of aggregates

Properties of aggregates.

1- **Moisture content (MC)**,

- ✓ Since absorption represents the water contained in aggregate in a saturated and surface-dry condition, and the moisture content is the water in excess of that state, the total water content of a moist aggregate is equal to the sum of absorption and moisture content.

- ✓ As the moisture content of aggregate changes with weather, and changes also from one part of a stockpile to another, the value of the moisture content has to be determined frequently and a number of methods have been developed.

- ✓ The apparent specific gravity of the aggregate on a saturated and surface-dry basis, s, must be known. Then, if B is the mass of the pycnometer full of water, C the mass of the moist sample, and A the mass of the pycnometer with the sample and topped up with water, the moisture content of the aggregate is:

$$\text{moisture content} = \left[\frac{C}{A-B}\left(\frac{s-1}{s}\right)-1\right]\times 100.$$

- ✓ The test is slow and requires great care in execution but can yield accurate results. This method is described in BS 812-109: 1990.

Aggregate

The moisture content of aggregates can be calculated with respect either the OD or SSD condition.

- For the **oven dry** condition:

$$MC\,(OD) = \frac{W_{stock} - W_{OD}}{W_{OD}} \times 100\%$$

- For the **saturated surface dry** condition:

$$MC\,(SSD) = \frac{W_{stock} - W_{SSD}}{W_{SSD}} \times 100\%$$

where W stock is the weight of aggregate in the stock condition, and W_{OD} the weight of oven-dried aggregates. W_{SSD} is the weight of aggregate in the SSD condition.

Density and specific gravity.

Density (D) is defined as the weight per unit volume of solid material only, excluding the pores volume inside a single aggregate**:**

$$D = \frac{\text{weight}}{V_{\text{solid}}}$$

Bulk density (BD) is defined as the weight per unit volume of both solid material and the pores volume inside a single aggregate:

$$\text{BD} = \frac{\text{weight}}{V_{\text{solid}} + V_{\text{pores}}}$$

Unit weight (UW)

The unit weight is defined as the weight per unit bulk volume for bulk aggregates.

$$\text{UW (SSD)} = \frac{W_{\text{SSD}}}{V_{\text{solid}} + V_{\text{pores}} + V_{\text{spacing}}}$$

$$\text{UW (OD)} = \frac{W_{\text{OD}}}{V_{\text{solid}} + V_{\text{pores}} + V_{\text{spacing}}}$$

The percentage of spacing (voids) among the aggregates can be calculated as:

$$\text{Spacing (void)} = \frac{\text{BD} - \text{UW}}{\text{BD}} \times 100\%$$

Bulk density of aggregate.

The mass of unit volume of aggregate that would fill a container and this density is used to convert quantities by mass to quantities by volume.(kg/m^3).

The bulk density clearly depends on

1. how densely the aggregate is packed,
2. the size distribution and shape of the particles

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

3. The actual bulk density of aggregate depends not only on the various characteristics of the material which determine the potential degree of packing, but also on the actual compaction achieved in a given case.

Aggregate

Bulk density of aggregate.

Bulking of fine aggregate (sand)

The presence of moisture in aggregate necessitates correction of the actual mix proportions: the mass of water added to the mix has to be decreased by the mass of the free moisture in the aggregate, and the mass of the wet aggregate must be increased by a like amount. In the case of sand, there is a second effect of the presence of moisture: bulking. This is the increase in the volume of a given mass of sand caused by the films of water pushing the sand particles apart (a considerable increase in the bulk volume of the sand can occur in damp sands because the surface tension of water keeps the particles apart).

Depending on the amount of moisture and aggregate grading fine sands show more bulking. Since most sands are delivered at the job site in a damp condition

Wide variations can occur in the batch quantities if batching is done by volume. For this reason, proportioning of concrete mixture by mass has become the standard practice in most countries

Bulking of fine aggregate (sand)

Coarse aggregate shows only a negligible increase in volume due to the presence of free water, as the thickness of moisture films is very small compared with the particle size.
Because the volume of saturated sand is the same as that of dry sand, the most convenient way of determining bulking is by measuring the decrease in volume of the given sand when inundated.

A container of known volume is filled with loosely packed moist sand. The sand is then tipped out, the container is partially filled with water and the sand is gradually fed back, with stirring and rodding to expel all air bubbles. The volume of sand in the saturated state, Vs, is now measured. If Vm is the initial apparent volume of the sand (i.e. the volume of the container), then bulking is given by $(Vm - Vs)/Vs$.

With volume batching, bulking has to be allowed for by increasing the total volume of (moist) sand used. Thus, volume Vs is multiplied by the factor:

$$1 + \frac{V_m - V_s}{V_s} = \frac{V_m}{V_s},$$

sometimes known as the *bulking factor*

Bulking of fine aggregate (sand)

The bulking factor can also be found from the bulk densities of dry and moist sand, D_d and D_m, respectively, and the moisture content per unit volume of sand, m/V_m. The bulking factor is then

$$\frac{D_d}{D_m - \frac{m}{V_m}}.$$

Since D_d represents a ratio of the mass of dry sand, w, to its bulk volume V_s (the volumes of dry and inundated sand being the same),

$$\frac{D_d}{D_m - \frac{m}{V_m}} = \frac{\frac{w}{V_s}}{\frac{(w+m)}{V_m} - \frac{m}{V_m}} = \frac{V_m}{V_s},$$

i.e. the two factors are identical.

Aggregate

Hurtful materials in aggregate.

There are three broad categories of hurtful materials that may be found in aggregates : *impurities* which interfere with the processes of hydration of cement; *coatings* preventing the development of good bond between aggregate and the hydrated cement paste; and certain individual particles which are *weak* or *unsound* in themselves.
All or part of an aggregate can also be harmful through the development of chemical reactions between the aggregate and the cement paste.

1-Organic impurities : Natural aggregates may be sufficiently strong and resistant to wear and yet they may not be satisfactory for concrete-making if they contain organic impurities which interfere with the chemical reactions of hydration. The organic matter found in aggregate consists usually of products of decay of vegetable matter and appears in the form of organic soil. Such materials are more likely to be present in sand than in coarse aggregate.

Not all organic matter is harmful and it is best to check its effects by making actual compression test specimens. Generally, however, it saves time to ascertain first whether the amount of organic matter is sufficient to warrant further tests.

Aggregate

Hurtful materials in aggregate.

2- **Clay and other fine material.**

Although small amounts of dust are helpful in concrete, improving cohesiveness and reducing bleeding, excessive amounts may cause the aggregate particles to become coated with dust so that the necessary bonding between the particle and the cement matrix is not fully established. As a consequence the concrete will have poor durability and strength characteristics from early ages. Coatings of clay or other weak material can have similar effects.

There are two more types of fine material which can be present in aggregate: **silt** and **crusher dust**. Silt is material between 2 and 60 μm, reduced to this size by natural processes of weathering; silt may thus be found in aggregate won from natural deposits. On the other hand, crusher dust is a fine material formed during the process of comminution of rock into crushed stone or, less frequently, of gravel into crushed fine aggregate.

Aggregate

2- **Clay and other fine material.**

In a properly laid out processing plant, this dust should be removed by washing. Other soft or loosely adherent coatings can also be removed during the processing of the aggregate.
Well-bonded coatings cannot be so removed but, if they are chemically stable and have no deleterious effect, there is no objection to the use of aggregate with such a coating, although shrinkage may be increased. However, aggregates with chemically reactive coatings, even if physically stable, can lead to serious trouble.

Silt and fine dust may form coatings similar to those of clay, or may be present in the form of loose particles not bonded to the coarse aggregate.
Even when they are in the latter form, silt and fine dust should not be present in excessive quantities because, owing to their fineness and therefore large surface area, silt and fine dust increase the amount of water necessary to wet all the particles in the mix.

Aggregate

2- **Clay and other fine material.**

Therefore, it is necessary to control the clay, silt and fine dust contents of aggregate.

As no test is available to determine separately the clay content, this is not prescribed in British Standards. However, (BS EN 12620 : 2002) imposes a limit on the maximum amount of material passing the 75 μm (No.200) sieve: in coarse aggregate: 2 per cent, increased to 4 percent when it consists wholly of crushed rock; in fine aggregate: 4 per cent, increased to 16 percent when it consists wholly of crushed rock; and in all-in aggregate: 11 per cent.
For heavy duty floors, the limit is 9 percent.

Salt contamination

Sand won from the seashore or dredged from the sea or a river estuary, as well as desert sand, contains salt, and has to be processed.
Generally, sand from the sea bed, washed even in sea water, does not contain harmful quantities of salts.
Because of the danger of chloride-induced corrosion of steel reinforcement, BS 8110-1: 1997 (Structural use of concrete) specifies the maximum total chloride ion content in the mix.

for prestressed concrete	0.01
for reinforced concrete made with sulfate-resisting cement	0.03
for other reinforced concrete	0.05.

Aggregate

Unsound particles

The permissible quantities of unsound particles laid down by ASTM C 33-08 are summarized in Table below:

Type of particles	*Maximum content (per cent of mass)*	
	In fine aggregate	*In coarse aggregate*
Friable particles and clay lumps	3.0	3.0–10.0*
Coal	0.5–1.0†	0.5–1.0‡†
Chert that will readily disintegrate	—	3.0–8.0‡

*Including chert.
†Depending on importance of appearance.
‡Depending on exposure.

Aggregate

3. Alkali–silica reaction: deleterious aggregate reaction is that between the active silica constituents of the aggregate and the alkalis in cement. The reactive forms of silica are big size (amorphous), These reactive materials occur in: siliceous limestones.

The reaction starts with the attack on the siliceous minerals in the aggregate by the alkaline hydroxides in pore water derived from the alkalis (Na_2O and K_2O) in the cement. As a result, **an alkali-silicate gel** is formed, either in planes of weakness or pores in the aggregate.

Because the gel is confined by the surrounding hydrated cement paste, internal pressures result and may lead to expansion, cracking and disruption of the hydrated cement paste.

Aggregate

Thus, expansion appears to be due to hydraulic pressure ,but expansion can also be caused by the swelling pressure of the still solid products of the alkali-silica reaction. For this reason, the swelling of the hard aggregate particles that is most harmful to concrete.

The alkali–silica reaction occurs only in the presence of water. The minimum relative humidity in the interior of concrete for the reaction is about 85 % at 20 °C .

Higher temperature accelerates the progress of the alkali–silica reaction but does not increase the total expansion induced by the reaction, an increase in temperature lowers the solubility of $Ca(OH)_2$ and increases of silica.

Aggregate

Factors influencing the progress of alkali–aggregate reaction

1. the permeability of the hydrated cement paste because this controls the movement of water.
2. the alkali content and fineness of the cement, therefore using a cement with alkali content of not more than 0.6%.
3. aggregate particle size and porosity.
4. The number of wetting and drying cycles.
5. Ambient temperature from 10-38 increases the alkali–aggregate reaction.

Alkali–carbonate reaction

Another type of deleterious aggregate reaction is that between some dolomitic limestone aggregates and the alkalis in cement. The volume of the products of this reaction is smaller than the volume of the original materials so that the explanation for the deleterious reaction has to be sought in phenomena different from those involved in the alkali–silica reaction. It is likely that the gel which is formed is subject to swelling in a manner similar to swelling clays. Thus, under humid conditions, expansion of concrete takes place. Typically, reaction zones up to 2 mm are formed around the active aggregate particles. Cracking develops within these rims and leads to a network of cracks and a loss of bond between the aggregate and the cement paste.

Tests have shown that de-dolomitization, that is a change of dolomite, $CaMg(CO_3)_2$, into $CaCO_3$ and $Mg(OH)_2$, occurs.

Thanks For Your Listening

Al-Muthanna University
Engineering College
Civil Engineering Department

Concrete Technology

The 8th lecture

Sieve analysis of Aggregate

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2020 - 2019

Aggregate

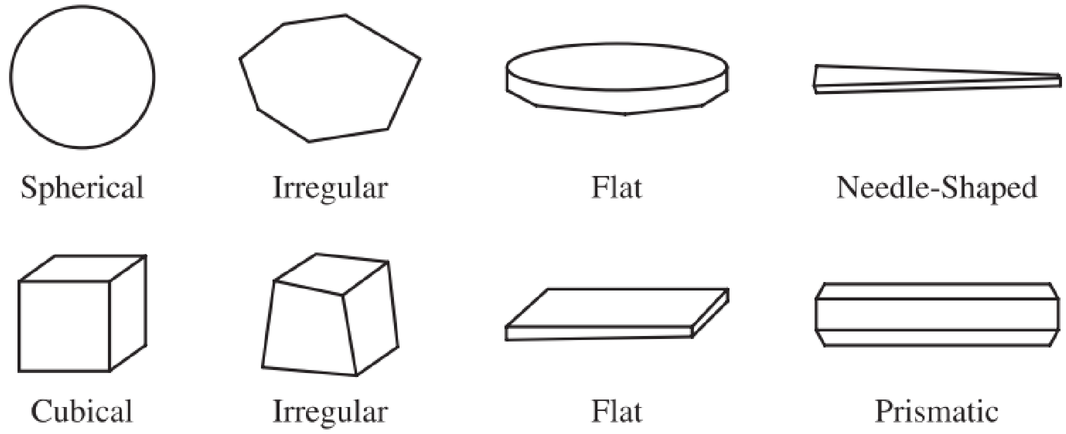
Shape and texture of aggregates.

The aggregate shape affects the workability of concrete due to the differences in surface area caused by different shapes. Sufficient paste is required to coat the aggregate to provide lubrication.

The typical shapes of aggregates are shown in Figure. Among these, spherical, cubical, and irregular shapes are good for application in concrete because they can benefit the strength.

Flat, needle-shaped, and prismatic aggregates are weak in load carrying ability and easily broken, because the surface-to-volume ratio of a spherical aggregate is the smallest.

Aggregate



The surface texture of aggregates has significant influence on the fluidity of fresh concrete and the bond between aggregate and cement paste of hardened concrete. And can be classified in 6 groups: glassy, smooth, granular, rough, crystalline, and honeycombed.

Aggregate

Soundness

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

The physical causes of large or permanent volume changes of aggregate are freezing and thawing, thermal changes at temperatures above freezing, and alternating wetting and drying, result in the deterioration of concrete.

Unsoundness is related to pore size distribution rather than to the total porosity of aggregate.

A British test for soundness of aggregate is prescribed in BS 812-121: 1989 (2000). This determines the proportion of aggregate broken up in consequence of five cycles of immersion in a saturated solution of magnesium sulfate alternating with oven drying. The original sample contains particles between 10.0 and 14.0 mm in size, and the mass of particles which remain larger than 10.0 mm, expressed as a percentage of the original mass, is called the soundness value.

The American test for soundness of aggregate is prescribed by ASTM C 88-05. A sample of graded aggregate is subjected alternately to immersion in a saturated solution of sodium or magnesium sulfate (the latter being the more severe of the two) and drying in an oven.

Aggregate

Maximum size of aggregate

The maximum size of aggregate is conventionally designated by the sieve size on which 15% or more particles are retained

Larger aggregate sizes is better from the point of economy and minimum surface area of cement paste. Another problem with larger materials is that, while the reduced surface area needs less wetting, it also provides less area for the paste to bond to the aggregate. This can lead to reduced cohesion. It also results in a higher bond stress, and may lead to weaker concrete.

The maximum aggregate size should not be larger than one-fifth of the narrowest dimension of the form in which the concrete is to be placed; also, it should not be larger than three-fourths of the maximum clear distance between the reinforcing bars. Larger particles of crushed rock will often be weaker than smaller particles of the same material.

As large particles tend to produce more microcracks in the interfacial transition zone between the coarse aggregate and cement paste, with high-strength concrete mixtures the maximum aggregate size is generally limited to 19 mm.

Aggregate

Fineness modulus is computed from screen analysis data by adding the cumulative percentages of aggregate retained on each of a specified series of sieves, and dividing the sum by 100, No. 100 (150 μm), No. 50 (300 μm), No. 30 (600 μm), No. 16 (1.18 mm), No. 8 (2.36 mm), No. 4 (4.75 mm), 3/8 in. (9.5 mm), 3/4 in. (19 mm), 11/2 in. (37.5) mm), it is often used as an index of the fineness of aggregate. And may be noted that the higher the fineness modulus, the coarser the aggregate.

Thermal properties

The expansion coefficient of cement paste is higher than that of aggregate. Because concrete consists mainly of aggregate, the thermal coefficient of expansion of concrete is largely determined by the coefficient of the aggregate and the aggregate content.

Angularity number رقم الحدة

angularity number = 67 - the percentage of solid volume in a compacted filled with aggregate in a standard manner.

The number 67 in the expression for the angularity number represents the percentage solid volume of the most rounded gravel.

The higher the number the more angular the aggregate, the range for practical aggregate being between 0 and 11. The test for angularity is rarely used, angular particles requiring more water for a given workability.

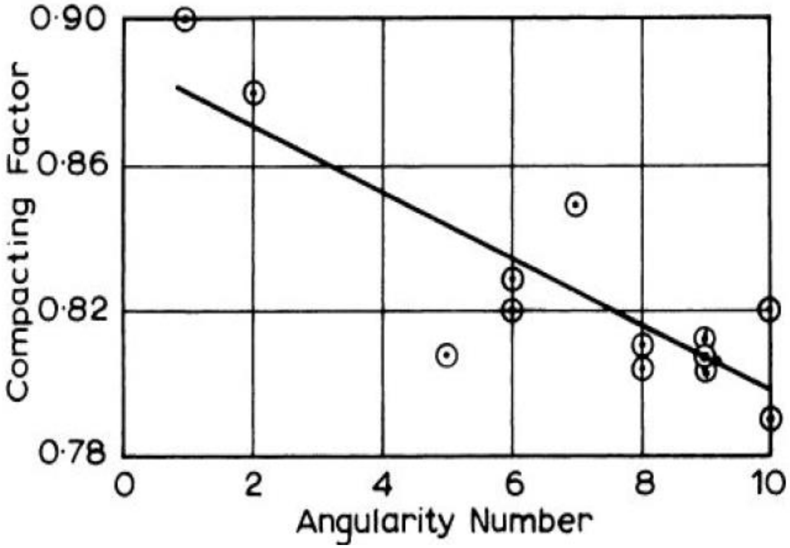


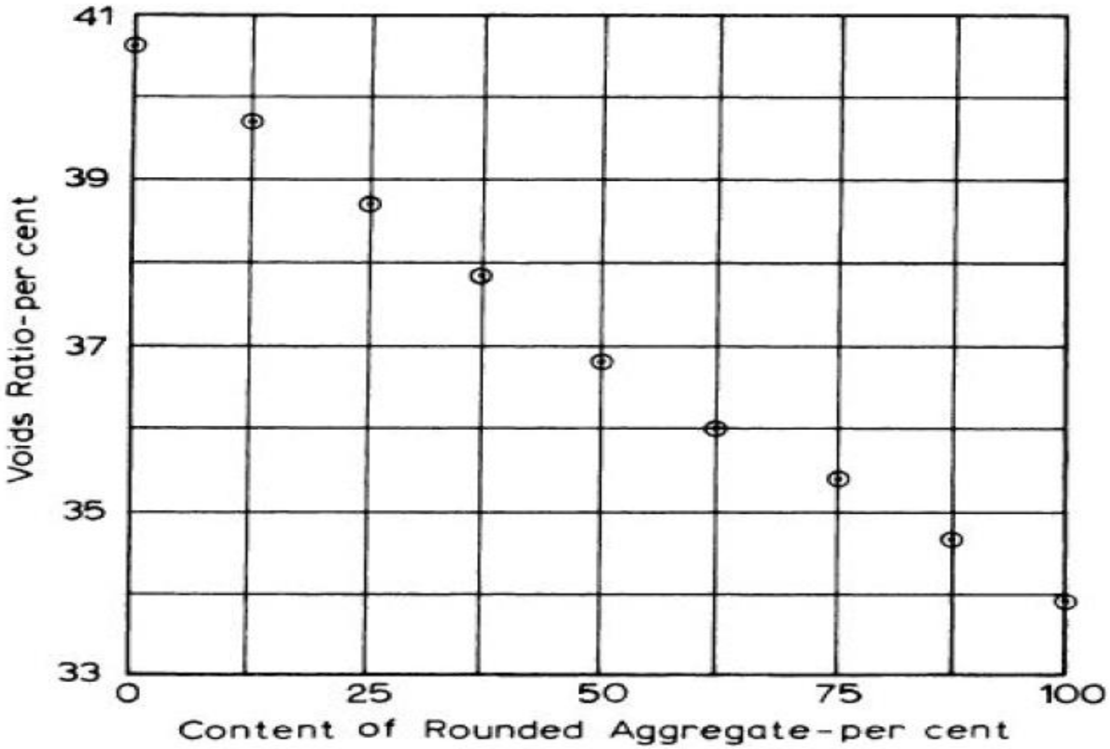
Figure. The relation between the angularity number of aggregate and the compacting factor of concrete

Aggregate

The void content of aggregate can be calculated from the change in the volume of air when decreased in the applied pressure; hence, the volume of air, i.e. the volume of space, can be calculated.

it can be seen that increasing the proportion of rounded particles decreases the percentage of voids. The volume of voids influences the density of the concrete.

Fig. 3.2. Influence of angularity of aggregate on voids.



Aggregate

Thermal properties of aggregate

There are three thermal properties of aggregate that may be significant in the performance of concrete: **coefficient of thermal expansion**, **specific heat**, and **conductivity**. The last two are of importance in mass concrete or where insulation is required, but not in ordinary structural work .

The coefficient of thermal expansion of aggregate influences the value of such a coefficient of concrete containing the given aggregate: the higher the coefficient of the aggregate the higher the coefficient of the concrete, but the latter depends also on the aggregate content in the mix and on the mix proportions in general.

There is, however, another aspect of the problem.

Nevertheless, when the two coefficients differ by more than 5.5×10^{-6} per °C the durability of concrete subjected to freezing and thawing may be affected.

The coefficient of thermal expansion can be determined by means of a dilatometer devised by Verbeck and Hass for use with both fine and coarse aggregate. The linear coefficient of thermal expansion varies with the type of parent rock.

Aggregate

Sieve analysis:

the operation of dividing a sample of aggregate into fractions, each consisting of particles of the same size. each fraction contains particles between specific limits, these being the openings of standard test sieves.

The test sieves used for concrete aggregate have square openings and their properties are prescribed by BS 410-1 and 2 : 2000 and ASTM E 11-09.Thus a No. 100 test sieve has 100 × 100 openings in each square inch.

The sieves used for concrete aggregate consist of a series in which the clear opening of any sieve is approximately one-half of the opening of the next larger sieve size. The BS test sieve sizes in Imperial units for this series were as follows: 3 in.,1.5 in., 0.75in., 3/8 in., 3/16 in., Nos. 7,14, 25, 52, 100, and 200, and results of tests on those sieves are still used.

Before the sieve analysis is performed, the aggregate sample has to be air-dried in order to avoid lumps of fine particles being classified as large particles and also to prevent clogging of the finer sieves.

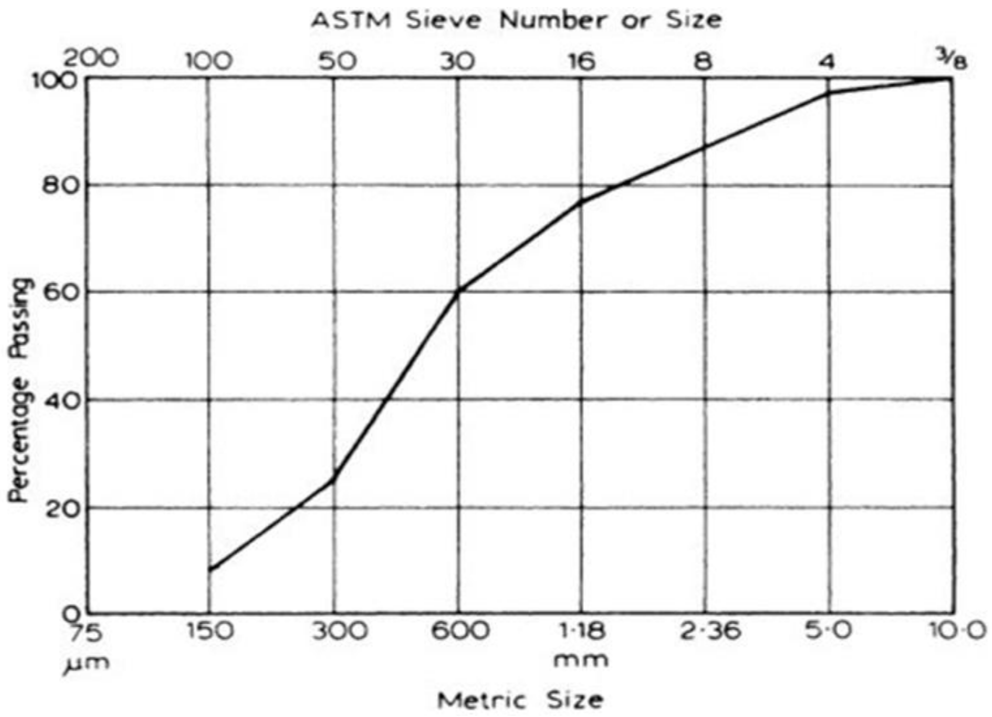
Aggregate

The results of a sieve analysis are best reported in tabular form, as shown in Table below .Column (2) shows the mass retained on each sieve. This is expressed as a percentage of the total mass of the sample and is shown in column (3). Now, working from the finest size upwards, the cumulative percentage (to the nearest 1 %) passing each sieve can be calculated (column (4)), and it is this percentage that is used in the plotting of grading curves.

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

Grading curves

The results of a sieve analysis can be much more easily if represented graphically. In the grading chart commonly used, the ordinates represent the cumulative percentage passing and the x-coordinate show the sieve opening plotted to a logarithmic scale. Since the openings of sieves in a standard series are in the ratio of 0.5



Aggregate

Fineness modulus

defined as 1/100 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.

the fineness modulus gives an indication of the probable behavior of a concrete mix made with aggregate having a certain grading, and the use of the fineness modulus of aggregates and in mix proportioning.

Aggregate

Grading requirements

Grading is important only as it affects workability, and achieving the strength corresponding to a given water/ cement ratio requires full compaction, it is necessary to produce a mix that can be compacted to a maximum density with a reasonable amount of work.

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- the relative volume occupied by the aggregate; the workability of the mix.

3- the tendency to segregation.

the easier it is for the particles of different sizes to pack, smaller particles passing into the voids between the larger ones, the easier it is for the small particles to be weaken of the voids.

There is a requirement for a mix to be satisfactorily **cohesive** and **workable**: it must contain a sufficient amount of material smaller than a 300 µm (No. 50 ASTM) sieve. Because the cement particles are included in this material,

If the grading of fine aggregate is such that it is deficient in finer particles, increasing the fine/coarse aggregate.

Aggregate

Practical Gradings

Important it is to use aggregate with a grading such that a reasonable workability and minimum segregation are obtained.

It should be remembered, however, that in practice the aggregate available locally or within an economic distance has to be used, and this can generally produce satisfactory concrete, given an intelligent approach and sufficient care.

In practice, the use of separate fine and coarse aggregate means that a grading can be made up to conform exactly with a type grading at one intermediate point, generally the 5 mm (3/16 in.) size.

Good agreement can usually also be obtained at the ends of the curve (150 μm (No. 100) sieve and the maximum size used). If coarse aggregate is delivered in single-size fractions, as is usually the case, agreement at additional points above 5 mm (3/16 in.) can be obtained, but for sizes below 5 mm (3/16 in.) blending of two or more fine aggregates is necessary.

Aggregate

Oversize and undersize

Strict adherence to size limits of aggregate is not possible: breakage during handling will produce some undersize material, and wear of screens in the quarry or at the crusher will result in oversize particles being present.

The grading requirements of BS 882: 1992 allow some under- and oversize for **coarse aggregate**.
The values show that between 5 and 10 per cent oversize is permitted.

For **fine aggregate**, BS 882: 1992 allows 11 percent oversize.

General grading requirements for coarse and fine aggregate are given in BS EN 12620: 2002 in terms of **upper sieve size D and lower sieve size d with $D/d \geq 1.4$.**

Aggregate

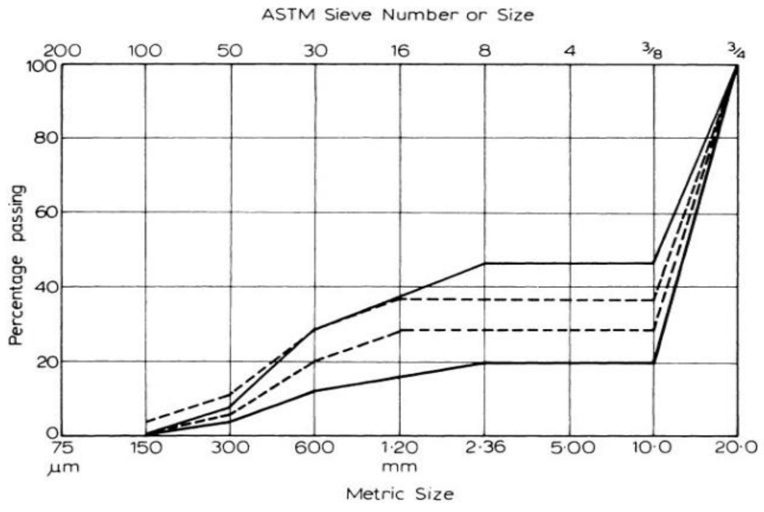
Gap-graded aggregate

defined as a grading in which one or more intermediate size fractions are omitted, On a grading curve, it is represented by a horizontal line over the range of sizes omitted.

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

aggregate particles of a given size pack form voids that can be penetrated only if the next smaller size of particles is sufficiently small, this means that there must be a minimum difference between the sizes of any two adjacent particle fractions.

For instance, the top grading curve of Fig below shows that no particles of size between 10 and 2.36 mm (No. 8 ASTM) sieve are present. In some cases, a gap between 10.0 and 1.18 mm (No. 16 ASTM) sieves is considered suitable. Omission of these sizes would reduce the number of stocks of aggregate required and lead to economy.



Aggregate

The particles smaller than 1.18 mm (No. 16 ASTM) sieve size could easily enter the voids in the coarse aggregate so that the workability of the mix would be higher than that of a continuously graded mix with the same fine aggregate content.

in the more workable range of mixes, gap-graded aggregate showed a greater proneness اكثر ميولة to segregation. For this reason, gap grading is recommended mainly for mixes of relatively low workability.
Gap-graded aggregate concrete is difficult to pump because of the danger of segregation.
gap-graded aggregate can be used in any concrete, but there are two cases of interest: preplaced aggregate concrete and exposed aggregate concrete.

Maximum aggregate size

larger maximum size is smaller the surface area and lowers the water requirement of the mix, so that, for a specified workability and cement content, the water/cement ratio can be lowered with a consequent increase in strength.

Aggregate

Grading of fine and coarse aggregates

The actual grading requirements depend, to some extent, on the shape and surface characteristics of the particles. For instance, sharp, angular particles with rough surfaces should have a slightly finer grading in order to reduce the possibility of interlocking and to compensate for the high friction between the particles. The actual grading of crushed aggregate is affected primarily by the type of crushing plant employed. A roll granulator usually produces fewer fines than other types of crushers, but the grading depends also on the amount of material fed into the crusher.

Grading of fine and coarse aggregates

grading curves were given as representing In BS 882, four grading zones were introduced. The division into zones was based primarily on the percentage passing the 600 μm (No. 30 ASTM) sieve.

The main reason for this was that a large number of natural sands divide themselves at just that size, the gradings above and below being approximately uniform.

The content of particles finer than the 600 μm (No. 30 ASTM) sieve has a considerable influence on the workability of the mix and provides a fairly reliable index of the overall specific surface of the sand.

Table below shown the BS 882 and ASTM C33 Grading Requirements for Fine Aggregate.

Sieve size		*Percentage by mass passing sieves*				
BS	*ASTM No.*	*BS 882 : 1992*				*ASTM C 33-08*
		Overall grading	*Coarse grading*	*Medium grading*	*Fine grading*	
10.0 mm	$\frac{3}{18}$ in.	100				100
5.0 mm	$\frac{3}{16}$ in.	89–100				95–100
2.36 mm	8	60–100	60–100	65–100	80–100	80–100
1.18 mm	16	30–100	30–90	45–100	70–100	50–85
600 μm	30	15–100	15–54	25–80	55–100	25–60
300 μm	50	5–70	5–40	5–48	5–70	5–30
150 μm	100	0–15*				0–10

Aggregate

Crushed fine aggregate tends to have different grading from most natural sands. Specifically, there is less material between 600 and 300 μm (Nos 30 and 50) sieve sizes.
The requirements of BS 882 : 1992 and ASTM C 33-08 for the grading of coarse aggregate are reproduced in Table below values are given both for graded aggregate and for nominal one-size fractions.

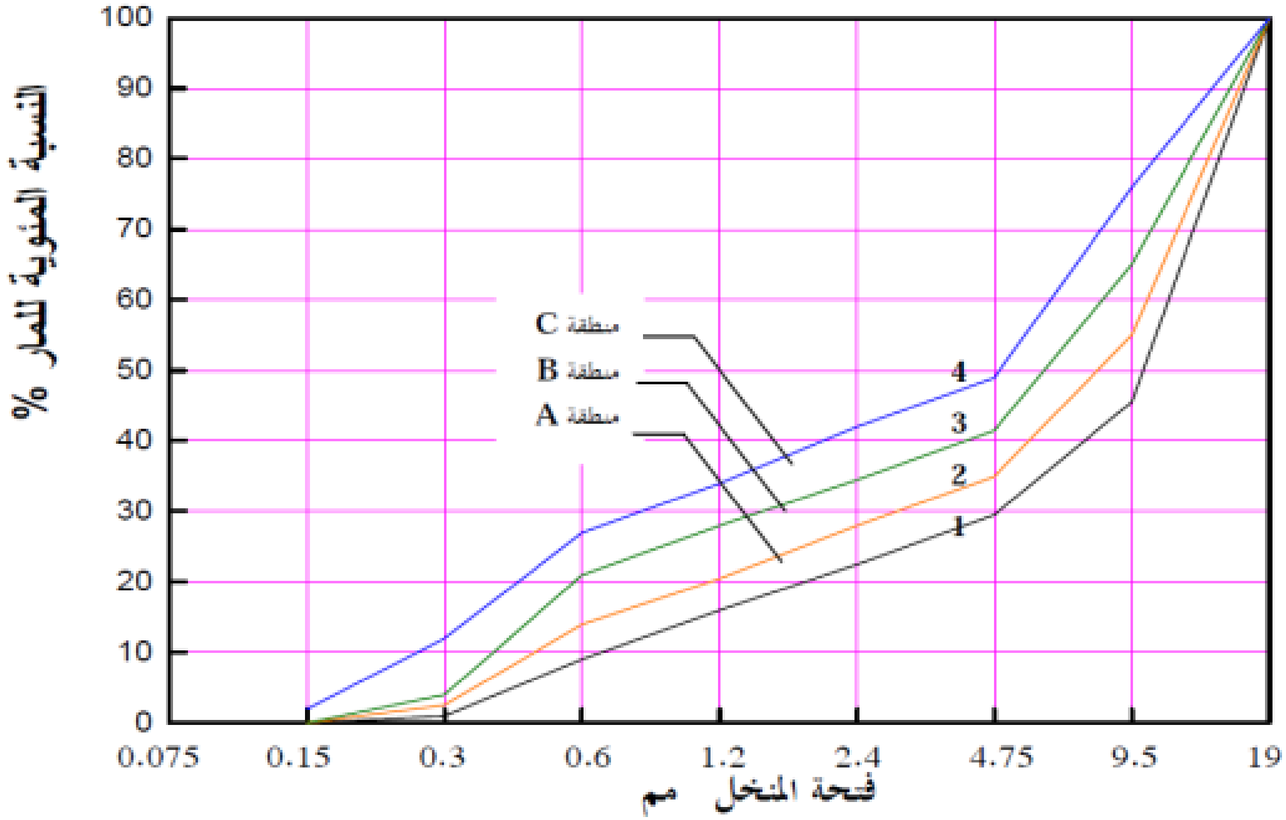
Sieve size		*Percentage by mass passing BS sieves*						
mm	*in.*	*Nominal size of graded aggregate*			*Nominal size of single-sized aggregate*			
		40 to 5 mm *$1\frac{1}{2}$ in. to $\frac{3}{16}$ in.*	*20 to 5 mm* *$\frac{3}{4}$ in. to $\frac{3}{16}$ in.*	*14 to 5 mm* *$\frac{1}{2}$ in. to $\frac{3}{16}$ in.*	*40 mm* *$1\frac{1}{2}$ in.*	*20 mm* *$\frac{3}{4}$ in.*	*14 mm* *$\frac{1}{2}$ in.*	*10 mm* *$\frac{3}{8}$ in.*
50.0	2	100	—	—	100	—	—	—
37.5	$1\frac{1}{2}$	90–100	100	—	85–100	100	—	—
20.0	$\frac{3}{4}$	35–70	90–100	100	0–25	85–100	100	—
14.0	$\frac{1}{2}$	25–55	40–80	90–100	—	0–70	85–100	100
10.0	$\frac{3}{8}$	10–40	30–60	50–85	0–5	0–25	0–50	85–100
5.0	$\frac{3}{16}$	0–5	0–10	0–10	—	0–5	0–10	0–25
2.36	No. 8	—	—	—	—	—	—	0–5

Aggregate

Sieve size		Percentage by mass passing sieves				
mm	in.	Nominal size of graded aggregate			Nominal size of single-sized aggregate	
		37.5 to 4.75 mm $1\frac{1}{2}$ in. to $\frac{3}{16}$ in.	19.0 to 4.75 mm $\frac{3}{4}$ in. to $\frac{3}{16}$ in.	12.5 to 4.75 mm $\frac{1}{2}$ in. to $\frac{3}{16}$ in.	63 mm $2\frac{1}{2}$ in.	37.5 mm $1\frac{1}{2}$ in.
75	3	—	—	—	100	—
63.0	$2\frac{1}{2}$	—	—	—	90–100	—
50.0	2	100	—	—	35–70	100
38.1	$1\frac{1}{2}$	95–100	—	—	0–15	90–100
25.0	1	—	100	—	—	20–55
19.0	$\frac{3}{4}$	35–70	90–100	100	0–5	0–15
12.5	$\frac{1}{2}$	—	—	90–100	—	—
9.5	$\frac{3}{8}$	10–30	20–55	40–70	—	0–5
4.75	$\frac{3}{16}$	0–5	0–10	0–15	—	—
2.36	No. 8	—	0–5	0–5	—	—

In practice the aggregates near the work site should be used .The curves shown below are used as a comparison tool for the aggregate available for concrete work, as the shapes include four slope curves (the first curve represents the aggregates and the latter represents the fine aggregates.

Aggregate



منحنيات التدرج للركام ذو مقاس أقصى 19.5ملم

Thanks For Your Listening

Al-Muthanna University
Engineering College
Civil Engineering Department

Concrete Technology

The 9th lecture

Composition of Concrete

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للعام الدراسي

2020 - 2019

Concrete

General Information about Composition of Concrete

Concrete:

Concrete is a non-homogeneous mixture of aggregate, cement and water with some pores, and some other materials (additives) can be added to obtain certain properties.

The proportions of these materials in the concrete mixture are chosen according to the type of work required and the available materials, and when mixing these materials together, concrete is obtained that begins with gradual hardening over time until it becomes solid and strong, and its strength varies according to the main components as well as the method of vibrating during casting and the type of curing.

Concrete

Concrete components:

1. Cement

It is a fine, dark-colored material that have cohesive and adhesive properties in the presence of water, which makes it able to bind the components of concrete together and bond with reinforcing bars and turn them into a complete interconnected unit.

Cement consists of three main raw materials:

calcium carbonate in limestone, **silica in clay and sand**, and **alumina (aluminum oxide).**

Cement has the property of setting and hardening due to chemical reactions and the presence of water, so it is known as hydraulic cement. Portland cement was discovered by the English builder Joseph Aspden in 1824 by burning a mixture of clay and hard limestone finely in the oven and named Portland cement relative to the island of Portland, England, which contains building stones of the same color and quality of portland cement.

Concrete

Types of cement:

There are several types of cement that take their name from their purpose and necessity to use them, but their main components remain one even if their percentage differs from one type to another, and the most important of these types are:

- Ordinary portland cement,
- Rapid-hardening Portland cement,
- low heat Portland cement,
- Sulfate Resistant Portland Cement ,
- alumina cement ... etc.

Concrete

The main components of ordinary Portland cement:

1. Tri-calcium silicate (C_3S) with a ratio of 45 - 55%, which is responsible for giving strength to concrete during the first 28 days.
2. Di-calcium silicate (C_2S), with a percentage of 15-25%, which is responsible for the self-healing phenomenon, as it closes the capillary cracks in the mortar and in the concrete, as well as the tensile strength of the concrete.
3. Tri-calcium aluminate (C_3A), ranging from 12-15%, reacts quickly when mixing and emits high heat, so it gives concrete its strength in the first day, but it does not affect the final strength of the concrete.
4. Tetra-calcium Alumina ferrite (C_4AF), ranging from 7 - 12%, reacts in the first days and gives high heat, but it is slower than tri-calcium aluminate.
5. In addition to the previous components, cement contains secondary compounds in the form of oxides such as potassium oxides, sodium, magnesium, titanium and sulfur dioxide, and these compounds constitute a small percentage of the weight of the cement.

2. Aggregate

The quality and properties of aggregates have a great influence on the properties of concrete and its quality because it occupies about (70 - 75)% of the total volume of the concrete mass. Aggregates are generally composed of rocky grains of gradual size, including small grains such as **sand** and the other large grains such as **gravel**.

In addition to the fact that the aggregate forms the bulk of the concrete structure, which gives the concrete structure its stability and resistance to external forces and various weather factors such as temperature, humidity and freezing, it reduces the volumetric changes resulting from the freezing and hardening of the cement paste or from the exposure of the concrete to moisture and dryness, therefore the aggregate gives the concrete better durability than if cement paste was used alone. From what has been previously mentioned, it is clear that the properties of aggregates greatly affect the durability and behavior of the concrete structure.

Concrete

When choosing aggregates for use in certain concrete, attention should be paid in general to three requirements: **the economy of the mixture**, the **inherent resistance of the hardened mass**, and **the potential strength of the concrete structure**.

Another important characteristic of concrete aggregates is the **gradation of its particls**. For the purpose of obtaining a dense concrete structure, the gradation of aggregates must be appropriate by determining the proportion of fine and coarse aggregates in the mixture.

In addition, the gradation of aggregate particls is an important factor in controlling the **workability of fresh concrete**, when determining the amount of aggregate present in the volume unit of concrete, the workability of the mixture is better when the aggregates are listed appropriate and thus the need for the amount of water required for the mixture is less, which leads to an increase in concrete strength. And the aggregate also affects the total cost of concrete.

Concrete

In general, the greater the amount of aggregates in a certain volume of concrete, the more economical the producing concrete will be, because the aggregates are cheaper than cement, and for the purpose of obtaining durable concrete, its aggregates must be distinguished by not being affected by various weather factors such as heat, cold and freezing, which lead to the disintegration of the aggregate. Also, there should be no harmful interaction between the aggregate minerals and cement compounds, in addition to the necessity to be free of clay and impure materials that affect the strength and stability of the cement paste, and the aggregate must be clean, strong, resistant to crushing and impact, and suitable in terms of absorption with an appropriate shape and texture and is not compatible dissolvable, and resistant to abrasion.

Concrete

Requirements for aggregates:

1. The aggregate particles should be semi-spherical and non-flattened, and preferably multifaceted.
2. Absorption rate should not exceed 5%.
3. The apparent specific gravity should not be less than 2.35.
4. The weight loss percentage of the aggregates when carrying out the stability test should not exceed 10-12% of the weight.
5. Aggregates used in concrete mixes should be graded within the limits of the overall gradient curves.
6. Aggregates must be washed before use to ensure that they are free of organic matter and harmful salts.

Concrete

3. Water

the importance of water:

1. Water is necessary to take place for the chemical reaction between the cement and the water
2. It is also necessary for the aggregate used in concrete to absorb it.
3. water gives the mixture of fine and coarse aggregate and cement an adequate degree of ductility that helps it to workability.
4. With water, a greater amount of aggregate can be mixed with the same amount of cement.
5. The water gives a volume of concrete ranging between 15-20%.
6. Part of the water in the concrete mixture is lost during the evaporation process.
7. Water is necessary for concrete curing processes during its hardening.

Properties of water used in concrete

1. The water used in mixing and treating concrete shall be free from harmful materials such as oils, greases, salts, acids, alkalis, organic materials, cork and fine materials, whether these materials are dissolved or suspended and other than materials that have an adverse effect on concrete in terms of fracture strength and durability.
2. Pure drinking water is suitable for mixing and curing concrete.
3. It is permitted to use non-potable water in the absence of potable water, provided that the concentration of impurities in it does not exceed certain percentages determined by the specifications.

4. Additions

Additives are materials or combinations of several materials that are added to concrete during mixing to improve one or more properties of the concrete mixture.

The benefits of using additives in concrete mixtures:

1. Improve the workability of the fresh concrete.
2. Accelerate hardening to obtain high strength in a short time.
3. Slow down the hardening process in hot climates or long-distance transportation.
4. Reduce heat generated and reduce Bleeding.
5. Improve corrosion resistance and reduce shrinkage during hardening.
6. Preventing corrosion.

Thanks For Your Listening

Al-Muthanna University
Engineering College
Civil Engineering Department

Concrete Technology

The 10th lecture
Mix Design - 1

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2020 - 2019

Design concrete mixes

Introduction

Designing concrete mixtures means determining the proportioning values of their components in accordance with the desired requirements of a particular job. This is done using empirical proportioning, and it may be by means of calculation based on a technical basis that include the properties of the materials used and the properties required in the hardened concrete (such as the extent of resistance to loads or resistance to abrasion) and the requirements for concrete manufacturing steps such as the placing and finishing the surface of concrete, taking into account the economic costs according to the type of construction work required.

Design concrete mixes

These computational methods aim to use the existing materials (available materials) in order to obtain from them concrete with the properties required in both fresh and hardened states, at the lowest costs (qualities at minimum cost). It can be considered that the strength of concrete to pressure indicates the quality of the hardened concrete, as well as the value of the slump indicates that the fresh concrete is good. Determining the proportions of the concrete mixture is considered one of the most important factors affecting the quality of concrete and the economics of the project. It is possible to obtain different types of concrete in terms of quality and price, even though they are all made of the same materials. The relative economy of concrete mixes depends on the prices of their components and on the wages of workers and the transportation costs of those components. Cement is one of the basic components of concrete, and the percentage of its presence in the mixture greatly affects its costs due to its high price in relation to the rest of the components.

Design concrete mixes

Expressing proportion of concrete components

The components of granular concrete, which are cement, small aggregates, and big aggregates are usually shown in the form of ratios by weight or volume, for example:

when a mixture of **1: 2: 4** is said to mean:

Cement: sand: gravel

1: 2: 4

That is, it contains a part of cement, two parts of sand and four of gravel, and it is preferable that these proportions be by weight because it is not possible to accurately determine the amount of cement by volume, as well as aggregates as a result of changing the amount that a certain size absorbs by changing the extent of compacting used. Also, small aggregates may change their size with an apparent effect the volume increases (bulking) by moisture.

Design concrete mixes

The granular materials have been shown as a ratio between cement and aggregate mixture (cement / aggregate ratio), for example, **1: 6** mixture, meaning one part cement and six parts aggregate by weight, and this ratio shows the richness of the lack of concrete (rich or lean mix), so the **1: 4** mixture is considered a **rich mixture**. The mixture **1: 8** is considered a **poor mixture**.

The proportions of granular materials have been indicated by what is contained in a cubic meter of fresh concrete of cement, small aggregates and big aggregates, provided that the cement is indicated by weight and aggregates by volume in order to facilitate the preparation of quantities when mixing, for example the following mixture:

Cement:	**sand:**	**gravel**
300 kg (6 bags of cement):	**0.4 m3:**	**0.8 m3**

Note: Weight of cement bag = 50 kg.

The sum of these quantities gives approximately one cubic meter of fresh concrete after mixing it with water.

Design concrete mixes

The amount of water needed for the mixture is indicated in the form of a percentage of cement by weight, for example, a mixture with the ratio of water to cement = **0.5** by weight, so if the weight of cement is known in the cubic meter of fresh concrete, the weight of the water needed for it to be mixed can be set, and thus the volume of that water can be determined in liters. And sometimes it may indicate the amount of mixing water needed for a cubic meter of fresh concrete directly, for example a mixture:

Cement:	Sand:	Gravel:	Water
300 kg:	**0.4 m3:**	**0.8 m3:**	**150 liters**.

Design concrete mixes

Specifications for mix design

The limiting values is covered a range of properties:-

1. 'Minimum' compressive strength necessary from structural considerations.
2. Maximum water/cement ratio and/or minimum cement content.
3. Maximum cement content to avoid shrinkage cracking under conditions of exposure to a low humidity.
4. Minimum density for gravity.
5. Minimum density for gravity dams and similar structures.

The calculated aggregate in mix design in saturated surface dry state, If mixing aggregate in **dry state** and has absorption moisture whose is say, **m %** of the mass of the dry aggregate, then multiply the calculated aggregate by (100/100+m) and the value of the mass water must be added to mixing water in order to not absorbed from mixing water.

Design concrete mixes

Example

The percentage absorption of fine aggregate is 2% ,and coarse aggregate 1% and the weight of fine and coarse aggregate 25.7 Kg and 69.2 Kg ,determined the weight of water must be added to the mix water ?

Solution

Weight of dry fine aggregate = (100/102) x 25.7 = 25.2 Kg

Weight of dry coarse aggregate = (100/101) x 69.2 = 68.5 Kg

Added absorption Water = (25.7-25.2) +(69.2-68.5) = 0.7+0.5 = 1.2 Kg

Design concrete mixes

American method of selection of mix proportions
The ACI Standard Practice ACI 211.1-91 describes a method of selection of mix proportions of concrete containing Portland cement alone or together with other cementitious materials, and containing also admixtures.

Step 1: Choice of slump
It should be noted that slump should be specified not only at the minimum end, but a maximum value should also be specified. This is necessary to avoid segregation.

Step 2: Choice of maximum size of aggregate usually by the structural designer, the geometric requirements of member size and spacing of reinforcement, or alternatively for reasons of availability.

Design concrete mixes

Step 3: Estimate of water content and air content

the water content required to produce a given slump depends on several factors:

1- the maximum size of aggregate, its shape, texture, and grading.

2- the content of entrained air.

3- the use of admixtures with plasticizing or water-reducing properties.

4- the temperature of concrete.

a selection of these is given in Table 1.

Slump, mm	*Water, kg/m³ of concrete for indicated nominal maximum sizes of aggregate*							
	9.5	*12.5*	*19*	*25*	*37.5*	*50*	*75*	*150*
Non-air-entrained concrete								
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	—
Amount of entrapped air, per cent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25 to 50	181	175	168	160	150	142	122	107
75 to 100	202	193	184	175	165	157	133	119
150 to 175	216	205	197	184	174	166	154	—
Total air content, (per cent) for:								
Improvement of workability	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
Extreme exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Step 4: Selection of water/cement ratio

Table 2 gives the optimum values of the water/ cement ratio by mass for non-air entraining concrete and air entraining concrete according to compressive strength at 28-days

Table 3-1 Relation between *w/c* and average compressive strength of concrete, according to ACI 211.1-81

Average Compressive Strength at 28 Days[a] (MPa)	Effective Water/Cement Ratio (by Mass)	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
45	0.38	—
40	0.43	—
35	0.48	0.40
30	0.55	0.48
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

Step 5: Calculation of cement content

The outcome of Steps 3 and 4 gives the cement content directly: it is the water content divided by the water/cement ratio.

Step 6: Estimate of coarse aggregate content

the optimum ratio of the bulk volume of coarse aggregate to the total volume of concrete depends only on the maximum size of aggregate and on the grading of fine aggregate. Table 3 gives values of the optimum volume of coarse aggregate when used with fine aggregates of different fineness moduli.

This volume is converted into mass of coarse aggregate per cubic meter of concrete by multiplying the value from the table by the oven-dry rodded mass of the aggregate (in kg/m3).

Table 3. Bulk Volume of Coarse Aggregate per Unit Volume of Concrete

Maximum size of aggregate		*Bulk volume of oven-dry rodded coarse aggregate per unit volume of concrete for fineness modulus of fine aggregate of:*			
mm	*in.*	*2.40*	*2.60*	*2.80*	*3.00*
9.5	$\frac{3}{8}$	0.50	0.48	0.46	0.44
12.5	$\frac{1}{2}$	0.59	0.57	0.55	0.53
20	$\frac{3}{4}$	0.66	0.64	0.62	0.60
25	1	0.71	0.69	0.67	0.65
37.5	$1\frac{1}{2}$	0.75	0.73	0.71	0.69
50	2	0.78	0.76	0.74	0.72
75	3	0.82	0.80	0.78	0.76
150	6	0.87	0.85	0.83	0.81

Design concrete mixes

Step 7: Estimate of fine aggregate content

The absolute volume of the mass of fine aggregate can be obtained by subtracting the sum of the absolute volumes of water, cement, entrained air, and coarse aggregate from the volume of concrete, that is, 1 m3.

For each ingredient, the absolute volume is equal to the mass divided by the absolute density of the material (kg/m^3).

the absolute density is the specific gravity of the material multiplied by the density of water ($1000\ kg/m^3$).

The absolute volume of fine aggregate is converted into mass by multiplying this volume by the specific gravity of the fine aggregate and by the density of water.

the mass of fine aggregate can be obtained directly by subtracting the total mass of other ingredients from the mass of a unit volume of concrete.

Step 8: Adjustments to mix proportions

if workability is to be changed, but the strength is to remain unaffected, the water/cement ratio must remain unchanged, changes can be made in the aggregate/ cement ratio or, if suitable aggregates are available, in the grading of the aggregate.

Example

A mix with a mean 28-day compressive strength of 35 MPa and a slump of 50 mm, ordinary cement being used. The maximum size of well shaped, angular aggregate is 20 mm, its bulk density is 1600 kg/m3, and its specific gravity is 2.64. The available fine aggregate has a fineness modulus of 2.60 and a specific gravity of 2.58. No-air entrainment is required.

Solution

Step 1: A slump of 50 mm is specified.

Step 2: The maximum size of aggregate of 20 mm is specified

Design concrete mixes

Step 3: From Table 1, for a slump of 50 mm and a maximum size of aggregate of 20 mm (or 19 mm), the water requirement is approximately190 kg /m3 of concrete.

Step 4: a water/cement ratio of 0.48 is expected to result in concrete with a compressive strength, measured on cylinders, of 35 MPa. From table 3-1

Step 5: The cement content is 190/0.48 = 395 kg/m3.

Step 6: From Table 2, when used with a fine aggregate having a fineness modulus of 2.60, the bulk volume of oven-dry rodded coarse aggregate with a maximum size of 20 mm is 0.64. Given that the bulk density of the coarse aggregate is 1600 kg/m3, the mass of coarse aggregate is 0.64 × 1600 = 1020 kg/m3.

Step 7: To calculate the mass of fine aggregate, we need first to calculate the volume of all the other ingredients. The required values are as follows

Design concrete mixes

Volume of water is 190/1000	$= 0.190\ m^3$
Solid volume of cement, assuming usual specific gravity of 3.15, is $395/(3.15 \times 1000)$	$= 0.126\ m^3$
Solid volume of coarse aggregate is $1020/(2.64 \times 1000)$	$= 0.396\ m^3$
Volume of entrapped air, given in Table 1 , is 0.02×1000	$= 0.020\ m^3$
Hence, total volume of all ingredients except fine aggregate	$= 0.732\ m^3$
Therefore, the required volume of fine aggregate is $1.000 - 0.732$	$= 0.268\ m^3$
Hence, the mass of fine aggregate is $0.268 \times 2.58 \times 1000$	$= 690\ kg/m^3$.

From the various steps, we can list the estimated mass of each of the ingredients in kilograms per cubic meter of concrete as follows:

Water	190
Cement	395
Coarse aggregate, dry	1020
Fine aggregate, dry	690
Therefore, the density of concrete is	$2295\ kg/m^3$.

Design concrete mixes

H.W

A mix with a mean 28-day compressive strength of 45 MPa and a slump of 85 mm, ordinary cement being used. The maximum size of well-shaped, angular aggregate is 12.5 mm, its bulk density is 1600 kg/m3, and its specific gravity is 2.64. The available fine aggregate has a fineness modulus of 2.60 and a specific gravity of 2.58. No-air entrainment is required. The percentage absorption of fine aggregate is 1.5% ,and coarse aggregate 2.5%

Thanks For Your Listening

Al-Muthanna University
Engineering College
Civil Engineering Department

Concrete Technology

The 11th lecture
Mix Design - 2

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2020 - 2019

Design concrete mixes

American method of selection of mix proportions
The ACI Standard Practice ACI 211.1-91 describes a method of selection of mix proportions of concrete containing Portland cement alone or together with other cementitious materials, and containing also admixtures.

Step 1: Choice of slump
It should be noted that slump should be specified not only at the minimum end, but a maximum value should also be specified. This is necessary to avoid segregation.

Step 2: Choice of **maximum size of aggregate** usually by the structural designer, the geometric requirements of member size and spacing of reinforcement, or alternatively for reasons of availability.

Design concrete mixes

Step 3: Estimate of ***water content*** and air content (**Table 1**)

Slump, mm	**Water, kg/m3 of concrete for indicated nominal maximum size of aggregate**							
	9.5	12.5	19	25	37.5	50	75	150
Non-air-entrained concrete								
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	-
Amount of entrapped air, %	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25-50	181	175	168	160	150	142	122	107
75-100	202	193	184	175	165	157	133	119
150-175	216	205	197	184	174	166	154	-
Total air content, (%) for:								
Improvement of workability	4.5	4	3.5	3	2.5	2	1.5	1
Moderate exposure	6	5.5	5	4.5	4.5	4	3.5	3
Extreme exposure	7.5	7	6	6	5.5	5	4.5	4

Step 4: Selection of *water/cement ratio*

Table 2 gives the optimum values of the water/ cement ratio by mass for non-air entraining concrete and air entraining concrete according to compressive strength at 28-days

Table 2 Relation between *w/c* and average compressive strength of concrete, according to ACI 211.1-81

Average Compressive Strength at 28 Days[a] (MPa)	Effective Water/Cement Ratio (by Mass)	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
45	0.38	—
40	0.43	—
35	0.48	0.40
30	0.55	0.48
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

Step 5: Calculation of cement content

The outcome of Steps 3 and 4 gives the cement content directly: it is the water content divided by the water/cement ratio.

Step 6: Estimate of *coarse aggregate content (Table 3)*

Maximum size of aggregate		Bulk volume of oven-dry rodded coarse aggregate per unit volume of concrete for fineness modulus of fine aggregate of:			
mm	*in.*	*2.40*	*2.60*	*2.80*	*3.00*
9.5	$\frac{3}{8}$	0.50	0.48	0.46	0.44
12.5	$\frac{1}{2}$	0.59	0.57	0.55	0.53
20	$\frac{3}{4}$	0.66	0.64	0.62	0.60
25	1	0.71	0.69	0.67	0.65
37.5	$1\frac{1}{2}$	0.75	0.73	0.71	0.69
50	2	0.78	0.76	0.74	0.72
75	3	0.82	0.80	0.78	0.76
150	6	0.87	0.85	0.83	0.81

Design concrete mixes

Step 7: Estimate of *fine aggregate content*

The absolute volume of the mass of fine aggregate can be obtained by subtracting the sum of the absolute volumes of water, cement, entrained air, and coarse aggregate from the volume of concrete, that is, 1 m3.

For each ingredient, the absolute volume is equal to the mass divided by the absolute density of the material (kg/m^3).

the absolute density is the specific gravity of the material multiplied by the density of water (1000 kg/m^3).

The absolute volume of fine aggregate is converted into mass by multiplying this volume by the specific gravity of the fine aggregate and by the density of water.
the mass of fine aggregate can be obtained directly by subtracting the total mass of other ingredients from the mass of a unit volume of concrete.

Step 7: Estimate of *fine aggregate content (Table 4).*

Max aggregate size	Weight of concrete (kg/m3)	
	No-air entrained concrete	air entrained concrete
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2506	2435

Step 8: Adjustments to mix proportions

if workability is to be changed, but the strength is to remain unaffected, the water/cement ratio must remain unchanged, changes can be made in the aggregate/ cement ratio or, if suitable aggregates are available, in the grading of the aggregate.

Design concrete mixes

Example 1:

A mix with a mean 28-day compressive strength of 35 MPa and a slump of 50 mm, ordinary cement being used. The maximum size of well shaped, angular aggregate is 20 mm, its bulk density is 1600 kg/m3, and its specific gravity is 2.64. The available fine aggregate has a fineness modulus of 2.60 and a specific gravity of 2.58. No-air entrainment is required.

Solution

Step 1: A slump of 50 mm is specified.

Step 2: The maximum size of aggregate of 20 mm is specified

Design concrete mixes

Step 3: From Table 1, for a slump of 50 mm and a maximum size of aggregate of 20 mm (or 19 mm), the **water requirement is approximately190 kg /m3 of concrete**.

Slump, mm	Water, kg/m3 of concrete for indicated nominal maximum size of aggregate							
	9.5	12.5	19	25	37.5	50	75	150
Non-air-entrained concrete								
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	-
Amount of entrapped air, %	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25-50	181	175	168	160	150	142	122	107
75-100	202	193	184	175	165	157	133	119
150-175	216	205	197	184	174	166	154	-
Total air content, (%) for:								
Improvement of workability	4.5	4	3.5	3	2.5	2	1.5	1
Moderate exposure	6	5.5	5	4.5	4.5	4	3.5	3
Extreme exposure	7.5	7	6	6	5.5	5	4.5	4

Design concrete mixes

Step 3: **water =190 kg /m3 of concrete**.

Step 4: From Table 2, **a water/cement ratio = 0.48,** measured on cylinders, of 35 MPa. .

Table 2 Relation between *w/c* and average compressive strength of concrete, according to ACI 211.1-81

Average Compressive Strength at 28 Days[a] (MPa)	Effective Water/Cement Ratio (by Mass)	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
45	0.38	—
40	0.43	—
35	0.48	0.40
30	0.55	0.48
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

Step 5: The **cement content is 190/0.48 = 395 kg/m3**.

Design concrete mixes

Step 6: From Table 3,
fineness modulus of 2.60,
maximum size of 20 mm
the bulk density of the coarse aggregate is 1600 kg/m3,

the bulk volume of oven-dry rodded coarse aggregate = 0.64
the mass of **coarse aggregate is 0.64 × 1600 = 1020 kg/m3.**

Maximum size of aggregate		*Bulk volume of oven-dry rodded coarse aggregate per unit volume of concrete for fineness modulus of fine aggregate of:*			
mm	*in.*	*2.40*	*2.60*	*2.80*	*3.00*
9.5	$\frac{3}{8}$	0.50	0.48	0.46	0.44
12.5	$\frac{1}{2}$	0.59	0.57	0.55	0.53
20	$\frac{3}{4}$	0.66	0.64	0.62	0.60
25	1	0.71	0.69	0.67	0.65
37.5	$1\frac{1}{2}$	0.75	0.73	0.71	0.69
50	2	0.78	0.76	0.74	0.72
75	3	0.82	0.80	0.78	0.76
150	6	0.87	0.85	0.83	0.81

Step 7: To calculate the mass of fine aggregate, we need first to calculate the volume of all the other ingredients. The required values are as follows

Volume of water is 190/1000	= 0.190 m^3
Solid volume of cement, assuming usual specific gravity of 3.15, is 395/(3.15 × 1000)	= 0.126 m^3
Solid volume of coarse aggregate is 1020/(2.64 × 1000)	= 0.396 m^3
Volume of entrapped air, given in Table 1 , is 0.02 × 1000	= 0.020 m^3
Hence, total volume of all ingredients except fine aggregate	= 0.732 m^3
Therefore, the required volume of fine aggregate is 1.000 – 0.732	= 0.268 m^3
Hence, the mass of fine aggregate is 0.268 × 2.58 × 1000	= 690 kg/m^3.

From the various steps, we can list the estimated mass of each of the ingredients in kilograms per cubic meter of concrete as follows:

Water	190
Cement	395
Coarse aggregate, dry	1020
Fine aggregate, dry	690
Therefore, the density of concrete is	2295 kg/m^3.

Example 2:

A mix with a mean 28-day compressive strength of 25 MPa and a slump of 75 - 100 mm, ordinary cement being used. The maximum size of well shaped, angular aggregate is 40 mm, its bulk density is 1600 kg/m3, and its specific gravity is 2.64. The available fine aggregate has a fineness modulus of 2.80 and a specific gravity of 2.58. The percentage absorption of fine aggregate is 7% ,and coarse aggregate 5%. No-air entrainment is required.

Solution

Step 1: A slump of 75 - 100 mm is specified.

Step 2: The maximum size of aggregate of 40 mm is specified

Step 3: From Table 1, for a slump of 50 mm and a maximum size of aggregate of 40 mm, the **water requirement is approximately178 kg /m3 of concrete**.

Design concrete mixes

Example 2:

Solution

Step 3: From Table 1,

water requirement = 178 kg /m3 of concrete.

Slump, mm	Water, kg/m3 of concrete for indicated nominal maximum size of aggregate							
	9.5	12.5	19	25	37.5	50	75	150
Non-air-entrained concrete								
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	-
Amount of entrapped air, %	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25-50	181	175	168	160	150	142	122	107
75-100	202	193	184	175	165	157	133	119
150-175	216	205	197	184	174	166	154	-
Total air content, (%) for:								
Improvement of workability	4.5	4	3.5	3	2.5	2	1.5	1
Moderate exposure	6	5.5	5	4.5	4.5	4	3.5	3
Extreme exposure	7.5	7	6	6	5.5	5	4.5	4

Design concrete mixes

Step 4: From Table 2, a **water/cement ratio of 0.62** is expected to result in concrete with a compressive strength, measured on cylinders, of 25 MPa.

Table 2 Relation between *w/c* and average compressive strength of concrete, according to ACI 211.1-81

Average Compressive Strength at 28 Days[a] (MPa)	Effective Water/Cement Ratio (by Mass)	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
45	0.38	—
40	0.43	—
35	0.48	0.40
30	0.55	0.48
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

Step 5: The **cement content** is **178/0.62 = 287 kg/m3.**

Design concrete mixes

Step 6: From Table 3,
fineness modulus of 2.80,
maximum size of 40 mm is 0.72 m3.
the bulk density of the coarse aggregate is 1600 kg/m3,
the mass of **coarse aggregate is 0.72 × 1600 = 1152 kg/m3.**

Maximum size of aggregate		*Bulk volume of oven-dry rodded coarse aggregate per unit volume of concrete for fineness modulus of fine aggregate of:*			
mm	*in.*	*2.40*	*2.60*	*2.80*	*3.00*
9.5	$\frac{3}{8}$	0.50	0.48	0.46	0.44
12.5	$\frac{1}{2}$	0.59	0.57	0.55	0.53
20	$\frac{3}{4}$	0.66	0.64	0.62	0.60
25	1	0.71	0.69	0.67	0.65
37.5	$1\frac{1}{2}$	0.75	0.73	0.71	0.69
50	2	0.78	0.76	0.74	0.72
75	3	0.82	0.80	0.78	0.76
150	6	0.87	0.85	0.83	0.81

Design concrete mixes

Step 7: To calculate the mass of fine aggregate, we need first to calculate the volume of all the other ingredients. The required values are as follows:

Water content = 178 kg
Cement content = 287 kg
Coarse aggregate content = 1152 kg/m3
The sum. = 1617 kg/m3

From table 4, weight of 1 m3 of concrete = 2420 kg,

Fine aggregate content
= 2420 – 1617 = 803 kg/m3.

Max aggregate size	Weight of concrete (kg/m3)	
	No-air entrained concrete	air entrained concrete
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2506	2435

Design concrete mixes

Step 8: Adjustments to mix proportions

From lab experimental, moisture content for coarse aggregate = 2%, for fine aggregate = 6%, therefore

Wet coarse aggregate = 1152 * 1.02 = 1175 kg

Wet fine aggregate = 803 * 1.06 = 851 kg

Water contact with the surface coarse aggregate = 2 – 0.5 = 1.5%

Water contact with the surface fine aggregate = 6 – 0.7 = 5.3%

Water required = 178 – 1152*0.015 – 803*0.053 = 118 kg

The material weights estimated for producing 1 m3 of concrete are

Water content = 118 kg

Cement content = 287 kg

Wet fine aggregate content = 851 kg

Wet coarse aggregate content = 1152 kg

The sum. = 2431 kg /m3

Example 3:

Design a concrete mixture according to the American Concrete Institute method of casting internal columns in a multi-storey building if the compressive strength required at 28 days is 20 Mpa, so that only one model out of every 20 examination models fails and that the dimensions and reinforcement of the column allow the use of gravel with a maximum size of 20 mm and a slump of 50 mm, the available aggregate has the following properties:

Fine Aggregate: specific gravity = 2.65, fineness modulus = 2.60

Coarse Aggregate: specific gravity = 2.65, bulk density is 1600 kg/m3

Solution:

F mean = F min + k * Sd

= 20 + 1.08 * 5.6 = 26 Mpa

Test No.	Standard deviation coefficient (K)
15	1.16
20	**1.08**
25	1.03
=> 30	1.0

Design concrete mixes

Solution

Step 1: A slump of 50 mm is specified.

Step 2: The maximum size of aggregate of 20 mm is specified

Step 3: From Table 1, for a slump of 50 mm and a maximum size of aggregate of 20 mm, the **water requirement = 187 kg /m3 of concrete**.

Slump, mm	**Water, kg/m3 of concrete for indicated nominal maximum size of aggregate**							
	9.5	12.5	19	25	37.5	50	75	150
Non-air-entrained concrete								
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	-
Amount of entrapped air, %	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25-50	181	175	168	160	150	142	122	107
75-100	202	193	184	175	165	157	133	119
150-175	216	205	197	184	174	166	154	-
Total air content, (%) for:								
Improvement of workability	4.5	4	3.5	3	2.5	2	1.5	1
Moderate exposure	6	5.5	5	4.5	4.5	4	3.5	3
Extreme exposure	7.5	7	6	6	5.5	5	4.5	4

Design concrete mixes

Step 4: From Table 2, a **water/cement ratio = 0.60** is expected to result in concrete with a compressive strength, measured on cylinders, of 26 MPa.

Table 2 Relation between *w/c* and average compressive strength of concrete, according to ACI 211.1-81

Average Compressive Strength at 28 Days[a] (MPa)	Effective Water/Cement Ratio (by Mass)	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
45	0.38	—
40	0.43	—
35	0.48	0.40
30	0.55	0.48
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

Step 5: The **cement content** is **187/0.60 = 312 kg/m3.**

Design concrete mixes

Step 6: From Table 3,
fineness modulus of 2.80,
maximum size of 20 mm is 0.62 m3.
the bulk density of the coarse aggregate is 1600 kg/m3,
the mass of **coarse aggregate is 0.64 × 1600 = 1024 kg/m3.**

Maximum size of aggregate		*Bulk volume of oven-dry rodded coarse aggregate per unit volume of concrete for fineness modulus of fine aggregate of:*			
mm	*in.*	*2.40*	*2.60*	*2.80*	*3.00*
9.5	$\frac{3}{8}$	0.50	0.48	0.46	0.44
12.5	$\frac{1}{2}$	0.59	0.57	0.55	0.53
20	$\frac{3}{4}$	0.66	0.64	0.62	0.60
25	1	0.71	0.69	0.67	0.65
37.5	$1\frac{1}{2}$	0.75	0.73	0.71	0.69
50	2	0.78	0.76	0.74	0.72
75	3	0.82	0.80	0.78	0.76
150	6	0.87	0.85	0.83	0.81

Design concrete mixes

Step 7: To calculate the mass of fine aggregate, we need first to calculate the volume of all the other ingredients. The required values are as follows:

Water content = 187 kg
Cement content = 312 kg
Coarse aggregate content = 1024 kg
The sum. = 1523 kg

From table 4,
weight of 1 m3 of concrete = **2355** kg,
Fine aggregate content
= 2355 – 1523 = 832 kg.

Max aggregate size	Weight of concrete (kg/m3)	
	No-air entrained concrete	air entrained concrete
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2506	2435

Design concrete mixes

H.W

1. A mix with a mean 28-day compressive strength of 45 MPa and a slump of 85 mm, ordinary cement being used. The maximum size of well-shaped, angular aggregate is 12.5 mm, its bulk density is 1600 kg/m3, and its specific gravity is 2.64. The available fine aggregate has a fineness modulus of 2.60 and a specific gravity of 2.58. No-air entrainment is required. The percentage absorption of fine aggregate is 1.5% ,and coarse aggregate 2.5% .

2. Design a concrete mixture according to the American Concrete Institute method of casting slab in a building if the compressive strength required at 28 days is 30 Mpa, slab thickness = 150 mm, sand fineness modulus = 2.50

Thanks For Your Listening

Al-Muthanna University
Engineering College
Civil Engineering Department

Concrete Technology

The 12th lecture

Mix Design - 3

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Design concrete mixes

1. American method of selection of mix proportions

The ACI Standard Practice ACI 211.1-91 describes a method of selection of mix proportions of concrete containing Portland cement alone or together with other cementitious materials, and containing also admixtures.

Design concrete mixes

Table 1, use to determined the **water requirement kg /m3 of concrete**.

Slump, mm	Water, kg/m3 of concrete for indicated nominal maximum size of aggregate							
	9.5	12.5	19	25	37.5	50	75	150
Non-air-entrained concrete								
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	-
Amount of entrapped air, %	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25-50	181	175	168	160	150	142	122	107
75-100	202	193	184	175	165	157	133	119
150-175	216	205	197	184	174	166	154	-
Total air content, (%) for:								
Improvement of workability	4.5	4	3.5	3	2.5	2	1.5	1
Moderate exposure	6	5.5	5	4.5	4.5	4	3.5	3
Extreme exposure	7.5	7	6	6	5.5	5	4.5	4

Design concrete mixes

Table 2, **use to determined a water/cement ratio**

Table 2 Relation between *w/c* and average compressive strength of concrete, according to ACI 211.1-81

Average Compressive Strength at 28 Days[a] (MPa)	Effective Water/Cement Ratio (by Mass)	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
45	0.38	—
40	0.43	—
35	0.48	0.40
30	0.55	0.48
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

Design concrete mixes

Table 3, **use to determined the volume of coarse aggregate m3**

.

Maximum size of aggregate		Bulk volume of oven-dry rodded coarse aggregate per unit volume of concrete for fineness modulus of fine aggregate of:			
mm	*in.*	*2.40*	*2.60*	*2.80*	*3.00*
9.5	$\frac{3}{8}$	0.50	0.48	0.46	0.44
12.5	$\frac{1}{2}$	0.59	0.57	0.55	0.53
20	$\frac{3}{4}$	0.66	0.64	0.62	0.60
25	1	0.71	0.69	0.67	0.65
37.5	$1\frac{1}{2}$	0.75	0.73	0.71	0.69
50	2	0.78	0.76	0.74	0.72
75	3	0.82	0.80	0.78	0.76
150	6	0.87	0.85	0.83	0.81

Design concrete mixes

From Table 4, determined weight of 1 m^3 of concrete

Max aggregate size	Weight of concrete (kg/m3)	
	No-air entrained concrete	air entrained concrete
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2506	2435

Design concrete mixes

Example 1:

Design a concrete mixture according to the American Concrete Institute method by using **absolute method** of casting a mix with a mean 28-day compressive strength of 35 MPa and a slump of 50 mm, ordinary cement being used. The maximum size of well shaped, angular aggregate is 20 mm, its bulk density is 1600 kg/m3, and its specific gravity is 2.64. The available fine aggregate has a fineness modulus of 2.60 and a specific gravity of 2.58. No-air entrainment is required.

Design concrete mixes

Solution by using absolute method **(الحل الاول باستخدام طريقة الحجوم المطلقة)**

1. From Table 1, **Water content (W) = 190 kg/m^3**
2. From Table 2, **W / c = 0.48**
3. **Cement content (C) = 190 / 0.48 = 395 kg/ m^3**
4. From Table 3, **volume of coarse aggregate = 0.64 m^3**
5. **Coarse aggregate = 0.64 * 1600 = 1020 kg / m^3**
6. From Table 1, Volume of air = 0.02 **m^3**
7. calculate the mass of fine aggregate:

   Volume of water = 190 / 1000 = 0.19 **m^3**

   Volume of cement = 395 / (3.15*1000) = 0.126 **m^3**

   Volume of coarse aggregate = 1020 / (2.64 *1000) = 0.396 **m^3**

   Volume of air = 0.02 **m^3**

   Total volume of all ingredients except fine aggregate = 0.732 **m^3**

   Volume of fine aggregate = 1 – 0.732 = 0.268 **m^3**

❖ **Mass of fine aggregate = 0.268 * 2.58 * 1000 = 690 kg / m^3**

From the various steps, we can list the estimated mass of each of the ingredients in kilograms per cubic meter of concrete as follows:

Water = 190 kg/m^3

Cement = 395 kg/ m^3

Coarse aggregate = 1020 kg / m^3

Fine aggregate = 690 kg / m^3

The sum. = 2295 kg /**m^3**

Design concrete mixes

Solution by using weight method **(حل ثانى للسؤال باستخدام طريقة الاوزان)**

1. From Table 1, **Water content (W) = 190 kg/m^3**
2. From Table 2, **W / c = 0.48**
3. **Cement content (C) = 190 / 0.48 = 395 kg/ m^3**
4. From Table 3, **volume of coarse aggregate = 0.64 m^3**
5. **Coarse aggregate = 0.64 * 1600 = 1020 kg / m^3**
6. calculate the mass of fine aggregate:

Water content = 190 kg
Cement content = 395 kg
Coarse aggregate content = 1020 kg/m^3
The sum. = 1605 kg/m^3

From Table 4, weight of 1 m^3 of concrete = 2420 kg,
Fine aggregate content = 2355 – 1605 = 750 kg/m^3.

From the various steps, we can list the estimated mass of each of the ingredients in kilograms per cubic meter of concrete as follows:

Water = 190 kg/m^3
Cement = 395 kg/ m^3
Coarse aggregate = 1020 kg / m^3
Fine aggregate = 750 kg / m^3
The sum. = 2355 kg /**m^3**

Example 2:

A mix with a mean 28-day compressive strength of 25 MPa and a slump of 75 - 100 mm, ordinary cement being used. The maximum size of well shaped, angular aggregate is 40 mm, its bulk density is 1600 kg/m3, and its specific gravity is 2.64. The available fine aggregate has a fineness modulus of 2.80 and a specific gravity of 2.58. The percentage absorption of fine aggregate is 0.7% ,and coarse aggregate 0.5%. No-air entrainment is required. Moisture contain are 2% for coarse agg. And 6% for fine agg.

Design concrete mixes

Solution by using weight method

1. From Table 1, **Water content (W) = 178 kg/m^3**
2. From Table 2, **W / c = 0.62**
3. **Cement content (C) = 178 / 0.62 = 287 kg/ m^3**
4. From Table 3, **volume of coarse aggregate = 0.72 m^3**
5. **Coarse aggregate = 0.72 * 1600 = 1152 kg / m^3**
6. calculate the mass of fine aggregate:

   Water content = 178 kg
   Cement content = 287 kg
   Coarse aggregate content = 1152 kg/m^3
   The sum. = 1617 kg/m^3

   From Table 4, weight of 1 m^3 of concrete = 2420 kg,
   Fine aggregate content = 2420 – 1617 = 803 kg/m^3.

6. Adjustments to mix proportions

From lab experimental, moisture content for coarse aggregate = 2%, for fine aggregate = 6%, therefore

Wet coarse aggregate = 1152 * 1.02 = 1175 kg

Wet fine aggregate = 803 * 1.06 = 851 kg

Water contact with the surface coarse aggregate = 2 – 0.5 = 1.5%

Water contact with the surface fine aggregate = 6 – 0.7 = 5.3%

Water required = 178 – 1152*0.015 – 803*0.053 = 118 kg

The material weights estimated for producing 1 $\mathbf{m^3}$ of concrete are

Water content = 118 kg

Cement content = 287 kg

Wet fine aggregate content = 851 kg

Wet coarse aggregate content = 1175 kg

The sum. = 2431 kg /$\mathbf{m^3}$

Design concrete mixes

Example 3:

Design a concrete mixture according to the American Concrete Institute method of casting internal columns in a multi-storey building if the compressive strength required at 28 days is 20 Mpa, so that only one model out of every 20 examination models fails and that the dimensions and reinforcement of the column allow the use of gravel with a maximum size of 20 mm and a slump of 50 mm, the available aggregate has the following properties: Standard deviation = 5.6

Fine Aggregate: specific gravity = 2.65, fineness modulus = 2.60

Coarse Aggregate: specific gravity = 2.65, bulk density is 1600 kg/m3

Solution:

1. **Determined compressive strength (F mean)**

F mean = F min + k * Sd

= 20 + 1.08 * 5.6 = 26 Mpa

Test No.	Standard deviation coefficient (K)
15	1.16
20	**1.08**
25	1.03
=> 30	1.0

Design concrete mixes

Solution by using weight method (حل السؤال باستخدام طريقة الاوزان)

1. From Table 1, **Water content (W) = 187 kg/m^3**
2. From Table 2, **W / c = 0.60**
3. **Cement content (C) = 187 / 0.6 = 312 kg/ m^3**
4. From Table 3, **volume of coarse aggregate = 0.62 m^3**
5. **Coarse aggregate = 0.62 * 1600 = 1024 kg / m^3**
6. calculate the mass of fine aggregate:

Water content = 187 kg
Cement content = 312 kg
Coarse aggregate content = 1024 kg/m^3
The sum. = 1623 kg/m^3

From Table 4, weight of 1 m^3 of concrete = 2420 kg,

Fine aggregate content = 2355 – 1623 = 732 kg/m^3.

From the various steps, we can list the estimated mass of each of the ingredients in kilograms per cubic meter of concrete as follows:

Water = 187 kg/m^3
Cement = 312 kg/ m^3
Coarse aggregate = 1024 kg / m^3
Fine aggregate = 732 kg / m^3
The sum. = 2355 kg /**m^3**

Design concrete mixes

H.W

1. A mix with a mean 28-day compressive strength of 45 MPa and a slump of 85 mm, ordinary cement being used. The maximum size of well-shaped, angular aggregate is 12.5 mm, its bulk density is 1600 kg/m3, and its specific gravity is 2.64. The available fine aggregate has a fineness modulus of 2.60 and a specific gravity of 2.58. No-air entrainment is required. The percentage absorption of fine aggregate is 1.5% ,and coarse aggregate 2.5% .

2. Design a concrete mixture according to the American Concrete Institute method of casting slab in a building if the compressive strength required at 28 days is 30 Mpa, slab thickness = 150 mm, sand fineness modulus = 2.50

2. British method of mix selection (mix design)

The British method consists of **5 steps**, as follows.

Design concrete mixes

Step 1. From Table 1, we find the value of **strength** (at a water/cement ratio of 0.5) corresponding to the **type of cement**, **type of aggregate**, and **age** which are to be used

Type of cement	Type of coarse aggregate	Compressive strength* (MPa (psi)) at the age of (days):			
		3	7	28	91 Age of curing
1. Ordinary Portland (Type I) 2. Sulfate-resisting Portland (Type V)	Uncrushed	22 (3200)	30 (4400)	42 (6100)	49 (7100)
	Crushed	27 (3900)	36 (5200)	49 (7100)	56 (8100)
3. Rapid-hardening Portland 4. (Type III)	Uncrushed	29 (4200)	37 (5400)	48 (7000)	54 (7800)
	Crushed	34 (4900)	43 (6200)	55 (8000)	61 (8900)

Design concrete mixes

From Fig.1 below, we mark a point corresponding to this strength at a **water/cement ratio** of 0.5.Through this point, we now draw a curve ‘parallel to the neighboring curves. Using this new curve, we read the water/cement ratio corresponding to the specified target mean strength.

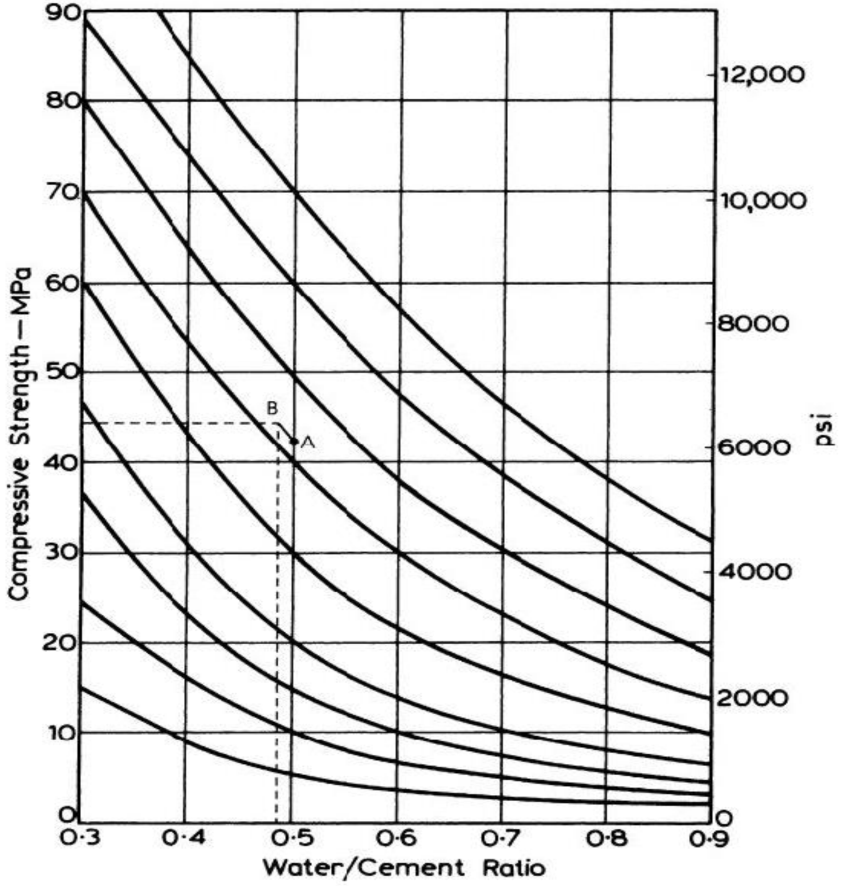


Fig. 1, Relation between compressive strength and free water/cement ratio for use in the British mix selection method.

Step 2. This deals with the determination of the **water content** for the required workability, expressed either as slump or as Vibe time, recognizing the influence of the maximum size of aggregate and its type, namely crushed or uncrushed. The relevant data are given in **Table 2.** It can be noted that the compacting factor is not used in mix selection, although it can be used for control purposes.

	Aggregate		Water content, kg/m³ (lb/yd³) for:				
	Max size mm (in.)	*Type*	*Slump, mm (in.)*	*0–10 ($0-\frac{1}{2}$)*	*10–30 ($\frac{1}{2}-1$)*	*30–60 ($1-2\frac{1}{2}$)*	*60–180 ($2\frac{1}{2}-7$)*
			Vebe time, s	*>12*	*6–12*	*3–6*	*0–3*
1.	10 ($\frac{3}{8}$)	Uncrushed		150 (255)	180 (305)	205 (345)	225 (380)
		Crushed		180 (305)	205 (345)	230 (390)	250 (420)
2.	20 ($\frac{3}{4}$)	Uncrushed		135 (230)	160 (270)	180 (305)	195 (330)
		Crushed		170 (285)	190 (320)	210 (355)	225 (380)
3.	40 ($1\frac{1}{2}$)	Uncrushed		115 (195)	140 (235)	160 (270)	175 (295)
		Crushed		155 (260)	175 (295)	190 (320)	205 (345)

Design concrete mixes

Step 3. This determines the **cement content** ,which is simply the water content divided by the water/cement ratio. This cement content must not conflict with any minimum value specified for reasons of durability or a maximum value specified for reasons of heat development.

Step 4. This deals with the determination of the total aggregate content. This requires an estimate of the fresh density of fully compacted concrete, which can be read off Fig. 2 for the appropriate water content (from Step 2) and **specific gravity** of the aggregate. If this is unknown, the value of **2.6 for uncrushed aggregate** and **2.7 for crushed aggregate** can be assumed.

The aggregate content is obtained by subtracting from the **fresh density** the value of the cement content and of the water content.

Design concrete mixes

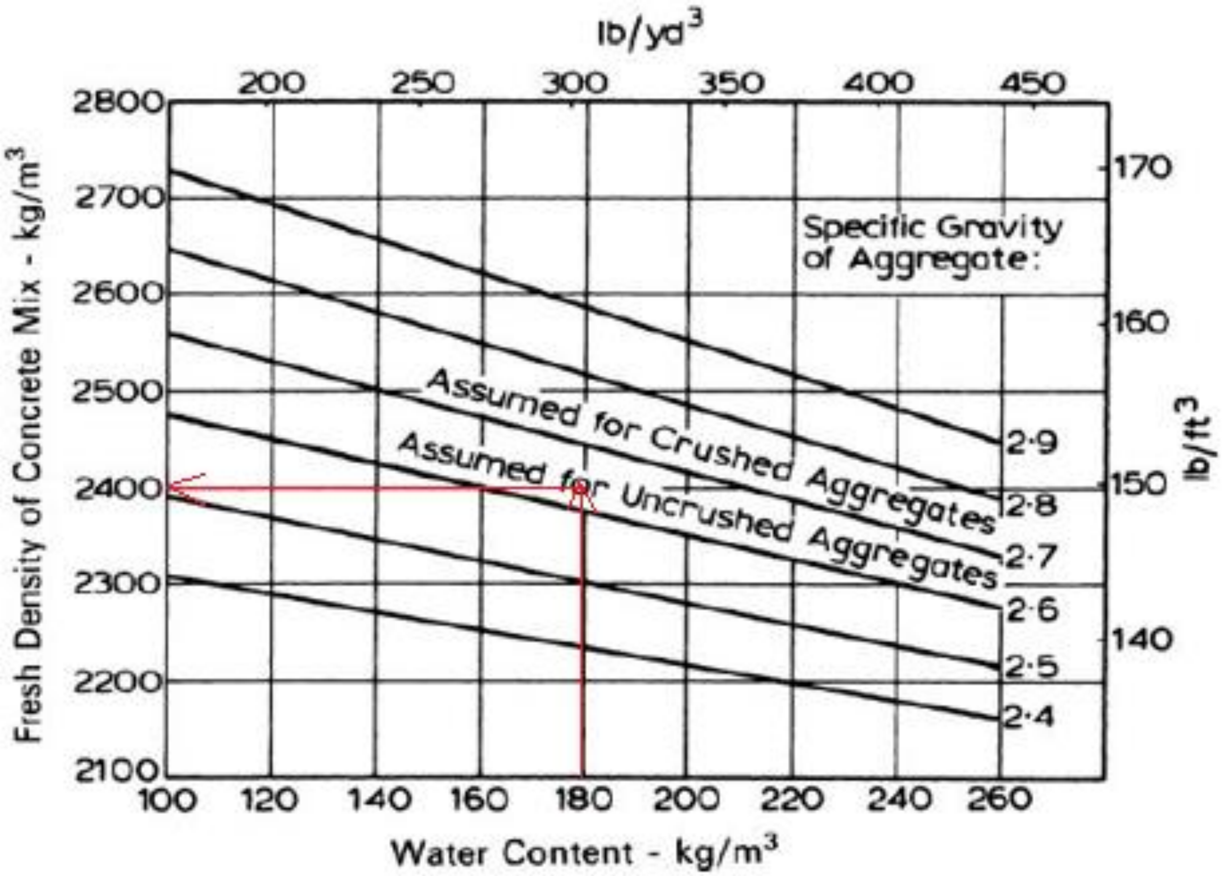


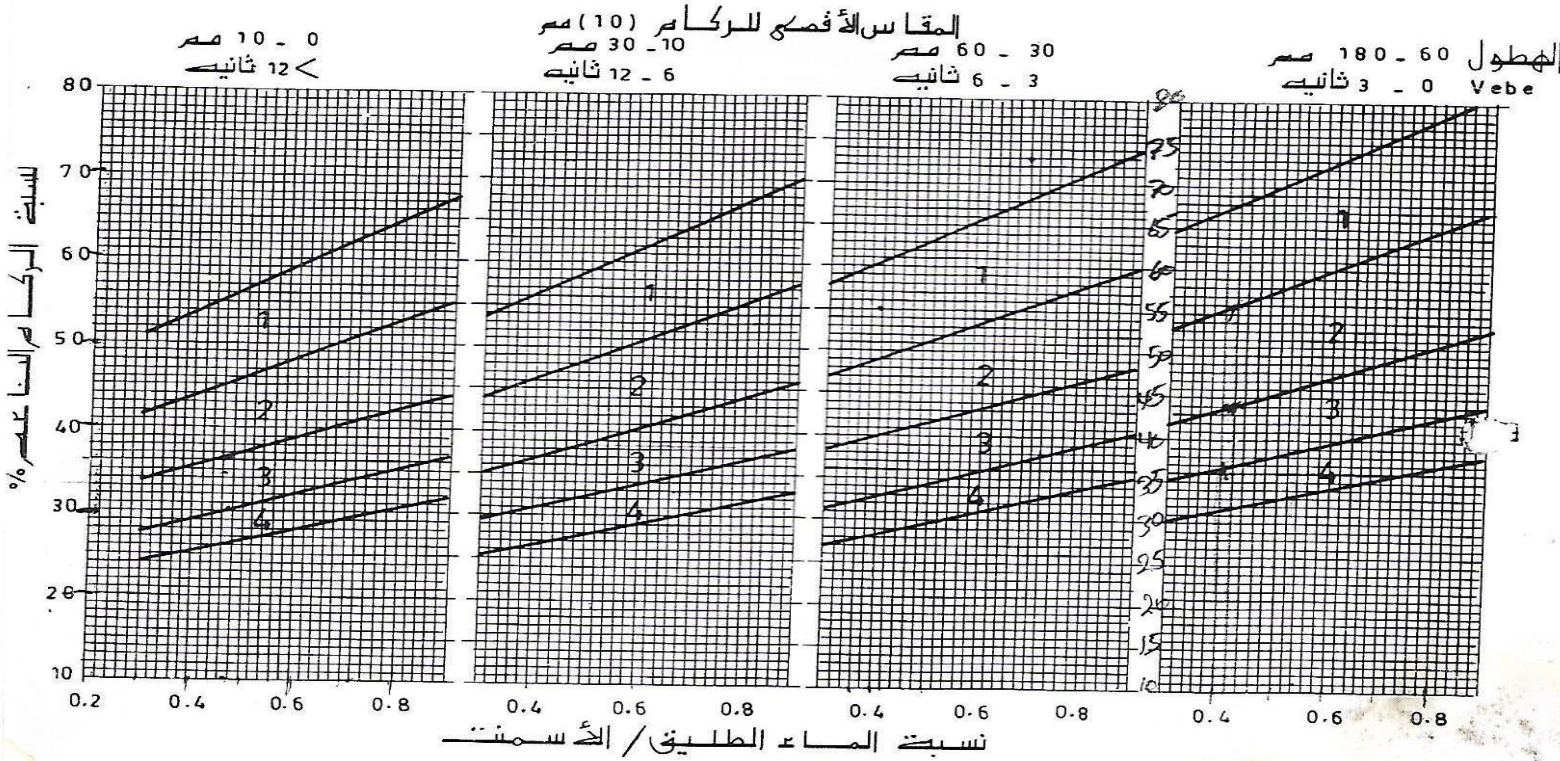
Fig. 2, Estimated wet density for fully compacted concrete (specific gravity is given for saturated and surface-dry aggregate)

Design concrete mixes

Step 5. This determines the **<u>proportion of fine aggregate</u>** in the total aggregate, using the recommended values of Fig.3; only data for 20 and 40 mm aggregates are shown.

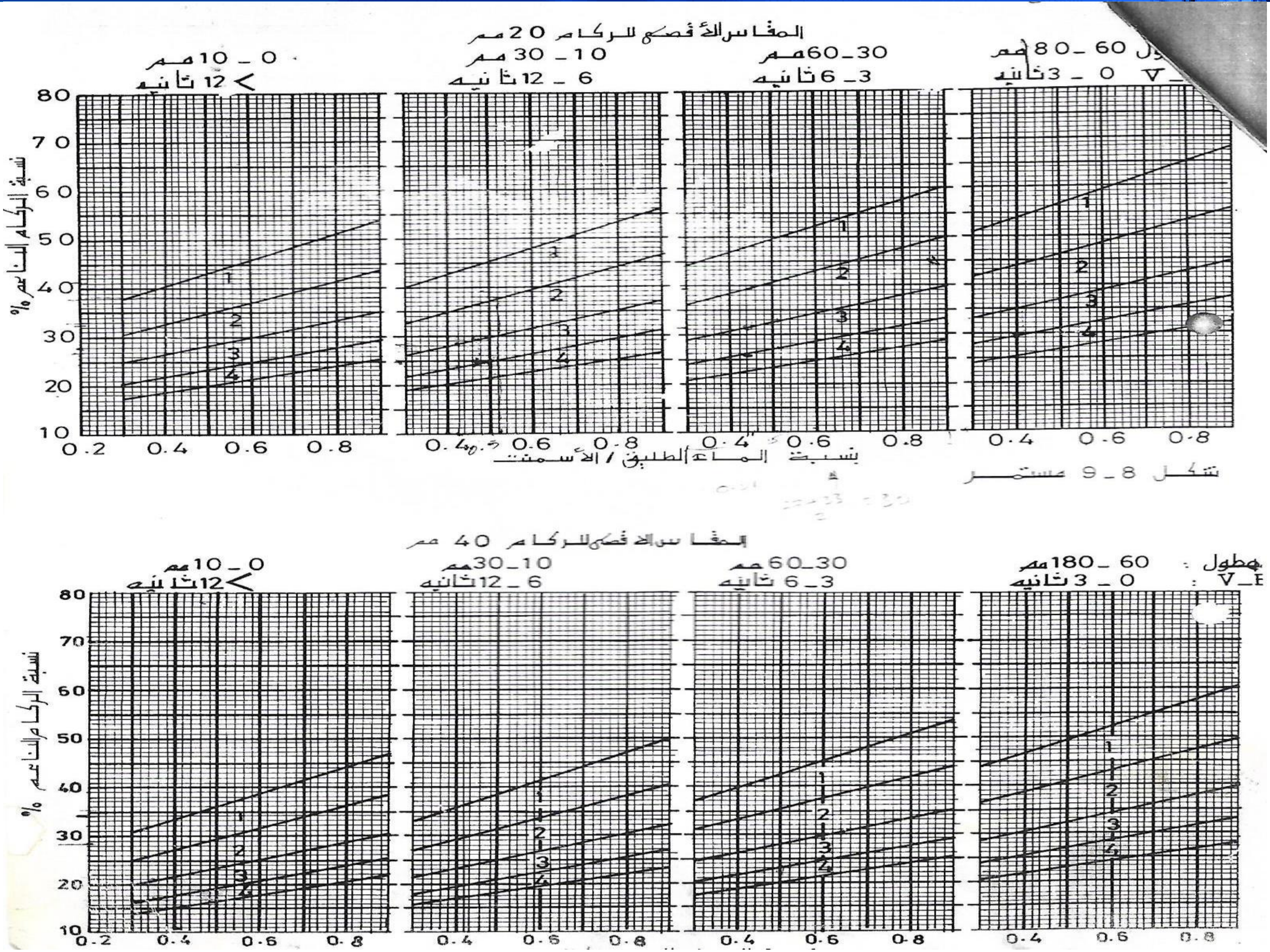
The governing factors are: the maximum size of aggregate, the level of workability, the water/cement ratio, zone of fine aggregate.

Once the proportion of fine aggregate has been obtained, multiplying it by the total aggregate content gives the content of fine aggregate.



شكل 8 - 9 النسب المقبولة لمناطق التدرج 1، 2، 3، 4 للركام الناعم حسب المواصفات القياسية البريطانية (B.S. 882)

Design concrete mixes



Example

select a mix proportional of 28-day compressive strength (measured on standard cubes) of 44 MPa , slump of 50 mm; uncrushed aggregate with a maximum size of 20 mm; specific gravity of aggregate of 2.64, zone 3 of fine aggregate, ordinary Portland cement to be used. The percentage absorption of fine aggregate is 1.5% ,and coarse aggregate 2.5% , the max. w/c = 0.55 and min. min. cement content 290 kg/m^3 .

Solution

Step 1. From Table 1, for ordinary Portland cement and uncrushed aggregate, we find the 28-day strength to be 42 MPa.

We enter this value on the ordinate corresponding to a water/cement ratio of 0.5 in Fig. 1 this point is marked A. Through A, we draw a line ‘parallel’ to the nearest curve until it intersects the ordinate corresponding to the specified strength of 44 MPa; this is point B. The ordinate through this point gives the water/cement ratio of **0.48**. **lower than 0.55 therefore used 0.48**

Design concrete mixes

Step 2. From Table 2, for 20 mm uncrushed aggregate and a slump of 50 mm, we find the **water requirement to be 180 kg/m3.**

Step 3. The cement content is 180/0.48 =375 kg/m3. **higher than 290 kg/m3. ok.**

Step 4. From Fig. 2, for a water content of 180 kg/m3 and aggregate with a specific gravity of 2.64, we read off the fresh density of concrete of 2400 kg/m3. The total aggregate content is thus: 2400 – 375 – 180 = 1845 kg/m3.

Step 5. In Fig. 3, we find the particular diagram for the maximum size of aggregate of 20 mm and a slump encompassing the value of 50 mm.
On the line representing fine aggregate with zone 3, at a water/cement ratio of 0.48, the proportion
of fine aggregate is 32 %(by mass of total aggregate). Hence,
the fine aggregate content is: 32% × 1845 = **590** kg/m3
and the **coarse aggregate content** is
1845 – 590 = **1255** kg/m3.
Advancement of dry state.
Weight of dry fine aggregate = 100/101.5 x 590 =581.3Kg
Weight of dry coarse aggregate = 100/102.5 x 1255=1224.4 Kg
Added absorption Water = (590-581.3) +(1255-1224.4)= 8.7+30.6=**39.3 Kg**

Design concrete mixes

1. From Table 1, Compressive strength (fcu) = 42 MPa.
2. From Fig. 1, water/cement ratio = **0.48**. **lower than 0.55 therefore used 0.48**
3. From Table 2, **water = 180 kg/m3.**
4. cement content = 180/0.48 = **375** kg/m3. **higher than 290 kg/m3. ok.**
5. From Fig. 2, fresh density of concrete = 2400 kg/m3.
6. The total aggregate content = 2400 – 375 – 180 = 1845 kg/m3.
7. proportion of fine aggregate is 32 % (by mass of total aggregate).
8. fine aggregate content = 0.32 × 1845 = **590** kg/m3
9. **coarse aggregate content** = 1845 – 590 = **1255** kg/m3.

Advancement of dry state.

Weight of dry fine aggregate = 100/101.5 x 590 =581.3Kg

Weight of dry coarse aggregate = 100/102.5 x 1255=1224.4 Kg

Added absorption Water = (590-581.3) +(1255-1224.4)= 8.7+30.6=**39.3 Kg**

Design concrete mixes

H.W

select a mix proportional of 28-day compressive strength (measured on standard cubes) of 56 MPa , slump of 65 mm; uncrushed aggregate with a maximum size of 10 mm; specific gravity of aggregate of 2.64, zone 2 of fine aggregate, repaid setting Portland cement to be used. The percentage absorption of fine aggregate is 1.25% ,and coarse aggregate 2.3% the max. w/c = 0.4 and min. cement content 390 kg/m3 .

Thanks For Your Listening

Al-Muthanna University
Engineering College
Civil Engineering Department

Concrete Technology

The 13th lecture

Fresh Concrete

أ.م.د حسين كريم سلطان

للعام الدراسي
2020 - 2019

Fresh Concrete

Fresh concrete.

When is a mixed concrete that has not yet been solidification , and if it is solidification, it loses its elasticity known as green concrete and in the hardening phase gain resistance so that you can withstand the loads.

Consistency: is the amount of stability which refers to the cohesion of the mix, and its resistance to segregation and degree of fluidity, measured by the slump-cone test or Vebe apparatus

If concrete have good consistency can be transported, placed, compacted, and finished sufficiently easily and without segregation.

Fresh Concrete

Cohesiveness (Stability of fresh concrete) : is an index for both the water-holding capacity (the opposite of bleeding) and the coarse-aggregate-holding capacity (the opposite of segregation) of a plastic concrete mixture.

Workability: is a composite property, with two main components:

■ Consistency (describes the ease of flow)

■ Cohesiveness (describes the stability or lack of bleeding and segregation characteristics.)

Fresh Concrete

Workability: is defined in ASTM C-125 as the property determining the effort required to placing, compacting, and finishing a freshly mixed quantity of concrete with minimum loss of homogeneity.

The effort required to place a concrete mixture is determined by the rheological property of the lubricant of cement paste and the internal friction between the aggregate particles on the one hand, and the external friction between the concrete and the surface of the formwork on the other.

Quality of mixing water

Mixing water should not contain undesirable organic substances or inorganic constituents in excessive proportions.

Sea water has a total salted of about 3.5 %(78 % of the dissolved solids being NaCl and 15 % $MgCl_2$ and $MgSO_4$), and produces a slightly higher early strength but a lower long-term strength;

Water containing large quantities of chlorides (e.g. sea water) tends to cause surface **efflorescence**.

the presence of chlorides in concrete containing embedded steel can lead to its **corrosion.**

Fresh Concrete

Factors affecting workability

1. the **water content** of the mix, for a given type and grading of aggregate the workability is increased with addition more water content.
2. aggregate/cement ratio ,when increasing the amount of cement content increased the workability of concrete .
3. fineness of cement.
4. the maximum size, grading, shape and texture of aggregate.
5. water/cement ratio .In particular, the higher the water/cement ratio the finer the grading required for the highest workability.
6. using the admixtures for concrete increased the workability.
7. effect of the time and heat. Freshly mixed concrete stiffens with time.

Measurement of workability

1-Slump test

The slump test is prescribed by ASTM C 143 and BS 1881 : 103. The mould for the slump test is a frustum of a cone, 300 mm high. Mixes of stiff consistency have a zero slump.

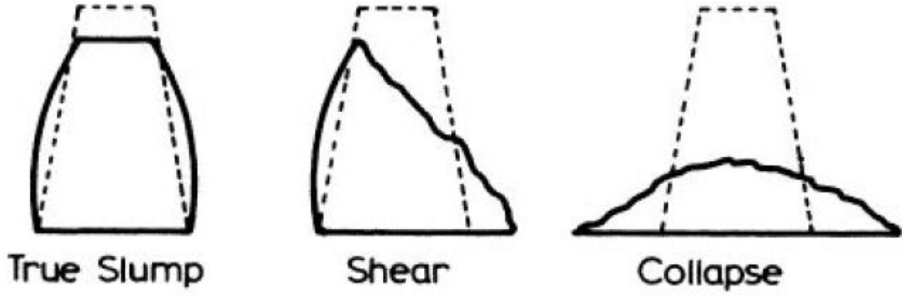


Table 4. Classification of Workability and Magnitude of Slump According to BS EN 206-1 : 2000

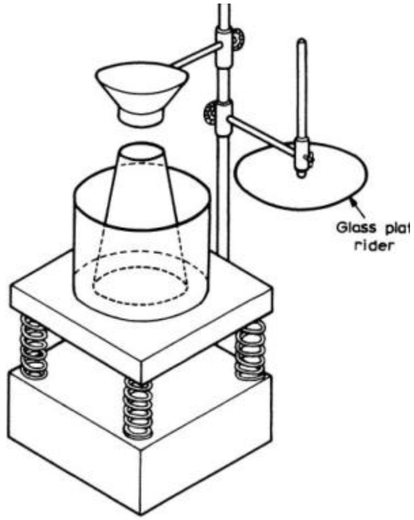
Description of workability	*Slump*	
	mm	*in.*
No slump	0	0
Very low	5–10	$\frac{1}{4}$–$\frac{1}{2}$
Low	15–30	$\frac{3}{4}$–$1\frac{1}{4}$
Medium	35–75	$1\frac{1}{2}$–3
High	80–155	$3\frac{1}{4}$–6
Very high	160 to collapse	$6\frac{1}{4}$ to collapse

Fresh Concrete

2-Compacting factor test is measured by the density ratio, i.e. the ratio of the density actually achieved in the test to the density of the same concrete fully compacted.

3-ASTM flow test laboratory test gives an indication of the consistency of concrete and its proneness to segregation by measuring the spread of a pile of concrete on a table subjected to jolting.

4-Vebe test apparatus is omitted and compaction is achieved by vibration instead of jolting.

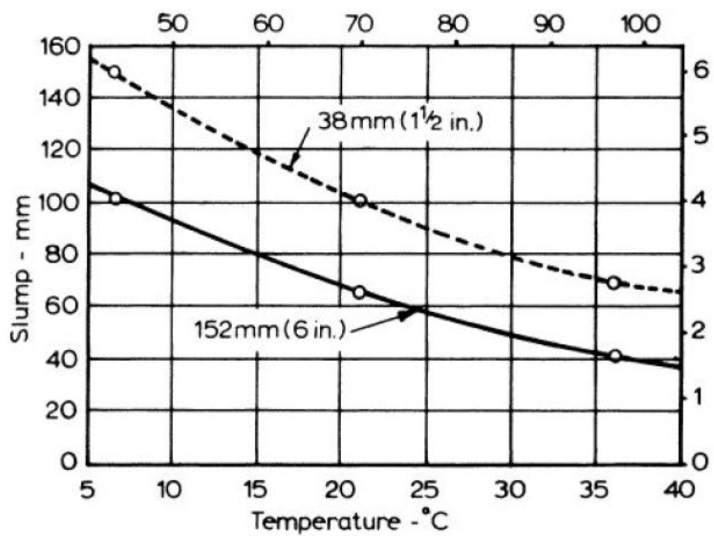


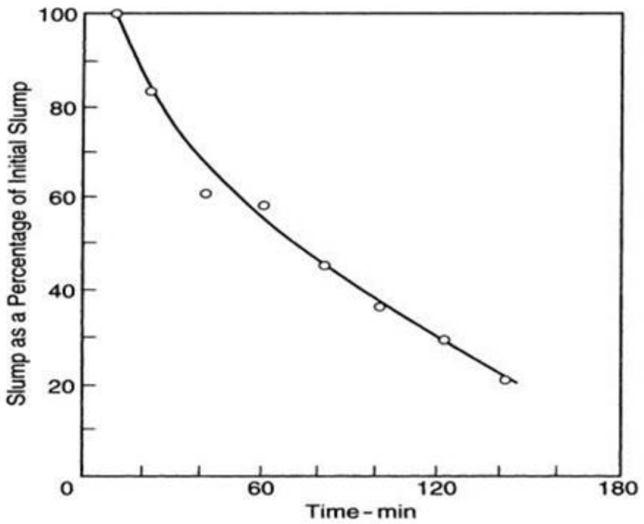
Effect of time and temperature on workability

The exact value of the loss in workability depends on several factors.

1. the higher the initial workability the greater the slump loss.
2. the rate of loss of slump is higher in rich mixes.

The change in workability with time depends also on the moisture condition of aggregate (at a given total water content): the loss is greater with dry aggregate due to the absorption of water by aggregate also affected by the ambient temperature.





The loss of slump with time is also affected by the temperature, as shown in Fig.

Fresh Concrete

Workability loss (Slump loss) is defined as the loss of consistency in fresh concrete with elapsed time, because it results from the gradual loss free water leading to setting of a hydrating cement paste and formation of hydration products such as ettringite and calcium silicate hydrates.

Causes

(1) the use of an abnormal-setting cement, and higher cement content.
(2) long time for mixing, transporting, placement, compaction, or finishing operation.
(3) high temperature of concrete due to excessive heat of hydration.
(4) mix water being absorbed by the aggregate if this not in a saturated state before mixing.
(5) Evaporation of the mix water.

Concrete starts losing slump at a rate determined mainly by elapsed time after hydration, temperature, cement composition, and the admixtures present

Control slump loss.

1. Starting with a higher initial slump of ready mixed concrete than is needed at the job site (in order to compensate for the expected slump loss)
2. elimination of every possible delay in concrete handling operations.
3. keeping the temperature of concrete as closed to the 10 to 21°C range as possible, not more 32°C.
4. laboratory check on the stiffening and setting characteristics of the cement.
5. used proper admixtures.
6. Adding extra water (within the permissible water cement ratio) just before the placement and remixing the concrete mixture thoroughly. The latter practice is known as ***retempering***.

Segregation

is the separation of the constituents of a heterogeneous mixture so that their distribution is no longer uniform.

Causes

1. A combination of improper consistency, excessive amount of large particles of coarse aggregate with either a too high or a too low density.
2. presence of less fines (due to a low cement content, a low sand content, or a poorly graded sand),
3. unsuitable placing and compacting methods.

Fresh Concrete

There are two forms of segregation

1. the coarser particles tend to separate out because they tend to travel further along a slope or to settle more than finer particles, when a lean mix is used.
2. In wet mixes, is explained by the separation of grout (cement plus water) from the mix.

if the mix is too dry, addition of water would improve the cohesion of the mix, but when the mix becomes too wet the second type of segregation would take place.

Methods of reducing the segregation

1. used entrained air reduces the danger of segregation.
2. the use of coarse aggregate whose specific gravity close from that of the fine aggregate and good grading aggregates .
3. Correct use of vibrators of concrete. And extra care is necessary during the placement.
4. Segregation in dry concrete mixtures can sometimes be reduced by increasing the water content slightly.
5. lowering of the maximum size of coarse aggregate and the use of more sand or a finer sand and cement content.

Fresh Concrete

Bleeding

Is a some of the water in the mix tends to rise to the surface of freshly placed concrete. This is caused by the inability of the solid constituents of the mix to hold all of the mixing water when they settle downwards, and it is form of segregation.

The initial bleeding proceeds at a constant rate, but subsequently the rate of bleeding decreases steadily.

Effect of bleeding on the concrete

1. if the rising water carries with it amount of the finer cement particles, a layer of **laitance** will be formed. If this is at the top of a slab, a porous and weak surface layer will result, with a permanently ‘dusty’ surface.
2. if evaporation of water from the surface of the concrete is faster than the bleeding rate, **plastic shrinkage and plastic settlement cracking** may result.
3. Some of the rising water becomes trapped on the underside of coarse aggregate particles or of reinforcement, thus creating zones of poor bond and the permeability of the concrete in a horizontal plane may be increased.

The bleeding depends on

1. the properties of cement. Bleeding is decreased by increasing the fineness of cement, possibly because finer particles hydrate earlier.
2. Use a large amount of mixing water.
3. the reducing of proportion of very fine aggregate particles (especially smaller than 150 μm (No. 100 sieve).
4. A higher temperature, increases the rate of bleeding.

It therefore depends not only on the mix constituents and section dimensions but also the ambient conditions. A major factor in the capacity of a mix to bleed is the grading and consistency of the mix.

Bleed can be measured in two ways:

The reduction in height (i.e. settlement) of concrete sample.

The amount of bleed water rising to the surface of an undisturbed sample.

Thanks For Your Listening

Al-Muthanna University
Engineering College
Civil Engineering Department

Concrete Technology

The 14th lecture

Mix Design - 4

أ.م.د حسين كريم سلطان
للعام الدراسي
2020 - 2019

1. American method of selection of mix proportions

Q1: Calculate the amount of materials needed to prepare (1.8 m^3) of concrete to be used in the casting of a combined footing, so that it meets the following requirements: the compressive strength required at 28 days is 26 Mpa, slump of 80 – 100 mm, Standard deviation (Sd) = 2.5 Mpa, K= 1.64, the available aggregate has the following properties:
Fine Aggregate: Specific gravity = 2.64, fineness modulus = 2.80, the percentage absorption is 2.5%, moisture contain are 6%
Coarse Aggregate: Specific gravity = 2.65, bulk density is 1650 kg/m^3, the percentage absorption is 0.5%, moisture contain are 2%.

Solution:

1. **Determined compressive strength (F mean)**

F mean = F min + k * Sd

= 26 + (1.64 * 2.5) = 26 + 4.3 = 30.3 = 30 Mpa

Design concrete mixes

From Table 1, **Water content (W) = 202kg/m^3**

Slump, mm	Water, kg/m3 of concrete for indicated nominal maximum size of aggregate							
	9.5	12.5	19	25	37.5	50	75	150
Non-air-entrained concrete								
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	-
Amount of entrapped air, %	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25-50	181	175	168	160	150	142	122	107
75-100	202	193	184	175	165	157	133	119
150-175	216	205	197	184	174	166	154	-
Total air content, (%) for:								
Improvement of workability	4.5	4	3.5	3	2.5	2	1.5	1
Moderate exposure	6	5.5	5	4.5	4.5	4	3.5	3
Extreme exposure	7.5	7	6	6	5.5	5	4.5	4

Design concrete mixes

Table 2, **use to determined a water/cement ratio**

W / c = 0.55

Table 2 Relation between *w/c* and average compressive strength of concrete, according to ACI 211.1-81

Average Compressive Strength at 28 Days[a] (MPa)	Effective Water/Cement Ratio (by Mass)	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
45	0.38	—
40	0.43	—
35	0.48	0.40
30	0.55	0.48
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

Cement content (C) = 202/ 0.55 = 373.6 = 374 kg/ m^3

.

Design concrete mixes

Table 3, **use to determined the volume of coarse aggregate m3**

volume of coarse aggregate = 0.62 m^3

Maximum size of aggregate		*Bulk volume of oven-dry rodded coarse aggregate per unit volume of concrete for fineness modulus of fine aggregate of:*			
mm	*in.*	*2.40*	*2.60*	*2.80*	*3.00*
9.5	$\frac{3}{8}$	0.50	0.48	0.46	0.44
12.5	$\frac{1}{2}$	0.59	0.57	0.55	0.53
20	$\frac{3}{4}$	0.66	0.64	0.62	0.60
25	1	0.71	0.69	0.67	0.65
37.5	$1\frac{1}{2}$	0.75	0.73	0.71	0.69
50	2	0.78	0.76	0.74	0.72
75	3	0.82	0.80	0.78	0.76
150	6	0.87	0.85	0.83	0.81

Coarse aggregate = 0.62 * 1650 = 1023 kg / m^3

Design concrete mixes

From Table 4, determined weight of 1 **m**^{3} of concrete

weight of 1 m^3 of concrete = 2355 kg,

Max aggregate size	Weight of concrete (kg/m3)	
	No-air entrained concrete	air entrained concrete
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2506	2435

calculate the mass of fine aggregate:

Water content = 202kg

Cement content = 374 kg

Coarse aggregate content = 1023 kg/m^3

The sum. = 1602 kg/m^3

From Table 4, weight of 1 m^3 of concrete = 2355 kg,

Fine aggregate content = 2355 – 1602 = 753 kg/m^3.

Design concrete mixes

Solution by using weight method (حل السؤال باستخدام طريقة الاوزان)

1. From Table 1, **Water content (W) = 202kg/m^3**
2. From Table 2, **W / c = 0.55.**
3. **Cement content (C) = 202 / 0.55 = 374 kg/ m^3**
4. From Table 3, **volume of coarse aggregate = 0.62 m^3**
5. **Coarse aggregate = 0.62 * 1650 = 1023 kg / m^3**
6. calculate the mass of fine aggregate:

Water content = 202 kg
Cement content = 374 kg
Coarse aggregate content = 1023 kg/m^3
The sum. = 1602 kg/m^3

From Table 4, weight of 1 m^3 of concrete = 2420 kg,

Fine aggregate content = 2355 – 1602 = 753 kg/m^3.

From the various steps, we can list the estimated mass of each of the ingredients in kilograms per cubic meter of concrete as follows:

Water = 202 kg/m^3
Cement = 374 kg/ m^3
Coarse aggregate = 1023 kg / m^3
Fine aggregate = 753 kg / m^3
The sum. = 2355 kg /**m^3**

7. Adjustments to mix proportions

From lab experimental, moisture content for coarse aggregate = 2%, for fine aggregate = 6%, therefore

Wet coarse aggregate = 1023 * 1.02 = **1023 + 1023 * 0.02** = 1043.5 kg

Wet fine aggregate = 753 * 1.06 = **753 + 753 * 0.06** = 798 kg

Water contact with the surface coarse aggregate = 2 – 0.5 = 1.5%

Water contact with the surface fine aggregate = 6 – 2.5 = 3.5%

Water required = 202 – 1023*0.015 – 753*0.035 = **160** kg

The material weights estimated for producing 1 $\mathbf{m^3}$ of concrete are

Water content = 160 kg

Cement content = 374 kg

Wet fine aggregate content = 798 kg

Wet coarse aggregate content = 1043.5 kg

The sum. = 2375.5 kg /$\mathbf{m^3}$

7. Adjustments to mix proportions

The material weights estimated for producing 1.8 $\mathbf{m^3}$ of concrete are
Water content = 160 * 1.8 = 291.6 kg
Cement content = 374 * 1.8 = 673 kg
Wet fine aggregate content = 798 * 1.8 = 1436 kg
Wet coarse aggregate content = 1043.5 * 1.8 = 1878 kg
The sum. = 4278.6 kg /$\mathbf{m^3}$

2. British method of mix selection (mix design)

Q2: Using the British method: select a mix proportional of 28-day compressive strength (measured on standard cubes) of 50 MPa , slump of 80 mm; uncrushed aggregate with a maximum size of 20 mm; specific gravity of aggregate of 2.65, zone 2 of fine aggregate, ordinary Portland cement to be used. The maximum w/c = 0.5 and min. minimum cement content 400 kg/m^3.

Design concrete mixes

From Table 1, Compressive strength (fcu) = 42 MPa.

Type of cement	Type of coarse aggregate	Compressive strength* (MPa (psi)) at the age of (days):			
		3	7	28	91 Age of curing
1. Ordinary Portland (Type I) / 2. Sulfate-resisting Portland (Type V)	Uncrushed	22 (3200)	30 (4400)	42 (6100)	49 (7100)
	Crushed	27 (3900)	36 (5200)	49 (7100)	56 (8100)
3. Rapid-hardening Portland 4. (Type III)	Uncrushed	29 (4200)	37 (5400)	48 (7000)	54 (7800)
	Crushed	34 (4900)	43 (6200)	55 (8000)	61 (8900)

Design concrete mixes

2. From Fig. 1, water/cement ratio = **0.44**. **lower than 0.50 therefore used 0.44**

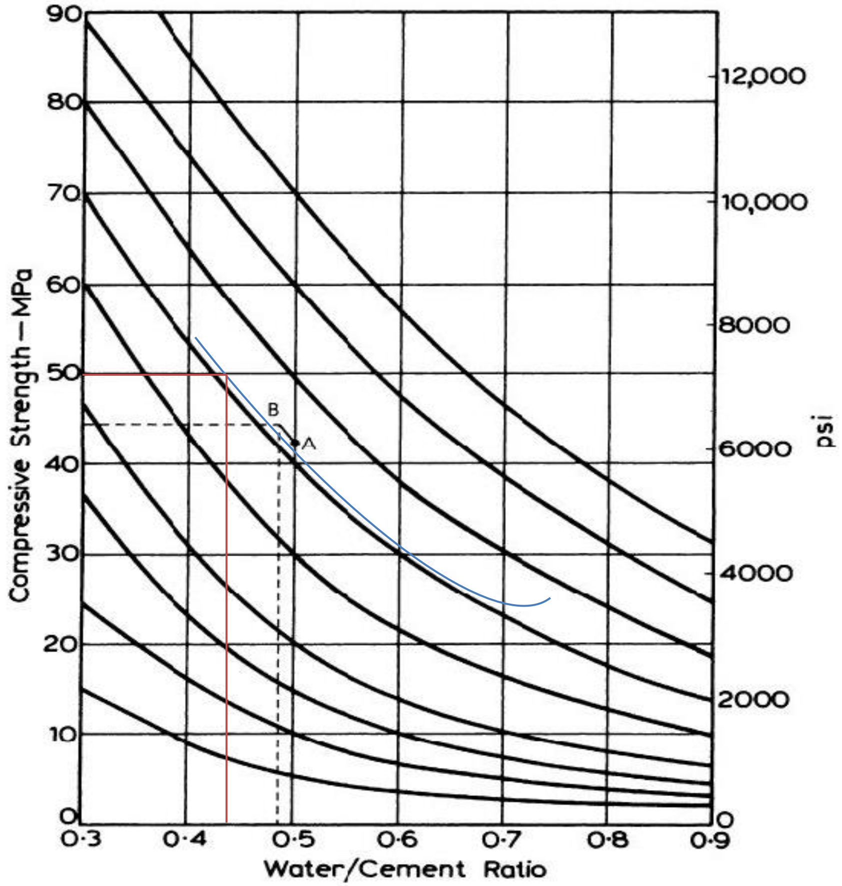


Fig. 1, Relation between compressive strength and free water/cement ratio for use in the British mix selection method.

Design concrete mixes

3. From Table 2, **water = 195 kg/m3.**

	Aggregate		Water content, kg/m³ (lb/yd³) for:				
	Max size mm (in.)	Type	Slump, mm (in.)	0–10 (0–$\frac{1}{2}$)	10–30 ($\frac{1}{2}$–1)	30–60 (1–2$\frac{1}{2}$)	60–180 (2$\frac{1}{2}$–7)
			Vebe time, s	>12	6–12	3–6	0–3
1.	10 ($\frac{3}{8}$)	Uncrushed		150 (255)	180 (305)	205 (345)	225 (380)
		Crushed		180 (305)	205 (345)	230 (390)	250 (420)
2.	20 ($\frac{3}{4}$)	Uncrushed		135 (230)	160 (270)	180 (305)	195 (330)
		Crushed		170 (285)	190 (320)	210 (355)	225 (380)
3.	40 (1$\frac{1}{2}$)	Uncrushed		115 (195)	140 (235)	160 (270)	175 (295)
		Crushed		155 (260)	175 (295)	190 (320)	205 (345)

4. cement content = 195/0.44 = **443** kg/m3. **higher than 400 kg/m3.** **ok.**

Design concrete mixes

5. From Fig. 2, fresh density of concrete = 2385 kg/m3.
6. The total aggregate content = 2385 – 443 – 195 = 1747 kg/m3.

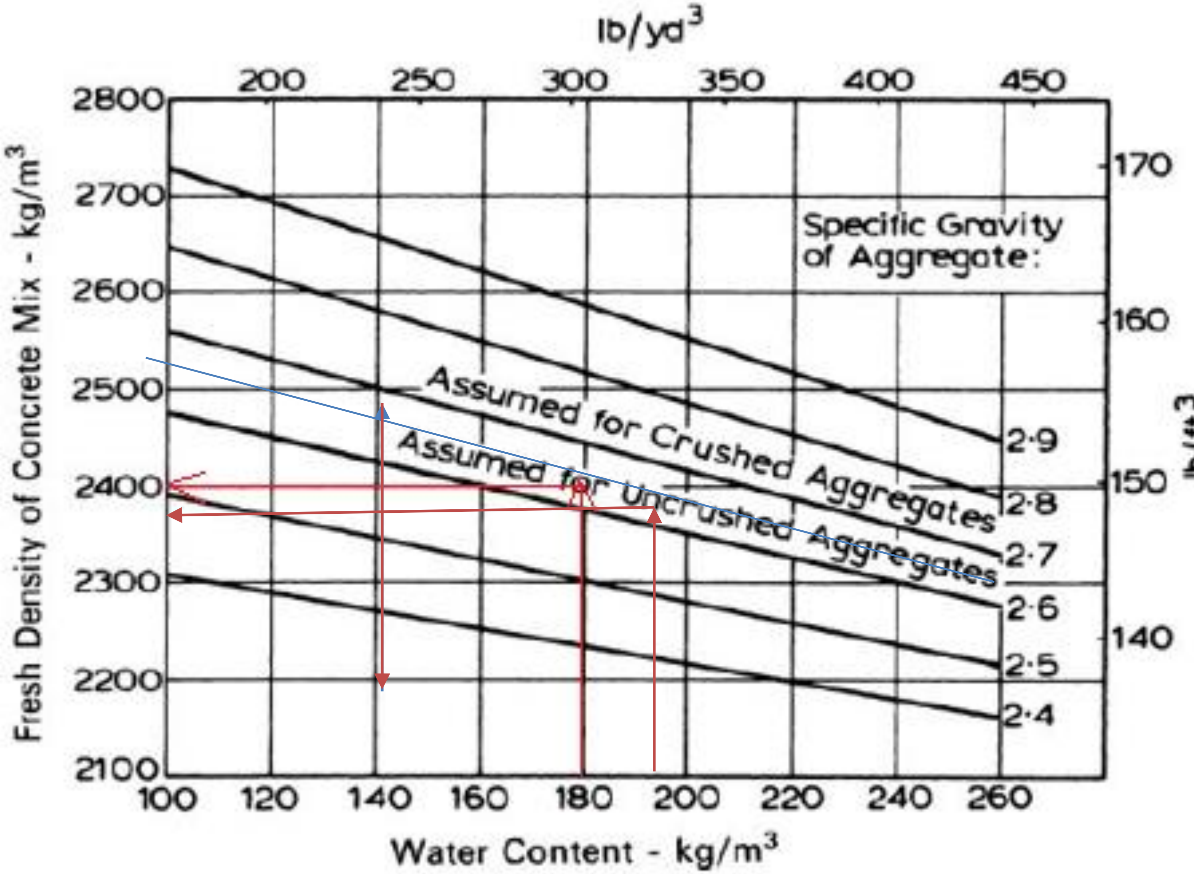
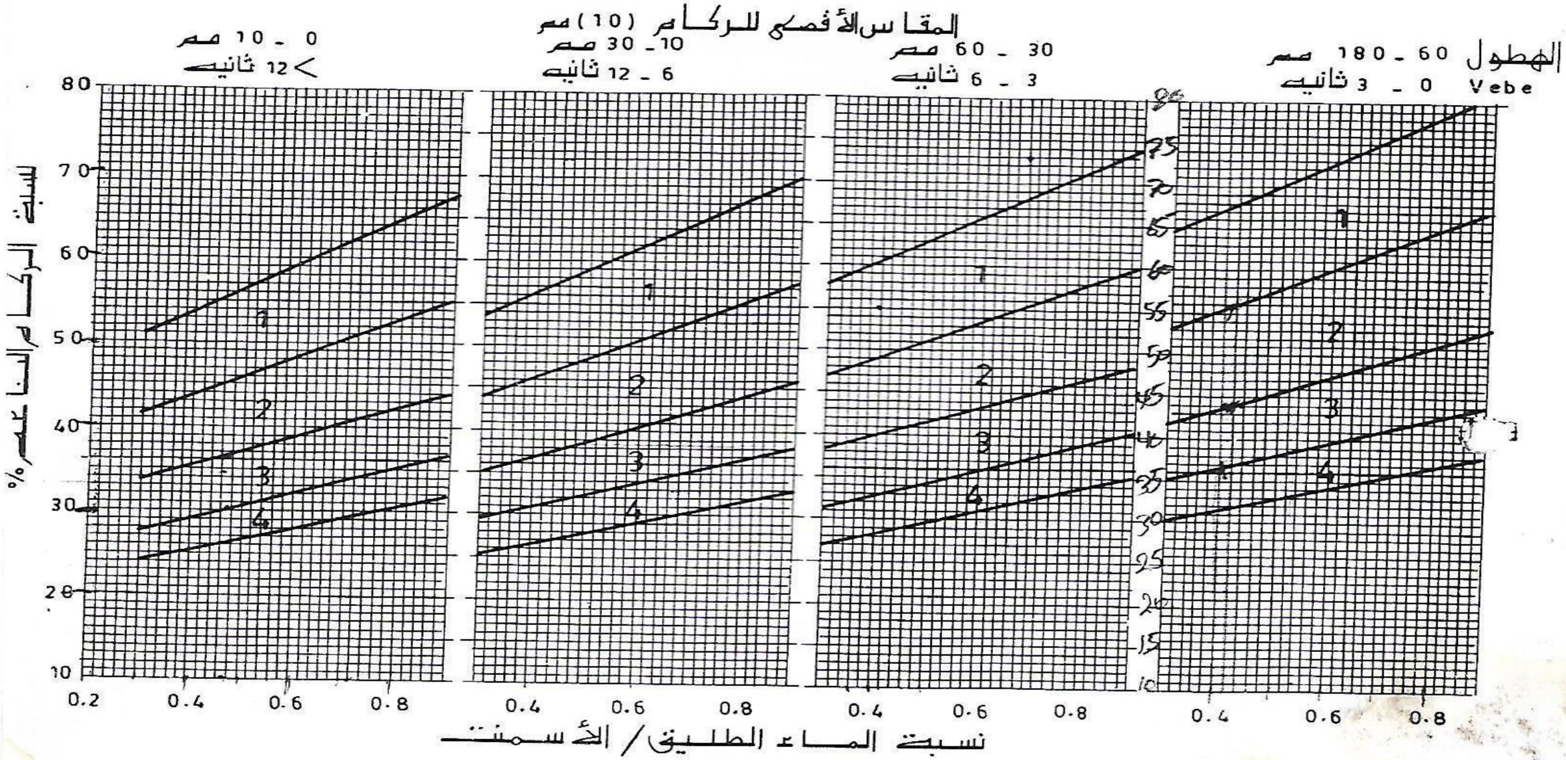
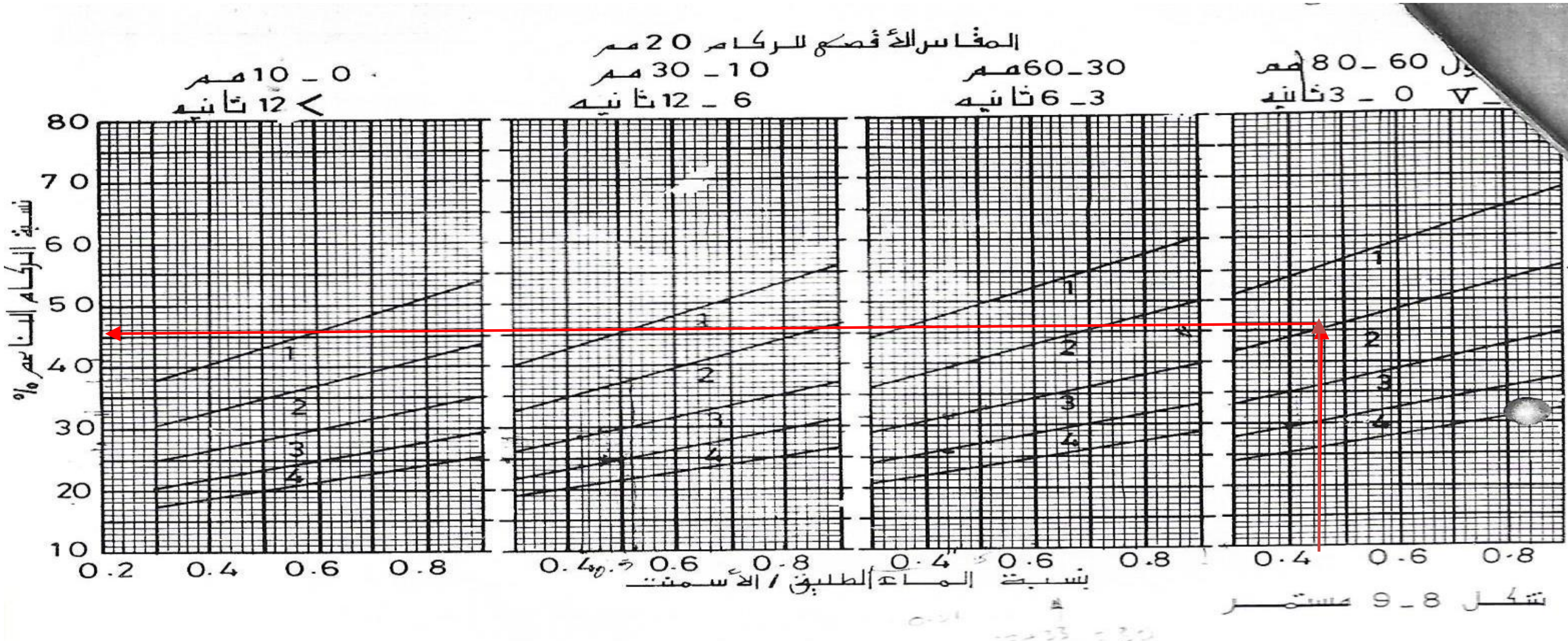


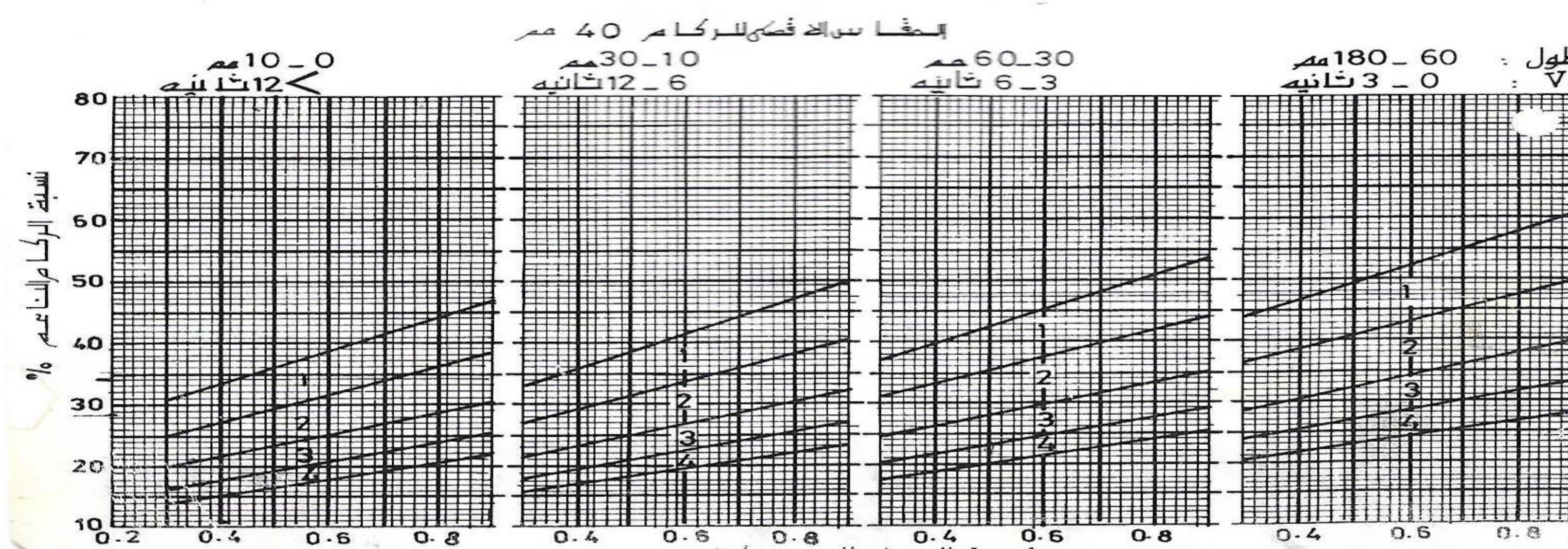
Fig. 2, Estimated wet density for fully compacted concrete (specific gravity is given for saturated and surface-dry aggregate)



شكل 8 - 9 النسب المقبولة لمناطق التدرج 1، 2، 3، 4 للركام الناعم حسب المواصفات القياسية البريطانية (B.S. 882)

Design concrete mixes





Design concrete mixes

1. From Fig. 2, fresh density of concrete = 2385 kg/m3.
2. The total aggregate content = 2385 – 443 – 195 = 1747 kg/m3.
3. proportion of fine aggregate is 45 % (by mass of total aggregate).
4. fine aggregate content = 0.45 × 1747 = **786** kg/m3
5. **coarse aggregate content** = 1747 – 786 = **961** kg/m3.

Design concrete mixes

1. From Table 1, Compressive strength (fcu) = 42 MPa.
2. From Fig. 1, water/cement ratio = **0.44**. **lower than 0.50 therefore used 0.44**
3. From Table 2, **water = 195 kg/m3.**
4. cement content = 195/0.44 = **443** kg/m3. **higher than 400 kg/m3. ok.**
5. From Fig. 2, fresh density of concrete = 2385 kg/m3.
6. The total aggregate content = 2385 – 443 – 195 = 1747 kg/m3.
7. proportion of fine aggregate is 45 % (by mass of total aggregate).
8. fine aggregate content = 0.45 × 1747 = **786** kg/m3
9. **coarse aggregate content** = 1747 – 786 = **961** kg/m3.

Thanks For Your Listening