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CONCRETE TECHNOLOGY

(COMPOSITION and PROPERTIES of CONCRETE)

Chapter one :

The Nature of Concrete

1.1. Introduction :

Concrete is the most widely used construction material in the world. It is Used in many different structures such as dams , pavements , building Frames or bridges. The present consumption of concrete is over 10 billion tons a year , that is , each person on earth consumes more than 1.7 ton of concrete per year. It is more than 10 times of the consumption by weight of steel. Concrete is neither as strong nor as tough as steel , so why is concrete so popular?

1.2. What is Concrete …

Concrete : is a composite material composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space between the aggregate particles and glues them together.

We can consider concrete as a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregates.

The inert (filler) material (aggregates) such as sand , gravel , stones , bricks , and etc…

1.3. Advantages of concrete :

(a) Economical : Concrete is the most inexpensive and the most readily available material. The cost of production of concrete is low compared with other engineering construction materials. Three major components : water , aggregate , and cement. Comparing with steel , plastic and polymer , they are the most Inexpensive materials and available in every corner of the world. This enables concrete to be locally produced anywhere in the world , thus avoiding the transportation costs necessary for most other materials.

(b) Ambient temperature hardened material : Because cement is a low temperature bonded inorganic material and its reaction occurs at room temperature , concrete can gain its strength at ambient temperature.

(c) Ability to be cast : It can be formed into different desired shape and sizes right at the construction site.

(d) Energy efficiency : Low energy consumption for production ,compare with steel especially.

(e) Excellent resistance to water : Unlike wood and steel , concrete can harden in water and can withstand the action of water without serious deterioration. This makes concrete an ideal material for building structures to control , store , and transport water.Examples include pipelines , dams , and submarine structures.

(f) High temperature resistance : Concrete conducts heat slowly and is able to store considerable quantities of heat from the environment (can stand 6-8 hours in fire) and thus can be used as protective coating for steel structure.

(g) Ability to consume waste : Many industrial wastes can be recycled as a substitute for cement or aggregate. Examples are fly ash , ground tire and slag.

(h) Less maintenance required : No coating or painting is needed for steel structures.

(i) Ability to work with reinforcing steel : Concrete and steel posses similar coefficient of thermal expansion (steel 1.2 x 10^{-5} ; concrete 1.0-1.5 x 10^{-5}). Concrete also provides good protection to steel due to existing of CH (this is for normal condition). Therefore ,while steel bars provide the necessary tensile strength , concrete provides a perfect environment for the steel , acting as a physical barrier to the ingress of aggressive species and preventing steel corrosion by providing a highly alkaline environment with PH about 13.5 to passivate the steel.

1.4. Limitations of concrete :

(a)Quasi-brittle failure mode : Concrete is a type of quasi-brittle material. (Solution : Reinforced concrete).

(b)Low tensile strength : About 1/10 of its compressive strength (Improvements : Fiber reinforced concrete ; polymer concrete).

(c) Low toughness : The ability to absorb energy is low. (Improvements : Fiber reinforced concrete).

(d) Formwork is needed : Formwork fabrication is labour intensive and time consuming , hence costly. (Improvements:Precast concrete).

(e)Long curing time : Full strength development needs a month. (Improvements : Steam curing).

(f) Working with cracks : Most reinforced concrete structures have cracks under service load. (Improvements : Prestressed concrete).

1.5. Composition of concrete :

The typical composition of ordinary concrete is shown in the following:

CONCRETE	
Inert material	**Cement paste**
(FILLER(Aggregate	**(BINDER)**
(Sand + Gravel(	**(Cement + Water + Air)**
(60 –80)% of total volume	**of total volume %(40 – 20)**
Cement Paste + Sand = Morter	
Morter + Gravel = Concrete	

The simplest representation of concrete is :

CONCRETE = FILLER + BINDER

1.6. Functions of cement paste and aggregates :

(a) Cement Paste: the binder material , the cement – water paste , is the active component of concrete . It has three main functions :

1. to fill the voids between the aggregate particles .
2. it provides lubrication to the fresh , plastic mass and water tightness in the hardened state .
3. to give strength to the concrete in its hardened state.

The properties of the hardened paste depend upon :

1. the characteristics of the cement .
2. the relative proportions of cement and water .
3. the completeness of chemical action (Hydration) between the cement and water.

(b) **Aggregates** : it is the embedded particles or fragments of a relatively inert mineral filler.

The filler material is generally graded in size from a fine sand to pebbles or fragments of stone which , in some concretes , may be several inches in diameter . It has three main functions :

1. to provide a relatively cheap filler for the cementing material .
2. to provide a mass of particles which are suitable for : resisting the action of applied loads , abrasion, the percolation of moisture , and the action of weather.
3. to reduce the volume changes resulting from the setting and hardening process and from moisture changes in the cement paste. (volume stability)

In practical concrete mixtures , the overall proportions of these principle components , the binder and the aggregate , are controlled by the requirements:

1. when freshly mixed , the mass be workable or placeable .
2. when the mass has hardened, it possess strength and durability adequate to the purpose for which it is intended.
3. cost of the final product be a minimum consistent with acceptable quality.

The composition of ordinary concrete can be represented diagrammatically (BAR CHART) as shown in the following Fig. :

Pores Solids

Air & Free Water	Cement	Aggregate	
		Fine	Coarse

Cement paste (binder) Inert mineral (filler)

Solved problem : Draw the bar chart for a mix proportions of (1 : 2 : 4) and W/C = 0.5 . (Specific gravities are : Water = 1.0, Cement = 3.15 Aggregate = 2.6 - 2.7)

Sol :

Mix Constituents	Absolute volumes	Percentages	Concrete Components
Cement	$\frac{1.0}{3.15} = 0.32$	$\frac{0.32}{3.13} \times 100 = 10\ \%$	**Cement Paste (26 %)**
Water	$\frac{0.5}{1.0} = 0.5$	$\frac{0.5}{3.13} \times 100 = 16\ \%$	
Sand	$\frac{2}{2.6} = 0.77$	$\frac{0.77}{3.13} \times 100 = 25\ \%$	**Agreggate (74 %)**
Gravel	$\frac{4}{2.6} = 1.54$	$\frac{1.54}{3.13} \times 100 = 49\ \%$	
Total	**3.13**	**100 %**	**100 %**

It is concluded that :

Aggregate (sand + gravel) occupies = 74 %

& Paste (cement + water + air) occupies = 26 % of concrete volume .

Therefore, the BAR CHART for this mix is as follows :

Water	Cement	Aggregate	
		Sand	Gravel
16 %	10 %	25 %	49 %

Question :

Draw the bar chart for a mix proportions of (1 : 1.96 : 4.31) , and w/c = 0.47.
(Specific gravities are : Water = 1.0 , Cement = 3.15 , Aggregate = 2.65) .

1.7. Types of concrete :

In concrete construction , the Portland cement concrete is utilized the most. Thus , in our course , the term CONCRETE usually refers to Portland cement concrete. For this kind of concrete , the composition can be presented as follows :

Cement
Admixture) = Cement paste +)
Water + = mortar +
Fine aggregate + = concrete
Coarse aggregate

Here we should indicate that <u>admixtures</u> are almost always used in modern .practice and thus become an essential component of modern concrete

<u>Admixtures</u> : are defined as materials other than aggregate (fine and coarse) , water , cement , which are added into concrete batch immediately before or during mixing , to improve the properties of concrete in both fresh (workability) and hardened states (strength).

: Classification of concrete 1.7.1

: a) <u>Based on reinforcement</u>)

Plain Concrete
Reinforced Concrete
Pre-Stressed Concrete
Pre-Cast Concrete
Pre-Fabricated concrete

:(b) <u>Based on unit weight</u> (Density)

.Ultra light concrete	< 1200 kg/m3
.Lightweight concrete	1200-1800 kg/m3
.Normal-weight concrete	≈ 2400 kg/m3
.Heavy-weight concrete	> 3200 kg/m3

: c) <u>Based on strength</u>)

Low-strength concrete	< 20 MPa compressive strength.
Moderate-strength concrete	20-50 MPa compressive strength.
High-strength concrete	50-200 MPa compressive strength.
Ultra high-strength concrete	> 200 MPa compressive strength.

: d) <u>Based on additives</u>)

(Normal concrete (without additives
Fiber reinforced concrete
Shrinkage-compensating concrete
Polymer concrete

:_e) <u>Based on the type of binder used</u>)

Portland cement concrete
Asphalt concrete
.Epoxy concrete

(f) <u>based on manufacturing method</u> :
Normal concrete
Prefabricated concrete

Chapter two :

2.Concrete - making Materials:

2.1. CEMENT: can be described as a material with adhesive and cohesive properties which make it capable of bonding mineral fragments into a compact whole, (the bonding materials used with stones, sand, bricks, building blocks and etc….).

<u>Hydraulic cements</u> consist mainly of silicates and aluminates of lime, and can be classified broadly as natural cements, Portland cements and high-alumina cements.

Historical Note: the use of cementing materials is very old.

1. The ancient Egyptians used calcined impure gypsum.
2. The Greeks and the Romans used calcined limestone and later learned to add to lime and water, sand and crushed stone or brick and broken tiles. This was the first concrete in the history.
3. The Middle Ages brought a general decline in the quality and use of cement, and it is only in the 18th century that an advance in the knowledge of cements can be reported.
   - John smeaton (1756).
   - James Parker.
   - Joseph Aspdin (1824).
   - Isaac Johnson (1845).

2.2. Portland Cement:

** The name PORTLAND CEMENT, given originally due to the resemblance of the colour and quality of the set cement to portland stone – a limestone quarried in Dorset – has remained throughout the world to this day to describe a cement.

2.2.1. Manufacture of portland cement:

There are TWO methods of manufacturing Portland Cement: the DRY Process & the WET Process.

In both methods, the process of manufacture of cement consists essentially of grinding the raw materials (consist mainly of lime, silica, alumina, and iron oxide) mixing them intimately in certain proportions and burning in a large rotary kiln at a temperature of approximately (1400)°C these compounds interact with one another in the kiln to form a series of more complex products. When the materials sinters and partially fuses into balls known as clinker, (it is the primary product of the rotary kiln , they are circular particles with 0.15- 5.0 cm. in size, black color, cooled and ground to a fine powder by adding 2-3 % gypsum ($CaSO_4.2H_2O$), the resulting product is the commertial portland cement so widely used throughout the world.

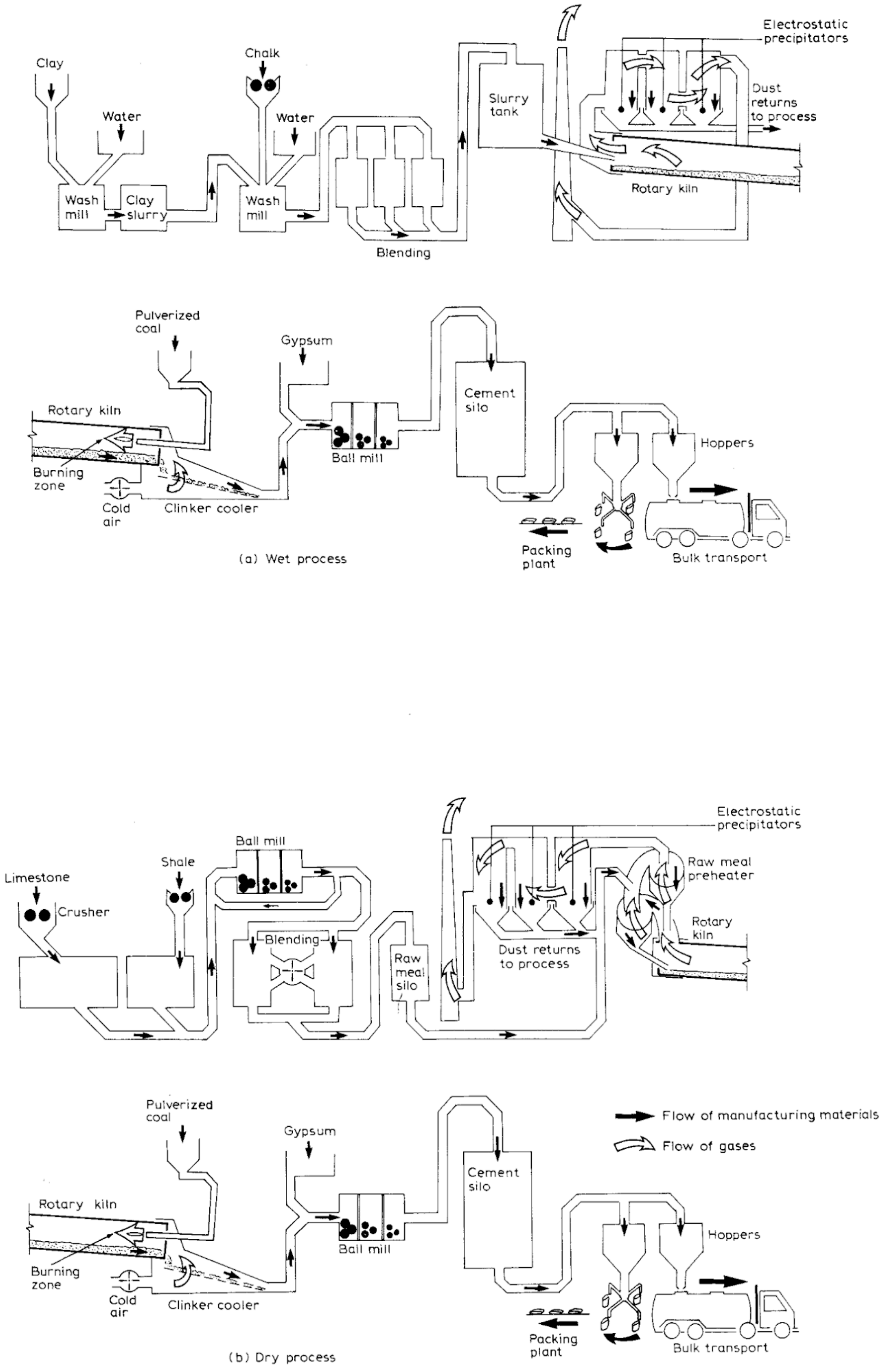


Fig. 1.1. *Diagrammatic representation of (a) the wet process and (b) the dry process of manufacture of cement*

<u>Why?</u> Clinker is ground with a small amount of gypsum (2-3 %) in the grinding process. OR Adding (2-3 %) of gypsum to clinker in the grinding process.

<u>Sol</u> :

(a) to control the time of setting of cement , (i.e. used as retarder).

(b) to obtain the desired degree of fineness.

Comparison between the <u>Dry</u> process and <u>Wet</u> process in manufacture of Portland Cement :

Process Wet	Dry process
Mixing and grinding raw materials .1 .with water	Mixing and grinding raw materials .1 .naturally
Kiln has larger size than for dry .2 .process	Kiln has smaller size than for wet .2 .process
.Needs more quantity of fuel .3	.Needs less quantity of fuel .3
.Economical less than dry process .4	.Economical more than wet process .4
Easy to obtain homogenious .5 .materials	Difficult to control mixing of raw .5 .materials
Machines need less maintenance than .6 .dry process	Machines need much maintenance .6 .than wet process

2.2.2. Chemical Composition of Portland Cement :

<u>Four</u> compounds are usually regarded as the <u>major</u> constituents of cement , they are listed in the following table :

Main compounds of portland cement		
Name of compound	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 Alluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

Where C=CaO , S=SiO_2 , A= Al_2O_3 , F= Fe_2O_3 and H_2O in hydrated cement is denoted by H .

**** In addition to the main compounds listed above , there exist minor compounds , such as MgO , TiO_2 , Mn_2O_3 , K_2O , and Na_2O ; they ususlly amount to not more than a few percent of the weight of cement.**

A knowledge of a percentages of the main chemical constituents of cement is important to an understanding of the nature and behavior of the cement.

The actual quantities of the various compounds vary consideraby from cement to cement, and indeed different types of cement are obtained by suitable proportioning of the materials.

A general idea of the composition of cement can be obtained from the following table (indicates the general proportions of the major constituents in the clinker , expressed as oxides) , which gives the oxide composition limits of Portland Cements :

Oxides	Percentages (by weight)	
	Range (%)	Average (%)
CaO (Lime) , calcium oxide	60 – 67	63
SiO_2 (Silica) , silicon dioxide	17 – 25	22
Al_2O_3 (Alumina) , aluminum sesquioxide	3.0 – 8.0	7
Fe_2O_3 (Iron) , ferrous oxide	0.5 – 6.0	3
MgO (Magnesia) , magnesium oxide	0.1 – 4.0	2
SO_3 (Sulfuric anhydride)	1.0 – 3.0	2
Alkalis (alkali oxide) : K_2O (Potassium) Na_2O (Sodium)	0.2 – 1.3	1

**** It may be noted that the first four major constituents account for over 90 % of the total.**

The above oxides which are included in the raw materials are interact with one another to form the four main compounds of Portland cement.

Bogue,s equations to calculate the percentages of main compounds in : cement are**

% C_3S = (4.071 x % CaO) – (7.600 x % SiO_2) – (6.718 x % Al_2O_3) – (1.430 x % Fe_2O_3) – (2.852 x % SO_3).
% C_2S = (2.876 x % SiO_2) – (0.754 x % C3S).
% C_3A = (2.650 x % Al_2O_3) – (1.692 x % Fe_2O_3).
% C_4AF = (3.043 x % Fe_2O_3).

Note : The terms in brackets represent the percentage of the given oxide of the total weight of cement.
It is interesting to observe the large influence of a change in the oxide composition on the compound composition of cement.

<u>Solved question</u> : by the use of Bogue's equations , calculate the oxide composition of a typical Portland Cement :

Typical oxide composition ,(%)		Calculated compound composition (using Bogue's equations), (%)	
CaO	63		
SiO_2	20	C_3S	54.1
Al_2O_3	6.0	C_2S	16.6
Fe_2O_3	3.0	C_3A	10.8
MgO	1.5	C_4AF	9.1
K_2O & Na_2O	1.0		
SO_3	2.0		
Others	1.0		

Czernin's data observed the large influence of a change in the oxide composition on the compound composition of cement as shown below :

Oxide	Percentage in cement No.		
	(1)	(2)	(3)
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

2.2.2.1. Influence of composition upon characteristics of cement :

The difference between types of Portland Cement comes from the variation between the main four major compounds (The properties of each compound are shown in the following table and fig. (1)) , in order to give the required properties in each type of cement .

Property	Relative behaviour of each compound			
	C_3S	C_2S	C_3A	C_4AF
Rate of reaction	Medium	Slow	Fast	Slow
Heat librated , per unit of compound	Medium	Small	Large	Small
Cementing value , per unit of compound :				
Early	Good	Poor	Good	Poor
Ultimate	Good	Good	Poor	Poor

From a consideration of the properties of the compounds it may be expected that , by altering their proportions , the properties of the cement may be controlled . For example , to secure a cement of Low – Heat generation , such as would be used in massive dam construction , a relatively high C_2S and low C_3S and C_3A contents are desirable , this type of cement is called Low-Heat Cement.

2.2.3. Types of portland cement :

The common types of Portland Cement are tabulated in the following table :

General description	Designation	Use
Normal – Genral purpose	Type I	For general concrete construction where special properties are not required.
Modified - General purpose	Type II	For general concrete construction exposed to moderate sulfate action or where it is required that the heat of hydration be somewhat lower than for normal cement.
High - early strength cement	Type III	For use when rapid hardening is required.
Low – heat cement	Type IV	For use where it is required that the heat of hydration be a practicable minimum.
Sulfate – resisting cement	Type V	For use where a high resistance to the action of sulfate is required.

- Representative average compound compositions for five types of portland cement are given in the following table :

Cement Types	General Description	Potential compound composition , (%)			
		C_3S	C_2S	C_3A	C_4AF
Type I	Normal-Genral purpose	49	25	12	8
Type II	Modified-General purpose	46	29	6	12
Type III	High early strength	56	15	12	8
Type IV	Low heat	30	46	5	13
Type V	Sulfate – resisting	43	36	4	12

Approximate relative strengths of concrete as affected by type of cement

Type of Portland Cement (ASTM American Society for Testing and Materials)	Compressive strength (% of strength of normal P.C.C.)		
	3 days	28 days	90 days
1. Normal-General Purpose	100	100	100
2.Modified-General Purpose	80	85	100
3.High-Earlystrength Cement	190	130	115
4. Low-Heat Cement	50	65	90
5. Sulfate-Resistance Cement	65	65	85

In general , the early strength of a portland cement will be higher with higher % of C_3S , but if moist curing is continuous , the later – age strengths, after about (6)months,will be greater for the higher % of C_2S .
A low C_3A cement generates less heat_, and develops higher ultimate strength than a cement containing larger amounts of this compound.

Why? Low heat portland cement should used in massive structures (Dams).
Sol : The total heat of hydration generated from reaction between cement and water is very high in the case of dams (due to the large quantities of concrete) , this will result in increasing the temperature (thermal expansion) of the concrete mass , and when the concrete return to the normal environmental temperature stresses will occur and it may be appear as cracks. This is explained below :

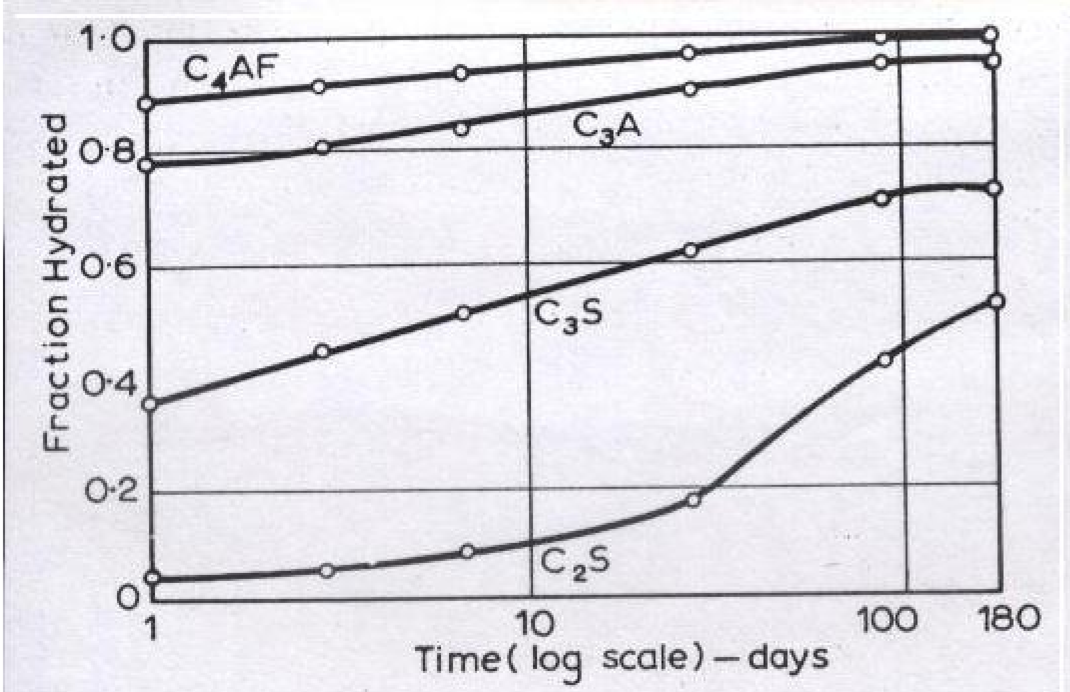
2.2.4. Hydration of cement :

It is the chemical reaction between the cement particles and water, heat is evolved due to this reaction (called heat of hydration).

In the presence of water , The main hydrates can be broadly classified as calcium silicate hydrates(C_3S , C_2S) and tricalcium aluminate hydrate(C_3A) and (C_4AF) form products of hydration , which at the same time produce a firm and hard mass called the hardened cement paste .
C_4AF is believed to hydrate into tricalcium aluminate hydrate and an amorphous phase .

The progress of hydration of cement can be determined by different means such as the measurement of :

1. The amount of $Ca(OH)_2$ in the paste .
2. The heat evolved by hydration .
3. The specific gravity of the paste .
4. The amount of chemically combined water .
5. The amount of unhydrated cement paste(using X-ray) .
6. Also indirectly from the strength of the hydrated paste.



Rate of hydration of pure compounds[1.47]

2.2.4.1. Heat of hydration of cement :

<u>It is the quantity of heat in joules per gram of cement (J/g), evolved upon complete hydration of cement at a given temperature .</u>

Strictly speaking , the heat of hydration , as measured , consists of :
The chemical heat of the reactions of hydration and the heat of adsorption of water on the surface of the gel formed by the processes of hydration .
In fact , the heat of hydration depends of the chemical composition of the cement .
The heat of hydration of cement is very nearly a <u>sum</u> of the heats of hydration of the individual compounds when hydrated separately.

**** Typical values of the heat of hydration of <u>pure</u> <u>compounds</u> are given in the table below:**

Compound	Heat of hydration (J/g)
C_3S	502
C_2S	260

C_3A	867
C_4AF	419

Woods, Steinour and Starke obtained the equation of the following type :

Heat of hydration of(1.0) gram of cement = 136(C_3S) + 62(C_2S) + 200(C_3A) + 30(C_4AF)

where the terms in brackets denote the (%) by weight of the individual compounds present in cement .

For the usual range of portland cements , Bogue observed that : about (50%) of the total heat is liberated between (1 and 3) days, and about (75%) of the total heat in (7) days, and (83 to 91%) of the total heat in (6) months.

The quantity of heat of hydration generated in the first seven days depending upon 100% for the Ordinary Portland Cement is :

- **(80-85) % for Modified Portland Cement ;**
- **(150) % for High early strength cement ;**
- **(40-60) % for Low heat cement ; and**
- **(60-75) % for Sulfate – resisting cement.**

It should be noted that one gram of Ordinary Portland Cement generates (80-100) calories when it react.

It is convenient at this stage to summarize the pattern of formation and hydration of cement schemetically as shown below :

COMPONENT ELEMENTS

O_2	Si	Ca	Al	Fe

COMPONENT OXIDES

CaO	SiO_2	Al_2O_3	Fe_2O_3

CEMENT COMPOUNDS

C_3S	C_2S	C_3A	C_4AF

PORTLAND CEMENTS

Various types of portland cement

HYDRATION PRODUCTS

Gel	**$Ca(OH)_2$**

2.2.5. Properties of Portland Cement :
(Specification requirements for Portland Cement)

;Setting and hardening of cement .2.2.5.1
;Strength of cement .2.2.5.2
;Fineness of cement .2.2.5.3
;Soundness of cement .2.2.5.4
Loss on ignition; and .2.2.5.5
.Specific gravity of cement .2.2.5.6

2.2.5.1. Setting and Hardening of cement :

Setting : This is the term used to describe the stiffening of the cement paste. Broadly speaking , setting refers to a change from a fluid to a rigid state.
For practical purposes it is convenient to distinguish setting from hardening , which refers to the gain of strength of a set cement paste.
In practice , the terms initial set and final set are used to describe arbitrarily chosen stages of setting.
The setting time of cement decreases with a rise in temperature , but above (30)^{o}C a reverse effect may be observed . At low temperatures setting is retarded.
Since the setting of cement is affected by the temperature and the humidity of the surrounding medium , these are specified by BS 4550 : Part 3 : Section 3.6 : 1978 : mixing room temperature of 20 ± 2 ^{o}C and minimum relative humidity of 65 % ; curing room temperature of 20 ± 1^{o}C and relative humidity of air of not less than 90 %.

False set : False set is the name give to the abnormal premature stiffening of cement within a few minutes of mixing with water.

Causes :

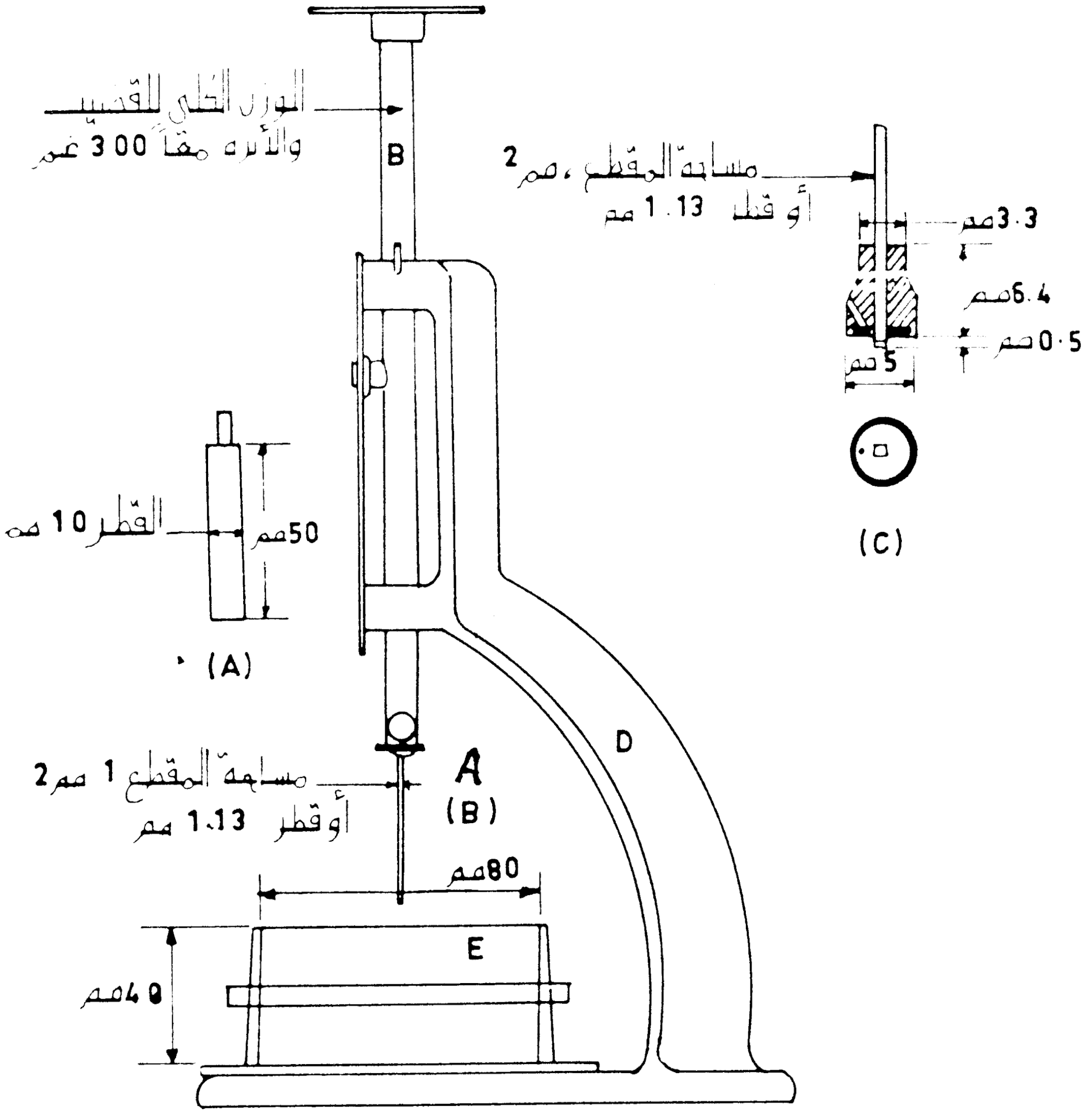
(a) Some of the causes of false set are to be found in the dehydration of gypsum when interground with a too hot clinker : hemihydrate ($CaSO_4$. --- H_2O) or anhydrite ($CaSO_4$) are formed , and when the cement is mixed with water these hydrate to form gypsum. Thus plaster set takes place with a resulting stiffening of the paste.

(b) Another cause of false set may be associated with the alkalis in the cement. during storage they may carbonate , and alkali carbonates react with $Ca(OH)_2$ librated by the hydrolysis of C_3S to form $CaCO_3$. This precipitates and induce a rigidity of the paste.

(c) It has also been suggested that false set can be due to the activation of C_3S by aeration at moderately high humidities. Water is adsorbed on the grains of cement , and these freshly activated surfaces can combine very rapidly with more water during mixing : this rapid hydration would produce false set.

Setting Time :

The setting times of cement are measured using the Vicat apparatus.



For the determination of the initial set a round needle with a diameter 1.13 ± 0.05 mm. is used. This needle , acting under a prescribed weight , is used to penetrate a paste of standard consistence placed in a special mould.

When the paste stiffens sufficiently for the needle to penetrate only to a point 5 ± 1 mm. from the bottom , initial set is said to have taken place.

A minimum time of 45 minutes is prescribed by BS 12 : 1978 for ordinary and rapid hardening Portland cements and for Portland blast-furnace cement ; for low heat Portland cement (BS 1370 : 1979) the minimum setting time is 60 minutes. The initial setting time of high-alumina cement is prescribed by BS : 915 : 1972 as between 2 and 6 hours.

Final set is determined by a similar needle fitted with a metal attachment hollowed out so as to leave a circular cutting edge 5 mm. in diameter and set 0.5 mm. behind the tip of the needle.
Final set is said to have taken place when the needle , gently lowered to the surface of the paste , makes an impression on it but the circular cutting edge fails to do so. The final setting time is reckoned from the moment when mixing water was added to the cement , and is required by the relevant British Standards to be not more than 10 hours for ordinary , rapid hardening , low heat , and blast-furnace Portland cements. For high-alumina cement BS : 915 : 1972 specifies the final setting time as not more than 2 hours after the initial set.

**** An approximate (within ± 15 min.) simple relation has been observed :**
final setting time (min.) = 90 + 1.2 x initial setting time (min.)

It should be remembered that the speed of setting and the rapidity of hardening (i.e. of gain of strength), are entirely independent of one another. For instant, the prescribed setting times of rapid hardening cement are no different from those for ordinary Portland cement, although the two cements hardened at different rates.

2.2.5.2. Strength of cement :

The mechanical strength of hardened cement is the propertry of the material that is perhaps most obviously required for structural use.

The strength of mortar or concrete depends on the :

- **(a) cohesion of the cement paste;**
- **(b) on its adhesion to the aggregate particles; and**
- **(c) to a certain extent on the strength of the aggregate itself.**

Strength Tests : Cement-Sand mortar and , in some cases , concrete of prescribed proportions and made with specified materials under strictly controlled conditions are used for the purpose of determining the strength of cement.

There are several forms of strength tests :

(a) Direct Tension;

(b) Direct Compression; and

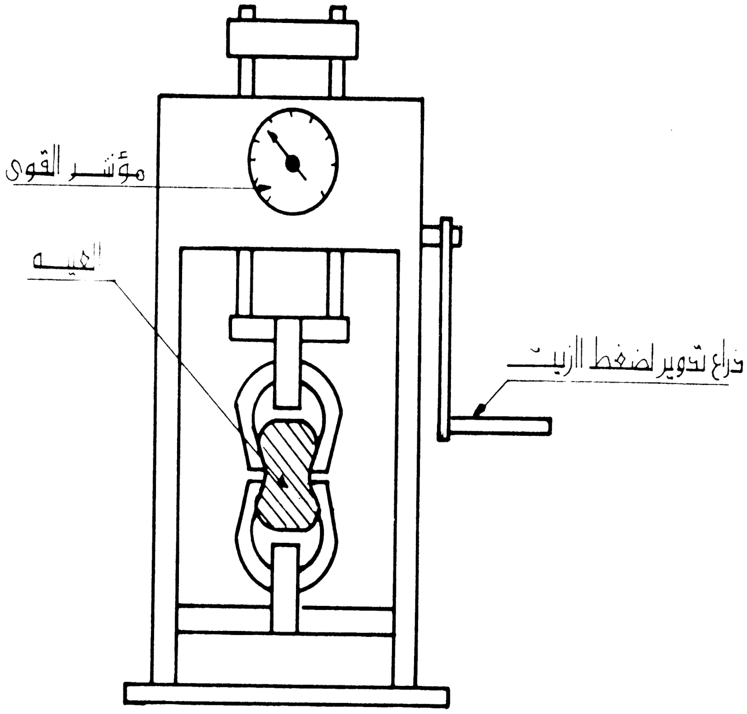
(c) Flexure.

The latter determines in reality the tensile strength in bending because , as is well known , cement paste is considerably stronger in compression than in tension.

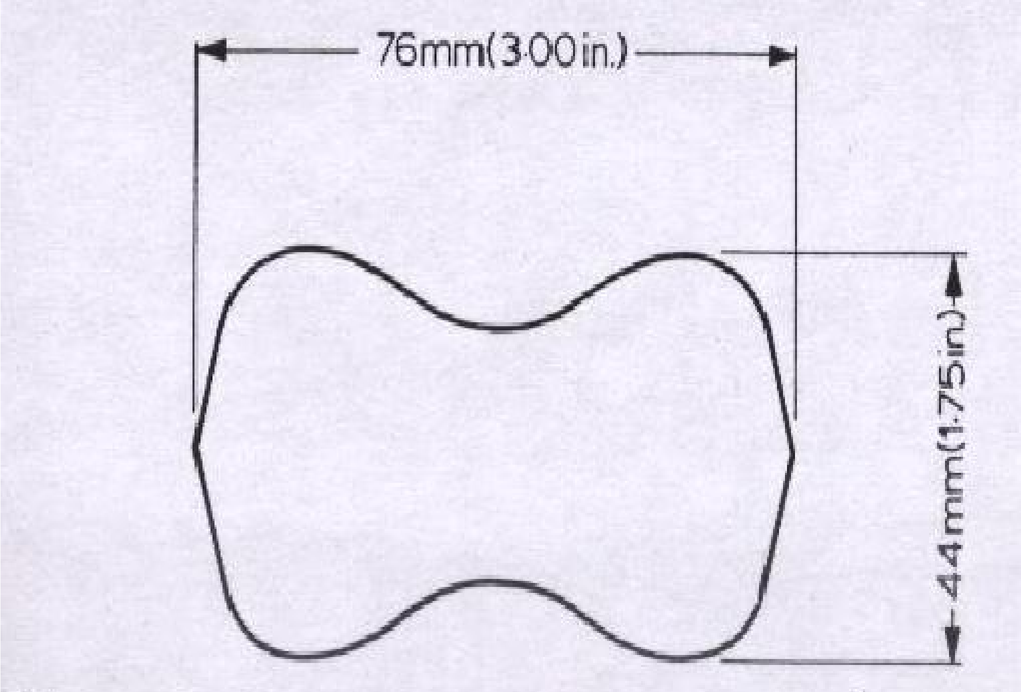
Tension Test :

The tension test still exist as a permitted test for a one-day strength of Rapid Hardening Portland Cement , and the details of the test as prescribed in the edition of BS 12 : 1971 may be of interest.

In this test , a 1:3 cement-sand mortar with a water content of 8% of the weight of solids is mixed and moulded into a briquette of the shape shown in the figure below:



شكل 27-1 جهاز فحص مقاومة الشد لملاط الاسمنت



Briquette for the tension test of mortar

The sand consists of pure siliceous material and is practically all of one size; all particles are nearly spherical and are smaller than a (No. 20 ASTM) sieve and at least 90% of the sand is retained on a (No. 30 ASTM) sieve.

The briquettes are moulded in a standard manner, cured for 24 hours at a temperature between 18 and 20 ºC in an atmosphere of at least 90% relative humidity, and tested in direct tension, the pull being applied through special jaws engaging the wide ends of the briquette.
BS 12 : 1958 prescribes the minimum one-day strength of rapid hardening Portland cement as 2.1 Mpa (300 psi), taken as the average value for six briquettes.

Compressive Strength: There are two standard methods of testing the compressive strength of cement: one uses mortar, the other concrete.
In the mortar test, a 1:3 cement-sand mortar is used. The sand is the same as for tension test, and the weight of water in the mix is 10% of the weight of the dry materials, expressed as a water/cement ratio, this corresponds to 0.40 by weight.
A standard procedure, prescribed by BS 4550 Part 3 : Section 3.4 : 1978, is followed in mixing, and 2.78 in. Cubes are made using a vibrating table with a frequency of 200 Hz applied for two minutes. The cubes are demoulded after 24 hours and further cured in water until tested in a wet-surface condition.
The BS 12 : 1978 requirements for minimum strengths (average values for three cubes) are given in the following table:

Age (days)	Minimum compressive strength							
	Mortar test				Concrete test			
	Ordinary Portland		Rapid-Hardening		Ordinary Portland		Rapid-Hardening	
	MPa	psi	MPa	psi	MPa	psi	MPa	Psi
3	23	3300	29	4200	13	1900	18	3300
28	41	5900	46	6700	29	4200	33	4800

<u>Solved problem</u> : Calculate the average compressive strength of a cement mortar in (kg / cm^2 , psi , and MPa) units , the loads assigned in the compression machine are (1.20 , 1.22 , and 1.18) Tons.

<u>Solution</u> :

$$\text{Average load} = \frac{1.20 + 1.22 + 1.18}{3} = 1.20 \text{ Tons .}$$

$$= 1.20 \times 1000 = 1200 \text{ kg.}$$

$$= 1200 \times 2.204 = 2644.8 \text{ lb.}$$

$$\text{Cross – Sectional Area} = 5 \times 5 = 25 \text{ cm}^2 .$$

$$= 2 \times 2 = 4 \text{ sq.in. (in}^2\text{)}$$

$$\text{Average compressive Strength} = \frac{\text{Average load}}{\text{Cross – Sectional Area}}$$

$$= \frac{1200}{25} = 48 \text{ kg / cm}^2$$

$$= \frac{2644.8}{4} = 661.2 \text{ psi}$$

$$= \frac{661.2}{150} = 4.4 \text{ MPa}$$

where :

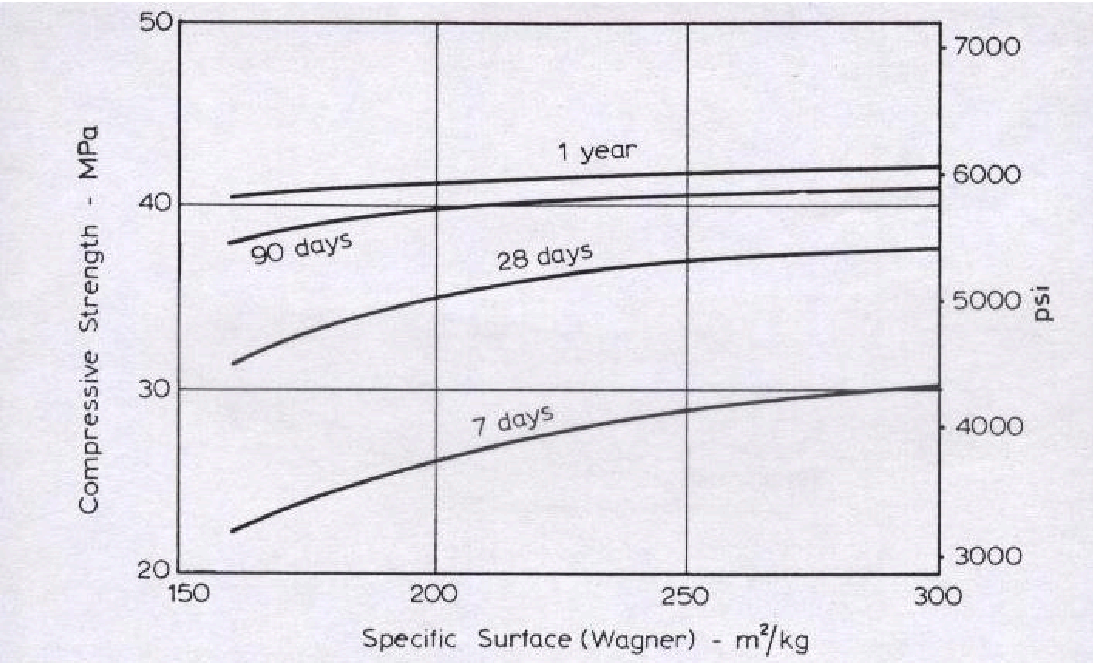
1.0 Ton = 1000 kg
1.0 kg = 2.204 pounds
1.0 Mpa = 145 – 150 psi.
(psi) is pounds per square inches , (lb / in^2).
(MPa) is Mega-Pascal , (N / mm^2).

2.11.1. Fineness of Cement : (Size of cement particles)

It is the total surface area of cement (m^2/kg or cm^2/g) that represents the material available for hydration , since the hydration starts at the surface of the cement particles.

Thus the rate of hydration depends on the fineness of the cement particles , and for a rapid development of strength high fineness is necessary.

**** The fineness of the cement also influences the rate of heat development , an increase in fineness speeding up the reactions of hydration and therefore the heat evolved , but the total amount of heat librated is not affected by the fineness of cement.**



Relation between strength of concrete at different ages and fineness of cement[1.43]

**** The finer the cement , the higher the specific surface (total surface area) of cement.**

Disadvantages of fineness of cement :

1. The cost of grinding to a higher fineness is considerable ,
2. Finer cement makes a paste exhibiting a higher shrinkage and a greater proneness to cracking.
3. Fine cement bleeds less than a coarser one .
4. An increase in fineness increases the amount of gypsum required for proper retardation.
5. In a finer cement more C_3A is available for early hydration .
6. The water content of a paste of standard consistence is greater in the fiiner cement .

7. An increase in fineness of cement slightly improves the workability of a concrete mix .

<u>Methods of determining fineness of cement</u> :

We can see that fineness is a vital property of cement and has to be carefully controlled.

1. <u>By Sieving</u> : *The fraction of cement retained on a 90 micron (No. 170 ASTM) test sieve was determined , and the maximum residue was limited to (10 %) by weight for Ordinary and (5 %) for Rapid Hardening Portland Cement.*

2. A direct approach is to measure the particle size distribution by <u>sedimentation or elutriation</u> : these methods are based on the *dependence of the rate of free fall of particles on their diameter*. Stoke's law <u>gives the terminal velocity of fall under gravity of a spherical particle in a fluid medium.</u>

However , the sieve test yields no information on the size of grains smaller than 90 microns (No. 170 ASTM) sieve , and for these reasons BS 4550 : Part 3 : Section 3.3 : 1978 prescribes a test for fineness by *determination of the specific surface of cement expressed as the total surface area in m^2/kg.*

3. A development of these methods is the <u>Wagner turbidimeter</u> (ASTM Standards C 115-79a). <u>In this test , *the concentration of particles in suspension at a given level in kerosene is determined using a beam of light , the percentage of light transmitted being measured by a photocell.*</u>

The turbidimeter gives generally consistent results , but an error is introduced by assuming a uniform size distribution of particles smaller than 75 microns.

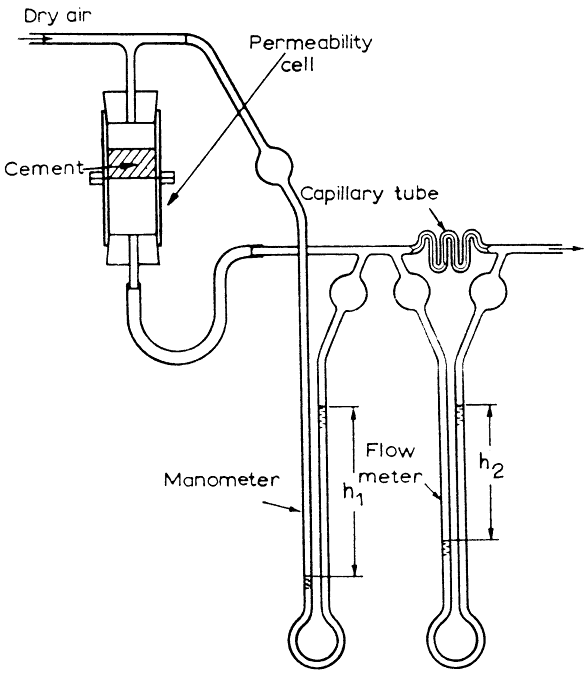
4. A more recent method of determination of the specific surface of cement is the <u>air permeability method</u> , using an apparatus developed by Lea and Nurse. This method is prescribed by BS 4550 : Part 3 : Section 3.3 : 1978.

This method is based on *the relation between the flow of a fluid through a granular bed and the surface area of the particles comprising the bed.*

From this the surface area per unit weight of the bed material can be related to the permeability of a bed of a given porocity , i.e. containing a fixed volume of pores in the total volume of the bed.

Knowing the density of cement , the weight required to make a bed of porocity of 0.475 and1.0 cm. thick can be calculated. This amount of cement is placed in a cylindrical container , a stream of dry air is passed through the cement bed at a constant velocity and the resulting pressure drop is measured by a manometer connected to the top and bottom of the bed. The rate of airflow is measured by a flowmeter consisting of a capilary placed in the circuit and a manometer across its ends.

The permeability apparatus is shown diagrammatically in the figure below :

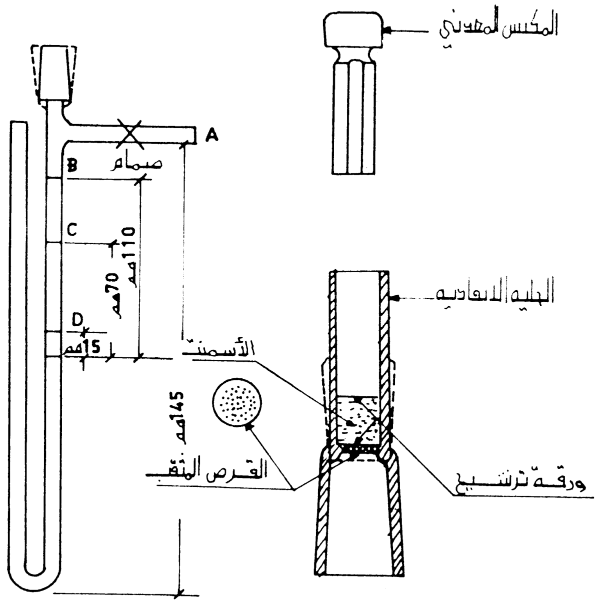


Lea and Nurse permeability apparatus

5. In the United States and in Germany , a modification of the Lea and Nurse method , developed by <u>Blaine</u> , is used. Here , *the air does not pass through the bed at a constant rate but a known volume of air passes at a prescribed average pressure , the rate of flow diminishing steadily.* The time (*t*) for the flow to take place is measured , and for a given apparatus and a standard porocity of 0.500 , the specific surface is given by :

$$F = K^2 \; t^{1/2}$$

Where K^2 is constant.



شكل 7-1 جهاز (Blaine) لقياس المساحة السطحية النوعية للاسمنت

The Lea and Nurse , and Blaine methods give values of specific surface in close agrement with one another but very much higher than the value obtained by the Wagner method. Some typical values are given in the following table :

Cement	Specific surface (m^2/kg) ---- measured by		
	Wagner method	Lea & Nurse method	Nitrogen adsorption
A	180	260	790
B	230	415	1000

2.11.2. Soundness of Cement :

Soundness refers to the ability of a hardened paste to retain its volume (It is the ability of the hardened cement paste to save its volume after setting).

It is essential that acement paste , once it has set , does not undergo a large change in volume (there must be no appreciable expansion) , the loss of this property is called unsoundness.

Why? Lack of the soundness property (expansion or unsoundness).

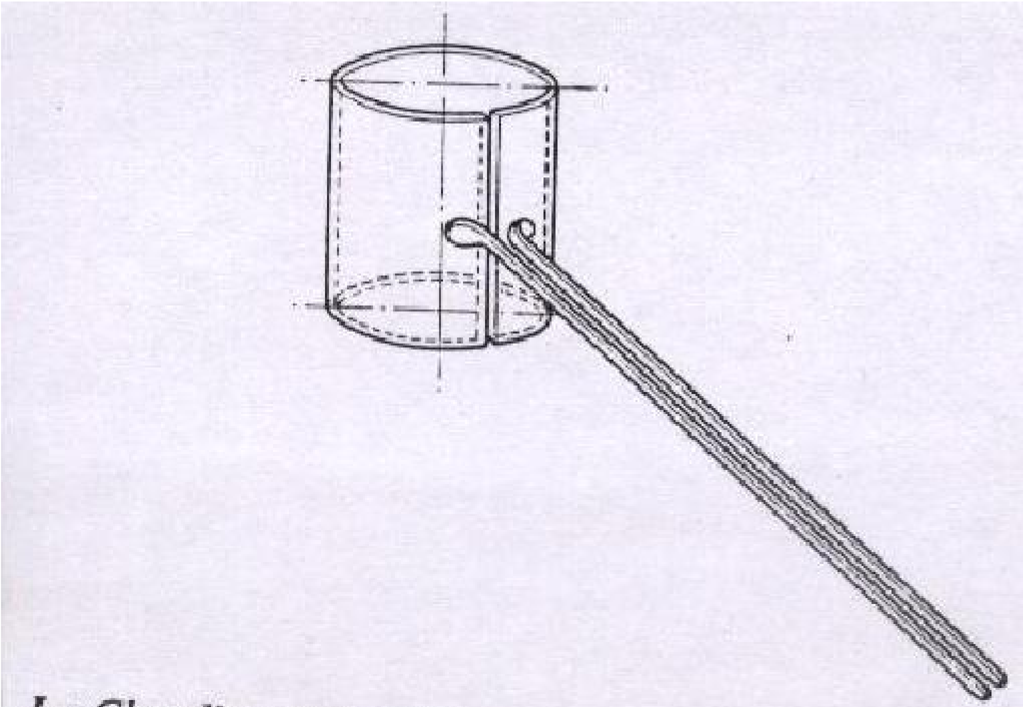
Sol : Expansion or unsoundness can be caused by excessive amounts of hard-burned free lime or magnesia.

Since unsoundness of cement is not apparent until after a period of months or years it is essential to test the soundness of cement in an accelerated manner. There are two methods :

: Soundness tests

1. A test devised by Le Chatelier is prescribed by (BS 4550 : Part 3 : Section 3.7 : 1978). The Le Chatelier apparatus , shown in the figure below consists of a

small brass cylinder split along its generatrix. Two indicators with pointed ends are attached to the cylinder on either side of the split ; in this manner , the widening of the split , caused by the expansion of cement , is greatly magnified and can be easily measured. The cylinder is placed on a glass plate , filled with cement paste of standard consistence , and covered with another glass plate. The whole assembly is then immersed in water at 20 ± 1 ºC for 24 hours. At the end of that period , the distance between the indicators is measured , and the mould is immersed in water again and brought to the boil in 25 to 30 minutes. After boiling for one hour the assembly is taken out , and , after cooling , the distance between the indicators is again measured. The increase in this distance represents the expansion of the cement , and for Portland cements is limited to 10 mm.



. *Le Chatelier apparatus*

2. In the United States soundness of cement is checked by the Autoclave test , which is sensitive to both free magnesia and free lime. In this test , prescribed by ASTM Standard C151-77 , a neat cement bar 25 mm. square in cross-section and with a 250 mm. gauge length is cured in humid air for 24 hours. The bar is then placed in an autoclave (a high-pressure steam boiler) , which is raised to a temperature of 216 ºC , steam pressure of 2 ± 0.07 MPa in 60 ± 15 min. , and maintained at this temperature for 3 hours. The expansion of the bar due to autoclaving must not exceed 0.8 %. The high steam pressure accelerates the hydration of both magnesia and lime.

: (Loss on Ignition (LOI .2.11.5

Loss on ignition of Portland cement is determined by heating a cement sample of known weight to between (900 to1000) ºC until a constant weight is obtained. The weight loss of the sample is then determined.
Normally, a high loss on ignition is an indication of prehydration and carbonation , which may be caused by improper or prolonged storage , or adulteration during transport. LOI values range from (0 to 3)% , and its test is performed in accordance with ASTM C114.

2.11.6. Specific Gravity of Cement (Relative Density) :

For mixture proportioning , it may be more useful to express the density as relative density (also called specific gravity).
The relative density is a dimensionless number determined by dividing the cement density by the density of water at 4ºC. (The density of water at 4ºC is 1.0 g/cm^3 , or 1000 kg/m^3).
The specific gravity of cement ranges from 3.10 to 3.25 , averaging 3.15 for all types of portland cement except for slag & pozzolanic cement it is 2.9.
The specific gravity of cement is determined by ASTM C188 , and it is not an indication of the cement quality , but its principal use is in mixture proportioning calculations.

: Typical values of Portland cement properties

Properties of Portland Cement	Types of cements		
	(Type I)	(Type III)	(Type V)
.Fineness (Blain method) , cm^2/gm	2250	3250	2500
: (Setting Time (Vicat method .a) Initial time (minutes) , min) .b) Final time (hours) , max)	 60 10	 60 10	 60 10
: (Compressive strength (average .a) 3 - days age (kg/cm^2) , min) .b) 7 - days age (kg/cm^2) , min)	 160 240	 210 285	 160 240
: Tensile strength , .day age (kg/cm^2) , min-1.0	 -	 21	 -
: Soundness .a) Le-Chatelier (expansion) , mm. , max) .b) Autoclave test (% increasing) , %, max)	 10 0.8	 10 0.8	 10 0.8
.Loss on Ignition , % , max	4.0	4.0	3.0
.of MgO (by weight) , max %	5.0	5.0	5.0
.of Al_2O_3 (by weight) , max %	-	-	3.5
.of SO_3 (by weight) , max %	3.0 – 2.5	3.0 – 2.5	2.5

2.12. Tests on Physical Properties of Cement :

Expirement No. 1 :
Method of Test for Normal Consistency of Hydraulic Cement :
This is considered to be standard in accordance with (ASTM C187).

Introduction :
In acceptance tests of cement , the water content is regulated by bringing the cement paste to a standard condition of wetness , called "normal consistency".

This normal consistency of cement has a marked effect upon the Initial and Final setting times and for the determination of the soundness test , therefore , normal consistency is necessary to determine the water content of the paste for any given cement which will produce the desired consistence.

Definition :
Normal consistency : is that condition (or optimum water content) for which the penetration of the plunger (10 mm. diameter of standard weighted fitted into the needle holder) of the Vicat apparatus into a cement paste is 10 mm. in 30 seconds.

Procedure :
A trial paste of 500 gm. of portland cement and a fixed percentage of water is mixed in a prescribed manner and placed in the mould of the Vicat apparatus . The plunger is then brought into contact with the top surface of the paste and released. Under the action of its weight the plunger will penetrate the paste , the depth of penetration depending on the consistence is defined.

Group No.	Weight of cement (gm.)	Water/Cement ratio (%)	Weight of water (gm.)	Penetration (mm.)
1	500	26	130	
2	500	28	140	
3	500	30	150	
4	500	32	160	

5	500	34	170	

Results :
The optimum water/cement ratio of the standard paste (expressed as a percentage by weight of the dry cements) is obtained at normal consistency for neat cement pastes using different percentages of water by projecting a curve explain the relation between the water/cement ratio and penetration of the plunger. The usual range of values being between 26 and 33 percent.

Discussion :
(a) What are the practical advantages of the normal consistency test?
(b) What did you mean by the normal consistency of cement paste?
(c) What is the optimum value of the normal consistency for the used cement?
(d) What are the factors affecting the results of this test?

Experiment No. 2 :

Method of testing the Initial and Final Time of Setting for cement paste :

Introduction :

Setting : This is the term used to describe the stiffening of the cement paste. Broadly speaking , setting refers to a change from a fluid to a rigid state.
For practical purposes it is convenient to distinguish setting from hardening , which refers to the gain of strength of a set of cement paste.
In practice , the terms initial set and final set are used to describe arbitrarily chosen stages of setting.

Definitions :

***Initial setting time* : It is the total time from the moment of adding mixing water to dry cement until the needle of Vicat apparatus penetrates to a distance equal to 35 mm. in the cement paste.**

***Final setting time* : It is the total time from the moment of adding mixing water to dry cement until the needle of Vicat apparatus makes an impression on the cement paste but the circular cutting edge fails to do so.**

Vicat apparatus :

The setting times of cement are measured using the Vicat apparatus.
For the determination of the initial set a round needle (A) with a diameter 1.13 ± 0.05 mm. is used. This needle , acting under a prescribed weight , is used to penetrate a paste of standard consistence placed in a special mould.
For the determination of the final set a round needle (B) with a diameter 3.3 ± 0.05 mm. is used.

Procedure :

1. We prepair a cement paste in the same manner of the normal consistency test using the determined w/c ratio obtained from the previous test (normal consistency).
2. We measure the penetration using the needle (A) at intervals (4 , 6 , 10 , 15 , 20 , 30 , --- , --- min.) until we reach the 35 mm. penetration reading.

Data :

Time (min.)	4	6	10	15						
Penetration (mm.)										

<u>Results</u> : From the results obtained draw the relation (a curve) between the time (min.) and the penetration (mm.) of the needle , the initial setting time (min.) is obtained at 35 mm. penetration.

<u>Specifications</u> :

A minimum time of 45 minutes is prescribed by BS 12 : 1978 for ordinary and rapid hardening Portland cements and for Portland blast-furnace cement ; for low heat Portland cement (BS 1370 : 1979) the minimum setting time is 60 minutes. The initial setting time of high-alumina cement is prescribed by BS : 915 : 1972 as between 2 and 6 hours.

<u>Discussion</u> :

1. What is the function of determining the initial and final time of setting.
2. can the cement be used after its initial setting? , and why?
3. Writedown the Standard Specifications for the initial and final time of setting of cement paste.
4. What are the factors affecting the results of the initial and final time of setting of cement paste.

Expirement No. 3 :

<u>Methods of determining fineness of Portland cement</u> :

1. <u>By Sieving</u> : *The fraction of cement retained on a 90 micron (No. 170 ASTM) test sieve was determined , and the maximum residue was limited to (10 %) by weight for ordinary and (5 %) for rapid hardening Portland cement.*

2. A direct approach is to measure the particle size distribution by <u>sedimentation or elutriation</u> : these methods are based on the *dependence of the rate of free fall of particles on their diameter*. Stoke,s law gives the terminal velocity of fall under gravity of a spherical particle in a fluid medium.
However , the sieve test yields no information on the size of grains smaller than 90 microns (No. 170 ASTM) sieve , and for these reasons BS 4550 : Part 3 : Section 3.3 : 1978 prescribes a test for fineness by *determination of the specific surface of cement expressed as the total surface area in m2/kg*.

3. A development of these methods is the <u>Wagner turbidimeter</u> (ASTM Standards C 115-79a). In this test , *the concentration of particles in suspension at a given level in kerosene is determined using a beam of light* , *the percentage of light transmitted being measured by a photocell*.
The turbidimeter gives generally consistent results , but an error is introduced by assuming a uniform size distribution of particles smaller than 7.5 microns.
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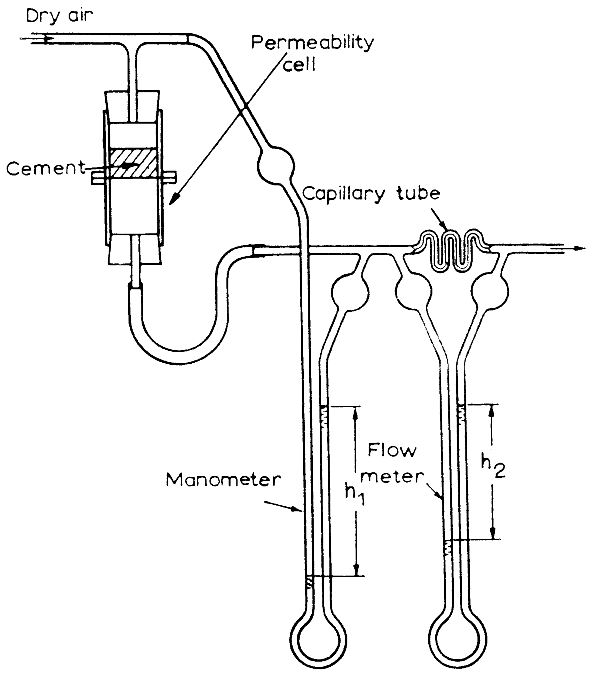
4. A more recent method of determination of the specific surface of cement is the <u>air permeability method</u> , using an apparatus developed by Lea and Nurse. This method is prescribed by BS 4550 : Part 3 : Section 3.3 : 1978.
This method is based on *the relation between the flow of a fluid through a granular bed and the surface area of the particles comprising the bed.*
From this the surface area per unit weight of the bed material can be related to the permeability of a bed of a given porocity , i.e. containing a fixed volume of pores in the total volume of the bed.

Knowing the density of cement , the weight required to make a bed of porocity of 0.475 and1.0 cm. thick can be calculated. This amount of cement is placed in a cylindrical container , a stream of dry air is passed through the cement bed at a constant velocity and the resulting pressure drop is measured by a manometer connected to the top and bottom of the bed. The rate of airflow is measured by a flowmeter consisting of a capilary placed in the circuit and a manometer across its ends.
The permeability apparatus is shown diagrammatically in the Figure below :

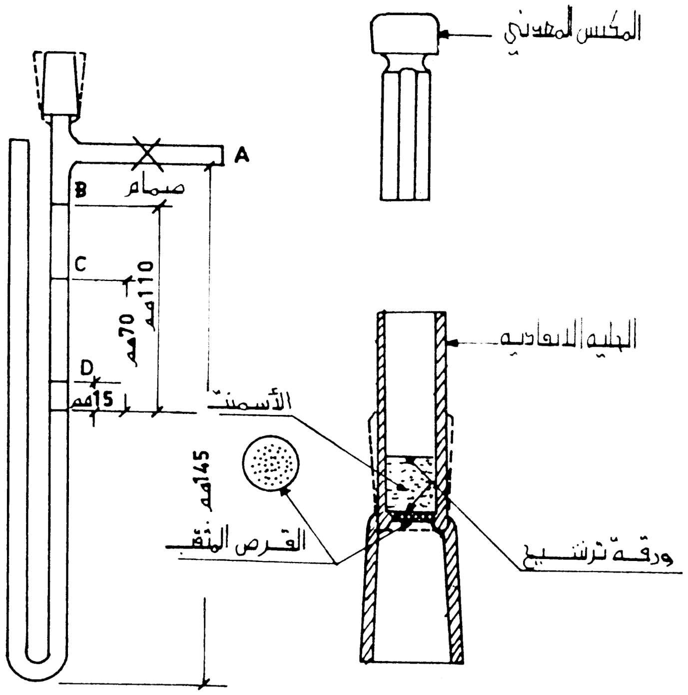


Lea and Nurse permeability apparatus

5. In the United States and in Germany , a modification of the Lea and Nurse method , developed by <u>Blaine</u> , is used. Here , *the air does not pass through the bed at a constant rate but a known volume of air passes at a prescribed average pressure , the rate of flow diminishing steadily.* The time (*t*) for the flow to take place is measured , and for a given apparatus and a standard porocity of 0.500 , the specific surface is given by :

$$S = K^2\ t^{1/2}$$

Where K^2 is constant.



شكل 7-1 جهاز (Blaine) لقياس المساحة السطحية النوعية للاسمنت

Expirement No. 4 :

<u>Method of determining compressive strength of cement mortar</u> :

<u>Compressive Strength</u> : There are <u>two</u> standard methods of testing the compressive strength of cement : one uses <u>mortar</u> , the other <u>concrete</u>.

In the <u>mortar test</u> , a 1:3 cement-sand mortar is used . The sand is the same as for tension test , and the weight of water in the mix is 10% of the weight of the dry materials , expressed as a water/cement ratio , this corresponds to 0.40 by weight.

A standard procedure , prescribed by BS 4550 Part 3 : Section 3.4 : 1978 , is followed in mixing , and 2.0 in. cubes are made using a vibrating table with a frequency of 200 Hz applied for <u>two</u> minutes. The cubes are demoulded after 24 hours and further cured in water until tested in a wet-surface condition.
The BS 12 : 1978 requirements for minimum strengths (average values for three cubes) are given in the following table :

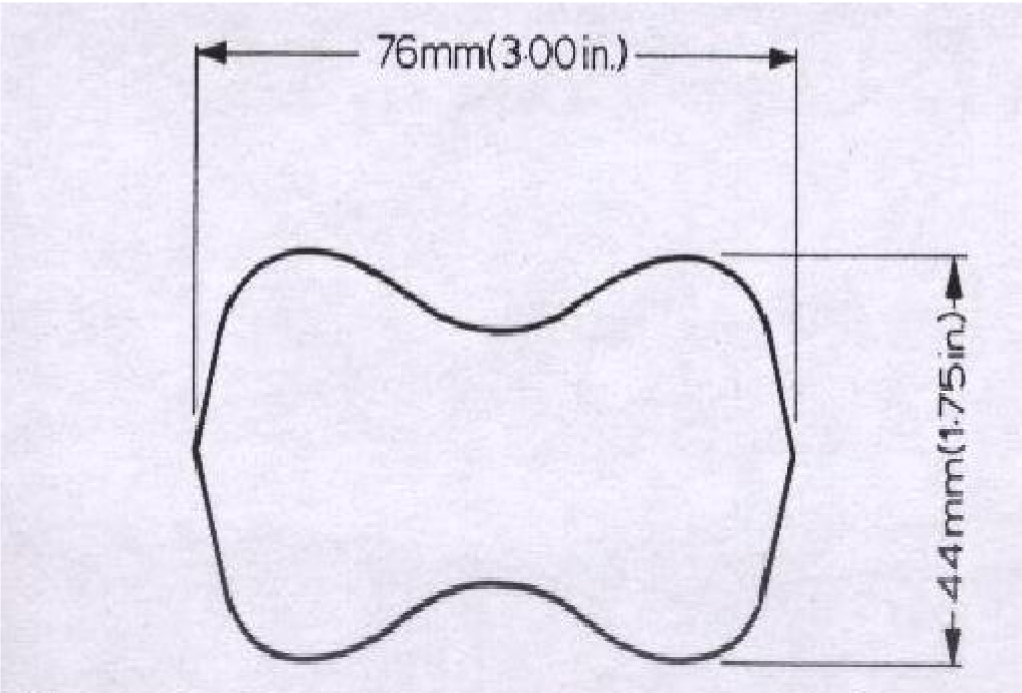
Age (days)	Minimum compressive strength							
	Mortar test				Concrete test			
	Ordinary Portland		Rapid-Hardening		Ordinary Portland		Rapid-Hardening	
	MPa	Psi	MPa	psi	MPa	psi	MPa	psi
3	23	3300	29	4200	13	1900	18	3300
28	41	5900	46	6700	29	4200	33	4800

Expirement No. 5 :

<u>Method of determining tensile strength of cement mortar</u> :

<u>Tension Test</u> **:The tension test still exist as a permitted test for a <u>one-day</u> strength of rapid hardening Portland cement , and the details of the test as prescribed in the edition of BS 12 : 1971 may be of interest.**

In this test , a 1:3 cement-sand mortar with a water content of 8% of the weight of solids is mixed and moulded into a briquette of the shape shown in the figure below :



Briquette for the tension test of mortar

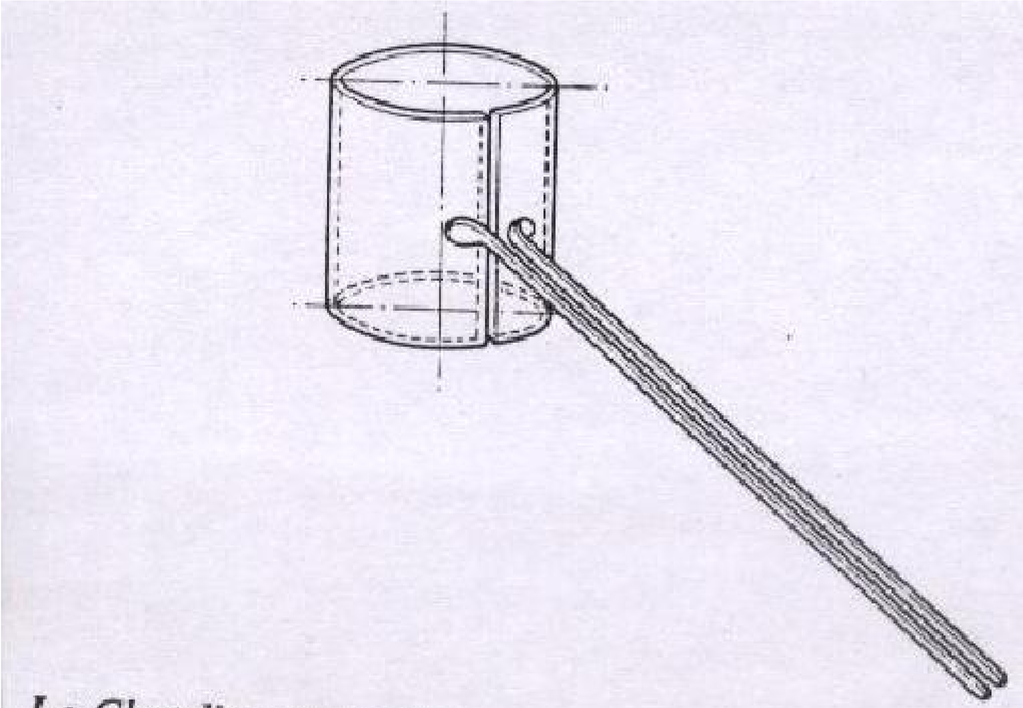
The sand consists of pure siliceous material and is practically all of one size ; all particles are nearly spherical and are smaller than a (No. 20 ASTM) sieve and at least 90% of the sand is retained on a (No. 30 ASTM) sieve.
The briquettes are moulded in a standard manner , cured for 24 hours at a temperature between 18 and 20 °C in an atmosphere of at least 90% relative humidity , and tested in direct tension , the pull being applied through special jaws engaging the wide ends of the briquette.
BS 12 : 1958 prescribes the minimum one-day strength of rapid hardening Portland cement as 2.1 Mpa (300 psi) , taken as the average value for six briquettes.

Expirement No. 6:

Methods of determining soundness of cement :

: Soundness tests

1. A test devised by Le Chatelier is prescribed by (BS 4550 : Part 3 : Section 3.7 : 1978). The Le Chatelier apparatus , shown in the Fig. below consists of a small brass cylinder split along its generatix. Two indicators with pointed ends are attached to the cylinder on either side of the split ; in this manner , the widening of the split , caused by the expansion of cement , is greatly magnified and can be easily measured. The cylinder is placed on a glass plate , filled with cement paste of standard consistence , and covered with another glass plate. The whole assembly is then immersed in water at 20 ± 1 °C for 24 hours. At the end of that period , the distance between the indicators is measured , and the mould is immersed in water again and brought to the boil in 25 to 30 minutes. After boiling for one hour the assembly is taken out , and , after cooling , the distance between the indicators is again measured. The increase in this distance represents the expansion of the cement , and for Portland cements is limited to 10 mm.



. *Le Chatelier apparatus*

2. In the United States soundness of cement is checked by the Autoclave test , which is sensitive to both free magnesia and free lime. In this test , prescribed by ASTM Standard C151-77 , a neat cement bar 25 mm. square in cross-section and with a 250 mm. gauge length is cured in humid air for 24 hours. The bar is then placed in an autoclave (a high-pressure steam boiler) , which is raised to a temperature of 216 °C , steam pressure of 2 ± 0.07 MPa in 60 ± 15 min. , and maintained at this temperature for 3 hours. The expansion of the bar due to

autoclaving must not exceed 0.8 %. The high steam pressure accelerates the hydration of both magnesia and lime.

2.13.Types of cements :

We have seen that cements differing in chemical composition and physical characteristics may exhibit different properties when hydrated.

The various types of PORTLAND CEMENT will now be described.

2.13.1. Ordinary Portland Cement (Type I);
2.13.2. Modified Portland Cement (Type II);
2.13.3. Rapid Hardening Portland Cement Cemen (Type III);
2.13.4. Low Heat Portland Cement (Type IV);
2.13.5. Sulphate-Resisting Cement (Type V);
2.13.6. Portland Blast-Furnace Slag Cement (Type IS);
2.13.7. Super-Sulphated Cement;
2.13.8. Portland-Pozzolana Cements and Pozzolanas (Type IP);
2.13.9. White Portland Cement;
2.13.10. Coloured Portland Cement; and
2.13.11. Special Types of Portland Cement.

2.13.1. Ordinary Portland Cement (Type I) :

It is the common cement in use , it is suitable for use in general concrete construction when there is no exposure to sulphate in the soil or in ground water.This cement has a 28-days strength of about (20-25)Mpa for continuously water-cured concrete with a w/c = 0.53.

2.13.2. Modified Portland Cement (Type II) :

It is the same as (Type I) but with certain modification such as :

(a) give a very low early strength;
(b) librating a moderately low amount of heat of hydration; and
(c) it can be used in concrete construction where moderate sulphate attack may occur.

Compare between Ordinary and Modified Portland Cement :

Modified Portland Cement	Ordinary Portland Cement
.It introduces less heat of hydration .1	.It introduces more heat of hydration .1
.It reacts slowly with water .2	.It reacts more rapidly with water .2
.It has higher resistance to sulphates .3	.It has less resistance to sulphates .3
It is used in all structures which are .4 .faced with moderate severe conditions	It is used in all structures which are .4 .not faced with severe conditions

2.13.3. Rapid Hardening Portland Cement (Type III) :

R.H.P.C. is very similar to (Type I) , but develops strength more rapidly , such that its 3-days strength is the same as 7- days strength of (Type I) using the same mix proportions.

The increased rate of gain of strength of this cement is achieved by:

(a) A higher C_3S content as high as 70%; and

(b) Finer grinding of the cement clinker (fineness = 3250 cm^2/gm and more).

The use of R.H.P.C. where a rapid strength development is desired , e.g. when the formwork is to be removed early for re-use or where sufficient strength for future construction is wanted as quickly as practicable.

However , the rapid gain of strength means a high rate of heat development , therefore R.H.P.C. should not be used in mass construction or in large structural sections (mass dams).

SPECIAL TYPES of R.H.P.C. :

1. Extra rapid hardening portland cement :

It is obtained by intergrinding calcium chloride (as admixtures , its quantity not exceed 2.0 %) with R.H.P.C. It is suitable for cold weather concreting , or when a very high early strength is required, but structural use with reinforcement is not permitted because of corrosion.

The strength of the EX. R.H.P.C. is about (25)% higher than that of R.H.P.C. at (1 or 2)days and (10 to 20) % higher at (7)days.

2. Ultra high early strength portland cement :

This cement contains no admixture and is therefore suitable for use in reinforced and prestressed concrete.The rapid strength development is due to the very high fineness of the cement (7000 - 9000 cm^2/gm). High fineness leads to rapid hydration , and therefore to a high rate of heat generation at early ages and to a rapid strength development (the 3-day strength is reached at 16 hours , and the 7-day strength at 24 hours).The use of Ultra high early strength cement results in lower workability. The SPEED cement is suitable for winter concreting or for urgent jobs such as road repair , well sealing , etc… .

2.13.4. Low - Heat Portland Cement (Type IV) :

The rise in temperature in the interior of a large concrete mass due to the heat developed by the hydration of cement can lead to serious cracking. For this reason , it is necessary to limit the rate of heat evolution of the cement used in this type of structure : a greater proportion of the heat can then be dissipated and a lower rise in temperature results.This type of cement was first produced for use in large gravity dams. In any case , to ensure a sufficient rate of gain of strength the specific surface (total surface area) of the cement must be not less than 3200 cm^2/gm.

2.13.5. Sulphate - Resisting Cement (Type V) :

The salts particularly active are Magnesium and Sodium sulphate. Sulphate attack is greatly accelerated if accompanied by alternate Wetting and Drying , as in a marine structures. It is a cement with low C_3A content (3.5%) and low C_4AF content. This means it has a high silicate content and this gives the cement a high strength but, because C_2S represents a high proportion of the silicates, the early strength is low.The minimum fineness is 2500 cm^2/gm.

2.13.6. Portland Blast - Furnace Slag Cement (Type IS) :

This type of cement is made by intergrinding Portland cement clinker and granulated blast-furnace slag , the proportion of the latter not exceed (65)% of the weight of the mixture.

SLAG : is a waste product in the manufacture of pig iron , the amounts of iron and slag obtained being of the same order.

The slag is a mixture the same oxides that make up portland cement , but not in the same proportions , such that :

42% lime;
30% silica;
19% alumina;
5% magnesia; and
1.0% alkalis.

It may be noted that slag is harder than clinker so that intergrinding presents some difficulties.

2.13.7. Super - Sulphated Cement :

It is made by intergrinding a mixture of (80 to 85)% of granulated blast - furnace slag with (10 to 15)% of calcium sulphate ($CaSO_4$) and about (5)% of portland cement clinker. A fineness of (4000 to 5000) cm^2/gm is usual.

This type of cement is highly resistant to sea water and can withstand the highest concentrations of sulphates normally found in soil or ground water , and also resistant to peaty acids and oils.

2.13.8. Portland-Pozzolana Cements and Pozzolanas (Type IP)

This name firstly given to interground or blended mixtures of portland cement and pozzolana.

Pozzolana is a natural or artificial material containing silica in a reactive form.

ASTM definition describes Pozzolana as a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but will , in finely divided form and in the presence of moisture , chemically react with calcium hydroxide $Ca(OH)_2$ at ordinary temperatures to form compounds possessing cementitious properties.

Pozzolana materials most commonly met with are : Volcanic Ash , Pumicite , Opaline Shales and Cherts , Burnt Clay , Fly Ash , etc..
Rice husks burnt at (450)°C have been found to produce a pozzolana.

Fly Ash : Known also as pulverized - fuel ash (pfa). It is a finely divided residue from the combustion of powdered coal in modern boiler plants such as power stations. OR it is the ash precipated electrostatically from the exhaust fumes of coal - fired power stations , and is the most common artificial pozzolana .

2.13.9. White Portland Cement :

For architectural purposes white or a pastel colour paint finish are sometimes required. White Portland Cement is made from raw materials containing very little iron oxide and manganese oxide. China clay is generally used , together with chalk or limestone , free from specified impurities.

A typical compound composition of white portland cement is given below :

Compound	Content (%)
C_3S	51
C_2S	26
C_3A	11
C_4AF	1
SO_3	2.6
Alkalis	0.25

White cement has a slightly lower specific gravity than ordinary portland cement , generally between (3.05 and 3.10). The strength of white portland cement is usually lower than that of ordinary portland cement.

2.13.10. Coloured Portland Cement :

Coloured Portland Cement is made by adding some kinds of colours (2 to 10) percent to the clinker of the Portland cement at the grinding stage.

Special Types of Portland Cement .2.13.11 :

a) <u>Anti - Bacterial Portland Cement</u> : It is made by grinding the Portland) cement with anti – bacterial agent. It is used in the concrete used in food .building and stores

يصنع من طحن السمنت البورتلاندي مع عامل مقاوم للبكتريا (anti - bacterial agent) ومانع لتخمر الاحياء المجهرية . يظهر فعل البكتريا واصحا في خرسانة الارضيات كمصانع الاغذية عندما تتفاعل الاحماض العضوية مع مكونات السمنت فتذيبها ويتبع ذلك التخمر بفعل البكتريا وبوجود الماء . يفضل استعمال هذا النوع من السمنت في احواض السباحة وفي ارضيات وجدران مصانع الاغذية مثل مصانع الالبان وتعبئة الماكولات .

b) <u>Hydrophobic Portland Cement</u>) : <u>السمنت البورتلاندي الغير المألوف للماء</u>

من المعروف عن السمنت انه يتلف ويتكتل اثناء الخزن الردىء بسبب امتصاصه لرطوبة الجو . وللتغلب على هذه الظاهرة ، تطحن مواد معينة مع السمنت البورتلاندي الاعتيادي اثناء صناعته فتشكل طبقة رقيقة مضادة للماء حول حبيبات السمنت . والمواد المستعملة لهذا الغرض هي : حامض الستياريك(Stearic acid) ، و حامض الاوليبك(Oleic acid) ، وحامض اللوريك (Lauric acid) ، وخماسي كلوروفينول (Pentachlorophenal) واكثر هذه المواد فعالية هو حامض الاوليبك ، اذ يضاف بنسبة (0.4 - 0.1) % الى كلنكرالسمنت البورتلاندي قبل عملية الطحن ، وان السمنت الذي يعامل بهذه الطريقة يمكن خزنه لفترة طويلة بدون تلف .

ان الغشاء المتكون حول حبيبات السمنت يتحطم اثناء عملية خلط الخرسانة وبذلك تستمر عملية الاماهة لهذا النوع من السمنت بصورة طبيعية ، ولكن يحدث بعض النقصان في مقاومة الخرسانة في الاوقات المبكرة جداً مقارنة بالسمنت البورتلاندي الاعتيادي .

c) <u>Water - Proof Portland Cement</u>) : <u>السمنت البورتلاندي المانع لنفاذ الماء</u>

يمكن تحضير هذا النوع من السمنت من اضافة مواد معينة مانعة لنفاذ الماء (waterproofing substances) الى كلنكر السمنت البورتلاندي الاعتيادي اثناء طحنه ، اذ تعطي هذه المواد خاصية عدم نفاذية السوائل للسمنت كما وتقلل من مقاومة خرسانته ولكن يمكن التغلب على ذلك بزيادة محتوى السمنت في الخلطة .

: d) <u>Masonary Cement</u>) <u>سمنت البناء</u>

It is used in mortar in brickwork. It is made by intergrinding very finely ground portland cement , limestone and an air - entraining agent .

يستعمل سمنت البناء في تحضير مونة البناء المستعملة لاغراض البناء بالطابوق او البلوك وذلك لان لدونتها تفوق لدونة مونة السمنت البورتلاندي الاعتيادي . ويمكن الحصول على هذا النوع من السمنت من طحن المواد السمنتية مع مواد اخرى.

.<u>Why</u>? Masonary Cement is used as a binding material in bearing wall building

: <u>.Ans</u>

;It has a high workability .1
;It has a high adhesive strength with the other materials .2
;It has a high plasticity , consistency , and cohesive strength .3
;It has a high volume stability due to variation in moisture and temperature .4
It protect mixing water when it touchs the dry bricks; and .5
.It has no bleeding .6

: e) <u>Natural Cement</u>(<u>السمنت الطبيعي</u>

This cement obtained by calcining and grinding a so-called cement rock , which is a clayey limestone containing up to (25)% of argillaceous material.

يصنع السمنت الطبيعي بتكليس احجار السمنت **(Cement Rocks)** الطبيعية المتكونة من الحجر الجيري الطيني **(Clayey Limestone)** الحاوي على نسب كافية من الالومينا والسيليكا ، يقصد بعملية تكليس هذه الاحجار معالجتها بالحرارة ، وبعد عملية التكليس يتم طحن كلنكر السمنت الطبيعي بحيث لا تقل المساحة السطحية النوعية بطريقة **(Blaine)** عن **(6000)** سم^2 /غم .

f) Expansive Cement) : السمنت التمددي

For many purposes it would be advantageous to use a cement which does not change in volume owing to drying shrinkage. This cement is developed by (H.Lossier) in France , who used a mixture of Portland Cement , an expanding agent , and a stabilizer.

بصورة عامة ، يخلط حوالي **(8 - 20)** جزء من كلنكر العامل التمددي (سلفو الومينات) مع **(100)** جزء من السمنت البورتلاندي و **(15)** جزء من المادة المثبتة .

هناك نوع اخر من السمنت التمددي يعرف بالسمنت التمددى ذو الطاقة العالية

High Energy Expanding Cement

(g) High - Alumina Cement : السمنت العالي الالومينا

This cement is very different in its composition and also in some properties from portland cements so that its structural use is severely limited , but the concreting techniques are similar.

The raw materials are : limestone or chalk , and bauxite.

Composition :

Oxide	Content (%)
SiO	3 to 8
AlO	37 to 41
CaO	36 to 40
FeO	9 to 10
FeO	5 to 6
TiO	1.5 to 2
MgO	1
Insolubale residue	1

For equal mix proportions , High - Alumina Cement produces a some what more workable mix than when portland cement is used. This may be due to the lower total surface area (3200-2250) cm^2/gm of High - Alumina Cement particles which have a smoother surface than portland cement particles.

يتميز السمنت العالي الالومينا بلونه الغامق ، وسرعة تصلبه، وتوليده لكميات من الحرارة العالية عند التميؤ ، ومقاومته لتأثيرات المواد الكيمياوية ، ويكون تركيبه غني بمادة الالومينا ، ويحتوي على نسبة اقل من اوكسيد الكالسيوم **(CaO)** مما يحتويه السمنت الاعتيادي .

لقد اوقف استعمال السمنت الالوميني في عدة دول اوروبية وذلك لحصول انهيار في بعض الابنية التي استعمل هذا النوع من السمنت في انشاء هياكلها وبعد فترة طويلة من اكمالها وخاصة في انكلترا عام **(1974)** ، ونتيجة لذلك جرت دراسات وبحوث عديدة حول اسباب هذا الفشل ، ومن الاستنتاجات الرئيسة لهذه الدراسات هو حصول نقصان في المقاومة عند تحول بلورات الومينات الكالسيوم المائية من الشكل السداسي والشبه المستقر **(CAH_8, CAH_{10})** الى الشكل المكعبي والمستقر **(C_3AH_6)** كما في المعادلة التالية :

$$\sout{CAH_8,}CAH_{10} \qquad C_3AH_6 + 2AH_3 + 18H$$

h) Oil - Well Cement) : سمنت الابار النفطية

يستخدم للآبار النفطية لغرض ملىء الفسح بين الانابيب الفولاذية وجدران البئر لمنع تسرب الماء او الغاز في الطبقات التي تحتوي على النفط . يجب ان يكون لهذا النوع من السمنت القابلية على الضخ الى حد (3) ساعات بالاضافة الى ذلك فأن سمنت الابار يجب ان يتصلب بسرعة بعد التماسك .

Why? It is preferable to use Rapid Hardening Cement in cold weather concreting.
Ans.: Because its advantage in reducing the time of saving the temperature of concrete.

Chapter three : Admixtures

3.1. Introduction :

Often , instead of using a special cement , it is possible to change some of the properties of the cement in hand by the use of a suitable additive, these additives are known as ADMIXTURES.

3.2. Definition : **Admixtures are defined as materials other than aggregate (fine and coarse) , water , cement , which are added into concrete batch immediately before or during mixing , to improve the properties of concrete in both fresh and hardened states.**

Admixtures may be classified according to the purpose for which they are used in concrete ; the approach of ASTM Standard C 494 – 70 can be used.

3.3. Types :

3.3.1. Accelerating Admixtures (Type C);
3.3.2. Retarding Admixtures (Type B);
3.3.3. Water - Reducing Admixtures (Type A);
3.3.4. Superplasticizers;
3.3.5. Air - Entrainment Admixtures;
3.3.6. Waterproofing Admixtures; and
3.3.7. Finely Divided Mineral Admixtures.

3.3.1. Accelerating Admixtures (Type C) :

Calcium Chloride ($CaCl_2$) is the common accelerator admixture.
The addition of this additive to the concrete mix has the following advantages :

- **(a) Increases the rate of development of strength , and therefore , it is used when concrete is to be placed at low temeratures (in the region of 2 to 4°C) , or when urgent repair work is to be done.**
- **(b) Increasing the early strength of rich mixes with a low water / cement ratio than lean ones.**
- **(c) Accelerates setting. The acceleration of setting makes the addition of ($CaCl_2$) useful in repair work.**
- **(d) Reduces the danger of frost attack during the first few days after placing.**
- **(e) Raises the resistance of concrete to errosion and abrasion at all ages.**

The following disadvantages of adding $CaCl_2$ to the concrete :

- **(a) Increases the rate of heat libration during the first few hours after mixing.**
- **(b) The resistance of cement to sulphate attack is reduced by the addition of ($CaCl_2$) , particularly in lean mixes, and the risk of an alkali – aggregate reaction , when the aggregate is reactive , is increased.**
- **(c) It increases the drying shrinkage usually about (10 to 15)% and possibly**

increases also the creep.

(d) The possibility of <u>corrosion</u> of reinforcing steel by $CaCl_2$.

Why? It is not preferable to use Calcium Chloride ($CaCl_2$) with more than 1.5 % in reinforced concrete.

Ans. : Because the possibility of corrosion of reinforcing steel by $CaCl_2$ will occur a .and this will damage the concrete

: (Retarding Admixtures (Type B .3.3.2

A delay in the setting of the cement paste can be achieved by the addition of a retarding admixture to the mix. These admixtures generally slow down the hardening of the paste.

Retarders are useful in concreting in hot weather , when the normal setting time is shortened by the higher temperatures.

The delay in hardening caused by the retarders can be used to obtain an architectural finish of exposed aggregate.

Retarding action is exhibited by: (Sugar, Carbohydrate derivatives, Soluble Zinc Salts, and others).

Retarders tend to increase the plastic shrinkage.

3.3.3. Water - Reducing Admixtures (Type A) :

According to ASTM Standards C494 - 79 the water- reducing admixtures are classified as :

(Type A) Admixtures which are water- reducing only;

(Type D) if the water- reducing properties are associated with set retardation ;

(Type E) water reducing and accelerating admixtures.

The principal active components of the admixtures are surface-active agents.These are substances which are concentrated and adsorbed on the cement particles.

The reduction in the quantity of mixing water that is possible owing to the use of admixtures varies between (5 and 15)%.

3.3.4. Superplasticizers (High-Range Water- Reducers) :

These are a modern type of water- reducing admixture , much more effective than the admixtures discussed in the preceding section. Chemically , they are Sulphonated Melamine Formaldehyde condensates and Sulphonated Napthalene Formaldehyde condensates , the later being probably the somewhat more effective of the two in dispersing the cement and generally having also some retarding properties.

Functions:

1. Increases the workability of concrete;
2. The mix remaining cohesive;
3. The resulting concrete can be placed with little or no compaction;
4. The resulting concrete is not subjec to excessive bleeding or segregation , such concrete is termed *flowing concrete* and is useful for placing in very heavily reinforced sections, in inaccessible areas,in floor or road slabs and also where very rapid placing is desired;

5. **The production of concrete of normal workability but with an extremely high strength owing to a very substantial reduction in the water/cement ratio. Generally speaking, superplasticizers can reduce the water content for a given workability by (25 to 35)% , compared with half that value in the case of co nvent additional water - reducing admixtures,and increase the 24-hour strength by (50 to 75)%;and even greater increase occurs at earlier ages; and**
6. **Superplasticizers do not influence Shrinkage , Creep , Modulus of Elasticity or resistance to Freezing and Thawing. Durability on exposure to sulphates is unaffected.**

3.3.5. Air–Entrainment Admixtures :

Entrained air in concrete is defined as : air internationally incorporated by means of suitable agent. This air should be clearly distinguished from accidentally entrapped air .

Entrained air bubbles are of the order of 0.05 mm. produces discrete cavities in the cement paste so that no channels for the passage of water are formed and the permeability of the concrete is not increased.

The main types of air - entraining agents are :

;(a) Animal and vegetable fats and oils and their fatty acids (beef tallow)

(b) Natural wood resins,which react with lime in the cement to form a soluble resinate; and

(c) Wetting agents such as alkali salts of sulphated and sulphonated organic compounds (e.g. Darex and Cormix).

The entraining agent represents between (0.005 and 0.05)% of the weight of cement.

Effects of Air – Entrainment :

(a)The original purpose of air - entrainment was to make frost-resistant concrete.

(b) One of the most important effect is the influence of VOIDS on the STRENGTH of concrete at all ages (Loss of strength). The decrease in the strength of concrete is proportional to the volume of air present. The average loss of compressive strength is (5.5)% for each (1.0)% of air present.

In order to avoid this loss in strength , the water content must be reduced as shown in the following figure :

(c) The entrainment of air has a cosiderable beneficial effect on the workability of the concrete.

In general terms , entrainment of (5)% of air increases the compacting factor by about (0.03 to 0.07) and the slump by (15 to 50 mm.).

The reason for the improvement ofworkability by the entrained air is probably that the air bubbles , kept spherical by the surface tension , act as a fine aggregate of very low surface friction and considerable elasticity.

(d) In the case of MASS concrete , where the development of heat of hydration of cement , and not strength , is of primary importance , air entrainment permits the use of mixes with low cement contents and therefore a low temperature rise.

(e)The presence of entrained air is also beneficial in reducing BLEEDING : the air bubbles appear to keep the solid particles in suspension so that sedimentation is reduced and water is not expelled.

(f) It is claimed sometimes that air entrainment reduces SEGREGATION. This is true as far as segregation during handling and transporting is concerned , as the mix is more cohesive.

(g)The addition of entrained air lowers the DENSITY of the concrete and makes cement and aggregate go further. This is an economic advantage.

(h) Air entrainment has been used successfully with sulphate-resisting and other Portland cements , and also when $CaCl_2$ is added as an accelerator.

(i) The effect of entrained air on the MODULUS OF ELASTICITY of concrete is much smaller.

3.3.6. Waterproofing Admixtures :

المضافات المانعة لنفاذ الماء : تصنف الى :

1. المضافات المقللة للنفاذية : ان المضافات التي تقع ضمن هذه المجموعة تقلل كلا من النفاذية الهيدرولية والمسامية للخرسانة وتملأ مساماتها ، ويمكن تصنيفها الى :

آ- المواد الدقيقة التجزئة

ب- الملدنات و مضافات الهواء المقصود

ج- المعجلات

2. المضافات الصادة للماء : مواد هذه المجموعة تقلل مرور الماء خلال الخرسانة الجافة الذي قد يحصل كنتيجة للفعل الشعري وليس كنتيجة لضغط الماء الخارجي. ان حركة رطوبة من هذا النوع قد تؤدي الى ظاهرة التزهر وبصورة عامة ظهور آثار رطوبة غير مرغوبة . وبصورة رئيسية يعتقد بأن كل هذه المواد تضفي على سطح الخرسانة خواصا صادة للماء اضافة الى تبطين مساماتها وفي بعض الاحيان غلقها.

3.3.7. Finely Divided Mineral Admixtures :

(a) **Admixtures for No – Slump Concrete.**
(b) **Pumping Aids for Concrete .**
(c) **Gas Forming Admixtures.**
(d) **Grouting Admixtures.**
(e) **Expansion Producing Admixtures .**
(f) **Binding Admixtures .**
(g) **Coloring Admixtures.**
(h) **Flocculating Admixtures.**

المضافات المعدنية الدقيقة التجزئة : هي مواد غير الركام والسمنت البورتلاندي تضاف الى خليط الخرسانة او المونة قبل عملية الخلط او خلالها كمكونات منفصلة . وهناك نوع اخر من هذه المضافات تعرف بالمزائج تطحن و تخلط عادة مع السمنت البورتلاندي لانتاج السمنت الهيدروليكي المخلوط .
ان هذه المضافات قد تكون ذات خواص سمنتية و بوزولانية ، ومعظم المواد المستخدمة هي بهيئة مسحوق يفوق السمنت البورتلاندي نعومة وبذلك تؤثر في الخواص الفيزيائية لعجينة السمنت الطرية بأسلوب مماثل للسمنت .
تستخدم المضافات المعدنية الدقيقة التجزئة في أي نوع من الخرسانة.

وتستخدم عادة لواحد او اكثر من الخواص الاتية :

آ- لتصحيح النقصان في كمية المواد الناعمة في الخليط .

ب- لتحسين واحد او اكثر من خواص الخرسانة ، على سبيل المثال : زيادة مقاومة تأثير الكبريتات او لتقليل التمدد الناتج عن تفاعل القلويات الموجودة في السمنت مع اجزاء السيليكا الفعالة في الركام او لتقليل النفاذية او لتقليل انبعاث الحرارة .

ج- لتقليل كلفة المواد المكونة للخرسانة او كافة عمليات انتاج الخرسانة او كليهما .

Compare between :

Accelerating Admixtures & Retarding Admixtures :

المضافات المعجلة (Accelerating Admixtures)	المضافات المبطئة (Retarding Admixtures)
1. كلوريد الكالسيوم المسرع الرئيسي (سائل او صلب).	1.الحوامض او الاملاح الحاوية على مجموعة الهيدروكسيل.
2. تعمل على تعجيل سرعة التفاعل بين الماء والسمنت .	2. تعمل على تأخير سرعة التفاعل بين السمنت والماء.
3. تستعمل في المناخ البارد .	3. تستعمل في المناخ الحار .
4. تضعف من مقاومة الخرسانة للاملاح ، لذلك لا تستعمل في الاماكن المعرضة للتأثيرات الشديدة .	4. لا تؤثر على مقاومة الخرسانة للاملاح .
5. تستعمل في العلاجات المستعجلة ولاقلال الوقت اللازم لرفع القوالب .	5. تستعمل عند الصب في الجو الحار حيث تكون الخرسانة صعبة الصب بسبب سرعة تماسكها .
6. سوء استعمال كلوريد الكالسيوم يؤدي الى صدأ فولاذ التسليح وتلف الخرسانة .	6. سوء استعمال هذه المواد تصبح نفس هذه المواد مواد معجلة للتفاعل .
7. يجب التريث عند استعمالها في المناخ الحار حيث ان السرعة في التصلب تؤدي زيادة في مقدار التقلص والتشقق .	7. يجب التحفظ بأستعمال هذه المواد في أي مشروع .

Compare between :

Entrained Air & Entrapped Air :

الهواء المقصود (Entrained Air)	الهواء المحبوس (Entrapped Air)
1.هواء مدمج يقصد في الخرسانة الطرية خلال عملية الخلط (مواد مضافة باعثة للفراغات الهوائية) .	1.هواء عرضي ناتج عن عدم اكتمال عملية الرص.
2. فقاعاته هوائية وصغيرة جداً يتراوح قطرها بين (0.01-1.0)مم.	2. تكون فجواته كبيرة جداً .
3. الفقاعات موزعة بصورة منتظمة خلال الكتلة الخرسانية .	3. الفجوات موزعة بصورة غير منتظمة .
4. تكون الفجوات مفصولة عن بعضها البعض وبذلك لا تشكل ممرات لجريان الماء مما يشير الى عدم نفاذية الخرسانة .	4. الفجوات تؤدي الى زيادة نفاذية الخرسانة .
5. نسبته (3-8) % من الحجم الكلي .	5. نسبته (1-2) % من الحجم الكلي .
6. يجب تعديل نسبة الماء/السمنت عند اضافته (تقليل كمية الماء) .	6. لا يشترط .