Coarse Aggregate

Coarse aggregate is used for making concrete. It may be in the form of irregular broken stone or naturally occurring rounded gravel. Materials which are large to be retained on sieve 5 mm are called coarse aggregates. Its maximum size can be up to 63 mm .

In coarse aggregate, foreign materials such as coal, clay lumps and soft fragments shall not exceed 5 % of its weight. The usual maximum size of aggregate that are specified for different works are given in table (1) below :

Table (1)

Type of Work	Maximum Size Specified
Non- reinforced Work	40 to 75 mm
Reinforced Concrete Foundation Work	40 mm
R.C. Work (Beams, Columns, Slabs in Buildings	20 mm
Shell Roof and Thin Members	10 mm

Testing of Aggregates

The tests usually prescribed on coarse aggregates are as follows:

1. **Routine Tests:**
   (a) Particle Size, Shape and Flakiness
   (b) Organic Impurities
   (c) Moisture Content
   (d) Water absorption and Specific Gravity

2. **Other Special Tests**
   (a) Aggregate Crushing Value
   (b) Aggregate Impact Value
   (c) Aggregate Abrasion Value
   (d) Bulk density and Void Ratio

1. Description of Routine Tests

The first four tests are important in many specifications. They are briefly described below:

(a)1 -Test for particle size : this is carried out in the field by sieve analysis.

(a)2 -Test for Shape and Flakiness : Aggregates are classified according to Their shape which may be (rounded), (irregular) , (angular) or (flaky).

(b) Test for organic impurities:

The clay content and fines can be found by immersing the aggregate in water and examining the suspended particles in the water.

(c) Test for moisture content:

The test is done by drying the aggregate in an oven or heating it in an open pan in the field.

(d) Test for water absorption and specific gravity:

A sample of aggregate, not less than 2kg is washed and immersed in water for 24 hours and its immersed weight in water is found (A). It is taken out of the water and weighed in the air (B). It is then oven - dried and weighed (C).

$$\text{Specific Gravity} = \frac{C}{B-A}$$

$$\text{Water Absorption \%} = \frac{B-C}{C} x\ 100$$

2. Description of Other Special Tests

(a) Aggregate Crushing Value:

In this test, we find the percentage of fines at a load of 40 tons. About 6.5 kg of aggregate is placed in a special machine and load of 40 ton is applied for 10 minutes. The load is released and the material is sieved through (2.40 mm) sieve. For ordinary concrete the sieved material should not be more than 30 %.

(b) Aggregate Impact Test:

This test is for aggregate in concrete that undergoes impact as in runways in airports. The material is placed in a standard cylinder. A hammer weighing 14 kg is dropped from a height of (40 cm) 15 times and the resulting material is sieved through 2.4 mm sieve . the percentage of fines should not be more than 45 % for aggregate used in ordinary concrete and should not be more than 30 % for that used in concrete for runways and pavements.

(c) Aggregate Abrasion value:

This test is for the stones used in road construction. Los Angeles abrasion machine is used for this purpose. The percentage of wear in this test is called the Los Angeles aggregate abrasion value. It should not be more than (16 %) for a good aggregate.

(d) Bulk density and Void Ratio:

The bulk density is determined by packing the aggregate into a special container of known volume and determining the weight of the aggregate packed.

Bulk density $= \gamma = \dfrac{Weight}{Volume}$

Void Ratio $= \dfrac{(Gs - \gamma)}{\gamma}$

Where : Gs = Specific gravity of aggregate.

Sand (Fine Aggregate)

Sources of Sand

Sand is sometimes classified according to the source of supply, which are:

1. Pit sand. This type of sand is obtained from old stream beds. It is sharp and generally coarse .
2. River sand. This is obtained from large rivers, it is usually fine in size. While taking it from rivers, care should be taken so that there is no clay mixed with the sand. ,
3. Stream sand. It is obtained from small streams near hills that may dry out in summer . This type of sand is generally coarse in size.
4. Sea sand. It is obtained from beaches. It is generally good for most works except reinforced concrete, if they are free from salts. Even though many specifications do not allow this type of sand to be used in construction, one may be forced to use them in works in faraway areas , they can then be washed in fresh water and used.

Impurities in Sand

Clay ,silt, sulphates salt and organic matters are the main impurities in sand. Sand should also be free from shells, wood particles, etc. It is sometimes specified that the sum of all impurities should not exceed (5 %) . Generally a maximum of (8 %) of silt is allowed in sand for mortar and concrete. The Iraqi specifications allows up to (0.5 %) of sulphates salts in sand for general construction.

Classification of Sand for Making Concrete

Sand for making concrete is usually grouped into five zones –zone 1 to zone5, (very coarse to very fine). The main criterion for division of sand into coarse and fine can be taken as (0.6 mm) in size. If major part is above 0.6 mm in size, then it is called coarse sand. If major part is below 0.6 mm in size, then we can call it fine sand. Sand is further divided in soil mechanics by examining the particle sizes as follows:

Coarse sand : (4.5) mm to (2.0) mm

Medium sand : (2.0) mm to (0.425) mm

Fine sand : (0.425) mm to (0.075) mm

Uses of Sand

(a) Sand for concrete work

Very fine sands (zone 4 and zone 5) are not suitable for structural concrete. Very coarse sand shows difficulties in surface finishing of concrete but provide good strength. Fine sand provides more cohesion than coarse sand and hence less sand will be needed if fine sand is used. While making concrete, coarse aggregate from crushed rocks will need more sand than rounded coarse aggregate such as river gravel.

(b) Sand for Mortars and Plasters

In general, mortars made of very coarse sand does not adhere easily to the bricks during bricklaying. Fine sand is the ideal material for making mortar and plaster for brick work.

The sand used for mortar for brickwork should pass through a sieve of 8 meshes per inch (3.2 mm) and the sand for plastering must pass through a sieve of 12 meshes to the inch (2 mm). Another recommendation for sand used for plaster and mortar work is that the sand passing through a 600 micron sieve should be (40 to 100) % for mortars and (80 to 100) % for plasters.

(c) Sand for Filling

Sand is also used in building construction for filling underground floors and also used for filling behind retaining walls, etc. Sand used for filling underground floors has to reduce the capillary suction by which water will travel from foundation soil to the floor . This will require coarse sand with large voids between the grains.

For sands required for filling behind retaining walls it should be non-expansive and free draining. Most of the sands are not expansive and free draining and thus are suitable for general filling purposes.

Tests for Quality of Sand

The main tests for sand are:

1. Test for grading
2. Test for organic impurities
3. Test for clay and silt content.

1.Test for grading;

This test is made by sieve analysis. It gives the data regarding the zone into which the sand can be placed. The various zones are classified as very coarse, coarse, fine or very fine.

2. Test for organic impurities:

This is an important test for dirty sands .It consists of adding a sample of the sand to a 3% solution of sodium hydroxide in a bottle and the bottle is shaken well and left for 24 hours. If the liquid above the sand is colorless or a straw colour, the sand is acceptable. If the colour of liquid above the sand is dark , then it is not acceptable and should be washed if it is to be used.

3.Test for clay and silt content :

The test is similar to that carried out in soil mechanics . Chemical solutions are added to a sample of sand and the quantity of clay and silt is determined. The sand should not contain more than (8 %) of clay and silt.

Metals

Metals are used for various engineering purposes. They are used for making structural members, doors, windows, roofing materials, pipes and many other products. In order to find the suitability of various metals to be used for a specific work, it is essential to study their composition and properties.

Classification of metals

All the metals used in engineering works can be classified into two categories:

a. Ferrous metals

Ferrous metals are those metals in which the chief constituent is iron. Besides iron, other constituents like carbon, sulfur, manganese and phosphorus etc. which exist in varying proportions. The ferrous metals which find their common are:

1. Cast iron 2. Wrought iron 3. Steel

b. Nonferrous metals.

Nonferrous metals are those, which do not contain iron, and are used widely in building industry. The important nonferrous metals are copper, lead, tin, zinc and aluminum.

Ferrous metals

1. Cast iron

Besides iron, cast iron contains carbon, silicon, and manganese in varying proportions and traces of impurities such as sulfur, and phosphorus:

Iron – 92-95%; Carbon – 2- 4.5 %; Silicon- 1-3 %.

Properties:

Cast iron possesses the following important properties:

1. It has a fibrous crystalline structure.

2. Brittle and has low resistance to tension and high strength in compression. Tensile and compressive strength of the average quality of cast iron are 150 N/mm^2 and 500 N/mm^2 respectively.

3. Its melting point is about 1200 °C.

4. It cannot withstand sudden shocks.

5. Difficult to weld it.

6. Its specific gravity is 7.2.

7. It cannot be magnetized.

8. It’s neither malleable nor ductile.

9. It does not rust easily.

10. Formation is not accepted

Uses:

1. It is used for manufacture of steel and wrought iron.

2. Its high compressive strength makes it suitable for use in making such parts which are subjected to compressive stresses such as supports of heavy machinery.

3. Since it does not rust easily, therefore it is used for parts generally exposed to the atmosphere, such as lamp posts.

4. It is also used for making rail chairs and carriages wheels.

2. Wrought iron

It is the purest form of iron and it contains: Iron about 98 % Carbon – 0.1-0.25 % Slag – 2-3 % Sulfur, Manganese, Phosphorus, Silicon are present in traces.

Properties:

1. It has fibrous structure with a silky luster.
2. Its melting point is about 1500 °C.
3. It can withstand sudden shocks.
4. Its ultimate tensile strength is about 400 N/mm2.
5. Its ultimate compressive strength is about 200 N/mm^2.
6. Its specific gravity is 7.25.
7. Its Brinell hardness number is 105.
8. It cannot be form permanent magnets, but can be temporary magnetized.
9. It is malleable and has got high ductility.
10. It can rust more easily than cast iron.
11. It softens at about 1000°C and then it can be hammered to any desired shape.

Uses:

1. It is used for making agricultural implements.
2. It is used for making rails, crane hooks and

any article capable of withstand sudden loads.

3. Because it is extremely easy to weld, it is largely used in ornamental iron work.
4. It is used as a raw material for the manufacture of steel.

3. Steel

Steel is ***the most important*** material for engineering construction. It contains carbon from 0.15 % (very soft steel) to 1.5 % (very hard steel). It also contains small number of other elements. It contains from: Iron = 99 %; Carbon content 0.15 – 1.5 %; Phosphorus and Sulfur less than o.1 %; Manganese up to 0.5 %; Silicon up to o.3 %.

The higher is the percentage of the carbon, the harder and tougher is the steel. Depending upon the percentage of carbon contents, Steel can be classified into different groups as under:

1. Very low carbon steel – having percentage of carbon below 0.15 %.
2. Low carbon steel or mild steel –Carbon contents 0.15 – 0.3 %.
3. Medium carbon steel–Carbon contents range from 0.3 – 0.6 %.
4. High carbon steel or hard steel–Carbon contents range from 0.6 – 1.5 %.

Low carbon steel – mild steel

The percentage of carbon in mild steel varies from 0.15 to 0.3, sulfur, phosphorus, manganese, silicon are present only in minute quantities.

Properties:

1. It has a bright dark bluish color.
2. It has fibrous structure.
3. Its melting point is about 1400 °C.
4. It can withstand sudden shocks.

5. Its tensile strength is high.
6. Its specific gravity is 7.85.
7. It is malleable, ductile and elastic.
8. It can form permanent magnets.
9. It can rust easily and rapidly.
10. It can take a good amount of compression.
11. It can easily forge and welded.

Uses:

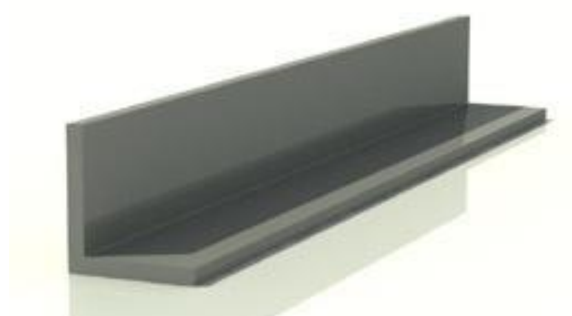
The chief uses of mild steel are:

1. It is used for making rolled structural steel sections like girders, angle sections, channel and T- sections… etc.

Cannel section

I-Section

T-section



Angle Section

2. It is extensively used for making bars and rods which are used as a reinforcing material in reinforced concrete.

3. It is used for making refrigerators and air conditioners.
4. It is used for making plain and corrugated sheets.

5. Structural mild steel is most commonly used for general construction purposes of buildings, bridges, towers and industrial buildings.
6. It also used for making tubes.

High carbon steel

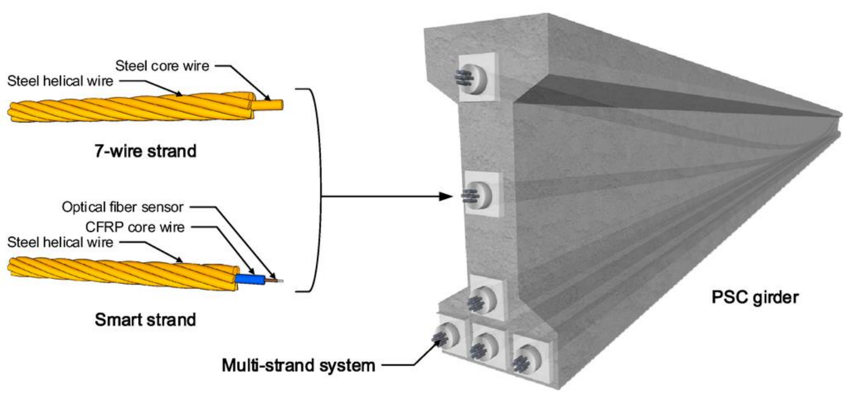
These are also termed as hard steels and contain carbon varying from 0.6 to 1.5 %. Besides carbon, small percentage of Sulfur, phosphorus, manganese and silicon are also present.

Properties:

1. It has granular structure.
2. It is very hard.
3. Its specific gravity is 7.9.
4. It cannot easily forge and welded.
5. It can absorb shocks and vibrations in better way.
6. It is more elastic than mild steel.
7. It is brittle and less ductile than mild steel.
8. It rusts readily.
9. It can form permanent magnets.
10. It cannot take much of compression.

Uses:

1. It is used for parts of structures and machinery where hard, tough, elastic, shock- proof and durable material is required.
2. It is used in prestressed concrete.

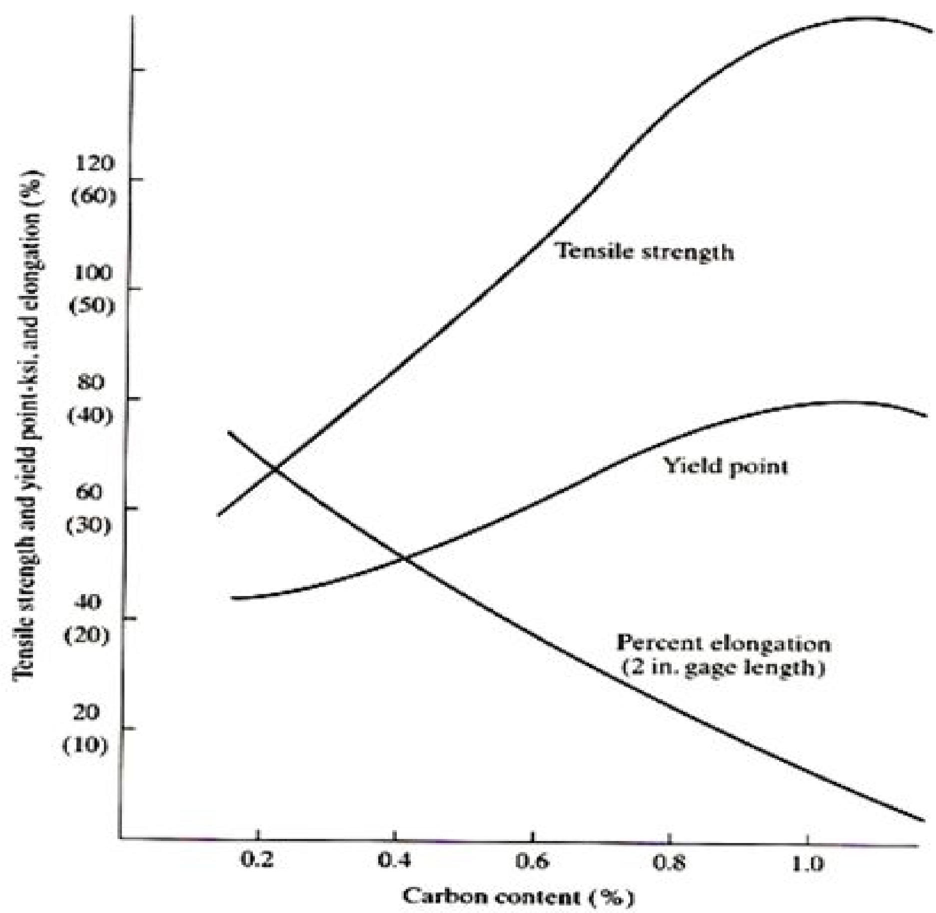


3. It is used for making knifes, needles, bolts and surgical instruments.

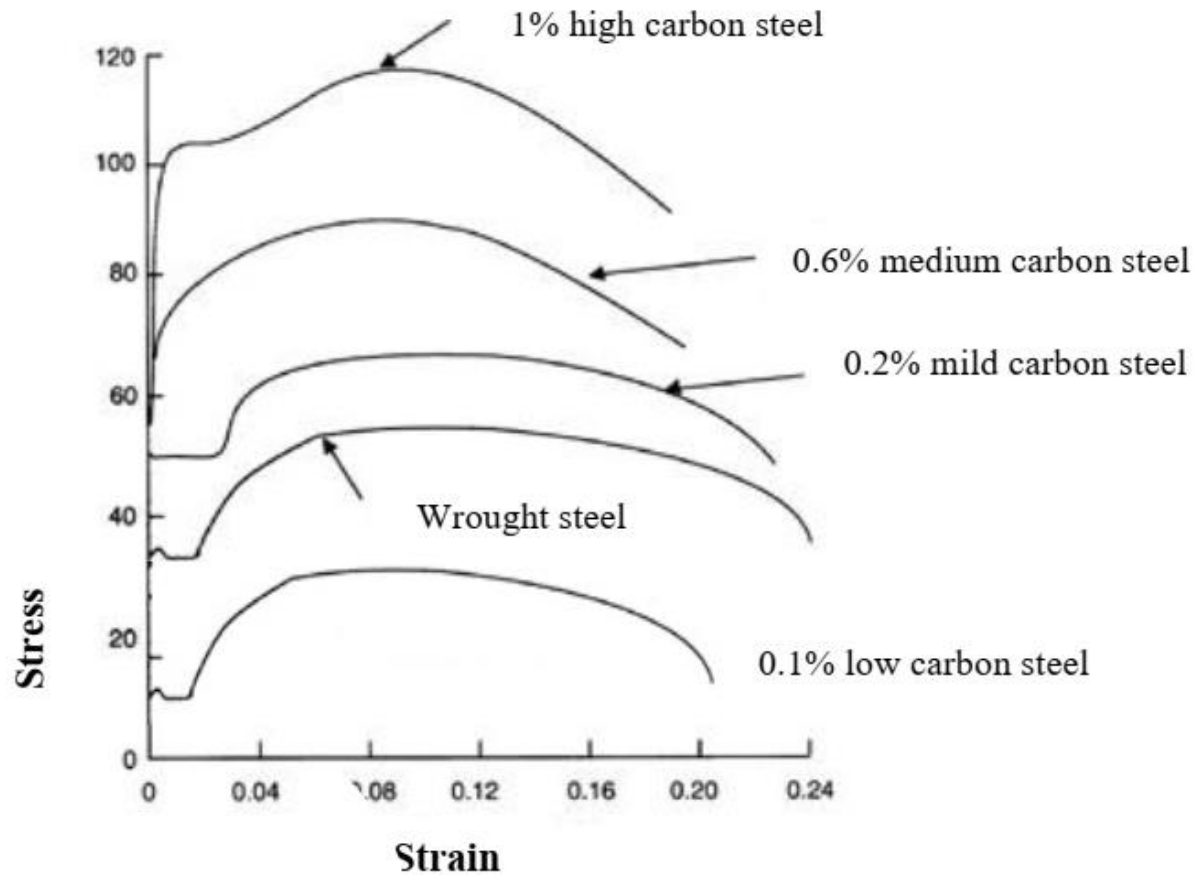
Factors affecting physical properties of steel

1. Carbon content

a. The strength and hardness of steel increases as a percentage of carbon increases up to 1.5 %.
b. The elongation decreases as the carbon content increases and the metal becomes less resistance to impact.
c. The elastic range remains nearly on the same linearity, indicating that the modulus of elasticity is nearly the same and can be considered constant for various types of steel.
d. The plastic region decreases as the carbon content increases and appears to be nil for hard steel (high carbon steel).
e. The area under stress – strain curve varies with carbon content; it decreases as the percentage of carbon increases. This area represents the amount of work stored in specimen.



Effect of carbon content on mechanical properties of steel



Effect of carbon content on stress strain behavior of steel

2. The percentage of impurities

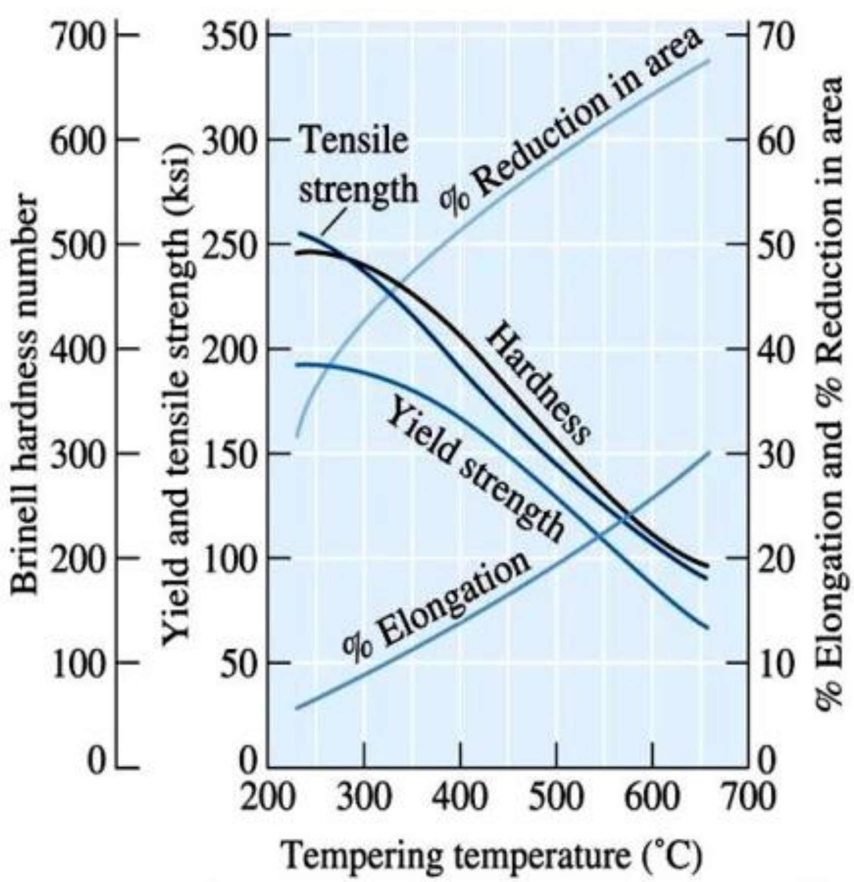
The impurities present in steel are:

a. Silicon: If percentage of silicon is less than 0.2%, it has no appreciable effect on physical properties of steel, but when silicon content is between 0.3-0.4%, the strength and modulus of elasticity are increased without decreasing ductility.
b. Sulfur: If Sulfur content is between 0.02-0.1%, it has no effect on ductility and strength, but when the percentage of Sulfur is higher than 0.1%, the strength and ductility decreases.

c. Phosphorus: If the percentage of phosphorus exceed 0.12%, the strength, ductility and resistance to impact are decreased.
d. Manganese: When the manganese content is between 0.3-1 %, it helps to improving the strength of mild steel, but when its content exceeds 1.5%, the steel becomes brittle and losses it's structural value.

3. Heat treatment

It is possible to alter the properties of steel by heating and cooling steel under controlled conditions. The term heat treatment is used to indicate the process in which the heating the heating and cooling of solid steel is involved to change the structural and physical properties of steel. The purposes of heat treatment are:



Effect of temperature on mechanical properties of steel

a. To alter magnetic properties of steel.
b. To change the structure of steel.
c. To increase resistance to heat and corrosion.
d. To increase surface hardness.
e. To make steel easily workable.
f. To vary strength and hardness.

Tensile requirements – ASTM – A615 – 86

Tensile requirements	Grade	
	Grade 300	Grade 400
Tensile strength, min., MPa	500	600
Yield strength, min., MPa	3	400
Elongation in 200mm, min., % For bar diameter (mm):		
1	1	9
1	1	9
2	-	8
3	-	7
3	-	7
45,55	-	7

Bar for grade 300 fabricated with diameter 10-20 mm only

Tensile properties – B.S. 4449-1988

Grade	Nominal size of bar mm	Specified Characteristic	Minimum elongation of gauge length*, %
250	All sizes	250	22
460/425	6 up to and including 16	460 425	12 14

* Gauge length is five times the diameter of the bar

CEMENT

1. General

Cement is the most important material in building construction . The name cement refers to the material manufactured from limestone and clay and made available in powder form, which when mixed with water can set to a hard durable mass. In 1756, John Smeaton, a British engineer patented the production of cement obtained by heating a mixture of lime and clay. As the resulting material looked like the stone in the town Portland, he called it Portland cement. The modern method of manufacture was later patented by Joseph Aspdin in 1824.

2. Manufacture of Portland Cement

Cement is manufactured from limestone and clay by the old wet process or the new dry process. In the old **Wet Process**, the limestone is crushed and the clay is made into a liquid form by addition of water. They are again mixed together and very finely ground. It is then transported into tanks and then to a long cylindrical rotary kiln where it is heated to a high temperature of (1300 - 1500 º C). It is then ground in mills to a very fine powder to form cement.

Dry Process: In modern cement plants, the wet process is replaced by the dry process in which the lime stone and clay are crushed to powder form and blended together. This is then mixed in the dry form by means of compressed air. This mixture behaves like a fluid and is sieved and sent to a container which converts it into clinker and is ground to cement.

2.1 Main Ingredients of Cement

The main ingredients of cement that give cementing properties are the following four compounds:

(a) Di-calcium Silicate ($2CaOSiO_2$) denoted as (C_2S).
(b) Tri-calcium Silicate ($3CaOSiO_2$) denoted as (C_3S).
(c) Tri-calcium Aluminate ($3CaOAl_2O_3$) denoted as (C_3A).
(d) Tetra-calcium Aluminum Ferrite ($4CaOAl_2O_3Fe_2O_3$) denoted as (C_4AF).

Note: Generally, the content of (C_2S) is about 25 % of cement while (C_3S) is about 45 % of cement.

2.2 Setting Action of Cement

When water is added to cement, the ingredients of cement react chemically and form complicated compounds. First a cement paste is formed which slowly thickens. In about 30 minutes, it is said to have attained its initial set. In about 10 hours, it becomes rock hard and it is said to have reached its final set.

since the chemical reaction takes place under water, cement is called hydraulic i.e., set under water.

3. Composition of Portland Cement

The cementing properties of cement is due to the chemical reaction of the above mentioned compounds. Of all the main ingredients of cement, (C3S) and (C3A) control the setting and early strength and heat of hydration. The compound (C2S) is responsible for strength at longer ages. (C3A) also generates higher heat than other compounds. Increase in (C3S) results in higher long - term strength and high heat of hydration . If (C3A) and (C4AF) are kept low, then the resistance to chemicals such as sulphates is increased. Portland cement itself is produced in different types by varying the proportions of the ingredients of cement as shown in table (3.1) below.

Table -1 Composition of Portland Cement

(Approximate Percentage of Ingredients)

Description	C2S	C3S	C3A	C4AF
1. Ordinary	25	45	12	8
2. Rapid hardening	26	45	5	15
3. Low Heat	31	21	6	14

Quality Tests on Cement in the laboratory

Quality Tests on cement are carried out to check the strength and quality of the cement used in construction. It helps to identify the usage of cement for different purposes based on its durability and performance. The following tests are conducted on cement in the laboratory are as follows:

1. Fineness Test
2. Consistency Test
3. Setting Time Test
4. Strength Test
5. Soundness Test
6. Heat of Hydration Test
7. Tensile Strength Test
8. Chemical Composition Test

1. Fineness test on cement

The fineness of cement is responsible for the rate of **hydration**, rate of **evolution of heat** and the rate of **gain of strength**. Finer the grains, more is the surface area and faster is the development of strength.

The **fineness** of cement can be determined by Sieve Test or Air Permeability test.

Sieve Test: The cement is sieved continuously in a circular and vertical motion for a period of 15 minutes. The residue left on the sieve is weighed, and it should not exceed 10% for ordinary cement. This test is rarely used for fineness

Air Permeability Test: Air Permeability Test is used to find the specific surface, which is expressed as the total surface area in sq.cm/g. of cement. The surface area is more for finer particles.

2. Consistency test on cement

This test is conducted to find the **setting time of cement** using a standard consistency test apparatus, Vicat's apparatus. Standard consistency of cement paste is defined as that water content which will permit a Vicat plunger of 10 mm diameter and 50 mm length to penetrate depths of (33-35) mm within (3-5) minutes of mixing. The test is repeated three times, each time the cement is mixed with water varying from (24 - 27) % of the weight of cement.

3. Setting Time of Cement

Vicat's apparatus is used to find the setting times of cement i.e., initial setting time and final setting time.

Initial Setting Time: For this test, a needle of 1 mm square size is used. The needle is allowed to penetrate into the paste (a mixture of water and cement as per the consistency test). The time taken to penetrate (33-35) mm depth is recorded as the initial setting time.

Final Setting Time: After the paste has attained hardness, the needle does not penetrate the paste more than 0.5 mm. The time at which the needle does not penetrate more than 0.5 mm is taken as the final setting time.

4. Strength test of cement

The strength of cement cannot be defined directly on the cement. Instead the strength of cement is indirectly defined on cement-mortar of **1:3**. The compressive strength of this mortar is the strength of cement at a specific period.

5..Soundness Test of Cement: This test is conducted in Le Chatelier's apparatus to detect the presence of uncombined lime and magnesia in cement.

6. Heat of Hydration Test

During the hydration of cement, heat is produced due to chemical reactions. This heat may raise the temperature of concrete to a high temperature of 50°C. To avoid this in large scale constructions low-heat cement has to be used.

This test is carried out using a calorimeter adopting the principle of determining heat gain. It is concluded that Low-heat cement should not generate (65 calories per gram of cement in 7 days) and (75 calories per gram of cement in 28 days).

7. Tensile Strength of Cement

This test is carried out using a cement-mortar molds in a tensile testing machine. A **1:3** cement-sand mortar with the water content of 8% is mixed and poured into the molds.

This mixture is cured for 24 hours at a temperature of (25°C - 29°C) and in an atmosphere at 90% relative humidity. The average strength for six molds tested after 3 and 7 days is recorded.

8. Chemical Composition Test

Different tests are conducted to determine the amount of various constituents of cement. The requirements are as follows:

- The ratio of the percentage of alumina to that of iron oxide should not be less than (0.66).
- Lime Saturation Factor (L.S.F) i.e., the ratio of the percentage to that of alumina, iron oxide and silica should not be less than (0.66) and not be greater than (1.02).
- Total loss on ignition should not be greater than (4)%.
- Total sulphur content should not be greater than (2.75)%.
- Weight of insoluble residue should not be greater than (1.5) %.
- Weight of magnesia should not be greater than (5)%.

Field Tests of Cement

The following tests should be performed before mixing the cement at construction sites:

1. Colour Test of Cement

The colour of the cement should not be uneven. It should be a uniform grey colour with a light greenish shade.

2. Presence of Lumps

The cement should not contain any hard lumps. These lumps are formed by absorption of moisture content from the atmosphere. The cement bags with lumps should be avoided in construction.

3. Date of Manufacturing

It is very important to check the manufacturing date because the strength of cement decreases with time. It's better to use cement before **3 months** from the date of manufacturing.

Types of Portland Cement

The properties of cement during hydration vary according to:
- Chemical composition
- Degree of fineness

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

Types of Portland Cement

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

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

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

1. Type I - Ordinary Portland cement

This type of cement is used in constructions when there is no exposure to sulfates in the soil or groundwater. The chemical composition requirements are listed in Iraqi specification No. 5, as shown below:

$$L.S.F. = (CaO)-0.7(SO_3)\ 2.8(SiO_2)+1.2(AL_2O_3)+0.65(Fe_2O_3)$$

Lime Saturation Factor (L.S.F.) is limited between **(0.66-1.02)** Where, each term in brackets denotes the percentage by mass of cement composition. This factor is limited - to assure that the lime in the raw materials, used in the cement manufacturing is not so high, so as it causes the presence of free lime after the occurrence of chemical equilibrium. **Free lime** will cause the cement to be **unsound.**

2. Type II - Modified Cement:

This modified cement successfully combines a lower heat of hydration than ordinary cement and higher rate of heat development than that of low heat cement with gain of strength similar to that of ordinary Portland cement.

Modified cement is recommended for use in structures where a moderately low heat generation is desirable or where moderate sulfate attack may occur. This cement is extensively used in the United States.

3. Type III - Rapid Hardening Portland Cement:

Properties of Rapid hardening Cement:

1. This type develops strength more rapidly than ordinary Portland cement. The initial strength is higher, but they equalize at **(2-3)** months .
2. Setting time for this type is similar for that of ordinary Portland cement.
3. Rate of heat evolution is higher than in ordinary Portland cement due to the increase in C3S and C3A, and due to its higher fineness
4. Chemical composition and soundness requirements are similar to that of ordinary Portland cement
5. The rate of strength gain occur due to increase of C3S compound, and due to finer grinding of cement clinker.

Comparison of Rapid Hardening Cement with Ordinary Portland Cement

1. Rapid hardening cement develops **strength faster** than ordinary Portland cement.
2. **Setting time** of rapid hardening cement is **similar** to ordinary Portland cement.
3. **Heat evolution** of rapid hardening cement is **higher** than ordinary Portland cement.
4. **Chemical composition** and **soundness** of rapid hardening cement is **similar** to that of ordinary Portland cement.

Uses of Rapid Hardening Portland Cement:

(**a)** The uses of this cement is indicated where a rapid strength development is desired (to develop high early strength, i.e. its **3 days'** strength equal that of **7 days** ordinary Portland cement), for example:

i) When formwork is to be removed for re-use

ii) Where sufficient strength for further construction is wanted as quickly as possible, like concrete blocks for sidewalks that cannot be closed for a long time.

(b) For construction at low temperatures, to prevent the frost damage .

(c) This type of cement is not used at mass concrete constructions.

4. Type IV - Low Heat Portland Cement

Composition:

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

Properties

1) Heat of hydration of this type of cement is low as compared with ordinary Portland cement.
2) It has lower early strength (**half** the strength at **7 days** age and **two third** the strength at **28 days** age) compared with ordinary Portland cement.
3) Its fineness is not less than 3200 cm /g (according to B.S. 1370 : 1974).

Uses:

It is used in mass concrete constructions because it limits the rate of heat evolution in this type of construction.

5- Sulfate Resisting Cement

Composition: This type of cement contains the following:-

1. Lower percentage of C_3A and C_4AF, which are considered to be the most affecting compounds to sulfates.
2. Higher percentage of silicates, in comparison with ordinary Portland cement.
3. For this type of cement, C_2S represents a high proportion of the silicates.
4. Iraqi specification No. (5) limits: max. C_3A content by 3.5%, min. fineness by 2500 cm /g.

Properties of Sulfate Resisting Cement:

a) Low early **strength**.
b) Its **heat** of hydration is little higher than that resulting from low heat cement.
c) Its **cost** is higher than ordinary Portland cement , because of the special requirements of material composition, including addition of iron powder to the raw materials.

For **the hardened sulfate resisting cement**, the effects of sulfates are of **two** types:

1- Hydrated calcium aluminates, react with sulfates (present in fine aggregate, or soil and ground water), producing hydrated calcium sulfa aluminate, leading to increase in the volume of the reacted materials by about 227% causing gradual cracking.

2- Exchange between $Ca(OH)_2$ and sulfates resulting gypsum, and leading to increase in the volume of the reacted materials by about 124%.

The resultant of reaction C_4AF with sulfates is calcium sulfa aluminate and calcium sulfa ferrite, leading to expansion. C_4AF is more resistant to sulfates than C_3A.

Properties :-

1) Its early strength is **lower** than that of ordinary cement, but their strength is equal at late age (about 2 months).

2) The requirements for **fineness** and setting time and soundness are similar for those of ordinary cement.

3) The workability is higher than that of ordinary cement.

4) Heat of hydration is lower than that of ordinary cement.

5) Its sulfate resistance is high.

Uses :-

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

7- Pozzolanic Cement

Production This type of cement consists of a mixture of Portland cement and Pozzolana. American standard limit the Pozzolanic content by (15-40) % of Pozzolanic cement.

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

Types of Pozzolana :

- **Natural** Pozzolanic materials, such as : volcanic ash
- **Industrial** Pozzolanic materials, such as : silica fume, rice husks ash

Properties & Uses: They are similar to those of Portland blast-furnace cement.

8- White Cement

White Portland cement is made from raw materials containing very little iron oxide and magnesium oxide (which gives the grey color in ordinary Portland cement). China clay (white kaolin) is generally used, together with limestone.

Properties:

1. Its **manufacture** needs higher firing temperature, because of the absence of iron element that works as a catalyst in the formation process of the clinker.
2. The **compounds** in this cement are similar to those in ordinary Portland cement, but C4AF percentage is very low.
3. **The cost of grinding is higher**, and this, coupled with the more expensive raw materials, makes white cement rather expensive.
4. It has a **slightly lower specific gravity** (3.05-3.1), than ordinary Portland cement.
5. The **strength** is usually somewhat lower than that of ordinary Portland cement.
6. Its **fineness** is higher than ordinary Portland cement.

9- Colored Portland Cement:

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

The 28-day compressive strength is required to be not less than 90% of the strength of a pigment-free control mix, and the water demand is required to be not more than 110% of the control mix. It is required that pigments are insoluble. They should be chemically inert and don't contain gypsum that is harmful to the concrete.