



PORTLAND CEMENT

General

Portland cement is one of the most widely used construction material and is the most important hydraulic cement.

TYPES OF PORTLAND CEMENT

Even if the raw materials and the manufacturing process are the same different types of cement are in use today.

The difference in properties of the various kinds of cement arises from the relative proportions of the four major compounds.

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The Ethiopian standard ESC.DS.201 classifies Portland cement into:

- Ordinary Portland cement (Type O) and
- Rapid-hardening Portland cement (Type R)

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American Society for Testing and Materials (ASTM) recognizes eight types of Portland cement under specification ASTM C150.

The standard five types of Portland cement are the types that are usually produced.

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- Type I or Normal Portland cement
- Type II or Moderate Portland cement
- Type III or High-Early-Strength Portland cement
- Type IV or Low - Heat of Hydration Portland Cement
- Type V or Sulfate - Resisting Portland cement
- Types IA, IIA, IIIA or air-entraining cements

Type I or Normal Portland cement

- Is a general-purpose cement
- Is used when the special properties specified for any other type are not required
- Is used where there would be no severe climate changes
- Is used where there is no severe exposure to sulfate attack from water or soil
- Its uses include reinforced-concrete buildings, bridges, reservoirs, floors, and retaining walls
- In general, it is used in nearly all situations calling for Portland cement.

Type II or Moderate Portland cement

- Used when moderate sulfate resistance or moderate heat of hydration is desired
- It is used in structures of considerable mass, such as abutments and piers and retaining walls.
- Its use also minimizes temperature rise when concrete is placed in warm weather.

Type III or High-Early-Strength Portland cement

- Is used when high early strength is desired, usually less than one week
- It is usually used when a structure must be put into service as quickly as possible
- This cement is made by changing the proportions of raw materials, by fine grinding, and by better burning
- Contains less di-calcium silicate and the tri-calcium silicate is greater

Type IV or Low - Heat of Hydration Portland Cement

- Is used when a low heat of hydration is required
- Develops strength at a slower rate than does than Type I
- It is intended for mass structures such as **large gravity dams** where the temperature rise on a continuous pour is great

Type V or Sulfate - Resisting Portland cement

- Is used when high sulfate resistance is desired
- It is used when concrete is to be exposed to severe sulfate action by soil or water
- Contains less C3A

Types IA, IIA, IIIA

- Are used in concrete for improved resistance to freezing and thawing action and the action of salt scaling and chemical attack
- Disintegration due to freezing and thawing is caused by the expansion of the water, as it freezes. The pressure caused by this expansion forces the pore open after thawing, the large pore is re saturated with water and subsequent freezing increase the pore volume again

Typical Compound Composition for Various Portland Cements

Types of Portland Cement	Compound Composition%			
	C_3S	C_2S	C_3A	C_4AF
I. Normal	50	24	11	8
II. Moderate	42	33	5	13
III. High-early-strength	60	13	9	8
IV. Low-Heat	26	50	5	12
V. Sulfate-Resisting	40	40	4	9

Approximate Relative Strength of Concrete as Affected by Type of Cement

Types of Portland Cement	Compressive Strength (% Of Normal Portland Cement)				
	1 Day	3 Days	7 Days	28 Days	3 Months
I. Normal	100	100	100	100	100
II. Moderate	75	80	85	90	100
III. High-early-strength	190	190	120	110	100
IV. Low-Heat	55	55	55	75	100
V. Sulfate-Resisting	65	65	75	85	100

Portland Pozzolana Cement (PPC)

- The term **pozzolana** is used to describe naturally occurring and artificial siliceous materials, which in themselves possess little or no cementations 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 cementations properties.

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- Portland pozzolana cement (PPC) is manufactured by blending 20-30% by weight of pozzolanic material with ordinary Portland cement (OPC); either by simple mixing or by inter-grinding with cement clinker.

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- The calcium hydroxide liberated during the process of hydration of the cement combines slowly with the pozzolana to give it cementations properties, thereby contributing to water tightness and long continued gain in strength of the concrete.

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The most important effects accompanying the use of PPC in Concrete Construction Work are:

- ❖ Improved workability
- ❖ No increase in dry shrinkage
- ❖ Improved resistance to sulfate attack etc.

SPECIAL TYPES OF PORTLAND CEMENT

Varieties of special cements exist that are limited for specific uses and purposes.

The following are few examples:

- White Portland Cement
- Colored Cements
- Oil-Well Cements
- Regulated cements
- Waterproofed Cement
- Hydrophobic cement
- Antibacterial cements
- Barium and Strontium cements etc.



PROPERTIES OF PORTLAND CEMENT

PROPERTIES

Physical Properties

- Fineness
- Setting time
- Soundness
- Compressive strength
- Heat of hydration
- Specific gravity

Chemical Properties

- Lime Saturation Factor (L)
- Alumina Ratio
- Magnesia
- Sulfur trioxide
- Loss on ignition
- Insoluble residue

Fineness

- The fineness of the cement has an important effect on the rate of hydration
- The finer the cement the quicker the rate of hardening and the greater is the heat evolution at early ages.
- A finely ground cement is more liable to suffer from shrinkage cracking than a coarser cement (for cement of the same composition)

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- The fineness of grinding does not affect the total heat evolved but only the rate at which that heat is evolved
- Extremely fine size does not improve the ultimate strength of the cement

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The fineness of cement can be measured in a number of ways:

- The sieve test
- Specific surface test by :
 - Wagner Turbid meter method
 - Blaine air permeability method

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The Ethiopian Standard specifies the fineness of grinding should not be less than $2250 \text{ cm}^2/\text{gm}$ for OPC cement by Blaine air permeability method.

Setting time

- Setting is the **stiffening of the cement paste**
- Broadly speaking, setting refers to a change from a fluid to a rigid stage
- During setting, the paste acquires some strength
- Hardening, refers to the gain of strength of a set cement paste

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Setting is not an abrupt process,
which may complete immediately
after its start; it is rather a
progressive phenomenon, which has:
beginning,
full development and
an end.

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- It is on this latter basis, setting is distinguished into:



Initial setting time



Final setting time

qualified by the time required in each case.

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- Initial setting time is the duration of cement paste of standard consistency related to 25 mm penetration of the Vicat needle into the paste in 30 seconds after it is released.
- Final setting time is that related to zero penetration of the Vicat needle into the paste.

Ethiopian standard recommends that the initial setting time for cement not be less than 45 minutes and the final setting time not to exceed 10 hours.

Vicat apparatus



- The setting times of cement are measure using the Vicat apparatus with different penetration attachments. The test is performed at standard conditions of temperature and humidity and on cement pastes of standard consistency.



Time required for setting is influenced by:

1. **Temperature:** the setting time of cement decreases with a rise in temperature. At low temperatures setting is retarded.
2. **Water content:** less water result in incomplete hydration, extra quantity will bleed out after cement is set.
3. **Humidity:** the humidity of the atmosphere in which setting is allowed to take place acts through temperature and moisture conditions.

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4. **Fineness of the Cement:** the greater the cement fineness the greater the rate of hydration and hence the shorter the setting time.
5. **Chemical Composition:** Setting is caused by a selective hydration of cement compounds: the two first to react are C3A and C3S.

Soundness

- Incomplete combination of the lime with other raw constituents, through under burning of clinker, results in free or uncombined lime (CaO) in the finished cement. If this is present in excess amount **expansion** and **disruption** of concrete may eventually occur. This phenomenon is known as **soundness**.
- Cement exhibiting this property is termed as **unsound cement**. (unsoundness -slow expansion of cement)

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- Cement can be unsound due to:

1. Insufficient burning
2. The presence of excess CaO
3. The presence of excess MgO
4. Addition of excess gypsum

In order to determine the soundness of cement the **Le Chatelie'r test** is used.

Heat of Hydration

Heat of hydration is the quantity of heat in joules/gram generated when cement and water react.

For practical purpose, it is not necessarily the total heat of hydration that matters but the rate of heat evolution.

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The amount of heat generated depends on:

➤ The chemical composition

In the early stages of hydration the different compounds hydrate at different rates, the rate of heat evolution, as well as the total heat, depends on the compound composition of the cement

By reducing the proportions of the compounds that hydrate most rapidly (C3A & C3S) the high rate of heat evolution in the early life of concrete can be lowered.

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➤ The fineness of the cement

The early rate of hydration of each compound in cement is proportional to the surface area of the cement. However, at later stages, the effect of the surface area is negligible and the total amount of heat evolved is not affected by the fineness of

Heats of Hydration of the Pure Compounds of Portland cement

Compound	Heat of Hydration
C_3S	503 J/g = 120 cal/g
C_2S	260 J/g = 62 cal/g
C_3A	867 J/g = 207 cal/g
C_4AF	419 J/g = 100 cal/g

Compressive strength

- The mechanical strength of hardened cement is the property of the material that is perhaps most obviously required for structural use.
- Strength tests are not made on a neat cement paste because of difficulties of molding and testing with a consequent large variability of test results.

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- Strength of cement can be determined by two methods i.e. **mortar test** and **concrete test**.
- In the mortar test,
A mortar mix with 1:3 cement- standard sand with W/C ratio of 0.4 by mass is prepared.
Following mixing, and 70.7mm cubes are made using a vibrating table with a frequency of 200Hz applied for two minutes. The cubes are demolded after 24 hours and further cured in water until tested in a wet-surface condition.

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- The compressive strength of mortar & concrete cubes has to confirm to the following according to Ethiopian standard.

For Ordinary Portland cement:

3 days: not less than 8N/mm^2 (8MPa)

7 days : not less than 14N/mm^2 (14MPa)

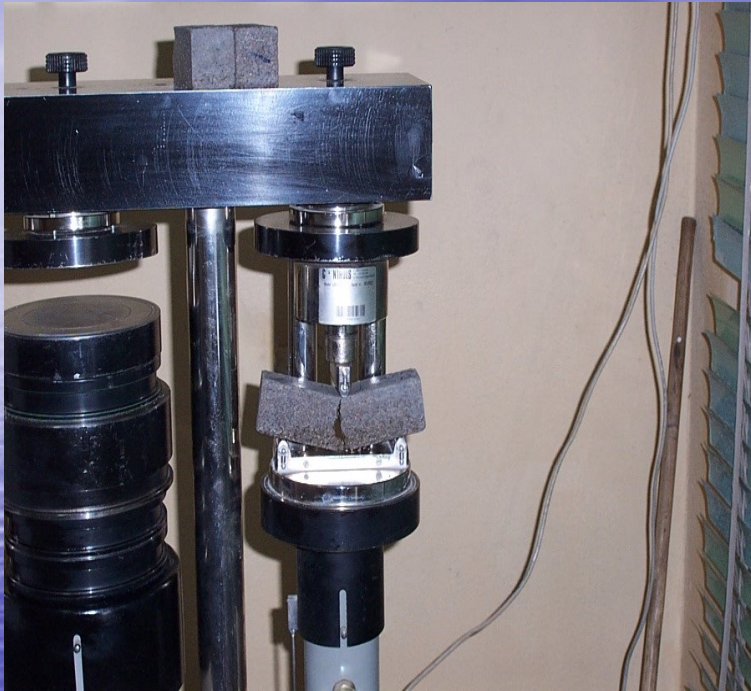
Determination of flexural strength of mortar prisms



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Chemical Properties

- Chemical tests are conducted by the manufacturer or in research laboratories in order to check on the quality of Portland cement. But of little importance to the ordinary consumer. The results of chemical tests are reported in terms of oxides, which are used to calculate the compound composition by Bogue method.

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It is also important to know the amounts of:

- The four major oxides- (CaO) , (SiO_2) , (Al_2O_3) and (Fe_2O_3)
- Free lime , (SO_3) , and magnesium oxide
- Sodium and potassium (Na_2O K_2O) oxides play also importance incase the cement is used in concrete with alkali reactive aggregates.

Quality requirements of Portland cement

- **Lime Saturation Factor (LSF)**

$$0.66 < \text{L.S.F} < 1.02$$

$$\text{L.S.F} = \frac{\text{CaO} - 0.7(\text{SO}_3)}{2.8(\text{SiO}_2) + 1.2 (\text{Al}_2\text{O}_3) + 0.65 (\text{Fe}_2\text{O}_3)}$$

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- **Alumina Ratio (AR)**

$$AR = \frac{Al_2O_3}{Fe_2O_3}$$

AR shall not be less than 0.66

Magnesia (MgO)

- The mass of magnesia (magnesium oxide) contained in Portland cement shall not exceed 5 %.
- The upper percentage limit is to avoid the long-term unsoundness that results from higher percentage content of MgO.

Sulfur trioxide (SO_3)

- The mass of sulfur trioxide contained in Portland cement:
 - shall not exceed 3% if the C_3A is $\leq 8\%$
 - shall not exceed 3.5 % if the $\text{C}_3\text{A} > 8\%$.

An upper limit on SO_3 is specified in order to avoid unsoundness resulting from the delayed hydration of the

Loss of Mass On Ignition

- The loss in mass on ignition is determined in order to check on possible pre-hydration or carbonation that may result from improper or prolonged storage of the clinker or resulting cement.
- The total loss in mass when Portland cement is heated to a temperature of 950°C shall not exceed 4%.

Insoluble Residue

- The insoluble residue is that part of a cement sample which is insoluble in hydrochloric acid (HCl)
- The insoluble residue derives from the clay minerals of the raw materials, which have not reacted to form the cement compound.

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- The amount of insoluble residue indicates the efficiency of the burning process and the completeness of the reactions in the kiln. The mass of insoluble residue shall not exceed 1.5 %.

FIELD TESTING OF CEMENT

- Cement is manufactured in factories under controlled conditions, but during its transit and storage there are chances of its deterioration or being adulterated of quality. The quality of cement at site can be judged by the following methods:

1. Visual inspection

- A sample of cement taken from the bag showing bright gray color (as specified by the manufacturer) gives an indication of freshness & purity of cement.

2. Adulteration

- Place about 100 grams of cement on a steel plate and heat it for about 20 minutes. No change in color is again an indication of unadulterated cement.
- Shake a small quantity of cement in glass jar $\frac{1}{2}$ full of water and allow it to settle. Adulterated particles (coal, ash etc) if any shall float on the surface.

STORAGE OF CEMENT

- At all stages up to the time of use, cement must be kept dry so as to prevent or minimize deterioration from the effects of moisture, atmospheric humidity and carbonation
- Airtight drums and internally coated bulk silos are ideal storages.
- Cement in multi wall paper bags should be stored in a waterproof building with close-fitting doors, which should be kept closed as much as possible.

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- The bagged cement should be stacked on pallets or on a dry board platform; some 150mm clear of the surface kept 150-300mm clear of the walls.
- In regions of high relative humidity, insulation and a storage temperature of 45 °c are advisable.
- Bags of cement should be stacked close together, so as to restrict the circulation of air around them.

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- Cement which is **four months old** should be classified as aged and be restricted before use.



End of Presentation