# Types of Cement:

The properties of cement during hydration vary according to:

- ✓ Chemical composition.
- ✓ Physical characteristics.

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

## Types of Portland Cement (Table 2-2):

- 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 Portland cement to produce the following types:*

- Portland blastfurnace cement – Type IS
- Pozzolanic cement - Type IP
- White cement

**Table (2-2) Main types of Portland cement**

| Traditional British description | ASTM description |
|---|---|
| Ordinary Portland | Type I |
| Rapid-hardening Portland | Type III |
| Extra rapid-hardening Portland | |
| Ultra high early strength Portland | Regulated set |
| Low heat Portland | Type IV |
| Modified cement | Type II |
| Sulfate-resisting Portland | Type V |
| Portland blastfurnace | Type IS<br>Type I (SM) |
| White Portland | ----------------- |
| Portland-pozzolana | Type IP<br>Type I (PM) |
| Slag cement | Type S |

## Ordinary Portland cement (O.P.C)- (Type I):

This type of cement is the most commonly used cement for general concrete construction when there is no exposure to sulfates in the soil or groundwater.

❖ *Chemical requirements:*

- The limitation on the clinker composition is that not less than two-thirds of its mass consists of $C_3S$ and $C_2S$ taken together.
- $\frac{CaO}{SiO_2} \geq 2$
- $MgO < 5\%$
- Lime saturation factor "L.S.F" is determined from the following equation:

$$L.S.F = \frac{CaO - 0.7\,SO_3}{2.8\,(SiO_2) + 1.2\,(Al_2\,O_3) + 0.65\,(Fe_2O_3)}$$

$$0.66 < L.S.F < 1.02$$

*Free lime* – cause the cement to be unsound

The lower limit of L.S.F indicates that the burning in the kiln is difficult and the proportion of $C_3S$ in the clinker is too low for the development of early strength

The upper limit of L.S.F indicates that the amount of lime is not so high as to result in *free lime* appearing at the clinkering temperature in equilibrium with the liquid present

- The expansion is Le Chatelier must not be more than 10 mm according to BS:12: 1991, and EN-196-3:1987.
- $SO_3 \leq 3.5\,\%$ *according to BS* 12: 1991.
- *Insoluble Residue* $(I.R) \leq 1.5\,\%$
- Loss on Ignition (L.O.I) < 4%

❖ *Physical requirements:*

- According to IQS NO.5: compressive strength: for 3 days ≥ 15 MPa.
  for 7 days ≥ 23 MPa.
- According to BS12:1991: Portland cements are classified according to their compressive strength as shown in the table (2-5):

**Table (2-5) Compressive strength requirements of cement According to B.S.12:1991**

| Class | Minimum strength (MPa) at the age of : | | | Maximum strength (MPa) at the age of 28 days |
|---|---|---|---|---|
| | **2 days** | **7 days** | **28 days** | **28 days** |
| 32.5N | - | 16 | 32.5 | 52.5 |
| 32.5R | 10 | - | | |
| 42.5N | 10 | - | 42.5 | 62.5 |
| 42.5R | 20 | - | | |
| 52.5N | 20 | - | 52.5 | - |
| 52.5R | 30 | - | | |
| 62.5N | 20 | - | 62.5 | - |

- ✓ The 28 days minimum strength in MPa gives the name of the class: 32.5, 42.5, 52.5 and 62.5.
- ✓ The 28 days strengths of the two lower classes are prescribed by a range (each class of cement has a maximum value of strength as well as a minimum).
- ✓ Cements of class 32.5 and 42.5 are each subdivided into two subclasses:
  - o One with an ordinary early strength.
  - o The other with a high early strength.

A high early strength, denoted by the letter "**R**", is rapid-hardening cements.

## Rapid-hardening Portland cement (R.H.P.C)- (Type III):

- R.H.P.C develops strength more rapidly.
- Setting time for R.H.P.C is similar for that of O.P.C.
- Higher content of $C_3S$ and $C_3A$ ($C_3S$ > 55 %, but sometimes as high as 70 %).
- R.H.P.C has higher fineness (450- 600 $m^2/kg$) measured by Blaine method.
- The higher fineness increases the strength at 10- 20 hrs up to about 28 days.

- Rate of heat evolution is higher than in O.P.C due to the increase in $C_3S$ and $C_3A$, and due to its higher fineness.

- ***Uses:***

  **1**) R.H.P.C is used when rapid strength development is desired (to develop high early strength :3 days strength of R.H.P.C = 7 days strength of O.P.C), for example:

  ***a)*** when formwork is to be removed for re-use.

  ***b)*** where sufficient strength for further construction is wanted as quickly as practicable, such as:

  - ✓ concrete blocks manufacturing.
  - ✓ Sidewalks.
  - ✓ places that can not be closed for a long time.
  - ✓ repair works needed to construct quickly.

  **2**) For construction at low temperatures, to prevent the frost damage of the capillary water.

  **3**) R.H.P.C does not use at mass concrete constructions.

## Special types of Rapid-Hardening Portland cement:

### *Ultra High Early Strength Cement*

- ❖ This type of cement is manufacture by separating fines from R.H.P.C by a cyclone air elutriator.

- ❖ The rapid strength development of this type of cement is achieved by grinding the cement to a very high fineness : (700-900 $m^2/kg$).

  *Due to high fineness of this cement:*

  - The gypsum content has to be higher (4% expressed as $SO_3$) than in cements complying with ENV 197-1:1992.

    **Q./**Why high gypsum content has no adverse effect on long-term soundness?

    **A./** The gypsum is used up in the early reactions of hydration.

- o This type of cement has low bulk density and deteriorates rapidly on exposure.

- o High fineness leads to rapid hydration, hence, high rate of heat generation at early ages as well as rapid strength development:
  - ✓ The 3 day strength of (R.H.P.C) is reached at 16 hrs.
  - ✓ The 7 day strength is reached at 24 hrs.

- ❖ It is used successfully in a number of structures where:
  - ✓ early prestressing .
  - ✓ putting into service is of importance.

## Low heat Portland cement (L.H.P.C)- (Type IV):

- This type of cement contains less $C_3S$ and $C_3A$ percentage, and higher percentage of $C_2S$ in comparison with O.P.C.
- Reduce and delay the heat of hydration. BS 1370:1979 limits the heat of hydration of this cement to:
- o 250 J/g (60 cal/g) at the age of 7 days.
- o 290 J/g (70 cal/g) at 28 days.
- It has lower early strength (½ the strength at 7 days age and ⅔ the strength at 28 days age) compared with O.P.C.
- Fineness is not less than 3200 $cm^2/g$.
- **Uses:** L.H.P.C is used in large concrete mass. The interior faces of the concrete mass has a high temperature due to the heat development by the hydration of cement, coupled with a low thermal conductivity of concrete while the exterior faces has dissipated the heat of hydration thus serious cracking occurred.

## Modified Cement (Type II) :

- Modified Portland cement made from 40% O.P.C+ 60% L.H.P.C.
- This cement combines higher rate of heat development than that of L.H.P.C with a rate of gain of strength similar to that of O.P.C
- It is recommended for use in structures where:
  - ✓ moderately low heat generation is desirable
  - ✓ moderate sulfate attack may occur.

## Sulfate- resisting Cement (S.R.P.C)-( Type V) :

- ***Compositions:*** this type of cement contains:
  - Lower percentage of $C_3A$ and $C_4AF$: which considers as the most affected compounds by sulfates.
  - Higher percentage of silicates in comparison with O.P.C.
  - Iraqi specification no. (6) limits: . $C_3A \leq 3.5\%$ , fineness $\geq 2500\ cm^2/g$.

- ***Properties:***
  - Low early strength because $C_2S$ represents a high proportion of the silicates.
  - Its resulted heat of hydration is not much higher than that of L.H.P.C
  - It is not preferable when there is chloride ions.

## *Sulfate attack :*

*for the hardened cement, the effects of sulfates are on two types:*

**1-** Hydrated calcium aluminates ($C_3A$) in their semi-stable hexagonal form (before its transformation to the stable state $C_3AH_6$ as cubical crystal form ) which have high sulfate resistance) react with sulfates (present in fine aggregate, or soil and ground water), producing hydrated calcium sulfoaluminate **(check Lecture#3 : page 16)**. This reaction is 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 remedies for sulfate attack***:*

*Use cement with low $C_3A$ (use S.R.P.C):*

$C_3A \leq 3.5$ % (Iraqi specification).

$C_3A \leq 5\%$ (ASTM C-150)

$2C_3A + C_4AF \leq 25\%$ (ASTM C-150)

$MgO \leq 6\%$

## White Cement:

- This cement is used for architectural purposes.
- White Portland cement is made from raw materials containing:
  - very little iron oxide (less than 0.3% by mass of clinker) .
  - magnesium oxide (which give the grey color in ordinary Portland cement).
- Raw materials used for the production of white cement are:
  - China clay (white kaoline).
  - Chalk or limestone, free from specified impurities.
- White cement manufacture needs higher firing temperature (up to 1650ºC) because of:

  * the absence of iron element that works as a flux in the formation process of the clinker.

- Contamination of the cement with iron during grinding of clinker has also to be avoided. For this reason, instead of the usual ball mill, the expensive nickel and molybdenum alloy balls are used in a stone or ceramic-lined mill.
- White cement rather expensive (about 3 times the price of Ordinary Portland cement) because :

  *higher cost of grinding: due to the use of special grinding mill.

  *more expensive raw materials are used.

  *special fuel is used for firing.

  *increasing the quantity of the fuel needed for firing as the firing temperature may be up to 1650ºC.

- It has a slightly lower specific gravity (3.05-3.1), than ordinary Portland cement.
- The strength is lower than that of O.P.C.
- Its fineness is higher (400-450 $kg/m^2$) than O.P.C.

## Portland Blastfurnace Cement :

- This type of cement consists of an intimate mixture of :
  Portland cement + ground granulated blastfurnace slag (ggbs).

  ***Slag*** : is a waste product in the manufacture of pig iron.

  ***Chemically,*** slag is a mixture of lime, silica, alumina, that is, the same oxides that make up Portland cement but not in the same proportions.

- The specific gravity of ground granulate balstfurnace slag (ggbs) is about 2.9.
- When Portland blastfurnace cement is mixed with water:
  *immediate reaction of ggbs with water releases calcium and aluminium irons onto solution.
  *The ggbs reacts with alkali hydroxide and followed by another reaction by Portland cement, C-S-H being formed.

- Its sulfate resistance is high.
- ***Uses :***
  - Mass concrete
  - May not be use in cold weather concreting.

## Supersulfated cement:

- **Production:** this cement is made by intergrinding a mixture of 80 to 85 % of granulated blastfurnace slag (ggbs) with 10 to 15 % of calcium sulfate [in the form of dead-burnt gypsum or anhydrite ($CaSO_4$) ] and up to 5 % of Portland cement clinker.
- Fineness : 400 to 500 $m^2$/kg.
- Stored under very dry conditions as otherwise it deteriorates rapidly.
- It is highly resistant to sea water and can withstand the highest concentrations of sulfates in soil or ground water.
- **Uses:**
  *in the construction of sewers (pH< 3.5).
  *in mass concrete construction (because of its low heat of hydration).
  **Note:** In cold weather, care must be taken if this cement used *because the rate of strength development reduced at low temperatures.*

## Pozzolanic Cement :

- This type of cement consists of an intimate mixture of Portland cement and pozzolana.

* American standard limit the pozzolana content by 15-40% of Pozzolanic cement.

***Pozzolana*** (according to ASTM C618-94a): is 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.

**Types of Pozzolana :**

(a) Natural Pozzolanic materials, such as volcanic ash.
(b) Industrial Pozzolanic materials, such as fired clay, rice husks ash.

**Properties & Uses :** they are similar to those of Portland blastfurnace cement.

## Other Cements:

### 1- High-alumina cement (H.A.C):

- **Compositions:**
  - It contains a large proportion of alumina
  - 40 % each of alumina and lime.
  - 15 % of ferrous and ferric oxides.
  - about 5 % of silica.
  - Small amounts of $TiO_2$, magnesia, and the alkalis.
- H.A.C is manufactured from limestone and bauxite.

  ***Bauxite:*** is a residual deposit formed by the weathering, under tropical conditions, of rocks containing aluminium, and consists of hydrated alumina, oxides of iron and titanium, and small amount of silica.

- **Resistance to chemical attack:**

  *H.A.C is resistance to sulfate attack due to the absence of $Ca(OH)_2$.

  *H.A.C is resistance to attack by $CO_2$ dissolved in pure water.

- **Physical properties of H.A.C:**

*H.A.C has very high rate of strength development.
*80% of H.A.C strength is obtained at 24hrs age.

## 2- Expansive Cement

- It has the property of expanding in its early life so as to counteract contraction induced by drying shrinkage.
- Its made from mixing (P.C + expanding agent+ stabilizer):
  - Expanding agent is obtained by burning a mixture of gypsum, bauxite, and chalk which form calcium sulfate and calcium aluminate. These materials react with water to form calcium sulfoaluminate hydrate (ettringite) which cause an expansion of the cement paste.
  - The stabilizer is blastfurnace slag which slowly take up the excess calcium sulfate and brings expansion to an end.

## 3- Natural Cement

- This name is given to a cement obtained by calcining and grinding a so-called cement rock, which a clayey limestone containing up to 25% of argillaceous material.
- This cement is similar to Portland cement and it is really intermediate between Portland cement and hydraulic lime.
- It contains no $C_3S$ and is therefore slow hardening.
- This type of cement is rarely used nowadays.