Concrete Technology

Syllabus

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2. Cement
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Text Book


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1. INTRODUCTION

Concrete is the most commonly used man made construction material. It has become very popular not only among civil engineers but among common people also. The secret of its popularity lies in the simple fact that except cement, all other ingredients of concrete are commonly available local materials like aggregate and water. The word “concrete” originates from the Latin verb “concretus”, which means to grow together.

Concrete is a composite material. The basic ingredient of concrete are:

**Cement**: It is the most important and costliest ingredient of concrete. Its affects the overall economy of the structure too. Different types of cements are available for different type of structures. Cement produces a crystalline structure and binds aggregates together.

**Aggregate**: The aggregate give volume to the concrete because these occupy maximum space in the total volume of concrete.

**Large aggregates**, provide density (fill space) and provide strength. May be either gravel or crushed stone. Makes up 40%-45% of the mixture, comprised of particles greater than 1/4”.

**Fine aggregates**, fill small voids between large aggregates and Increases strength of the cement binder. Normally called sand, this component can be natural sand or crushed stone, and represents particles smaller than 3/8". Generally accounts for 30%-35% of the mixture.
**Water:** It is indispensable because it is required for reaction of hydration. But its use should be restricted to minimum as possible considering the requirement for chemical reaction with cement and workability only.

**Admixture:** It is an optional ingredient which is used only for some specific purpose. It is used to modify some of the properties of concrete like setting time, workability or surface finishing characteristics.

### 2. CEMENT

**Cement:** is a material with adhesive and cohesive properties which make it capable of bonding minerals fragments into a compact whole.

For constructional purposes, the meaning of the term "cement" is restricted to the bonding materials used with stones, sand, bricks, building stones, etc.

The cements of interest in the making of concrete have the property of setting and hardening under water by virtue of a chemical reaction with it and are, therefore, called hydraulic cement.

The name "Portland cement" given originally due to the similarity of the color and quality of the hardened cement to Portland stone - Portland island in England.

**Manufacture of Portland Cement**

**Raw Materials**

**Calcereous material:** such as limestone or chalk, as a source of lime (CaO).

**Clayey material:** such as clay or shale (soft clayey stones), as a source of silica and alumina.
Methods of Cement Manufacturing

1- Wet process: grinding and mixing of the raw materials in the existence of water with 40%

2- Dry process: grinding and mixing of the raw materials in their dry state. Water percentage is 12%.

Wet Process

When limestone is used, it has to be blasted, then crushed, usually in two progressively smaller crushers (initial and secondary crushers), and then fed into a ball mill with the clay dispersed in water. The resultant slurry is pumped into storage tanks.

The slurry is a liquid of creamy consistency, with water content of between 35 and 50%, and only a small fraction of material - about 2% - larger than a 90 µm (sieve No. 170).

The slurry analyze chemically to check the achievement of the required chemical composition, and if necessary changing the mix constituents to attain the required chemical composition.

Finally, the slurry with the desired lime content passes into the rotary kiln. This is a large, refractory-lined steel cylinder, up to 8 m in diameter, sometimes as long as 230 m, which is slightly inclined to the horizontal. The slurry is fed in at the upper end while the fuel at the lower end of the kiln, where the temperature reaches about 1450°C.

The slurry, in its movement down the kiln, encounters a progressively higher temperature. At first, the water is driven off and CO₂ is liberated; further on, the dry material undergoes a series of chemical reactions until finally, in the hottest
part of the kiln, some 20 to 30% of the material becomes liquid, and lime, silica and alumina recombine. The mass then fuses into balls, 3 to 25 mm in diameter, known as clinker. The clinker drops into coolers.

**Dry Process**

The raw materials are crushed and fed in the correct proportions into a grinding mill, where they are dried and reduced in size to a fine powder. The dry powder, called raw meal, is then pumped to a blending silo, and final adjustment is now made in the proportions of the materials required for the manufacture of cement. To obtain a uniform mixture, the raw meal is blended in the silo, usually by means of compressed air.

The blended meal is sieved and fed into a rotating dish called a granulator, water weighing about 12% of the meal being added at the same time. In this manner, hard pellets about 15 mm in diameter are formed.

The pellets are baked hard in a pre-heating grate by means of hot gases from the kiln. The pellets then enter the kiln, and subsequent operations are the same as in the wet process of manufacture.

**Grinding of the Clinker**

The cool clinker (produced by wet or dry process), which is Black and hard, is interground with gypsum $\text{CaSO}_4.2\text{H}_2\text{O}$ with 4% in order to prevent flash setting of the cement, and to facilitate the grinding process. The grinding is done in a ball mill. The cement discharged by the mill is passed through a separator, fine particles being removed to the storage silo by an air current, while the coarser particles are passed through the mill once again.
**Comparison between wet and dry process**

<table>
<thead>
<tr>
<th>No.</th>
<th>Wet Process</th>
<th>Dry Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Moisture content of the slurry is 35-50%</td>
<td>Moisture content of the pellets is 12%</td>
</tr>
<tr>
<td>2</td>
<td>Size of the kiln needed to manufacture the cement is bigger</td>
<td>Size of the kiln needed to manufacture the cement is smaller</td>
</tr>
<tr>
<td>3</td>
<td>The amount of heat required is higher, so the required fuel amount is higher.</td>
<td>The amount of heat required is lower, so the required fuel amount is lower.</td>
</tr>
<tr>
<td>4</td>
<td>Less economically</td>
<td>More economically</td>
</tr>
<tr>
<td>5</td>
<td>The raw materials can be mix easily, so a better homogeneous material can be obtained</td>
<td>5- Difficult to control the mixing of raw materials process, so it is difficult to obtain homogeneous material.</td>
</tr>
<tr>
<td>6</td>
<td>The machinery and equipments do not need much maintenance</td>
<td>The machinery and equipments need more maintenance</td>
</tr>
</tbody>
</table>

**Chemical composition of Portland cement**

The raw materials used in the manufacture of Portland cement consist mainly of lime, silica, alumina and iron oxide. These compounds interact with one another in the kiln to form a series of more complex products and, apart from a small residue of uncombined lime which has not had sufficient time to react, a state of chemical equilibrium is reached. The resultant of firing is the clinker.

**Four compounds** are usually regarded as the major compounds of cement (Clinker):

- Tricalcium silicate (3CaO.SiO₂), \( C_3S \)
- Dicalcium silicate (2CaO.SiO₂) \( C_2S \)
- Tricalcium aluminate (3CaO.Al₂O₃), \( C_3A \)
- Tetracalcium aluminoferrite. (4CaO.Al₂O₃. Fe₂O₃), \( C_4AF \)
Where each oxide symbol with one letter:

\[
\begin{align*}
\text{CaO} & - C \\
\text{SiO}_2 & - S \\
\text{Al}_2\text{O}_3 & - A \\
\text{Fe}_2\text{O}_3 & - F \\
\text{H}_2\text{O} & - H
\end{align*}
\]

The percentage of the main composition of cement can be calculated according to the Bogue equations, based on the assumption that the reactions reached the chemical equilibrium state

\[
\begin{align*}
\text{C}_3\text{S} &= 4.07 \text{(CaO)} - 7.6 \text{(SiO}_2) - 6.72 \text{(Al}_2\text{O}_3) - 1.43 \text{(Fe}_2\text{O}_3) - 2.85 \text{(SO}_3) \\
\text{C}_2\text{S} &= 2.876 \text{(SiO}_2) - 0.754 \text{(C}_3\text{S)} \\
\text{C}_3\text{A} &= 2.65 \text{(Al}_2\text{O}_3) - 1.69 \text{(Fe}_2\text{O}_3) \\
\text{C}_4\text{AF} &= 3.04 \text{(Fe}_2\text{O}_3)
\end{align*}
\]

Where, the terms in brackets represent the percentage of the given oxide in the total mass of cement. Recently, these compositions are determined by x-ray diffraction.

\(\text{C}_3\text{S}\) which is normally present in the largest amount. On cooling below 1250\(^\circ\), it decomposes slowly but, if cooling is not too slow, \(\text{C}_3\text{S}\) remains unchanged and is relatively stable at ordinary temperatures.

\[
\begin{align*}
\alpha\text{C}_2\text{S} & \text{ exist at high temperature and invert to} \\
\text{C}_2\text{S} & \rightarrow \beta\text{C}_2\text{S} \text{ form at about 1450}\text{C} \text{ and invert to} \\
\gamma\text{C}_2\text{S} & \text{ form at about 670}\text{C}.
\end{align*}
\]

\(\text{C}_3\text{A}\) forms rectangular crystals, but \(\text{C}_3\text{A}\) in frozen glass forms an amorphous interstitial phase.

\(\text{C}_4\text{AF}\) is solid solution ranging from \(\text{C}_2\text{F}\) to \(\text{C}_6\text{A}_2\text{F}\), but the description of \(\text{C}_4\text{AF}\) is a convenient simplification.
Minor compounds

In addition to the main compounds mentioned above, there exist minor compounds.

K₂O and Na₂O

Oxides of Sodium and Potassium known as the alkalis (about 0.4-1.3% by weight of cement). They have been found to react with the reactive silica found in some aggregates, the products of the reaction causing increase in volume leading to disintegration of the concrete. The increase in the alkalis percentage has been observed to affect the setting time and the rate of the gain of strength of cement.

SO₃

Sulfur oxide form low percentage of cement weight. SO₃ comes from the gypsum added (4% by weight) during grinding of the clinker, and from the impurities in the raw materials, also from the fuel used through firing process. Iraqi specification No. 5 limited max. SO₃ by 2.5% when C₃A ≤5%, and by 2.8% when C₃A > 5% for ordinary cement. For sulfate resistance cement, SO₃ ≤ 2.5%.

MgO

Magnesium oxide present in the cement by 1-4%, which comes from the magnesia compounds present in the raw materials. Iraqi specification No. 5 limited max. MgO by 5%, to control the expansion resulted from the hydration of this compound in the hardened concrete. When the magnesia is in amorphous form, it has no harmful effect on the concrete.

Other minor compounds such as TiO₂ (Titanium oxide), Mn₂O₃ (Manganese oxide), P₂O₅ (phosphorus oxide) represent < 1%, and they have little importance.
Usual Composition Limits of Portland Cement

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>60-67</td>
</tr>
<tr>
<td>SiO₂</td>
<td>17-25</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>3-8</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.5-6</td>
</tr>
<tr>
<td>MgO</td>
<td>0.1-4</td>
</tr>
<tr>
<td>Alkalis (Na₂O + K₂O)</td>
<td>0.2-1.3</td>
</tr>
<tr>
<td>SO₃</td>
<td>1-3</td>
</tr>
</tbody>
</table>

Typical Compound Composition in Ordinary Portland Cement

<table>
<thead>
<tr>
<th>Compound</th>
<th>Content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₃S</td>
<td>54</td>
</tr>
<tr>
<td>C₂S</td>
<td>17</td>
</tr>
<tr>
<td>C₃A</td>
<td>11</td>
</tr>
<tr>
<td>C₄AF</td>
<td>9</td>
</tr>
</tbody>
</table>

Loss on Ignition (L.O.1)

It is the loss of the cement sample weight when it expose to temperature (at 1000°C). It shows the extent of carbonation and hydration of free lime and free magnesia due to the exposure of cement to the atmosphere. Also, part of the loss in weight comes from losing water from the gypsum composition. The maximum loss on ignition permitted by Iraqi specification No. 5 is 4% by weight.

Insoluble Residue

It is that part of cement sample that is insoluble in HCl. It comes from the unreacted silica, to form soluble cement compounds diluting in this acid, largely arising from impurities in gypsum. The maximum insoluble residue permitted by Iraqi specification No. 5 is 1.5% by weight.