Properties of Cement

Dr. Ravi Kant Mittal, BITS, Pilani
1. Fineness

- Fineness of cement is a measure of the sizes particles of cement.
- 95% of cement particles are smaller than 45 micrometer, with the average particle around 15 micrometer.
- Also, it is expressed in terms of specific surface (m\(^2\)/kg) of cement.
Using Sieve

• Using 90 μm (No9) sieve.
• Should be less than 10% for OPC
• Should be less than 5% for Rapid hardening (RHC) and Portland Puzzolana (PPC)

Dr. Ravi Kant Mittal, BITS, Pilani
Fineness...

• Fineness tests indirectly measures the **surface area** (m²/kg) of the cement particles per unit mass
  – Wagner turbidimeter test
  – Blaine air-permeability test
  – Lea and Nurse
• Should not be less than
  - 225 m²/kg for OPC 33, 43, 53, PSlagC, Sulphate resisting PC and White PC.
    -- 300 m²/kg for PPC
  – 320 m²/kg for Low Heat PC
  – 325 m²/kg for Rapid hardening PC
  – 350 m²/kg for Hydrophobic cement,
  - 400 m²/kg for supersulphated cement

Dr. Ravi Kant Mittal, BITS, Pilani
Fineness Testing

- On left, Blaine test apparatus.

- On right, Wagner turbidimeter

Dr. Ravi Kant Mittal, BITS, Pilani
Fineness

v Process of Hydration
• Since hydration starts at the surface of the cement particles it is the total surface area of cement that represents the material available for hydration
• The finer the cement is ground, the greater will be its specific surface.
• So the rate of hydration depends on the fineness of cement particles & for rapid development of strength higher fineness necessary.
Fineness of cement affects heat released and the rate of hydration.
More is the fineness of cement more will be the rate of hydration.
Thus the fineness accelerates strength development principally during the first seven days

Dr. Ravi Kant Mittal, BITS, Pilani
• Fine cement is more liable to suffer from shrinkage cracking than a coarse cement.
• However, fine cement bleed less than a coarse one.
• Fine cement will show faster rate of hardening than coarse cement.
• Total quantity of heat evolved is SAME as coarse cement.
• Fine cement shows the same setting time as coarse cement. (30 min and 10 hour)
Fineness……

- Fineness exhibiting a higher shrinkage & a creates proneness to cracking.
- Finer grinding increases the speed with which the various constituents reacts with the water.
- Fineness of grinding is of some importance in relation on the workability of concrete mixes.
- Greater fineness increases the cohesiveness of a concrete mix.
- In some special type of cement the strength increases slowly than normal though they are finely grounded.

Dr. Ravi Kant Mittal, BITS, Pilani
2. Soundness

• Soundness is the ability of a hardened paste to retain its volume after setting.

• A cement is said to be unsound (i.e. having lack of soundness) if it is subjected to delayed destructive expansion.

• Unsoundness of cement is due to presence of excessive amount of hard-burned free lime or magnesia.

Dr. Ravi Kant Mittal, BITS, Pilani
Cont. on Soundness

• Unsoundness of a cement is determined by the following tests:
  – Le-Chatelier accelerated test
  – Autoclave-expansion test

  When tested by ‘Le Chatelier’ method and autoclave test described in IS 4031 (Part 3) : 1988, unaerated cement shall not have an expansion of more than 10mm and 0.8% respectively.

Dr. Ravi Kant Mittal, BITS, Pilani
IS 5514 : 1996

TOP VIEW WITHOUT GLASS PLATES

GLASS PLATES

1A LE-CHATELIER APPARATUS

Dr. Ravi Kant Mittal, BITS, Pilani
Le-Chatelier accelerated test

- For OPC, RHC, LHC and PPC it is limited to 10 mm,
- whereas for HAC (High Alumina) and SSC (Super sulphated) it should not exceed 5 mm.

Dr. Ravi Kant Mittal, BITS, Pilani
Autoclave-expansion test

25 × 25 × 250 mm specimen

Dr. Ray Kant Mittal, BITS, Pilani
• In the event of cements failing to comply with any one or both the requirements specified earlier, further tests in respect of each failure shall be made as described in IS 4031 (Part 3) : 1988 from another portion of the same sample after aeration.

• The aeration shall be done by spreading out the sample to a depth of 75 mm at a relative humidity of 50 to 80 percent for a total period of 7 days.

• The expansion of cements so aerated shall be not more than 5 mm and 0.6 percent when tested by ‘Le Chatelier’ method and autoclave test respectively.
3. Consistency

• Consistency refers to the relative mobility of a freshly mixed cement paste or mortar or its ability to flow.

• Normal or Standard consistency of cement is determined using the Vicat’s Apparatus. It is defined as that percentage of water added to form the paste such that Vicat plunger (10mm dia) penetrates up to a point 5 to 7 mm from the bottom of the mould (33-35 mm from top).

Dr. Ravi Kant Mittal, BITS, Pilani
Normal or Standard consistency of cement is determined using the Vicat’s Apparatus. It is defined as that percentage of water added to form the paste such that Vicat plunger (10mm dia) penetrates up to a point 5 to 7 mm from the bottom of the mould (33-35 mm from top).
4. Setting Time

• This is the term used to describe the stiffening of the cement paste.

• Setting time is to determine if a cement sets according to the time limits specified in IS Code.

• Setting time is determined using the Vicat apparatus.

Dr. Ravi Kant Mittal, BITS, Pilani
Vicat Needle

Dr. Ravi Kant Mittal, BITS, Pilani
• Cement paste is prepared by mixing cement with 0.85 times the water required to give a paste of standard consistency ($0.85^*P$).

• The period elapsing between the time when water is added to the cement and the time at which the needle (~1 mm) fails to pierce the test block to a point $5.0 \pm 0.5$ mm measured from the bottom of the mould shall be the initial setting time.

• IS Code prescribes a minimum initial setting time of 30 minutes for (OPC, PPC, RHPC, PSC), 60 minutes LHPC.

Dr. Ravi Kant Mittal, BITS, Pilani
• “Final setting time” the time required for the paste to acquire certain degree of hardness.

• **Final Setting Time.** The square needle is replaced with annular collar. Experiment is continued by allowing this needle to freely move after gently touching the surface of the paste.

• Final setting time corresponds to the time at which the Viact’s final set needle makes an impression on the paste surface but the annular attachment fails to do so.

• IS Code prescribes a maximum final setting time of 10 hours for Portland cements.

• Gypsum in the cement regulates setting time. Setting time is also affected by cement fineness, w/c ratio, and admixtures.

Dr. Ravi Kant Mittal, BITS, Pilani
Early Stiffening (False Set and Flash Set)

- Early stiffening is the early development of stiffening in the working plasticity of cement paste, mortar or concrete. This includes both false set and flash set.

**FALSE SET**

The rapid development of rigidity in freshly mixed Portland cement paste, mortar or concrete **without the evolution of much heat**, shortly after mixing, which is mostly due to re-hydration of dehydrated gypsum in cement.

Dr. Ravi Kant Mittal, BITS, Pilani
FALSE SET

• False set is evidenced by a significant loss of plasticity, i.e. stiffening, without the evolution of much heat shortly after mixing within few minutes.

• Stiffening caused by rapid crystallization of interlocking needle-like secondary gypsum.

• False set cause no difficulty in placing and handling of concrete if the concrete is mixed for a longer time than usual
  • or if it is remixed without additional water before it is transported or placed.

Dr. Ravi Kant Mittal, BITS, Pilani
• The rapid development of rigidity in freshly mixed Portland cement paste, mortar or concrete with the evolution of considerable heat, which is due to uncontrolled hydration of C\textsubscript{3}A.

• It is occurring due to gypsum deficiency in the cement which allows rapid hydration of aluminate phase.

Dr. Ravi Kant Mittal, BITS, Pilani
FLASH SET (Contd…)

• Flash set cannot be dispelled, nor can the plasticity and workability be regained by further mixing without the addition of water.

• It can be prevented by adding appropriate amount of gypsum during cement manufacturing.

Dr. Ravi Kant Mittal, BITS, Pilani
5. Compressive Strength

Figure 3  Compressive strength test for a cube

Dr. Ravi Kant Mittal, BITS, Pilani
5. Compressive Strength

• Compressive strength of cement is the most important property.

• It is determined by conducting compression tests on standard 70.6 mm mortar cubes having face area of 50 cm\(^2\) in accordance with IS Code (Cement: Standard Sand=1:3, and water \((0.25*P+3)\)% of combined mass of cement plus sand.

• In general, cement strength (based on mortar-cube tests) can not be used to predict concrete compressive strength with great degree of accuracy because of many variables in aggregate characteristics, concrete mixtures, construction procedures, and environmental conditions in the field.

Dr. Ravi Kant Mittal, BITS, Pilani
5. Compressive Strength

Figure 3  Compressive strength test for a cube

Dr. Ravi Kant Mittal, BITS, Pilani
<table>
<thead>
<tr>
<th>Sample</th>
<th>Strength in N/mm² not less than for</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gr. 33</td>
</tr>
<tr>
<td>Age at testing</td>
<td></td>
</tr>
<tr>
<td>72 + 1 hr</td>
<td>16</td>
</tr>
<tr>
<td>168 + 2 hrs</td>
<td>22</td>
</tr>
<tr>
<td>672 + 4 hrs</td>
<td>33</td>
</tr>
</tbody>
</table>

Table 5.4 Minimum Specified Strength in N/mm²

<table>
<thead>
<tr>
<th>Type/Days</th>
<th>1 day</th>
<th>3 days</th>
<th>7 days</th>
<th>28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordinary Portland cement (33 grade)</td>
<td>-</td>
<td>16.0</td>
<td>22.0</td>
<td>33.0</td>
</tr>
<tr>
<td>Portland Puzzolana cement</td>
<td>-</td>
<td>16.0</td>
<td>22.0</td>
<td>33.0</td>
</tr>
<tr>
<td>Low heat Portland cement</td>
<td>-</td>
<td>10.0</td>
<td>16.0</td>
<td>35.0</td>
</tr>
<tr>
<td>Rapid hardening cement</td>
<td>16.0</td>
<td>27.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>High alumina cement</td>
<td>30.0</td>
<td>35.0</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
IS 1489 (Part 1) : 1991 PORTLAND-POZZOLANA CEMENT —SPECIFICATION PART 1 FLY ASH BASED

- Compressive strength of 1cement, 3 sand mortar
  - a) At 72 ± 1 h , 16 MPa, Min
  - b) At 168 ± 2 h , 22 MPa, Min
  - c) At 672 ± 4 h , 33 MPa, Min

For construction of structures using rapid construction methods like slipform construction, Portland-pozzolana cement shall be used with caution since 4 to 6 hour strength of concrete is considered significant in such construction.

Dr. Ravi Kant Mittal, BITS, Pilani
8. Loss on Ignition (LOI)

• The test for loss on ignition is performed in accordance with IS4032-1985 (ASTM C 114).

• A high weight loss on ignition of a cement sample (between 900 to 1000ºC) for 15 min. is an indication of pre-hydration and carbonation, which may be caused by:
  – Improper and prolonged storage
  – Adulteration during transport and transfer

• Generally, Loss on ignition values range between 0 to 3%. However, maximum permissible is 4-5%.

Dr. Ravi Kant Mittal, BITS, Pilani
Loss on Ignition Test of cement

Dr. Ravi Kant Mittal, BITS, Pilani
9. Density and Specific Gravity

• **Weight** of one bag of cement 50 kg
• **Volume** of one bag of cement 35 liters = 0.035 m³
• **Density** is the mass of a unit volume of the cement (including air between particles).
  
  Density is approx. 1.43 gm/cc.

• **Specific gravity** of cement particles) of Portland cement ranges from 3.10 to 3.25, averaging 3.15.
• It (take 3.15 if not given) is used in concrete mixture proportioning calculations.
7. Heat of Hydration

- It is the quantity of heat (in joules) per gram of unhydrated cement evolved upon complete hydration at a given temperature.

- The heat of hydration can be determined by a calorimeter.

- The temperature at which hydration occurs greatly affects the rate of heat development.

- Fineness of cement also affects the rate of heat development but not the total amount of heat liberated.
6.7 Heat of Hydration for Low Heat PC
When tested by the method described in IS 4031 (Part 9): 1988, the heat of hydration of cement shall be as follows:

a) 7 days: not more than 272 kJ/kg, and

b) 28 days: not more than 314 kJ/kg.
Heat of Hydration determined by ASTM C 186 (left) or by a conduction calorimeter (right).

Dr. Ravi Kant Mittal, BITS, Pilani
Cont. on Heat of Hydration

- The amount of heat generated depends upon the chemical composition of cement. Following are the heat of hydration generated on hydration of the four compounds of cement.

- Compound Heat of hydration Remarks $C_3S$ 502 j/g--$C_2S$ 260 j/gMinimum$C_3A$ 867 j/g Maximum$C_4AF$ 419 j/g-

- $C_3S$ and $C_3A$ are the compounds responsible for the high heat evolution.

- The approximate amount of heat generated using ASTM C 186, during the first 7 days (based on limited data) are as follows:

Dr. Ravi Kant Mittal, BITS, Pilani
<table>
<thead>
<tr>
<th>Compound</th>
<th>( C_3S )</th>
<th>( C_2S )</th>
<th>( C_3A )</th>
<th>( C_4AF )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 days</td>
<td>58</td>
<td>12</td>
<td>212</td>
<td>69</td>
</tr>
<tr>
<td>90 days</td>
<td>104</td>
<td>42</td>
<td>311</td>
<td>98</td>
</tr>
<tr>
<td>13 years</td>
<td>122</td>
<td>59</td>
<td>324</td>
<td>102</td>
</tr>
</tbody>
</table>

**TABLE 6-4**  Heat of Hydration of Portland Cement Compounds

Heats of hydration at the given age (cal/g)
<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Heat of hydration (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Normal</td>
<td>349</td>
</tr>
<tr>
<td>II</td>
<td>Moderate</td>
<td>263</td>
</tr>
<tr>
<td>III</td>
<td>High early strength</td>
<td>370</td>
</tr>
<tr>
<td>IV</td>
<td>Low heat of hydration</td>
<td>233</td>
</tr>
<tr>
<td>V</td>
<td>Sulfate resistant</td>
<td>310</td>
</tr>
</tbody>
</table>

Dr. Ravi Kant Mittal, BITS, Pilani
Cont. on Heat of Hydration

- Cements do not generate heat at constant rate as illustrated in Figure for a typical type I Portland cement.
Stage 1: heat of wetting or initial hydrolysis
$C_3A$ and $C_3S$ Hydration. 7 min after mixing.

Stage 2: dormant period related to initial set.

Stage 3: accelerated reaction of the hydration products. That determine the rate of hardening and final set.

Stage 4: decelerates formation of hydration products and determines the rate of early strength gain.

Stage 5: is a slow, steady formation of hydration products.
Storage of Cement

• Cement is moisture-sensitive material; if kept dry it will retain its quality indefinitely.

• When exposed to moisture, cement will set more slowly and will have less strength compared to cement that kept dry.

• At the time of use cement should be free-flowing and free of lumps.

Dr. Ravi Kant Mittal, BITS, Pilani
Storage of Cement

Dr. Ravi Kant Mittal, BITS, Pilani