Thermal Behaviour of Concrete

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Abstract
Concrete is a man-made rock which comprises of cement, aggregates & water. The aim of this investigation is to study the strength characteristics of M20 cement concrete when the concrete is exposed to different increments of temperatures under laboratory conditions. The concrete cubes are casted for identifying the 7 days strength. The preliminary tests on ingredients (sand, coarse aggregates & cement) of concrete are performed in the laboratory. The mix design for M20 grade concrete is derived as 1:1.378:3.265 by maintaining W/C ratio as 0.5 by using IS code (IS 10262) method. Cubes are casted in the laboratory and kept for curing in curing tank for 7 days. All the cubes are heated to temperatures greater than casting and curing temperatures. For that cubes heated to different temperatures compressive strengths are noted using compressive testing machine and graph is drawn and results are tabulated.

Keywords
Temperature, Ingredients, Cubes, Compressive Strength

I. Introduction

A. Concrete
Concrete is a mixed material which can be moulded into any shape. The relative quantities of cement, aggregates and water mixed together, controls the concrete properties. The strength of concrete which is a main criterion for a structure depends on the proportions of the ingredients. Admixtures are the other ingredient which may accelerate or retard the specific properties of concrete mix in any state.

B. Cement
Cement is a hardened material with adhesive as well as cohesive properties. It is a building material that is a powder made of a mixture of calcined limestone and clay; used with water and sand or gravel to make concrete and mortar. Cement when mixed with water gets hardened. Cement and strength criteria are directly proportional to one another. Cement is useful to construct the walls, bricks, R.C.C works, plastering purposes etc.

C. Aggregates
Aggregates are the important constituents of concrete which influence the strength of hardened concrete. Aggregate should be durable, strong & well graded. It nearly occupies 75% of the volume of concrete. This helps in reducing the shrinkage effect & gives more durable concrete.

D. Water
The normal range for pH in surface water systems is 6.5 to 8.5 and for groundwater systems 6 to 8.5. In general, water with a low pH (< 6.5) could be acidic, soft, and corrosive which is not suitable in concrete mix. The primary function of water used in a concrete mix is to start the hardening process of the concrete through hydration of the cement. The secondary function is to make the mix workable enough to satisfy the requirements of the job. Water used in mixing concrete must be clean and free from oils, alkalis, acids, and organic materials. Impure water used to make concrete can cause problems, when setting, or in causing premature failure of the structure.

II. Experiments Conducted

The materials used in the manufacture of cement concrete are:
1. Cement
2. Fine aggregate
3. Coarse aggregate
4. Water

III. Tests on Cement

The cement was produced in single consignment and properly stored. Ordinary Portland cement of 53 grade was used. The following are the field tests:
1. The cement should look greenish gray in color. There should not be any presence of lumps.
2. The cement should give smooth feeling when rubbed between the fingers.
3. It should give a cool feeling when a hand is thrust into a cement bag.
4. If a handful of cement is thrown in water, the cement should float for a few minutes before it sinks.

The laboratory tests conducted are:
• Finess test
• Specific gravity test
• Water absorption test

Fine Ness Test
The object of this test is to check the proper grinding of cement. The rate of hydration depends on the fineness of cement. Take 100 gm of cement from sample and place it on a standard IS sieve no.9 continuously.
Sieve the sample with a gentle wrist motion for 15 minutes. The residue of the cement is 7%.

Note
The residue shall not exceed 10% in case of OPC.

The specific gravity of solid is the ratio of the mass density of solids to that of standard fluid. It is determined in the laboratory using the relation.

\[ G = \frac{(M_2 - M_1)}{M_4 - M_3 - M_1} \]

Tests on Fine Aggregate (Sand)
Locally available natural sand was used. The following tests were made on sand:
• Sieve analysis
• Specific gravity
• Bulk density

\[ G = \frac{(M_2 - M_1)}{M_4 - M_3 - M_1} \]

Where,
\[ M_1 = \text{Mass of empty bottle} \]
\[ M_2 = \text{Mass of bottle and cement} \]
\[ M_3 = \text{Mass of bottle, cement and kerosene} \]
M₄ = Mass of bottle with kerosene
Specific gravity of cement (G) = 3.15

1. Sieve Analysis
To know about the grading of the aggregate of fine aggregate sieve analysis are carried out.

Table 1: Grading Requirements for Fine Aggregate

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Zone-I</th>
<th>Zone-II</th>
<th>Zone-III</th>
<th>Zone-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mm</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>4.75mm</td>
<td>90-100</td>
<td>90-100</td>
<td>90-100</td>
<td>90-100</td>
</tr>
<tr>
<td>2.36mm</td>
<td>60-95</td>
<td>75-100</td>
<td>85-100</td>
<td>95-100</td>
</tr>
<tr>
<td>1.18mm</td>
<td>30-70</td>
<td>55-90</td>
<td>75-100</td>
<td>90-100</td>
</tr>
<tr>
<td>600 µm</td>
<td>15-34</td>
<td>35-59</td>
<td>60-79</td>
<td>80-100</td>
</tr>
<tr>
<td>300 µm</td>
<td>5-20</td>
<td>8-30</td>
<td>12-40</td>
<td>15-50</td>
</tr>
<tr>
<td>150 µm</td>
<td>0-10</td>
<td>0-10</td>
<td>0-10</td>
<td>0-10</td>
</tr>
</tbody>
</table>

Table 2:

<table>
<thead>
<tr>
<th>IS Sieve Size</th>
<th>Weight Retained</th>
<th>% Weight Retained</th>
<th>FINE AGGREGATE</th>
<th>Zone-II range IS-383:1970</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cum.% Retained</td>
<td>Cum.% Passing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16mm</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>4.75mm</td>
<td>12</td>
<td>0.4</td>
<td>4</td>
<td>99.6</td>
</tr>
<tr>
<td>2.36mm</td>
<td>33</td>
<td>1.1</td>
<td>1.5</td>
<td>98.5</td>
</tr>
<tr>
<td>1.18mm</td>
<td>255</td>
<td>8.5</td>
<td>10.0</td>
<td>90.0</td>
</tr>
<tr>
<td>600 µm</td>
<td>1250</td>
<td>41.6</td>
<td>51.6</td>
<td>48.4</td>
</tr>
<tr>
<td>300 µm</td>
<td>1058</td>
<td>35.2</td>
<td>86.8</td>
<td>13.2</td>
</tr>
<tr>
<td>150 µm</td>
<td>365</td>
<td>12.16</td>
<td>98.96</td>
<td>1.04</td>
</tr>
<tr>
<td>&lt;150 µm</td>
<td>25</td>
<td>0.83</td>
<td>99.79</td>
<td>0.21</td>
</tr>
</tbody>
</table>

TOTAL = 349.05
FINENESS MODULUS = \frac{349.05}{100} = 3.49
The ranges for different types of sands
Therefore the given sand belongs to Zone-II and of coarse type.

2. Specific Gravity Test
Specific gravity of solid particles is the ratio of mass density of solids to that of standard fluid. It is determined in the laboratory using the relation.

\[ G = \frac{(M_2 - M_1)}{(M_4 - M_1) - (M_3 - M_1)} \]

3. Bulk Density
Bulk density is the compacted weight of material in a given volume. It is normally expressed in kgs/lit. Bulk density of aggregate is used to fledge the type of aggregate; computing with normal density. It is also used in converting weigh batching of concrete to volume batching.

\[ \text{Bulk density}(p) = \frac{(W_3 - W_1)}{(W_2 - W_1)} \]

Where,
\[ W_1 = \text{weight of empty cylinder} = 3.975\, \text{kg} \]
\[ W_2 = \text{weight of empty cylinder with water} = 6.930\, \text{kg} \]
\[ W_3 = \text{weight of empty cylinder with f.a} = 9.040\, \text{kg} \]
\[ W_2 - W_1 = \text{volume of cylinder} = 2.955\, \text{kg} \]
\[ W_3 - W_1 = \text{net weight of fine aggregate} = 5.065\, \text{kg} \]

Table 3:

<table>
<thead>
<tr>
<th>Fine aggregate</th>
<th>Min. Finess modulus</th>
<th>Max. Finess modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine sand</td>
<td>2.20</td>
<td>2.60</td>
</tr>
<tr>
<td>Medium sand</td>
<td>2.60</td>
<td>2.90</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>2.90</td>
<td>3.20</td>
</tr>
</tbody>
</table>

\[ W_1 = \text{weight of empty cylinder with f.a} = 9.040\, \text{kg} \]
\[ W_2 - W_1 = \text{volume of cylinder} = 2.955\, \text{kg} \]
\[ W_3 - W_1 = \text{net weight of fine aggregate} = 5.065\, \text{kg} \]

Bulk density of fine aggregate = 1.71 kg/litre

V. Tests on Coarse Aggregate
Crushed stone chips of maximum size of 20 mm available the local quarries were obtained.
The following tests were made for this 20 mm aggregate:
- Specific gravity test
- Bulk density test
- Sieve analysis

1. Specific Gravity Test
Specific gravity of solid particles is the ratio of mass density of solids to that of water.

\[ G = \frac{(M_2 - M_1)}{(M_4 - M_1) - (M_3 - M_1)} \]

Where,
\[ M_1 = \text{mass of pycnometer bottle} = 0.644\, \text{kg} \]
\[ M_2 = \text{mass of bottle and coarse aggregate} = 1.483\, \text{kg} \]
\[ M_3 = \text{mass of bottle, coarse aggregate water} = 2.022\, \text{kg} \]
\[ M_4 = \text{mass of bottle with water} = 1.480\, \text{kg} \]

\[ G = \frac{1.483 - 0.644}{(0.1483 - 0.644) - (2.022 - 0.644)} = 2.8 \]

Specific gravity of coarse aggregate = 2.8

2. Bulk Density
Bulk density is the weight of material in a given volume. It is normally expressed in kgs/lit. Bulk density of aggregate is used to fledge the type of aggregate; computing with normal density. It is also used in converting weigh batching of concrete to volume batching.

\[ \text{Bulk density}(p) = \frac{(W_3 - W_1)}{(W_2 - W_1)} \]

Where,
\[ W_1 = \text{weight of empty cylinder} = 3.975\, \text{kg} \]
\[ W_2 = \text{weight of empty cylinder with water} = 6.930\, \text{kg} \]
\[ W_3 = \text{weight of empty cylinder with C.A} = 8.965\, \text{kg} \]
\[ W_2 - W_1 = \text{volume of cylinder} = 2.955\, \text{kg} \]
\[ W_3 - W_1 = \text{net weight of coarse aggregate} = 4.99\, \text{kg} \]

\[ \text{Bulk density}(p) = \frac{4.99}{2.955} = 1.68\, \text{kg/litre} \]

Bulk density of coarse aggregate = 1.68 kg/litre

3. Sieve Analysis
Weight of sample taken: 1000 g

Table 4:

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Weight retained</th>
<th>% retained</th>
<th>% Cumulative weight retained</th>
<th>Fineness modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 mm</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>40 mm</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>20 mm</td>
<td>480</td>
<td>48</td>
<td>48</td>
<td>52</td>
</tr>
<tr>
<td>10 mm</td>
<td>520</td>
<td>52</td>
<td>100</td>
<td>48</td>
</tr>
<tr>
<td>4.75 mm</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>2.36 mm</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1.18 mm</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>600 μm</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>300 μm</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>150 μm</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Fineness Modulus Of Coarse Aggregate = \frac{748}{100} = 7.48
VI. Mix Design For M20 Grade Concrete
Mix design can be defined as a method of selecting suitable proportions of the ingredients mixed in concrete. Strength is directly proportional to water-cement ratio up to some extent and further it is inversely proportional to water-cement ratio. The concrete proportions involve a balance between economy and requirements of workability, strength, durability, density and appearance.

A properly designed concrete should have minimum possible cement content without sacrificing the concrete quality in order to make it an economical mix. It is essential to know the complete details under which freshen and hardened concrete will be used. The proportions of materials will differ with different requirements. In general a fresh concrete must be workable and hardened concrete must be durable and have the desired strength and appearance. If fresh concrete is not properly workable it will not be possible to achieve full compaction with the result strength and durability of hardened concrete will be significantly hampered. Hence design of concrete remains more of an art than a science.

VII. Procedure
The National Council of cement and building materials, New Delhi formerly Cement Research Institute of India (CRI) has developed a method of mix design based on extensive tests on Indian materials and cements. This method is applicable to design of normal concrete mixes (non-air entrained) for different grades of cement based on their 28-day strengths.

The following basic data are required for design namely,
1. Characteristic compressive strength (fck) at 28 days. (i.e. below which only 5% of test results are allowed to fall)
2. Degree of workability desired.
3. Limitations of water cement ratio and the minimum cement content to ensure adequate durability for the type of exposure.
4. Type and maximum size of the aggregate to be used.
5. Standard deviation for the compressive strength of concrete.

The step by step procedure of mix proportioning is as follows.

Step 1: Determine the target or design laboratory strength based on 28-day characteristic strength and standard deviation referring to IS: 10262-2009. (referred from table1). The corresponding formula is

\[ f_t = f_{ck} + K \cdot S \]

\[ f_t \] = target mean compressive strength at 28 days.
\[ f_{ck} \] = characteristic compressive strength at 28-days.
\[ K \] = a statistical value depending upon accepted proportion of low results & number of tests.
\[ S \] = standard deviation

Table 5:

<table>
<thead>
<tr>
<th>ACCEPTED PROPORTION OF RESULTS</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in 5</td>
<td>0.84</td>
</tr>
<tr>
<td>1 in 10</td>
<td>1.28</td>
</tr>
<tr>
<td>1 in 15</td>
<td>1.50</td>
</tr>
<tr>
<td>1 in 20</td>
<td>1.65</td>
</tr>
<tr>
<td>1 in 40</td>
<td>1.86</td>
</tr>
<tr>
<td>1 in 100</td>
<td>2.33</td>
</tr>
</tbody>
</table>

Step 2: The water cement ratio for the target mean strength is chosen from Fig 2 of IS-10262-2009.

Step 3:
For 20mm nominal maximum size of aggregate nominal size of aggregate the entrapped air =2%. From table: 3 of IS 10262-2009

Table 5:

<table>
<thead>
<tr>
<th>APPROXIMATE AIR CONTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal max. size of aggregate</td>
</tr>
<tr>
<td>-------------------------------</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>40</td>
</tr>
</tbody>
</table>

Step 4:
Selection of water content and fine to total aggregate ratio from table no.4 of IS: 10262-1980
For 20mm nominal maximum size of aggregate;
An approximate sand and water content for cubic metre of concrete is upto M35 grade.
Table 6:

<table>
<thead>
<tr>
<th>Nominal size of aggregate</th>
<th>Water content /m² of concrete (kg/m²)</th>
<th>Sand as % of total aggregate by absolute volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>208</td>
<td>40</td>
</tr>
<tr>
<td>20</td>
<td>186</td>
<td>35</td>
</tr>
<tr>
<td>40</td>
<td>165</td>
<td>30</td>
</tr>
</tbody>
</table>

Water content corresponding to saturated surface dry aggregate is known.

Step 5:
For other conditions of workability, water cement ratio, grading of fine aggregate and for rounded aggregates, adjustments in water content and percentage are done.

Step 6:
The cement content is calculated from the water cement ratio and the final water content arrived after adjustment. The cement content so calculated is checked against the minimum cement content from the requirements of durability.

Step 7:
With the quantities of water and cement per unit volume of concrete and the percentage of sand in the total aggregate already determined, the coarse and fine aggregates content per unit volume of concrete are calculated from the following equations:

\[ V = W + \frac{C}{S} + \frac{1}{P} \frac{F_a}{S_{fa}} + \frac{1}{1000} \]

\[ V = W + \frac{C}{S} + \frac{1}{P} \frac{C_a}{S_{ca}} + \frac{1}{1000} \]

Where,
- \( V \) = absolute volume of fresh concrete
- \( W \) = mass of water (kg) per m³ of concrete
- \( C \) = mass of cement (kg) per m³ of concrete
- \( S \) = specific gravity of cement
- \( P \) = ratio of fine aggregate to total aggregate by absolute volume
- \( F_a \) = total mass of fine aggregate (kg/m³) of concrete respectively
- \( S_{fa} \) = specific gravity of saturated surface dry fine aggregate
- \( C_a \) = total mass of coarse aggregate (kg/m³) of concrete respectively
- \( S_{ca} \) = specific gravity of saturated surface dry coarse aggregate

VIII. Design of Concrete Mix

1. Design Stipulations
1. Characteristic compressive strength required at 28 days (\( f_{ck} \)) = 20 N/mm²
2. Maximum size of aggregate = 20 mm
3. Degree of workability (Compacting factor) = 0.90
4. Degree of quality control = Good
5. Type of exposure = Moderate

2. Test Data For Materials
1. Cement used = OPC 53 grade as per (IS: 269-1976)
2. Specific gravity of cement = 3.15
3. i) Specific gravity of coarse aggregates = 2.80
   ii) Specific gravity of fine aggregates = 2.40
4. Water absorption
   i) Coarse aggregate = 0.5%
   ii) Fine aggregate = 1.0%
5. Free (surface) moisture
   i) Coarse aggregate = NIL
   ii) Fine aggregate = 2.0%

3. Mix Design
Step 1: Target Mean Strength Of Concrete:
For a tolerance factor of 1.65, target mean strength for the specified characteristic cube strength.
\[ f_t = f_{ck} + k_s = 20 + 1.65 \times 4.6 = 27.6 \text{ N/mm}^2 \]

Step 2: Selection Of Water Cement Ratio:
The free water-cement ratio required for the target mean strength of 27.6 N/mm² is 0.5 (approx.) from IS: 10262-2009

Step 3: SELECTION OF WATER AND SAND CONTENT:
From Table 4, for 20 mm nominal maximum size aggregate and sand conforming to grade II, water content per meter of concrete = 186 kg and sand content as percentage of total aggregate by absolute volume = 35 %. For change in values in water cement ratio, compacting factor and sand belonging to zone II, the following adjustment is required:

4. Adjustments
Table 7:

<table>
<thead>
<tr>
<th>Change in condition</th>
<th>Water content (%)</th>
<th>Sand in total aggregate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>For decrease in water cement ratio by (0.6-0.375): i.e. 0.225</td>
<td>0%</td>
<td>-2%</td>
</tr>
<tr>
<td>For increase in compacting factor by (0.9-0.8): i.e. 0.1</td>
<td>+3%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Therefore, required sand content as percentage of total aggregate by absolute volume = 35% - 2% = 33 %

Required water content = 186 + 186 x 3%
= 186 + 5.58
= 191.6 l/m³

Step 4:
Determination Of Cement Content
Water- cement ratio = 0.5
Water = 191.6 liters
Cement = 191.6 / 0.5 = 383 kg/m³

This cement content is adequate for moderate exposure condition

Step 5: Determination Of Coarse And Fine Aggregate Content:
For the specified maximum size of the aggregate of 20mm, the amount of entrapped air in the wet concrete is 2 %. Taking this into account and applying equations.
Step 6: Mix Proportion

Table 8:

<table>
<thead>
<tr>
<th>CEMENT</th>
<th>FINE AGGREGATE</th>
<th>COARSE AGGREGATE</th>
<th>WATER</th>
</tr>
</thead>
<tbody>
<tr>
<td>383 kg</td>
<td>528.1 kg</td>
<td>1250.9 kg</td>
<td>191.6</td>
</tr>
</tbody>
</table>

No. of cubes = 18
Volume of single cube = 0.15 × 0.15 × 0.15 = 3.375 × 10⁻³ m³
Total volume of concrete required for 18 cubes = 18 × 3.375 × 10⁻³ × 1.5 = 0.091125 m³.

5. Weight of Materials For 18 Cubes

- Weight of cement = 0.09112 × 383 = 34.899 kg
- Weight of sand = 528.1 × 0.09112 = 48.12 kg
- Weight of coarse aggregate = 1250.9 × 0.09112 = 113.98 kg
- Weight of water = 191.6 × 0.09112 = 17.44 lit.

6. Procedure

The cubes were casted and they are exposed to temperatures of 30°C, 40°C, 50°C, 60°C, 70°C, 80°C, 90°C, 100°C, and 120°C. The compressive strengths of cubes for 28 days are identified after they were exposed to different temperatures etc.: 30°C, 40°C, 50°C, 60°C, 70°C, 80°C, 90°C, 100°C, and 120°C. The variations of strengths are represented by graph.

IX. Results

Table 9:

<table>
<thead>
<tr>
<th>TEMPERATURE°C</th>
<th>28 days Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>28.21 N/mm²</td>
</tr>
<tr>
<td>40</td>
<td>23.56 N/mm²</td>
</tr>
<tr>
<td>50</td>
<td>21.38 N/mm²</td>
</tr>
<tr>
<td>60</td>
<td>21.58 N/mm²</td>
</tr>
<tr>
<td>70</td>
<td>31.39 N/mm²</td>
</tr>
<tr>
<td>80</td>
<td>35.31 N/mm²</td>
</tr>
<tr>
<td>90</td>
<td>35.30 N/mm²</td>
</tr>
<tr>
<td>100</td>
<td>35.32 N/mm²</td>
</tr>
<tr>
<td>120</td>
<td>35.30 N/mm²</td>
</tr>
</tbody>
</table>

Fig. 1:

X. Conclusion

- The M20 concrete has given least strength (21.38 N/mm²) when it is exposed to 50°C.
- This concrete gives uniform strength when it is exposed to beyond 80°C.

References

[1] (IS 10262(2009)),”Indian Standard recommended guidelines for concrete mix design”.