Measuring specific heat of normal strength concrete and the comparison of the specific heat with different types of concrete

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Abstract: Specific heat is the amount of heat that a unit mass of a material must gain or lose to change its temperature by a given amount. The specific heat of a material is associated with the heat capacity, except the specific heat doesn’t depend on an object’s mass, though it depends on the types of material. Specific heat measures the index of the facility with which concrete can undergo temperature changes. Specific heat is also related to thermal conductivity and thermal diffusivity. For this reason measurement of specific heat of concrete is very essential. The aim of this study is to build up an arrangement for measuring specific heat of normal strength concrete and the comparison of the specific heat with different types of concrete and also to observe the variation of current and voltage with respect to time. Unit weight, Voids, Moisture content and Specific Gravity was measured for measuring specific heat by using bricks khoa and stone chips as coarse aggregate and the samples are covered with and without glass wool. The specific heat of concrete varies with the mixing ratios of ingredients of concrete. The specific heat of concrete with denser mixing ratio is greater than concrete having looser mixing ratios.

Keywords: Concrete, Specific Heat, Thermal Conductivity, Density, Moisture Content, Coarse Aggregates

Introduction:
Now-a-days temperature change is becoming a burning issue across the world. For global warming, temperature increases quickly. As a result of urbanization, huge amount of carbon di oxide (CO₂) and carbon monoxide (CO) are produced and causing global warming. For this reason various civil engineering structures go through temperature changes. With the increase of temperature concrete goes in elongation and with the decrease of temperature it goes in contraction which may fail structures in bonding. [1]
Heat is defined as the flow of thermal energy and expressed in Joules. A quantity of heat cannot be measured directly; a measurement for the amount of thermal energy in transit (heat) can be made by determining its effects. When a ingredient gains heat, its total internal energy is improved, the total internal energy of a ingredient being defined as the sum of the kinetic energies and potential of all the molecules in the ingredient. The temperature change in an object is therefore a measure of the heat flow to or from that material. [2]
The heat capacity of the object is a measure of how much the object must gain or lose to change its temperature by a given amount. Heat capacity would be expressed in units of Joules per degree Centigrade (°C) in the MKS system that is, the heat capacity of the object would be the amount of heat that the object would have to gain or lose for its temperature to alterate by 1°C. Another common unit of heat capacity is the calorie per °C, where one calorie is defined as the amount of heat required to raise the temperature of 1 gram of pure water (at 3.98°C, 14.5°C, or 19.5°C, depending on who’s doing the defining) by 1°C at standard sea level pressure. [2] A relation between the heat gained or lost (ΔQ) by an object and the change in temperature it undergoes can be written
\[ ΔQ = C_H ΔT \]
Where, \( C_H \) is the object’s heat capacity (which depends on the various things described above)
The specific heat of a material is connected to the heat capacity of an object made of that material as follows
\[ c_H = \frac{C_H}{m} \]
Where, \( c_H \) is the specific heat and \( m \) is the mass of the . [2]
Concrete is an artificial stone like material which is a mixture of coarse aggregate, fine aggregate and binding material with water. Concrete has relatively lower tensile strength but compressive strength, much higher, and for this reason is usually reinforced with materials that are strong in tension (regularly steel). The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking improve. Thermal expansion coefficient was very low of Concrete and shrinks as it matures. Concrete is one of the most durable building materials. It provides more fire resistance related with wooden construction, can improvement strength finished time. Service life of Structures can have a long made of concrete. Concrete is the most broadly used construction material in the world. [4]
Concrete is a construction material obtained by mixing a binder (such as cement, lime, mud etc.), aggregate and water in certain proportion. Binding material is basically known by the type of concrete. It is the binding material which plays the main role in the behavior and characteristics of the ensuing concrete. Based on the binding materials the communal concrete can be classified as: Polymer concrete, Lime concrete and Cement concrete.

Specific heat is therefore a property of the material. The specific heat is demoted by ‘C’. In MKS units it would be expressed in terms of Joules per kilogram per °C (J/kg°C). The specific heat of a substance is defined as the amount of heat required to raise a unit mass of the substance through a unit rise in temperature. The symbol C will be used for specific heat.

\[ C = \frac{Q}{m \Delta T} \]

Where, \( Q \) is the amount of heat transfer (J) \( m \) is the mass of the substance (Kg) \( \Delta T \) is the raise in temperature (K)

The goals of this study are measuring the specific heat, specific heat capacities and to compare the behavior and characteristics of the cement concrete and polymer concrete. Based on the binding materials the communal concrete can be classified as: Polymer concrete, Lime concrete and Cement concrete.

Methodology:
- There are several methods such as calorimetry method, electrical method, method of mixing etc. but electrical method is considered here.
- In this method, a calorimeter is made. The calorimeter is a wooden box of size 1'8"×1'3"×2'6". Other small box of size 9"×9"×1'9" is made and insert into the large wooden box. The inside wall of large box is surrounded by 1” thickness of coksheet layer. The outside wall of small box is covered with 1’ thickness of coksheet layer and ½” thickness of glass wool layer. The inside wall is covered with mild steel plate. A hole is made on the top face of the box to insert the cable into the box.
- Put a concrete sample into the calorimeter and a heater is put into its one hole and a temperature sensor in the other hole. The cable of temperature sensor and heater is drawn out through the hole of the calorimeter.
- Electricity is supplied and different parameters such as current (I), voltage (V), time (t), initial temperature (\( \theta_0 \)), final temperature (\( \theta_f \)) etc. are measured.
- Finally the specific heat of concrete is calculated by using specific heat equation

\[ C = \frac{Q_2 - Q_1}{(m_2 - m_1)(\theta_1 - \theta_0)} \]

Aggregate Test Procedure:

A. Test Procedure for Unit weight, Voids and Moisture content

Materials:
- Coarse Aggregate — Oven dried at 110°C, and then cooled to room temperature.
- Fine Aggregate — Oven dried at 110°C, and then cooled to room temperature.

Note: Amount of sample should be approximately 125 to 200% of the quantity required to fill the measure. [5]

Procedure for unit weight and voids

1. Measure Calibration:
- Determine weight of dry measure.
- Fill the quantity wholly full with water and determine the weight of measure plus water.
- Evaluate the weight of water by captivating the difference between the measurements obtained above.

Calculate the volume of the container \( V = \frac{W_w}{\gamma_w} \)

Where, \( W_w \) is the weight of water used to fill the container and \( \gamma_w \) is the unit weight of water (Use than for water density). The computed volume should be close to the nominal value state in the apparatus section.

1. Loose unit weight (Shovelling procedure):
- Fill the measure to overflowing by revenues of a exposé, discharging the aggregate from the height not to overdo 2 in. (50 mm) overhead the top of the measure.
- The aggregate with a straightedge by leveling surface
- Determine the weight of the measure plus content, recording values to the nearest 0.1 lb (0.05 kg) and the weight of the measure alone.

2. Compact unit weight (Rodding method):
- The measure one-third full is filled and leveled the surface by the fingers.
- Evenly distributed by The Tamping rod over the surface on the layer of aggregate with 25 strokes.
- Follow the again steps the two-thirds full level, level with the fingers, and rod again with 25 strokes of the tamping rod.
- Lastly, add extra aggregate to overflowing and rod again using 25 strokes of the tamping rod.
- The aggregate level the surface with a straightedge.
- Conclude the weight of the measure plus content, the weight of the measure alone and recording values to the nearest 0.1 lb (0.05 kg).

Note: When roding the first layer, do not strike the bottom of the measure. When roding the following layers, do not power the rod into the previous layer of aggregate. [6]
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**Calculation for unit weight:**
Evaluate the unit weight in both the loose and compact conditions for both the fine and coarse aggregates.

\[ \text{bulk} = \frac{(G - T)}{V} \]

Where,
- \( \text{bulk} \) = The unit weight of the aggregate, kg/m\(^3\)
- \( G \) = mass of aggregate plus the measure, kg
- \( T \) = mass of the measure, kg
- \( V \) = volume of the measure, m\(^3\)

**Calculation for voids:**
Calculate the void content, \( n(A) \), in the aggregate (for fine and coarse compact unit weights only)

\[ n(\%) = \left( \frac{G \cdot w - \text{bulk}}{G \cdot w} \right) \times 100 \]

Where,
- \( \text{bulk} \) = unit weight of the aggregate, kg/m\(^3\)
- \( G_w \) = bulk specific gravity, dry basis (Ervin ASTM C127 or C128)
- \( w \) = unit weight of water (62.3 lb/ft\(^3\) or 998 kg/m\(^3\))

**Procedure for moisture content**
- Take approximately 1 kg for coarse aggregate and 500 gm for fine aggregate sample and weigh it.
- Dry the sample in an oven at 110°C for at least four hours or until the dry sample is at a constant weight. Take out the sample from the oven, let cool, weigh and record.

**Calculation for moisture content:**
Evaluate the moisture content in the manner shown by the following:

\[ \text{Moisture content} = \frac{W}{A} \]

Where,
- \( W \) = Weight of water present in aggregate in gm
- \( A \) = Weight of dry aggregate in gm

**B. Test Procedure for Specific Gravity**

**Materials:**
- Coarse Aggregate (>No. 4 sieve, i.e., gravel) - soaked for 24 hour, then saturated-surface-dried
- Coarse Aggregate - Oven dried at 1100°C

**Procedure:**
- Constant weight of dry the sample at a temperature of 110 + 5°C.

**Calculation:**
- Weight of Displaced Water (W): \( W = V \cdot w \)
- Bulk Specific Gravity (Gsb): \( \text{Gsb} = \frac{A}{W} \)
- Bulk SSD Specific Gravity (Gsb SSD): \( \text{Gsb SSD} = \frac{B}{W} \)

Where,
- \( V \) = volume of displaced water
- \( w \) = unit weight of water in gm/cc (use water calibration chart)

**C. Test Procedure for Sieve Analysis Materials:**
- Fine Aggregate (<No. 4 sieve) — 500 g (oven dried)
- Coarse Aggregate (>No. 4 sieve) — 10 lb (oven dried).

**Sampling:**
Mix the sample and moderate; it is an amount, so that the sample for trial shall be approximately of the weight preferred when dry.

**Coarse aggregate:**
The weight of the test sample of coarse aggregate (C, A) shall conform to the following requirement: Aggregate with nominal maximum size of 3/4" = 10 lbs.

**Procedure:**
- Select suitable sieve sizes to obtain the required information as definite. The following sieves are appropriate with reference to ASTM C 33:
- Nest the sieves in order of decreasing size of opening from the top to bottom. The bottom sieve was placed the pan below, place the sample on the top sieve and place lid over top sieve.
- Agitate the sieves by hand or by mechanical apparatus for a sufficient period such that not more than 1% by weight of the residue on any individual sieve will pass that sieve during 1 min. of additional hand sieving. Ten minutes of original sieving will usually accomplish this criterion.
- Regulate the weight of material retained on each sieve. The total retained weights should strictly match the original weight of the sample (within 0.3%).

**Calculation:**
Calculate percentages passing and total percentages retained to the nearest 0.1% of the initial dry weight of the sample. Evaluate the fineness modulus as follows:

Fine aggregate:
\[ \text{F.M.} = \frac{[(\text{Cumulative % Retained on #4, #8, #16, #30, and #100 Sieves})/100]}{100} \]
Coarse aggregate: \( \text{F.M.} = [(\text{Cumulative % Retained on 1.5", 3/4", 3/8", #4, #8, #16, #30, #50, and #100 Sieves})/100] \)

**Instrumental Setup**
Apparatus required: Electrical calorimeter: This is a wooden box of size 18" × 13" × 26" , Immersion heater (Capacity: 2000 watt, Voltage: 220-250 volt), Concrete cylinder (Sizes are 4" × 8" and 6" × 12" cylindrical shape), Temperature sensor, Multi meter, Stop watch, Balance
Figure 1: Line diagram of possible arrangements of electrical calorimeters with a concrete sample.

Figure 2: Pictorial view of Calorimeter

Figure 3: Pictorial view of cylindrical shape concrete sample covered with glass wool.

Figure 4: Pictorial view of cylindrical shape concrete sample without glass wool

Figure 5: Pictorial view of temperature sensor

Figure 6: Pictorial top view of calorimeter
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Sample Preparation
A. Ingredients:
Cement: Ordinary Portland cement (Product name: King Brand Cement), Fine aggregate: Sylhet sand and Coarse aggregate: Bricks khoa and Stone chips

Table 1: Properties of coarse aggregate

<table>
<thead>
<tr>
<th>Name of Test</th>
<th>Bricks chips</th>
<th>Stone chips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>9.4%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Voids</td>
<td>50.56%</td>
<td>56.8%</td>
</tr>
<tr>
<td>Unit weight</td>
<td>898 kg/m³</td>
<td>1138 kg/m³</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.82</td>
<td>2.64</td>
</tr>
</tbody>
</table>

For Brick chips

For Stone chips

Figure 7: Gradation curve for coarse aggregate

B. Mixing ratios:
Cement: Fine aggregate: Coarse aggregate=1:2:3 and 1:1.2:2
Amount of Water= 50% of Cement

C. Size of sample:
Height: 8” and 12” and Diameter: 4” and 6”

D. Sample Identifications
ID: B48R2, B612R1.5, S48R2, S612R1.5

Experimental procedure
A. Preparation of specimens:
The test specimens are 4”x8” and 6”x12” cylindrical shape with two holes at the middle third point. One hole is through one end to other and another hole is up to middle. The holes are complete by drilling of a drill bid of 3/8” in diameter. The molded specimens would be damp cured prior to testing for 28 days. [4]

B. Procedure
The procedures are
- Prepare 48 no. of concrete cylindrical specimens of size 4”x8” and 6”x12”.
- Cure the concrete specimen at room temperature minimum 28 days.
- After curing make two hole (diameter 3/8”) by drilling on it and measure mass (m) of concrete.
- Insert the immersion heater and thermometer into the hole and put the concrete into the calorimeter.
- Supply electricity for a certain time period and temperature are recorded continuously.
- Current and voltage are also recorded continuously. [6]

C. Calculation procedure
If the initial temperature ($\theta_i$) and final temperature($\theta_f$) are measured and all other parameter such as current ($I$), voltage ($V$), time ($t$), mass ($m$) of the sample etc are measured then the specific heat of concrete is calculated by the following formula

Specific heat capacity, $C = \frac{\theta_f - \theta_i}{(m_2 - m_1)(\theta_1 - \theta_0)}$
Result and Discussion:

Table 2: Test results of coarse aggregate

<table>
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<th>Name of Test</th>
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<td>1138 kg/m³</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.82</td>
<td>2.64</td>
</tr>
</tbody>
</table>

Table 2: Test results of coarse aggregate

The test procedure of testing the properties of coarse aggregate follows ASTM guideline. The data collection and calculation are shown in Appendix-A.

Calculation

For 1st experiment:
Voltage, \( V = 239 \) V
Current, \( I = 1.22 \) A
Flow time, \( t = 28 \) min = 1680 sec
Initial temperature, \( \theta_0 = 29^\circ \)C
Final temperature, \( \theta_1 = 94^\circ \)C
Mass of the sample, \( m = 3654.1 \) gm = 3.65 kg
\[ Q_1 = V_1I_1t_1 = 239 \times 1.22 \times 1680 = 489854.4 \text{ J} \]

For 2nd experiment:
Voltage, \( V = 234 \) V
Current, \( I = 1.24 \) A
Flow time, \( t = 30 \) min = 1800 sec
Initial temperature, \( \theta_0 = 29^\circ \)C
Final temperature, \( \theta_1 = 94^\circ \)C
Mass of the sample, \( m = 3169.3 \) gm = 3.17 kg
\[ Q_2 = V_2I_2t_2 = 234 \times 1.24 \times 1800 = 522888 \text{ J} \]
\[ C = \frac{Q_2 - Q_1}{(m_2-m_1)(\theta_1-\theta_0)} = \frac{522888 - 489854.4}{(3.65-3.17)(94-29)} = 1039.55 \text{ J/kg}^{-1}^\circ \text{C}^{-1} \]

Table 3: Specific heat of different samples

<table>
<thead>
<tr>
<th>S. No</th>
<th>Sample ID</th>
<th>Mixing Ratio (Cement: Fine aggregate: Coarse aggregate)</th>
<th>Coarse Aggregate</th>
<th>Specific heat (J/kg°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B48R2</td>
<td>1:2:3</td>
<td>Brick khoa</td>
<td>1039.55</td>
</tr>
<tr>
<td>2</td>
<td>S48R1.2</td>
<td>1:1.2:2</td>
<td>Stone chips</td>
<td>937.00</td>
</tr>
<tr>
<td>3</td>
<td>S48R2</td>
<td>1:2:3</td>
<td>Stone chips</td>
<td>1083.31</td>
</tr>
<tr>
<td>4</td>
<td>B48R1.2</td>
<td>1:1.2:2</td>
<td>Brick khoa</td>
<td>1279.57</td>
</tr>
<tr>
<td>5</td>
<td>B48R2</td>
<td>1:2:3</td>
<td>Brick khoa</td>
<td>1306.77</td>
</tr>
<tr>
<td>6</td>
<td>B48R2</td>
<td>1:2:3</td>
<td>Brick khoa</td>
<td>1358.32</td>
</tr>
<tr>
<td>7</td>
<td>B612R1.2</td>
<td>1:1.2:2</td>
<td>Brick khoa</td>
<td>682.57</td>
</tr>
<tr>
<td>8</td>
<td>B612R2</td>
<td>1:2:3</td>
<td>Brick khoa</td>
<td>928.26</td>
</tr>
<tr>
<td>9</td>
<td>B612R2</td>
<td>1:2:3</td>
<td>Brick khoa</td>
<td>1204.5</td>
</tr>
<tr>
<td>10</td>
<td>S612R1.2</td>
<td>1:1.2:2</td>
<td>Stone chips</td>
<td>987.8</td>
</tr>
<tr>
<td>11</td>
<td>S612R2</td>
<td>1:2:3</td>
<td>Stone chips</td>
<td>1356.92</td>
</tr>
<tr>
<td>12</td>
<td>S48R1.2</td>
<td>1:1.2:2</td>
<td>Stone chips</td>
<td>1421.05</td>
</tr>
<tr>
<td>13</td>
<td>S48R2</td>
<td>1:2:3</td>
<td>Stone chips</td>
<td>1039.81</td>
</tr>
<tr>
<td>14</td>
<td>S48R1.2 (with glass wool)</td>
<td>1:1.2:2</td>
<td>Stone chips</td>
<td>1098.17</td>
</tr>
<tr>
<td>15</td>
<td>S48R1.2 (with glass wool)</td>
<td>1:1.2:2</td>
<td>Stone chips</td>
<td>1356.84</td>
</tr>
<tr>
<td>16</td>
<td>S48R2 (with glass wool)</td>
<td>1:2:3</td>
<td>Stone chips</td>
<td>1158.03</td>
</tr>
<tr>
<td>17</td>
<td>B48R1.2 (with glass wool)</td>
<td>1:1.2:2</td>
<td>Brick khoa</td>
<td>1039.22</td>
</tr>
<tr>
<td>18</td>
<td>B48R1.2 (with glass wool)</td>
<td>1:1.2:2</td>
<td>Brick khoa</td>
<td>1688.24</td>
</tr>
<tr>
<td>19</td>
<td>B48R2 (with glass wool)</td>
<td>1:2:3</td>
<td>Brick khoa</td>
<td>1202.27</td>
</tr>
</tbody>
</table>

The specific heat of all sample mentioned Table 3 lies between the typical ranges of specific heat of normal strength concrete discussed in the literature review chapter.
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**Figure 8: Specific heat of 4"x8" samples**

**Figure 9: Specific heat of 4"x8" samples covered with glass wool**

**Figure 10: Specific heat of 6"x12" samples**
As shown in Figure 8, the specific heat of concrete is greater when brick khoa used as coarse aggregate than the specific heat of concrete when stone chips used as coarse aggregate and the samples are not covered with glass wool. In Figure 9, it is seen that, the specific heat of concrete is greater when brick khoa used as coarse aggregate than the specific heat of concrete when stone chips used as coarse aggregate and the samples are covered with glass wool. In Figure 10, it is seen that, the specific heat of concrete is less when brick khoa used as coarse aggregate than the specific heat of concrete when stone chips used as coarse aggregate and the samples are not covered with glass wool. Again, when all parameters are constant, the specific heat of concrete varies with the mixing ratios, as shown in above all the figures. Here, it has been seen that the specific heat of concrete specimen containing denser mixing ratio (Cement: Sand: Coarse aggregate) is greater than the specific heat of concrete specimen containing looser mixing ratios. So, it is seen that the specific heat of concrete having brick khoa as coarse aggregate is 30.63% greater than the concrete having stone chips for mixing ratio 1:2:3 and the specific heat of concrete having brick khoa is 36.56% greater than the concrete having stone chips for mixing ratio 1:1.5:2. Again, the specific heat of concrete having mixing ratio 1:1.5:2 is 23% greater than mixing ratio 1:2:3 when using brick khoa as coarse aggregate. The specific heat of concrete having mixing ratio 1:1.5:2 is 36.66% greater than mixing ratio 1:2:3 when using stone chips as the aggregate. The specific heat of 4"x8" samples is 12.77% greater than 6"x12" samples having brick khoa as coarse aggregate and the specific heat of 6"x12" samples is 25.26% greater than 4"x8" samples having stone chips as coarse aggregate.

The specific heat of concrete varies with the mixing ratios of ingredients of concrete. The specific heat of concrete with denser mixing ratio is greater than concrete having looser mixing ratios.

References:


