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LOW THERMAL CONCRETE

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Abstract: The weather in Malaysia is getting hotter by the day and the issue of affected foundation concrete in structures leads to thermal cracking. Concrete members will expand and contract when exposed to hot and cold ambient temperatures, respectively. Cracking will occur if bulk volume charge resulting from temperature variations. Concrete will hit to a certain degree of temperature which is 75°C to 80°C and the dehydration takes place where the process of thermal cracking occurs. The objective of this study are (i) To invent a new low thermal concrete with optimum ratio. (ii) To determine low thermal concrete able to withstand thermal cracking. (iii) To achieve a concrete mixture at 23°C temperature. The mixture of low temperature concrete is cement, aggregate, sand and ice. 1:3:6 mixture ratio is the optimum based on prior experiment for the foundation concreting. The temperature test and workability test are conducted. The normal temperature for a concrete is 34°C. The target concrete temperature of the study is 23°C. The findings show the target concrete temperature achieved at 23.04°C. The content of ice and water combined in the concrete are 100% (186kg). The optimum ice content in the concrete is 41.4% (77kg), water content in the concrete is 58.6% (109kg). This research has successfully achieved the target concrete temperature 23°C which is below the normal concrete temperature 34°C to prevent thermal cracking from occurring. A further investigation and test are needed to ensure low thermal concrete is relevant to apply in construction.

Keywords: *low thermal concrete; thermal cracking; ice: temperature*

1. Introduction

Thermal cracking occurs due to excessive temperature differences causes the cooler portion to contract more than the warmer portion, which restrains the contraction. Thermal cracks appear when the restrain results in tensile stresses that exceed the in-place concrete tensile strength. The key to reducing thermal or temperature-related cracking is to recognize when it might occur and to take steps to minimize it. Surface contraction due to cooling restrained by the hotter interior concrete that doesn't contract as rapidly as the surface. This restraint creates tensile stresses that can crack the surface concrete as a result of this uncontrolled temperature difference across the cross section. In most cases thermal cracking occurs at early ages. In rare instances thermal cracking can occur when concrete surfaces are exposed to extreme temperature rapidly. Concrete members will expand and contract when exposed to hot and cold ambient temperatures, respectively. Cracking will occur if this bulk volume change resulting from temperature variations is restrained. This is sometimes called temperature cracking and is a later age and longer term issue.

2. Materials and Methods

The mixture of the concrete is cement, fly ash, aggregate, sand, water, additive/adhesive (hardener) and ice. The aggregate grade is 20mm (35^{o}c), cement type is OPC (60^{o}c), and the ice was chilled (10^{o}c) with 1:3:6 (cement: sand: aggregate) concrete mixture ratio for the foundation concrete. The total weight of concrete every mixture is 2390.48 kg/m^{3}. Testing that has been conducted are slump test and cube test with size of cube 150mm x 150mm x 150mm. 20 trials have been done to achieved concrete mixture at temperature 23^{o}C. However, testing data are only state of 4th trial to show the different of trial mixture. Temperature reading using formula of ice/water factor calculation, material heat unit calculation, and achieved temperature calculation. Other than that, temperature difference formula also has been used to calculate the value for ice needed for next trial.

- Equation 1: Achieved temperature $= \frac{\text{Total Heat}}{\text{Total unit heat}}$
- Equation 2: Ice/water Factor $= \frac{\text{Ice Weight}}{\text{Water weight}}$
- Equation 3: Required Ice $= \frac{\text{Temp.Difference}}{\text{Specific heat of ice}} \div 186 \times 100$
- Equation 4: Materials Total Heat $= \text{Material heat unit} \times \text{Material Temperature}$
- Equation 5:

  Temp. Difference $= \frac{(\text{Target concrete temperature} - \text{Achieved temperature})}{\text{Total Heat unit}}$
- Equation 6: $\sum$ Materials Heat Unit $= \sum (\text{Material weight} \times \text{Specific heat})$
- Equation 7: Total heat $= \sum \text{Material total heat}$

3. Results

All mixture and testing are conducted at the Laboratory of Research and Development Lafarge, Petaling Jaya, Kuala Lumpur. The data below shows 4th trial of concrete mixture.

3.1 First Trial Mix Design

Table 1. First Trial achieving normal concrete temperature

Materials	Mat. Wt - kg/m^3	Specific Heat kj/(kg/c^0)	Unit heat kj/(m^{3}c^0)	Mat. temp	Total Heat kj	
Cement - OPC	315	0.92	289.8	60	17388	
Fly Ash	135	0.92	124.2	35	4347	
Ice	**0**	-335			0	
Water - Chilled	**186**	4.184	778.224	10	7782.24	
Aggregate	1748	0.92	1608.16	35	56285.6	
Additive (Hardener)	6.48	4.184	27.112	35	948.9	Achieved Temperature
Total Mat.	2390.48			**Total heat**	86751.8	30.68
		Total unit heat	2827.496			

The total weight of water and ice for the first trial is 186 kg/m^3. On the first trial, concrete is excluded ice to obtain normal concrete mixture temperature. The unit heat of chilled water for first is 778.224 kj/(m^{3}c^0), the heat unit for aggregate is 1608.16 kj/(m^{3}c^0). The heat unit for cement is 289.8 kj/(m^{3}c^0), heat unit for fly ash is 124.2 kj/(m^{3}c^0), and the heat unit for adhesive (Rapid Hardener) is 27.11232 kj/(m^{3}c^0). The total heat for water is 7782.24, and the total heat for aggregate is 56285.6. The total heat for cement is 17388, fly ash 4347, additive 948.9. Total heat unit for first trial is 2827.50. The achieved concrete mixture temperature for this trial is 30.68^{o}C.

3.2 Second Trial Mix Design

Table 2. Second Trial achieving concrete temperature

Materials	Mat. Wt - kg/m^3	Specific Heat kj/(kg/c^0)	unit heat kj/(m^{3}c^0)	Mat. Temp	Total Heat kj	
Cement - OPC	315	0.92	289.8	60	17388	
Fly Ash	135	0.92	124.2	35	4347	
Ice	**65**	-335			-21719.36	
Water - Chilled	**121.2**	4.184	506.96	10	5069.59	
Aggregate	1748	0.92	1608.16	35	**56285.6**	
Additive (Hardener)	6.48	4.184	27.112	35	948.9	Achieved Temperature
Total Mat.	2390.48			**Total heat**	62319.77	24.38
		Total unit heat	2556.231			

The total weight of water and ice for the second trial is 186 kg/m^3. On the second trial, researcher mix ice as to obtain targeted concrete mixture temperature. The unit heat of chilled water for second trial is 506.96 kj/(m^{3}c^0), the total heat of water is 5069.59. The specific heat of ice is -335, the total heat is -21719.36, the total unit heat for second trial is 2556.23kj/(m^{3}c^0). The achieved concrete mixture temperature for this trial is 24.38^{o}C.

3.3 Third Trial Mix Design

Table 3. Third Trial achieving concrete temperature

Materials	Mat. Wt - kg/m^3	Specific Heat kj/(kg/c^0)	Unit heat kj/(m^{3}c^0)	Mat. Temp	Total Heat kj	
Cement - OPC	315	0.92	289.8	60	17388	
Fly Ash	135	0.92	124.2	35	4347	
Ice	**75**	-335			-25245.8	
Water - Chilled	**111**	4.184	462.92	10	4629.15	
Aggregate	1748	0.92	1608.16	35	**56285.6**	
Additive (Hardener)	6.48	4.184	27.112	35	948.9	Achieved Temperature
Total Mat.	2390.48			**total heat**	58352.88	23.23
		Total unit heat	2512.187			

The total weight of water and ice for the third trial is also186 kg/m^3. On the third trial, researcher mix ice as to obtain targeted concrete mixture temperature. The unit heat of chilled water for second trial is 462.92 kj/(m^{3}c^0), the total heat of water is 4629.15. The specific heat of ice is -335, the total heat is -25245.8, the total unit heat for third trial is 2512.19 kj/(m^{3}c^0). The achieved concrete mixture temperature for this trial is 23.23ºC.

3.4 Fourth Trial Mix Design

Table 4. Fourth Trial achieving concrete temperature

Materials	**Mat. Wt -** kg/m^3	**Specific Heat** kj/(kg/c^0)	**Unit heat** kj/(m^{3}c^0)	**Mat. Temp**	**Total Heat** kj	
Cement - OPC	315	0.92	289.8	60	17388	
Fly Ash	135	0.92	124.2	35	4347	
Ice	**77**	-335			-25818.37	
Water - Chilled	**109**	4.184	455.76	10	4557.64	
Aggregate	1748	0.92	1608.16	35	**56285.6**	
Additive (Hardener)	6.48	4.184	27.112	35	948.9	Achieved Temperature
Total Mat.	2390.48			**Total heat**	57708.8	23.04
		Total unit heat	2505.036			

The total weight of water and ice for the fourth trial is also186 kg/m^3. On the Fourth trial, researcher mix ice as to obtain targeted concrete mixture temperature. The unit heat of chilled water for second trial is 455.76 kj/(m^{3}c^0), the total heat of water is 4557.64. The specific heat of ice is -335, the total heat is -25818.37, the total unit heat for fourth trial is 2505.04 kj/(m^{3}c^0). The achieved concrete mixture temperature for this trial is 23.04ºC. This mixture is the best optimum mixture that achieved target concrete temperature.

3.5 Mix Design summary for Low Thermal Concrete

Table 4. Mix design summary

Materials	Material Weight	Material Temp.	1st Trial	2nd trial	3rd trial	4th Trial	Final quantities
Cement	315 kg/m^3	60ºc					315 kg/m^3
Fly Ash	135 kg/m^3	35ºc					135 kg/m^3
Ice (added)			0	65	75	77	77 kg/m^3
Chilled Water	186 kg/m^3	10ºc	186	121	111	109	109 kg/m^3
Aggregate	1748 kg/m^3	35ºc					1748 kg/m^3
Adhesive (Hardener)	6.48 kg/m^3	35ºc					6.48 kg/m^3
Concrete Temp.			30.68ºc	24.38ºc	23.23ºc	23.04ºc	23.04ºc

Material temperatures of fly ashes, aggregate and adhesive are 35°c, Water is chilled until its temperature drop to 10°c; and the highest temperature among the material used is Ordinary Portland Cement 60°c. The material weight of cement is 315 kg/m^3, and fly ash weight is 135 kg/m^3. Cement and fly ash combined must be total of 100%. Fly ash 30% and Cement 70%. The total weight of water and ice must be 186 kg/m^{3}as for ice act as substitution for water.

3.6 Ice/Water Factor Calculation

Formula to get ice/water factor value:

Ice/water Factor $= \frac{\text{Ice Weight}}{\text{Water weight}}$

$= \frac{77}{186}$

= 0.414 kg/m^3

3.7 Materials Heat Unit Calculation

Formula to get materials heat unit value (kj) is $\text{Material weight} \times \text{Specific heat}$:

Materials Heat Unit (Fly ash) = $\text{Fly ash weight} \times \text{Fly ash specific heat}$

$= 135 \times 0.92$

= 124.2

Materials Heat Unit (agg.) = $\text{Aggregate weight} \times \text{aggregate specific heat}$

$= 1748 \times 0.92$

= 1608.16

Materials Heat Unit (Additive)= $\text{Adhesive weight} \times \text{adhesive specific heat}$

$= 6.48 \times 4.184$

= 27.11232

Materials Heat Unit (Cement)= $\text{Cement weight} \times \text{Cement specific heat}$

$= 315 \times 0.92$

= 289.8

3.8 Materials Total Heat Calculation

Formula to get materials total heat value (kj) is $\text{Heat unit} \times \text{Material Temperature}$:

Materials Total Heat (Fly ash) $= 124.20 \times 35$

= 4347

Materials Total Heat (Aggregate) $= 1748 \times 35$

= 56285.6

Materials Total Heat (Additive) $= 6.48 \times 4.184$
= 948.9

Materials Total Heat (Cement) $= 315 \times 60$
= 17388

3.9 Achieved Temperature Calculation

Formula to get achieved temperature value:

Achieved temperature (1st trial) $= \frac{\text{Total Heat}}{\text{Total unit heat}}$

$= \frac{86751.8}{2827.49632}$

= 30.68°c

Achieved temperature (2nd trial) $= \frac{62319.77}{2556.231291}$

= 24.38°c

Achieved temperature (3rd trial) $= \frac{58352.88}{2512.187567}$

= 23.23°c

Achieved temperature (4th trial) $= \frac{57708.80}{2505.036444}$

= 23.04°c

3.10 Temperature Difference Calculation

Formula to get temperature difference value:

Temp. Difference (1st trial)$= \frac{(\text{Target concrete temperature} - \text{Achieved temperature})}{\text{Total Heat unit}}$

$= \frac{(23.00-30.68)}{2827.49632}$

= -21719.4

Temp. Difference (2nd trial)$= \frac{(23.00-24.38)}{2556.231291}$

= -3526.45

Temp. Difference (3rd trial) $= \frac{(23.00-23.23)}{2512.187567}$

= -572.57

Temp. Difference (4th trial)= $\frac{(23.00-23.04)}{2505.036444}$

= -92.26

3.11 Temperature Difference Calculation

Formula to get value for ice need for next trial:

Required Ice (1st trial) $= \frac{\text{Temp.Difference}}{\text{Specific heat of ice}}$

$= \frac{-21719.4}{-355}$

= 61.18 = 65

Required Ice (2nd trial) $= \frac{-3526.45}{-355}$

= 9.934 = 10

Required Ice (3rd trial) $= \frac{-572.57}{-355}$

= 1.61 = 2

Required Ice (4th trial) $= \frac{-92.96}{-355}$

3.12 Concrete Temperature

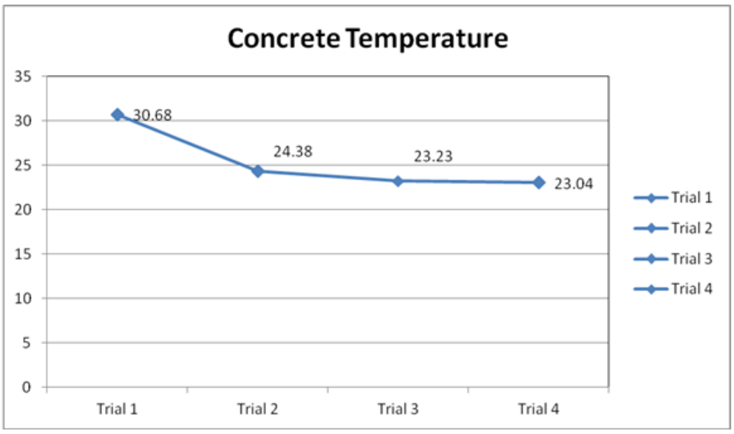

Figure 1. Concrete Temperature

3.13 Ice Factor Against Ice Weight and Water Weight

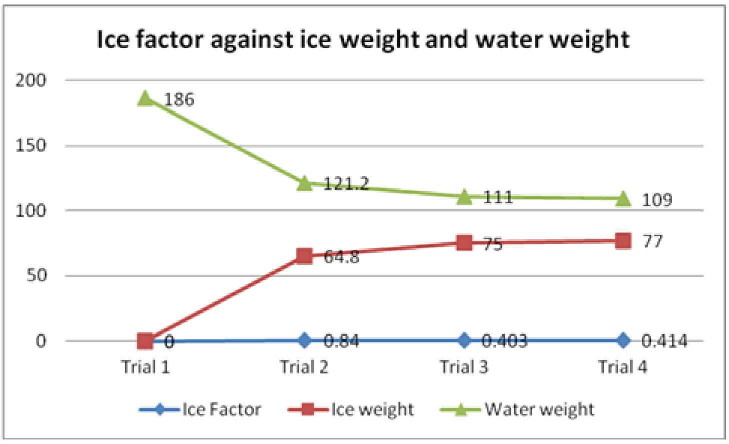

Figure 2. Ice factor against ice weight and water weight

3.14 Ice Percentage and Water Percentage Against Achieved Temperature

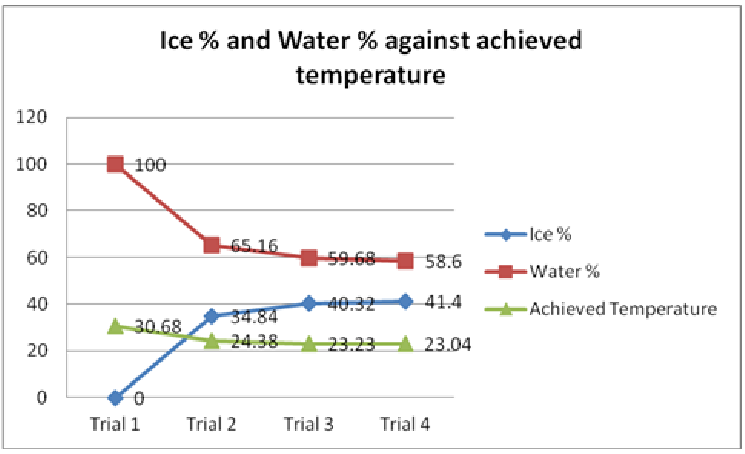

Figure 3. Ice Percentage and water percentage against achieved temperature

3.15 Total Heat of Ice And Water Against Temperature Achieved

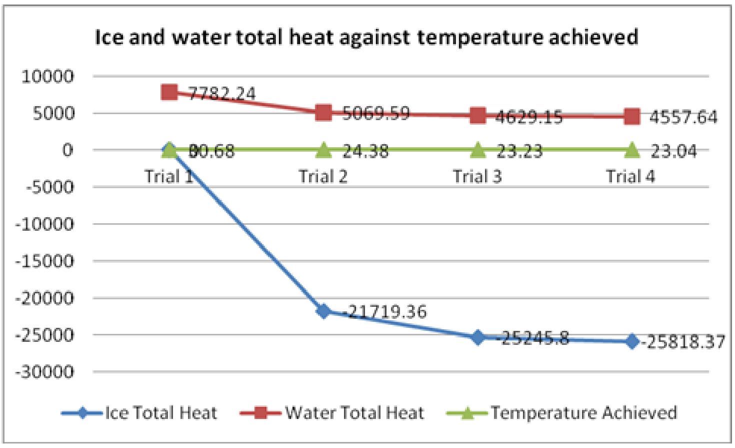

Figure 4. Ice and water total heat against temperature achieved

3.16 Temperature Difference and Total Heat Unit

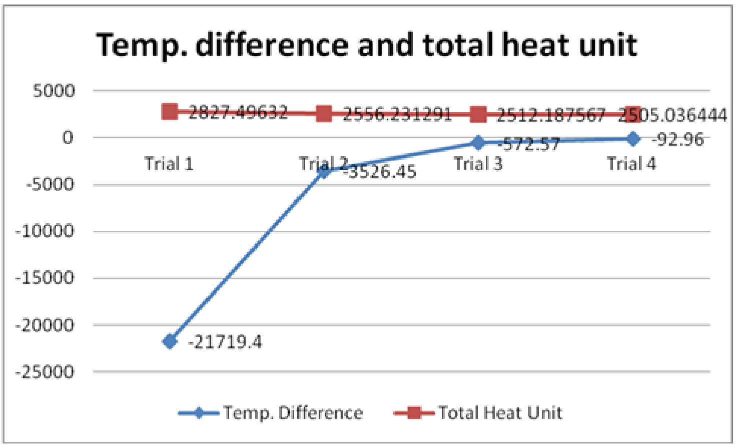

Figure 5. Temperature differences and total heat unit

3.17 Total Heat for Every Trial

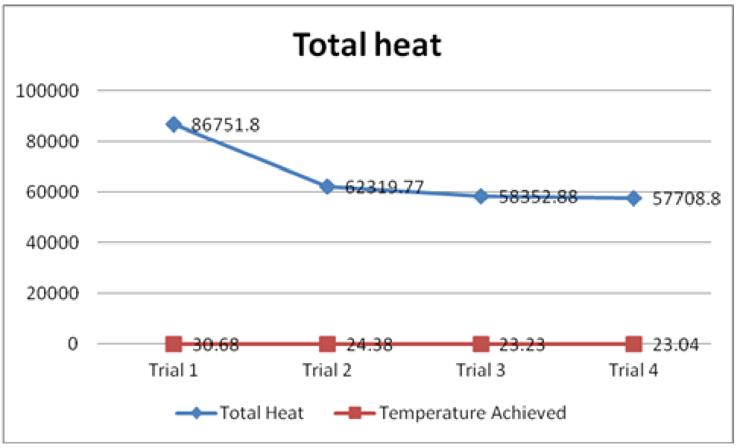

Figure 6. Total heat

4. Discussion

Based on the data analysis, the concrete temperature is achieved based on the weight of material and its temperature. From the material weight and its temperature, researchers can get the formula to obtain the heat unit, total heat of material, ice weight needed and the temperature difference between target concrete temperature and achieved concrete temperature. It is also related to each other; researchers finds that all the elements are need to get the concrete mixture temperature. The normal concrete mixture temperature is 34 degrees Celsius. On 1st trial researchers achieved concrete mixture with temperature of 30.68 degree Celsius, this trial is conducted with 0kg of ice and 186kg of water in the mixture. On 2nd trial researchers achieved concrete mixture with temperature of 24.38 degree Celsius, this trial is conducted with 64.8kg of ice and 121.2kg of water. On 3rd trial researchers achieved concrete mixture with temperature of 23.23 degree Celsius, in this trial the concrete mixture consists of 75kg of ice and 111kg of water to achieve the mentioned temperature. On 4th trial researchers achieved concrete mixture with temperature of 23.04 degree Celsius, on this last trial the concrete mixture consists of 77kg of ice and 108kg of water. Based on the trials conducted, the lower the material temperature, the lower the concrete mixture temperature can be mixed. The researchers obtained 23.04^{o}c concrete, this reduces the probability of the concrete reaching thermal cracking temperature during hydration process (75-80^{o}c). Also, researchers find that the lower the total heat unit, the lower the concrete mixture temperature can be obtained. After the data is analysed, the researchers highly recommend to chill materials that have the highest weight used in concrete mixture which is aggregate. By chilling highest weight material, the ice weight used to mix 23 degrees Celsius or lower can be significantly lessen. It also recommended that the concrete mixing can be conducted in a cold temperature room, to maintain the material temperature affected by atmospheric temperature.

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