EFFECT OF MIXING WATER TEMPERATURE ON CONCRETE PROPERTIES IN HOT WEATHER CONDITIONS

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DEDICATION

This thesis is dedicated to my beloved family. To my father, Amr Assal, you are and will always be my role model. Your unconditional support is fundamentally the reason that I reached what I am now. To my mother, Maha Elhalawagy, you are my constant source of inspiration and the person who I always look up to. You always nurtured us with endless love, kindness and affection. To my sisters and brother Reem, Mohamed and Farida you are the source of happiness and laughter in my life. Without you all none of this would have been even possible.
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To my beloved family, I am grateful for your support and understanding throughout this study. You provided the perfect atmosphere to accomplish this work. I comprehend that any amount of gratitude shown to you is woefully inadequate.
ABSTRACT

Environmental factors and hot weather conditions can drastically impact the properties, strength and durability of concrete structures. Whereby, higher slump loss rate, faster hydration with accelerated setting, reduced long term compressive strength and plastic shrinkage are more common. Literature review on the impact of hot weather on concrete is not sufficiently elaborated and at the same time majority of studies focused on curing temperature on overall concrete quality, however sufficient research on the effect of casting temperature on the concrete itself and its materials is lacking.

This study is carried out to investigate the direct impact of mixing water temperature and concrete temperature on the concrete properties serving in hot weather conditions, with special emphasis to the Egyptian hot climate throughout the year. Thus, the scope of this work is to study mixing water temperature’s impact on concrete properties being a key ingredient to the concrete mix, with direct impact on workability, strength and durability. The feasibility of cooling water as a remedial action in hot climate is covered for various project sizes.

To achieve the work objective, four categories of concrete mixtures with various cement contents and admixtures were studied while changing the mixing water temperature at 5, 25 and 45°C to yield a total 12 different test sets. All other concrete ingredients were heated to 45°C ahead of mixing to simulate hot weather conditions. Two sets of results were analyzed starting with fresh concrete tests of slump, unit weight and concrete temperature; in addition to hardened concrete tests of compressive and flexural strengths. Results showed an average 15% increase in the 28 days concrete compressive strength and enhanced workability in 5 °C temperature water Vs. 45 °C suggesting the strong impact of water temperature on concrete properties and need to add cool mixing water to concrete cast in hot weather conditions. Recommendations are provided towards the incorporation of cold water in concrete with a market feasibility conducted to study the technical and economic aspects resulting in up to 9% reduction in concrete cost with cold mixing water incorporated.

Keywords : (Water, Concrete, Temperature, Hot Weather, Cooling, Feasibility)
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CHAPTER 1: INTRODUCTION

1.1 Background

Weather conditions either of high or low temperatures directly influence the behavior, performance and properties of the concrete structures during mixing, transport, casting and curing. Such impacts make it of high concern to the concrete manufacturers and final users given its impact on both the technical and economical manufacturing aspects for the structures under design and study (Ortiz et. al. 2010).

Of the most common issues with high weather concrete is plastic shrinkage and cracks. Those induced cracks could appear in all structural members’ types, however more likely in the components where the surface area to thickness ratio is large, which is the case with slabs structures. Furthermore, plastic shrinkage cracking is seen as the main cause of initiating concrete structures deterioration in hot weather conditions, that is because those cracks allow and promote the diffusion of the harsh chemical species like $O_2$, $Cl^-$, $SO_4^{2-}$ and $CO_2$ inside the concrete matrix and mix with direct impact on the reinforced concrete causing its deterioration (Nasir et. al. 2017).

High temperatures and hot weather conditions specifically cause high water demand for concrete increasing the fresh concrete temperatures. This causes increased rate of loss of slump, faster hydration which in return leads to accelerated setting and reduces the long-term strength of concrete accompanied with more evaporation rate (Neville 1995).
A higher rate of evaporation from fresh concrete leads to reduced water content ratio and accordingly, lower water to cement ratio, in addition to a reduction in concrete workability. This mandates reacting with either water addition to enhance and restore workability or a deficient compaction (Mouret et. al. 1999). In parallel, with hot weather concreting, plastic cracking is more common and likely to occur in hardened concrete which shows why high temperature can greatly impact the mechanical properties and functionality of hardened concrete (Soudki et. al. 2001).

Additionally, chemical processes that give early concrete hardening during the first days after casting come with significant temperature changes, this is because hydration of cement is an exothermic reaction (Cervera et. al. 2002). This temperature changes coming from the heat of hydration and external environmental changes has a significant impact on the early concrete mechanical properties, and thus the impact of temperature on those properties must be carefully studied and quantified (Kim et. al. 2002).

### 1.2 Hot Weather Conditions and Impact on Concrete

Hover highlighted the deteriorating factors in hot weather that can negatively impact concrete structure to include; high temperature, high concrete temperature, low relative humidity, solar radiation and wind velocity (Hover 2005).

Whereby, those conditions cause difficulties for fresh concrete as;

- Increased water demand
- Accelerated slump loss which leads to more water addition in the jobsite
• Faster setting, thus difficulties in placing and finishing
• Higher tendency for plastic cracking
• Prompt early curing is critically needed
• Entrained air controlling difficulties
• Higher concrete temperature leads to long term strength losses
• Higher likelihood of thermal cracking (ACI Committee 305 2010).

Accordingly, several international standards restrict concreting temperature to overcome the negative impacts of hot weather. ACI 305 for example restricts the concrete temperature to 35°C (ACI Committee 305 2010), while other specifications require that concrete can only be casted when temperature is between 29°C and 32°C including ASTM C 94 (AASHTO M 157) that notes difficulties may arise when temperature approaches 32°C (Nassir et. al. 2016).

In addition, Park et. al conducted studies with the aim of clearly identifying the temperature effects in response to curing condition, hydration heat, and surrounding weather conditions on the strength development and long term durability of high-performance concrete. In his experiment the concrete walls were designed using three different sizes and three different types of concrete. All experimental work was carried out under typical summer and winter conditioned weather. At different locations in the walls, the temperature histories were logged and the development of concrete strength at those locations was measured. The main factors influencing the strength developments of the samples obtained were investigated and studied which were water contents, the hydration products, and the pore structure. Experimental results revealed
that elevated summer temperatures did not affect the early-age strength of concrete that was designed of ordinary Portland cement. In addition, strength developed was significantly leveraged at early ages in concrete made using belite-rich Portland cement or with that with fly ash added. The high temperatures further resulted in a long-term strength loss in both belite-rich and fly ash containing concrete. This long-term strength loss was influenced and due to the degree of hydration reduction and a total porosity increase in addition to total amount of smaller pores in the material (Park et. al. 2017).

### 1.3 Common Precautions with Hot Weather Concreting

Several precautions are commonly carried out during casting concrete structures to mitigate or avoid the negative drawbacks above stated including;

- Using materials and proportions with good record in hot-weather conditions
- Concrete cooling or one of its ingredients during casting and mixing. An example of which is the use of liquid nitrogen that is added during the mixing of concrete constituents at ready mix plants to decrease the concrete temperature shown in Figure 1 below.
Figure 1: Liquid nitrogen example added in mixer at ready mix plant to decrease concrete temperature (Hot Weather Concreting 2005)

- Use concrete consistency and mix that allows rapid placement.
- Keep the time of transporting, placing and finishing to minimum as applicable.
- Work on scheduling concrete placement and mixing in a way to limit exposure to environmental conditions as much as possible, including pouring at night or during favorable weather.
- Deploy methods to minimize moisture loss during mixing, casting and curing such as sunshades, wind-screens, spraying or fogging.
• Organizing pre-work and preconstruction conference entailing the precautions needed during the project (Hot Weather Concreting 2005).

1.4 Cooling Concrete Materials and Mixing Water

The most common practice in cooling concrete is by lowering the temperature of the concrete materials used ahead of mixing. In hot weather, materials with the highest impact on overall concrete temperature are aggregates and mixing water, therefore keeping their temperature as low as practicable is key. The specific impact of each ingredient to the overall temperature of fresh concrete is dependent and varies per several factors of the specific heat, temperature and the quantities of each material in the concrete mix. Example illustrated in below Figure 2 based on following mixture (aggregate 1360 kg, aggregate moisture 27 kg, mixing water 109 kg, cement 66C of 256 kg) that is equally applicable to similar mixtures (Burg 1996).
The approximate temperature of the fresh concrete mix can also be calculated using the following equation illustrated in below chart (Walker 1966).

\[
T = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa}}{0.22(M_a + M_c) + M_w + M_{wa}}
\]

where

- \( T \) = temperature of the freshly mixed concrete, °C (°F)
- \( T_a, T_c, T_w, \) and \( T_{wa} \) = temperature in °C (°F) of aggregates, cement, added mixing water, and free water on aggregates, respectively

Figure 3: Calculation method for fresh concrete temperature based on composite materials temperature (Walker 1966)
Among the materials used in concrete, water is the easiest one to cool during mixing. Even though water quantity is less than other ingredients in the concrete mix, cold water yields a reasonable reduction in concrete temperature needed. This could be directly achieved through storing cool water in tanks not directly exposed to sun heat. Different methods can be used to cool mixing water including refrigerators, ice or liquid nitrogen. Ice can be used in mixing water however it must be noted to not exceed more than 75% of total batch water, and to completely melt by the time concrete mixing is complete. Liquid nitrogen can also be directly added to the mixer with specific care to avoid liquid nitrogen from contacting the metal drum during application to lower concrete temperature as seen in Figure 4 (Hot Weather Concreting 2005).

Figure 4: A crusher delivering finely crushed ice to truck mixer reliably and continuously (Hot Weather Concreting 2005)
1.5 Heat of Hydration

Concrete heat of hydration is the heat produced due to the exothermic reaction between cement and water during concrete mixing and cement hydration, which also raises the temperature of concrete. The impact of temperature increase in concrete due to heat of hydration can be high or low depending on several factors including amount of cement, size of concrete placement and surrounding mixing environment. A general rule of probable increase of 5 °C to 9 °C per 45 kg. of Portland cement occurs during concrete mixing. That’s why specific care is driven to control and minimize heat of hydration in hot weather conditions and massive concrete placements (Lamond 2006).

1.6 Statement of the Problem

Deterioration of concrete in hot-humid or dry regions is attributed to strong climate conditions, inadequate construction materials and construction methods (Al-Ghatani 1998). Within those factors the impact of the severe and hot weather conditions significantly impacts the concrete structure performance and unfortunately this factor and its consequences have not been sufficiently studied (Nasir et. al. 2016). Water in this context is identified as a key component in the concrete mix due to its significant impact on the strength, workability and durability of concrete structure (Munoz et. al. 2005). Also, high concrete temperature during placement initiates several concrete deficiencies with one of the most distinct effects is strength reduction and durability drops (ACI Committee 305 2010).
Literature review on the impact of hot weather on concrete properties shows that majority of studies in the past were focusing on curing temperature on overall quality of concrete. In addition, the effect of casting temperature of concrete itself and materials on the long term concrete properties is lacking (Nasir 2016). Therefore, this study was carried out to study the direct impact of mixing water temperature and concrete temperature on the concrete properties in hot weather conditions, with special applicability to the Egyptian hot climate especially during summer concrete casting. The study also studies the heat of hydration impact on concrete strength and different admixtures impact on developing concrete strength and durability.

1.7 Work Objectives and Scope

The objective of this work is to study the impact of mixing water temperature on key concrete properties. To meet the study objective, various mixtures were prepared and tested as follows;

- Preparing four different concrete mixes under 45°C conditions during mixing with varying cement content (studying heat of hydration impact as well) of 300 kg, 350 kg, 450 kg and 450 kg with super plasticizers admixtures
- Different water temperatures are used with every concrete mix designed of 5 °C, 25 °C and 45 °C to study the impact of varying water temperature on the 1, 3, 7 and 28 days concrete strength developed.
Cubes sets will be tested for compressive strength developed with each variable mix design and concrete age tested, in addition to beams sections for flexural strength developed at 28 days.

Thermocouples are used to monitor the internal concrete temperature in beams sections and heat of hydration developed and impact on final concrete structure strength.

1.8 Thesis Organization

- Chapter 1: Introductory section on the topic with preliminary data on hot weather concreting, factors affecting concrete strength and durability, impact of hot weather and general practices used to mitigate and prevent those negative outcomes. In addition, the problem statement, study objectives and thesis scope of work is illustrated.

- Chapter 2: Literature review on the topic discussing the concrete structure, hot weather applications, current detailed studies of heat impact on concrete properties, mitigation plans, current research on controlling and minimizing impact of hot environments and heat of hydration.

- Chapter 3: Explains the experimental work carried out in fulfillment of the study. The detailed procedure and materials used in the experiments conducted.

- Chapter 4: Reveals the fresh and hardened concrete tests including, slump, concrete temperature, compressive strength of the cubes and flexural strength of the
beams specimens. In addition to detailed analysis of the results and correlations drawn.

- Chapter 5: Presents a feasibility study on the use of cold mixing water in relevance to the results, analysis and literature review on hot weather concreting. The chapter aims to provide insights on the practical use of cold water in the Egyptian industry, its technical and economic impacts incorporated for the different projects scale.

- Chapter 6: Presents the study conclusions reached from the experimental work and results. In addition to future recommendations and further studies proposed on the topic.

- Full list of references entailed in the study will be presented at the end section of the paper.
CHAPTER 2 : LITERATURE REVIEW

2.1 Hot Weather Concreting

Concrete is defined as a material used in construction and building consisting of aggregate which is a hard-particulate substance made from different types of gravels, sand, and has water and cement used as bonding agents. Different factors impact the final properties and strength development of concrete including aggregate structure, cement properties and type, water composition, water temperature and weather conditions. (Neville 2003).

According to Ortiz et. al. concrete casting and manufacturing is also directly impacted by the weather conditions, which involves high and low temperatures during initial mixing, transportation, casting and finally curing stages. The impact of temperature is thus a key parameter of focus and concern to the manufacturers and users due to its adverse effect on the technical and economic aspects of concrete structures construction (Ortiz et. al. 2010)

High ambient temperatures result in a higher demand of water for the concrete, higher heat of hydration in the concrete exothermic reaction, in addition to increasing the temperature of the fresh concrete casted. This leads to an increased rate of loss of slump and higher rate of hydration, finally giving an accelerated setting and decrease in the long-term strength of the concrete structure (Neville 1999). In addition, for hot temperatures, the concrete tends to have higher plastic cracking and crazing. This thus
results in an adverse impact on the mechanical properties of concrete and the serviceability of the hardened concrete structures (Mouret 1999)

On the other hand, the associated chemical processes to the hardening concrete in the early days after its casting are accompanied with substantial changes in temperature given the highly exothermic cement hydration and the thermally activated reaction (Cervera et. al 2002). This temperature variation caused by heat of hydration or the external environment change has a direct influence on the mechanical properties of the early concrete, and therefore must be thoroughly quantified and studied (Kim et. al. 2002).

2.2 Heat of Hydration

The hydration reaction of cement evolves as an exothermic process, whereby the total heat during hydration could be modeled as a function of cementitious materials, amount of cementitious materials composition, and the water-cementitious ratio of the mixture. With the criticality of this reaction, each of the cement constituents has been found to have a unique heat of hydration whereas the total heat of hydration of cement (Hcem) at complete hydration can be quantified as shown below in Figure 5 (Schnidler et. al. 2003).

\[
H_{cem} = 500p_{C_S} + 260p_{C_2S} + 866p_{C_A} + 420p_{C_AF} + 624p_{SO_3} + 1186p_{FreeCaO} + 850p_{MGO} \quad (1)
\]

where, 
- \( H_{cem} \) = total heat of hydration of the cement (J/g), and
- \( p_i \) = weight ratio of i-th compound in terms of total cement content.

Figure 5: Heat of Hydration Calculation (Schnidler et. al. 2003)
The heat of hydration of concrete under different curing temperatures can be characterized with knowledge of the temperature sensitivity (activation energy), the degree of hydration development at the reference temperature, and the total heat of hydration of the mixture under study. The degree of temperature influence on the concrete mixtures is varying and depends on factors including the amount of concrete poured, environment, type and amount of cement all being of key influence to the concrete properties especially in hot weather as the reaction is catalyzed and more heat can develop affecting the long term strength and durability of concrete (Schnidler et. al. 2005)

### 2.3 Accelerated Evaporation Rate

The high evaporation of surface water from concrete placed casted in hot and dry weather not only leads to a decreased degree of hydration in the surface or ‘cure affected zone’ (Cather B. 1992), but this can further lead to shrinkage and complementary shrinkage stresses in the freshly placed concrete. During the first few hours post batching and regardless of the ultimate strength of the material, the concrete at this stage withstands little or no tensile strength or ‘cracking resistance’, which makes it mainly exposed to so called ‘plastic shrinkage cracking (Abel et. al. 1998). This drying that induces this cracking begins as soon as the rate of evaporation of water from the surface of the concrete surpasses the rate of water supply to the surface. With such phenomena happening, it is reflected that the earlier the drying begins, the lower the cracking resistance of the concrete happening and the more likely the successive cracking (Al-Fadhala et. al.2001).
Accordingly, with hot dry weather such as those in African countries and the Arabian Gulf region, plastic shrinkage cracking could develop when the rate of evaporation tops the rate of bleed water rising to the concrete surface. Additionally, even with no plastic shrinkage cracking happening, surface drying can still lead to abrasion resistance reduction and porosity increase and permeability at the critical near surface, or ‘cure affected zone (Berhane 1992).

### 2.4 Plastic Shrinkage

Plastic shrinkage in concrete materials is and continues to mark one of the major causes of long-term durability and strength problems more significantly in hot weather climatic conditions. Whereby, plastic shrinkage happens in concrete material when the evaporation rate exceeds the bleeding rate. In addition, concrete plastic cracks occur whenever the induced shrinkage exceeds its tensile strength (Neville 2010). Those induced cracks could appear in all structural members’ types, however more likely in the components where the surface area to thickness ratio is large, which is the case with slabs structures. Furthermore, plastic shrinkage cracking is considered the main cause of initiating concrete structures deterioration in hot weather conditions, that is because those cracks allow and promote the diffusion of the harsh chemicals inside the concrete matrix and mix with direct impact on the reinforced concrete causing its deterioration (Nasir et. al. 2017).

Literature review highlights multiple factors influencing the plastic shrinkage of the concrete structure which includes; mix composition, construction methods and the accompanying environmental conditions. It was seen that those cracks increase with an
increase in cement content in the mix, water content or fine aggregates percentage. However, according to Mailvaganam et al. shrinkage due to admixtures is dependent on its type, dosage and method of adding to the concrete mixture (Mailvaganam et al. 1986).

In the same context, Hasanain et al. highlighted that in addition to concrete composition, the time of concrete placement, difference in the ambient temperature, temperature of the concrete casted and shading of the surface of concrete during casting and afterwards have a direct impact on the rate of evaporation of water in the concrete and accordingly the plastic shrinkage induced in those structures. While several guidelines showed the high impact of hot weather conditions on the fresh and hardened concrete material properties elaborating that the unwanted consequences are highly influenced and elevated if high air temperature is further joined with other hot weather elements including, low relative humidity, high wind speed and high sun rays and radiations (Telford 1986). Hot weather conditions were further attributed to crack development and plastic shrinkage in other studies based on experimental results, whereby the concrete specimens were exposed to varying hot weather conditions levels, including, air temperature, relative humidity and wind. It was thus concluded that air temperature at elevated levels primarily caused plastic shrinkage and cracks to develop in the tested concrete specimens (Almussallam 2001).

To constrain the undesirable impact of hot climate concreting and enhance the produced optimum quality, building authorities along with the ACI 305 thus limits the maximum allowable fresh concrete temperature to 35 °C. In addition, to make sure this
limit is in place, the code recommends to undertake precautionary measures when the evaporation rates exceed 1.0 kg/m²/hr (ACI Committee 305 2010). Some studies however indicated that in hot weather climates, concrete may crack due to plastic shrinkage at an evaporation rate that is lower than the above stated as seen by Berhane and Almussallam observing plastic shrinkage cracks appearance at evaporation rates of 0.4 and 0.2–0.7 kg/m²/hr, respectively. It was further concluded and reported that concrete exposed to elevated temperatures and hot weather condition specifically in Eastern Saudi Arabia exhibited plastic cracks and shrinkage due to higher rate of evaporation in concrete mixes (Almussallam 2001).

In addition to the recommendation of lowering the concrete temperature mixes and the constituent materials, one of the solutions suggested to minimize hot weather conditions impact is to use pozzolanic materials such as silica fume, fly ash, blast furnace slag, or natural pozzolans due to their technical, economic and environmental advantages (Soroka et. al. 1998)

### 2.5 Weather Impact on Concrete Strength and Durability

While concrete structures deterioration in hot-humid and dry regions is attributed to the strong climate, poor construction materials and unsuitable construction methods. Those factors thus adversely impact the concrete properties and strength developed (Al-Gahtani et. al. 1998).

High concrete temperature during placement and casting could initiate a series of damaging processes and one of the most noticeable effects of hot weather on concrete
structure is the reduced strength and loss of durability developed, which in result would ultimately impact and reduce the overall service-life of the reinforced concrete structure resulting in premature repair and maintenance (Nasir et. al. 2016).

Given that noted, several international stands put restrictions on the maximum allowable concrete temperature to overcome those deteriorating effects of hot weather conditions. This includes the ACI 305 and Saudi Building Code (SBC 304-C) restricting temperature to 35 °C. While its highly desirable it could constitute a burden on the ready-mix concrete supplier maintaining this temperature limitation at all times (ACI Committee 305 2010)

Nasir et al. in research to study the impact effect on casting temperature on the compressive and split tensile strength of the plain and blended concrete under 25, 32, 38 and 45°C showed a general increase in compressive strength with the increase of temperature in the early 7-day age of concrete. However, at later ages of 28-180 days, the strength increased up to about 32-38°C while a decrease was observed while further increasing the temperatures, results are illustrated in below Figure 6 (Nasir et. al. 2016).
In a similar research carried out by Ronald on the impact of temperature on the concrete strength and properties developed in early and later stages compressive strength, similar results were observed. In the methodology of the study concrete specimens at varying temperatures of 10, 23 and 32°C were mixed and casted and the compressive strength was studied for the different specimens. Results have shown a varying trend in compressive strength development in the mixes under study where, early age compressive strength cast and cured at high temperature was higher than concrete cast and cured at 23°C. It was noted however, that after seven days compressive strength of the specimens under high temperature was lower than the concrete specimens at 23°C. For the later age strength was either equal to or exceeded
that of the concrete at the 23° where results are illustrated in Figure 7 below. (Burg 1996)

<table>
<thead>
<tr>
<th>SI Units, MPa</th>
<th>Casting temperature/curing temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, days</td>
<td>23/23</td>
</tr>
<tr>
<td>3</td>
<td>25.8</td>
</tr>
<tr>
<td>7</td>
<td>30.3</td>
</tr>
<tr>
<td>14</td>
<td>36.2</td>
</tr>
<tr>
<td>28</td>
<td>40.0</td>
</tr>
<tr>
<td>56</td>
<td>44.3</td>
</tr>
</tbody>
</table>

Values represent the average of three 102x203-mm specimens.

<table>
<thead>
<tr>
<th>USC Units, psi</th>
<th>Casting temperature/curing temperature, °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, days</td>
<td>73/73</td>
</tr>
<tr>
<td>3</td>
<td>3740</td>
</tr>
<tr>
<td>7</td>
<td>4400</td>
</tr>
<tr>
<td>14</td>
<td>5250</td>
</tr>
<tr>
<td>28</td>
<td>5800</td>
</tr>
<tr>
<td>56</td>
<td>6420</td>
</tr>
</tbody>
</table>

Values represent the average of three 4x8-in. specimens.

Figure 7: Specimens Compressive Strength at 3,7,17,28 and 56 days for different casting temperatures (Burg 1996)

### 2.6 Mix Design Considerations

Given the criticality and importance of the concrete mix design for the properties and durability of the concrete structures, the design of a concrete mix is a complex procedure in this context. It depends on many factors including materials properties, preparation method, compaction, placement and curing of concrete, in addition to the necessities of a construction job including workability and durability. Once these factors are stated, the outstanding job includes quantities of materials proportioning to
achieve mix requirements. This is specifically done in terms of defining the water-cement ratio, aggregate-cement ratio or also referred to as cement content, sand to total aggregate ratio and maximum size of coarse aggregate. In hot weather conditions especially this procedure becomes more challenging and crucial for an optimum mix design. So as to develop a concrete mix design that is suitable for hot weather, the effects of the following factors are thus considered: (1) water-cement ratio, (ii) total aggregate to cement ratio, (iii) sand to total aggregate ratio, and (iv) temperature of the concrete mix during placement relevance to the field conditions for curing in hot weather (Al-Ghatani, 1985).

Developing concrete mix in the usual conditions suggests that increasing the water content of concrete with a subsequent increase in the W/C ratio would generally negatively impact the long-term strength and durability of concrete and lead to a fall in concrete strength. However, in hot weather, it is noted that water addition would not give the same negative result. This is attributed to the fact that this additional quantity of water can offer sufficient moisture to the hydration process to evolve under more or less valid conditions. In addition, it would also consist and aid in maintaining the needed workability while at the same time compensating the mixing water lost by evaporation during concrete hardening. This factor can thus be considered at the mix design of the concrete. This additional water requirement in hot weather can be estimated starting from the ACI abacuses, which can precisely calculate evaporation flow of the surface moisture of a freshly placed concrete according to the local climatic conditions (Alsayed et. al. 1994).
Ait-Aider in his study revealed in his study in contrary to the general notion that under severe conditions in a hot climate, the introduction of a supplementing quantity of water with higher concrete W/c ratio induced during mix design has no marked influence on the strength of concrete, and would yield better concrete durability compensating for lost water due to evaporation not vice versa (Ait-Aider 2007).

The effect of mix proportions, specifically cement content and water–cement ratio on plastic shrinkage and cracking of concrete in hot and dry environments was investigated by Almussalam. Whereby, the collective effect of those parameters on concrete plastic shrinkage was studied through measuring the bleeding rate, water evaporation, in addition to the time and intensity of induced cracks. The results further revealed that cement content and water–cement ratio considerably affect the parameters controlling plastic shrinkage of concrete. In Lean-stiff concrete mixes earlier cracks were developed compared with the rich-plastic concrete mixes. In addition, the cracks intensity in the former was, however, less than those developing in the latter mix. He revealed in his experimental work that plastic shrinkage cracking occurred when the rate of evaporation was in the range of 0.2–0.7 kg m$^{-2}$ h$^{-1}$. The rate of evaporation was least spotted with a cement content of 300 kg m$^{-3}$ and a water–cement ratio of 0.40, representing that this mix composition can be usefully applied in hot environments to minimize plastic shrinkage cracking (AA. 1998).

### 2.7 Concrete Admixtures in Limiting Hot Weather Impacts

An accelerated slump loss and setting times of concrete are common implications of hot weather concrete as noted. An accelerated slump loss and shorter setting times
are undeniably not desirable with concrete given their influence on reducing the time length in which the fresh concrete remains workable and can be properly handled, mixed and adequately compacted in the building site during manufacturing. It is thus noted that the accelerated slump loss marks one of the major problems of hot weather concreting. There are several consideration and means that could be deployed in order to overcome the practical problems associated with the accelerated slump loss and, in this context, the likely use of chemical and mineral (fly ash) admixtures is considered. The use of these admixtures, however, must be considered also with respect to their possible effect on plastic shrinkage cracking (Previte 1997).

Soroka studied the effect of high temperatures on the properties of the fresh concrete, specifically increased water demand, shorter setting times and increased slump loss with the possible use of chemical admixtures (ASTM C 494) to overcome these strong effects on concrete final properties and strength. The effect of water reducing and retarding admixtures (type D, ASTM C494) on plastic shrinkage and plastic shrinkage cracking, in addition to the fly ash class F (ASTM C 618) impact on slump loss, are also studied in this work. Results of the experimental work carried out concluded that type D admixtures accelerate, rather than slow down the slump loss rate in concrete when exposed to lengthy mixing, however such admixtures were advantageous when used to reduce water demand and setting times delay. In addition upon studying fly ash impact, it was found to significantly reduce the amount and rate of slump loss of both with and without admixtures concrete. He suggested however, that under hot weather conditions, the combined use of class F fly ash and type D admixtures is recommended. That is building on the results showing both retarders and
fly ash increasing the vulnerability of fresh concrete to plastic shrinkage cracking as shown in Figure 8 (Soroka 1998).

![Figure 8: Effect of Temperature and type D admixture on standard penetration and setting time of concrete (Soroka 1998)](image)

In addition to above noted admixture, supplementary cementing materials (SCMs) are widely used to improve the durability of concrete casted. With silica fume gaining worldwide acceptance due to its high pozzolanic reactivity compared to other SCMs, its main concern in application is its likeability to an increase plastic and drying shrinkage specially in hot weather conditions (OS 2001). In this study, Al-Amoudi reported the reports results of an assessment on properties of plain and silica fume cement concrete specimens that were cast and cured in the field under hot weather
conditions environment, whereby, the effect of size of specimen and curing method on plastic and drying shrinkage, in addition to other properties of silica fume and plain cement concrete specimens were evaluated. Results revealed that the cement type can significantly influence both drying and plastic shrinkage of concrete in the values where the silica fume cement concrete specimens were higher than of the plain cement concrete specimens. In addition, both plain and silica fume cement concrete specimens that were cured through continuous water-ponding were less than those in alike concrete specimens cured through being covered with wet burlap. The results highlight the importance of good quality silica fume selection in addition to quality curing to avoid concrete cracking whether to plastic or drying shrinkage in hot weather conditions, as illustrated in Fig 9 (Al-Amoudi et. al. 2007).
In hot weather conditions and to overcome the adverse possible impacts on concrete strength, properties and durability the need for proper early moist curing and investing in adequate curing methods and cementitious materials replacement is especially essential to improve concrete quality (Robins et. al. 1992). In this context, two main types of curing are used, first through the continuous and frequent water application via sprays, steam, ponding or cover materials on site including burlaps, cotton mats, sawdust and sand; the second is through excessive water loss prevention from concrete through materials such as sheets or plastic or reinforced paper, or by applying a membrane to form a curing compound to freshly

**2.8 Concrete Curing in Hot Weather**

![Figure 9: Average Strain in Silica Fume Specimens and Plain Concrete (Al-Amoudi et. al. 2007)](image-url)
cast concrete (AlAnni et. al. 1988). In recent years, lightweight aggregate (LWA) in addition to its other main benefit of reduced dead load of the construction structure and its thermal conductivity, it has also been used largely in construction projects for internal curing purpose (IC). It has been displayed as a very promising technique providing additional moisture to the concrete due to effective hydration of the cement and lower self-desiccation especially in low permeability concrete such as high performance concrete (HPC) that is typically made of very low water /cement ratio mixes (Al-Ani et. al. 1988). However, the use of internal curing can substitute the normal recommended curing practices which is essentially need to keep the surface of concrete moist throughout the curing process to avoid cracking of plastic of drying shrinkage in hot weather conditions (Cusson et. al. 2008).

In acknowledgment of the key importance and influence of the curing methods on limiting and controlling the negative impacts of hot weather on concrete properties, many experimental efforts were directed towards trying different curing techniques in construction. It is noted though that reported effects of those curing methods on the concrete cast properties are not always in agreement. The curing period effect and initial water curing on compressive strength of SLWA concrete specimens prepared outside the lab in summer season is covered by literature material (Al-Khaiat et al. 1998). While in the effect of early cuffing on compressive strength study field of normal concrete, the results reveal no clear effect on strength of concrete when curing started after 24 hours from casting (Bushlaibi 2002).

Ahmed et. al thus studied the effect of curing methods and early curing on some properties of lightweight concrete that was exposed to high temperature weather and dry conditions to improve concrete structures performance. In this context the experimental work
was carried out in hot Iraqi summer conditions with average temperature reaching 55°C and relative humidity RH 13% under actual atmospheric condition through using fixed mix proportions for the cast concrete specimens while applying different curing methods by water curing (WC) for 13 day, water based curing compound (WBC), and bitumen based curing compound (BBC), in addition to curing other specimens by burlap covered with sprinkling water 3 times a day (BWS) for 13 day, and air curing (AC). Following this experimental program, the effect of those selected curing methods on the properties of HPLWC was evaluated through compressive strength measurement and splitting tensile strength, modulus of rupture, static and dynamic modulus of elasticity and pulse velocity. The study results revealed several conclusions that could be reflected and drawn on the concrete curing techniques best suitable and adequate to the hot weather conditions following mixing and casting in the manufacturing job site and yielding optimum quality results on the long term strength and durability of the concrete structure under study. In this direction, it was concluded that the best performance illustrated through 28 day compression results and later ages were in the specimens which were curing through WBC application, followed with WC, and then BWS, and less order BBC and in the decreasing order specimens of AC whereby results of the study can be studied in below Figures 10 and 11 of compressive and splitting strength with days of the different cured specimens illustrated (Ahmed et. al. 2017)
Figure 10: Compressive and Splitting Tensile Strength results of the different curing methods under study (Ahmed et. al. 2017)

Figure 11: Splitting Tensile Strength of Specimens under testing (Ahmed et. al. 2017)
2.9 Controlling Concrete Materials Temperature

A key methodology to limit the adverse effects illustrated for the hot weather conditions concrete placement and casting is to lower the mix temperature during mixing and pouring primarily through ingredient materials temperature control; this includes cement, mixing water, aggregates through adding additional material such as cold nitrogen or ice during mixing to lower the overall concrete mixture temperature in the hot weather (Noumowe et al. 2009). In this respect, it is noted that form all materials that constitute the concrete, water stands as the easiest one to cool and control the mix temperature. Even though in composition water is used in smaller quantities compared to the other mix ingredients, cold water produced a moderate overall reduction in the concrete mix of hot weather conditions. In this front mixing water from a cool source should be used. It should then be stored in tanks not in direct sun rays of the sun or exposure to hot weather on site. In addition another key practice is burying the tanks and pipelines of mixing water, installed, shaded, or painted in white to keep the mixing water as cool as practically possible. Water used can be cooled through refrigeration, liquid nitrogen or direct use of ice particles. Cooling the mixing water temperature 2.0°C to 2.2°C (3.5°F to 4°F) will usually result in lowering the concrete temperature about 0.5°C (1°F). However, the key insight noted is due to having the mixing water is such a small overall percentage of the total mixture, it is thus difficult to lower concrete temperatures more than about 4.5°C (8°F) by only cooling the water. Ice can also be used as part of the mixing water provided it is all melted by the time mixing is completed and casting takes place. When ice is added however it is critical to note the effect of heat of fusion so the equation of temperature of fresh concrete is modeled as follows;
Where $M_i$ is the mass in kg (lb) of ice (Mindness 1981)

The effect of ice on the temperature of concrete can be summarized in table below;

<table>
<thead>
<tr>
<th>Material</th>
<th>Mass, M, kg</th>
<th>Specific heat, kJ/kg • K</th>
<th>Joules to vary temperature, °C</th>
<th>Initial temperature of material, $T$, °C</th>
<th>Total joules in material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>335 $(M_d)$</td>
<td>0.92</td>
<td>308</td>
<td>66 $(T_d)$</td>
<td>20,328</td>
</tr>
<tr>
<td>Water</td>
<td>123 $(M_d)$</td>
<td>4.184</td>
<td>515</td>
<td>27 $(T_w)$</td>
<td>13,905</td>
</tr>
<tr>
<td>Total aggregate</td>
<td>1839 $(M_d)$</td>
<td>0.92</td>
<td>1692</td>
<td>27 $(T_a)$</td>
<td>45,684</td>
</tr>
<tr>
<td>Ice</td>
<td>44 $(M_i)$</td>
<td>4.184</td>
<td>184</td>
<td>0 $(T_i)$</td>
<td>0</td>
</tr>
</tbody>
</table>

\[ T^{(C^\circ)} = \frac{0.22(T_aM_d + T_cM_d) + T_wM_w + T_{wa}M_{wa} - 80M_i}{0.22(M_a + M_c) + M_w + M_{wa} + M_i} \]

\[ T^{(F^\circ)} = \frac{0.22(T_aM_d + T_cM_d) + T_wM_w + T_{wa}M_{wa} - 112M_i}{0.22(M_a + M_c) + M_w + M_{wa} + M_i} \]

While the overall impact of concrete materials on the initial concrete temperatures can also be modeled and reflected in below table (Hot Weather Concreting 2005)

In addition Yazeed et. al. investigated the thermal-stress and mass concrete temperature impact and construction stage analysis, presenting analytical model for calculating placement temperature in concrete using the below equation; which can be used in comparison with experimental data results. (Sayed-Ahmed et.al. 2017)

\[ t_{\text{Aggregate stock pile}} = t_{\text{Average annual}} + \frac{2}{3}(t_{\text{Previous month}} - t_{\text{Average annual}}) + t_{\text{Added concrete processing}} \]

\[ t_{\text{Concrete placement}} = t_{\text{Aggregate stock pile}} + \frac{2}{3}(t_{\text{Aggregate stock pile}} - t_{\text{Average annual}}) + t_{\text{Added mixer}} \]

32
Mixing Water Temperature Impact on Concrete

Naganathan and Mustapha studied the impact of mixing water temperature on the concrete properties during casting and curing. Different concrete specimens were prepared, cast and cured under different water temperatures and accordingly concrete material properties were studied and analyzed. Tests carried out included fresh and hardened concrete tests which included; slump, compressive strength, ultrasonic pulse velocity (UPV), rebound hammer and water absorption. The results of the experimental work revealed that the high water temperature when used in concrete production will lead to strength reduction and negatively impact the quality of concrete. In addition, it was revealed that hot water in concrete mixture would lead to further defects and failures in the hardened concrete state including surface cracks. They concluded that optimally concrete should be prepared by using water temperature in the range of 20°C to 35°C in order to obtain good quality concrete and higher durability.

Madi et al. 2017 further studied the impact of mixing water temperature on the concrete strength. Whereby, there study aimed to assess and quantify the impact of mixing water on the

<table>
<thead>
<tr>
<th>Material</th>
<th>Mass, M, kg</th>
<th>Specific heat, kJ/kg * K</th>
<th>Joules to vary temperature, 1°C</th>
<th>Initial temperature of material, T, °C</th>
<th>Total joules in material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>335 (Mₐ)</td>
<td>0.92</td>
<td>308</td>
<td>66 (Tₐ)</td>
<td>20,328</td>
</tr>
<tr>
<td>Water</td>
<td>123 (Mₑ)</td>
<td>4.184</td>
<td>515</td>
<td>27 (Tₑ)</td>
<td>13,905</td>
</tr>
<tr>
<td>Total aggregate</td>
<td>1839 (Mₐₑ)</td>
<td>0.92</td>
<td>1692</td>
<td>27 (Tₐₑ)</td>
<td>45,684</td>
</tr>
</tbody>
</table>

Initial concrete temperature = \( \frac{29,917}{2515} \) = 31.8°C
To achieve 1°C reduction in initial concrete temperature:
- Cement temperature must be lowered = \( \frac{2515}{308} \) = 8.2°C
- Or water temperature dropped = \( \frac{2515}{515} \) = 4.9°C
- Or aggregate temperature cooled = \( \frac{2515}{1692} \) = 1.5°C

2.10 Mixing Water Temperature Impact on Concrete

Naganathan and Mustapha studied the impact of mixing water temperature on the concrete properties during casting and curing. Different concrete specimens were prepared, cast and cured under different water temperatures and accordingly concrete material properties were studied and analyzed. Tests carried out included fresh and hardened concrete tests which included; slump, compressive strength, ultrasonic pulse velocity (UPV), rebound hammer and water absorption. The results of the experimental work revealed that the high water temperature when used in concrete production will lead to strength reduction and negatively impact the quality of concrete. In addition, it was revealed that hot water in concrete mixture would lead to further defects and failures in the hardened concrete state including surface cracks. They concluded that optimally concrete should be prepared by using water temperature in the range of 20°C to 35°C in order to obtain good quality concrete and higher durability.

Madi et al. 2017 further studied the impact of mixing water temperature on the concrete strength. Whereby, there study aimed to assess and quantify the impact of mixing water on the
performance of fresh and hardened Portland cement concrete. In their experimental work, concrete mixtures were designed and prepared using four main variable temperatures of 5, 15, 30 and 45°C while controlling the aggregate and cement temperatures throughout the process. A total sixteen mixes were poured all at room temperature, with two mixes poured at 45 °C. In addition mineral admixtures were incorporated in order to study the impact of mixing water on their behavior and structure integrity. For all mixes, two sets of test were carried out, fresh and hardened, this included temperature measurement for the mix, unit weigh, air content and slump retention. Secondly, the hardened concrete tests set were conducted which included compressive and flexural strength tests as well as chemical durability. While, in addition a third set of tests were carried out to monitor the heat of hydration of the concrete cast with time. Compressive and flexural test results are summarized in below Figures 12-13. Results of the study revealed the strong impact of water temperature on the concrete properties, strength and performance at early ages, while suggesting the need to test and add cold water for hot concrete mixes. Results of the study concluded on the compressive strength of cube specimens tested is illustrated in below Figures 12 -13 respectively.
Figure 12: Compressive Test Results (Madie et al. 2017)
Above study results highlighted the strong water temperature impact on concrete performance mainly at early ages. The results as well suggests the need to incorporate colder water in hot concrete mixes for further analysis and focused conclusions.
CHAPTER 3 : EXPERIMENTAL WORK

As discussed and illustrated in the literature review, hot weather can impact the quality and durability of concrete structures during mixing, casting and hardening. While high early strength could be expected, the major concerns remain on the long-term properties of the concrete and its durability. Several measures typically considered while casting and preparing concrete in elevated temperature, including cooling the materials of concrete, mixing at times with limited heat exposure or at night and using special concrete materials or admixtures. Working on the concrete materials temperature remains one of the most practical ways to mitigate negative impacts of hot weather, and especially mixing water effect on the strength and durability of concrete. Thus, in the experimental work, the effect of mixing water temperature on the concrete strength will be studied through the following procedure.

Four different concrete mixes will be prepared, each with three sets of cubes and beams specimens while varying the water temperature in each of the three sets. First set of every concrete mix will be mixed with 5°C temperature water, second set will be at 25°C water and the final third set will be mixed with water of 45°C. For every tested set, 3 cubes will be tested for compressive strength at 1, 3, 7 & 28 days. In addition, to 3 beams for each set tested at 28 days. In addition, using thermocouples inserted through a separate beam set will be used to monitor and record the temperature of the concrete section, and the different mixing water impact on heat of hydration and concrete temperatures.
3.1 Materials Selection

In this section, the different materials used in testing will be illustrated with the key material source listed and specifications covered. Sika Corporation Egypt is the supplier of the admixtures and silica fumes listed below in the study. The selected materials from Sika are as follows; Sika Visco-Crete 10 Type F plasticizer and Silica Fumes.

3.1.1 Cement

Cement used in testing is Ordinary Portland Cement (ASTM C150), manufactured by Suez Cement company in compliance with international standards (EN 197/1-2011) and Egyptian standards (ES 5756/1-2013). The Portland cement used has specific gravity of 3.15 and a Blain fineness of 312 m2/kg, with the below composition 55% (C3S), 19% (C2S), 10% (C3A), 7% (C4AF), 2.8% MgO, 2.9% (SO3), 1.0% ignition loss, and 1.0% free CaO. Further test results are summarized in Table 1 below.

Table 1: Typical Test Results of Portland Cement Used

<table>
<thead>
<tr>
<th>Test</th>
<th>Standard(s)</th>
<th>Property</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fineness of Portland Cement</td>
<td>ASTM C204</td>
<td>Fineness</td>
<td>312 m²/kg</td>
</tr>
<tr>
<td>Density of Portland Cement</td>
<td>ASTM C188</td>
<td>Density</td>
<td>3.16</td>
</tr>
<tr>
<td>Setting Time of Portland Cement</td>
<td>ASTM C191</td>
<td>Initial setting</td>
<td>145 minutes</td>
</tr>
</tbody>
</table>
3.1.2 Coarse Aggregates

Coarse aggregate used in the experimental work below is crushed dolomite surface – dry stones for from OCI Crusher, Attakah. The dolomite had a maximum nominal size of 25 mm, with a saturated surface dry specific gravity of 2.62 and a percent absorption of 1.89%.

3.1.3 Fine Aggregates

Siliceous sand was used in all concrete mixtures. Fine aggregates were obtained from natural a local query near Suez. The sand had a fineness modulus of 2.57, saturated surface dry specific gravity of 2.54 and a percent absorption of 0.58%. Sieve analysis of the fine aggregate used is presented in below Table 2.

<table>
<thead>
<tr>
<th>Compressive Strength of Cement Mortar</th>
<th>Final setting</th>
<th>235 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength of Cement Mortar</td>
<td>3-day Comp. Strength</td>
<td>18.3 MPa</td>
</tr>
<tr>
<td>Compressive Strength of Cement Mortar</td>
<td>28-day Comp. Strength</td>
<td>46.4 MPa</td>
</tr>
</tbody>
</table>
Table 2: Fine aggregates Sieve Analysis Results

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>% Passing</th>
<th>ASTM C33 Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>100.0</td>
<td>100</td>
</tr>
<tr>
<td>5.00</td>
<td>100.0</td>
<td>95-100</td>
</tr>
<tr>
<td>2.36</td>
<td>96.0</td>
<td>80-100</td>
</tr>
<tr>
<td>1.18</td>
<td>82.0</td>
<td>50-85</td>
</tr>
<tr>
<td>0.60</td>
<td>43.0</td>
<td>25-60</td>
</tr>
<tr>
<td>0.30</td>
<td>17.2</td>
<td>10-30</td>
</tr>
<tr>
<td>0.15</td>
<td>4.6</td>
<td>2-10</td>
</tr>
<tr>
<td>0.0075</td>
<td>0.8</td>
<td>0-2</td>
</tr>
</tbody>
</table>

3.1.4 Water

Clean drinking water is used as mixing water for the concrete and for cleaning purposes associated with the experimental work hereunder.

3.1.5 Water Reducing Admixtures

Sika Viscocrete – 10 used is a fourth-generation super-plasticizer for concrete and mortar. This admixture meets the requirements of super plasticizers according to SIA 162
(1989) prEN-934-2 and ASTM-C-494 Types G and F. Silica Fumes were also used from Sika to enhance the durability and strength of concrete mixes in Figure 14.

![Silica Fumes](image)

**Figure 14: Silica Admixture Used in Testing**

## 3.2 Materials Preparation

This section covers the preparation of the materials used and tested specimen sets for conducting the experimental work in scope of concrete mixing and casting.

### 3.2.1 Mix Design of the Concrete

4 different mix designs were used in scope of the study, with key variable of the w/c ratio, cement quantities and higher quality concrete mix with superplasticizer added. Mix one with 300 kg cement, w/c ratio at 0.5; second with 350 Kg, w/c ratio of 0.45, third with 450 kg, w/c 0.4 and finally fourth mix with 450 kg with 50 kg Silica fumes. Concrete mixes illustrated in Table 3 below.
<table>
<thead>
<tr>
<th>Item</th>
<th>Mix1</th>
<th>Mix 2</th>
<th>Mix 3</th>
<th>Mix 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (kg)</td>
<td>300</td>
<td>350</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>Water (kg)</td>
<td>150</td>
<td>157.5</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>w/c</td>
<td>0.50</td>
<td>0.45</td>
<td>0.40</td>
<td>0.36</td>
</tr>
<tr>
<td>Fine Aggregates (kg)</td>
<td>681</td>
<td>658</td>
<td>605</td>
<td>594</td>
</tr>
<tr>
<td>Coarse Aggregates (kg)</td>
<td>1226</td>
<td>1184</td>
<td>1089</td>
<td>1069</td>
</tr>
<tr>
<td>Admixtures</td>
<td>-</td>
<td>2 Liters</td>
<td>5 Liters</td>
<td>10 Liters</td>
</tr>
<tr>
<td>Plasticizer type</td>
<td>“A”</td>
<td>Plasticizer type “F”</td>
<td>Plasticizer type “F”</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>+ 50 kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Silica Fume</td>
<td></td>
</tr>
</tbody>
</table>

For every mix design, three different mixing water temperatures were used (5°C, 25°C and 45°C) to yield a total 12 sets of specimens, where each test specimen is as follows:

- 12 total cubes of (15°Cm x 15°Cm x 15°Cm) divided into sets of 3 cubes broken at 4 time intervals (1 day, 3 days, 7 days and 28 days)
- 2 total beams (75°Cm x 15°Cm x 15°Cm) where one is broken for flexural strength after 28 days and the other used for heat of hydration measurement connected by thermocouple
Following the above mentioned concrete mixes, the following procedure was followed in preparing and casting the specimens needed for testing; in the steps of mixing, casting and curing.

3.2.2 Aggregates and Mixing Water Heating

To simulate the hot weather conditions in the lab (45°C), aggregates and cement were heated in the oven to 45°C ahead of mixing and placement as shown in Figure 15 below of all constituent materials pre-mixing heating. Also, mixing water at 45°C was heated to 45°C, for the 5°C mixing water was cooled in the fridge in the lab, and finally 25°C was obtained at room temperature, water temperatures was recorded as shown in Figure 16 to ensure quality of the mix and the test results coherence. The mixing was carried out per ASTM C192 – 07. The cement, aggregates in the required quantities were placed in the mixer, mixed dry for a minute then followed by water and admixtures addition as applicable as shown in Figures 15 – 17 below for the materials preparation and mixing part.
Figure 15: Aggregates and Cement Heating in Oven ahead of mixing

Figure 16: Mixing Water Temperature Recorded ahead of Mixing
3.2.3 Specimens Preparation and Casting

As shown below in Figures 18 - 19, the 12 cubes of every mix and beams were cast in the molds while resting on the vibrator to ensure proper mixing and consolidation of the concrete mix. After complete drying and proper setting of the mixes inside the molds, they were removed to the curing room after 24 hours. Curing was carried out manually in the curing room of the concrete laboratory of the American University.
Figure 18: Concrete Specimens after casting in molds

Figure 19: Lab Curing Room
3.2.4 Heat of Hydration Measurement

For the beam set used to monitor the heat of hydration, while casting, end wire junctions of the thermocouple apparatus were placed inside the mold to make sure the ends are measuring the heat of hydration and concrete mixture as it is drying inside the mold for the first 24 hours after casting. The wire junctions were connected to a data logger connected to the computer in the lab, measuring the temperature Vs. time of the concrete mix. Below Figure 20 shows the apparatus used in study and the nodes wired to the beams molds to record the temperature of the concrete at the different points of time stated.

![Thermocouple and Data Logger Reader](image)

Figure 20: Thermocouple and Data Logger Reader
3.3 Experimental Variables

Key variable in the experimental work is the mixing water temperature and studying its impact on the mix and concrete properties tabulated below. 25°C is the room temperature control group, 5°C is the yields lower temperature concrete and finally the 45°C as the hot temperature ones. Below Table 4 show the summary of the concrete mixes and specimen sets under study in the experimental scope.

Table 4: Concrete Mixes Specimens Summary

<table>
<thead>
<tr>
<th>Water Temperature</th>
<th>300 kg cement</th>
<th>350</th>
<th>450</th>
<th>450 with SP</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Specimen Set 1</td>
<td>Set 4</td>
<td>Set 7</td>
<td>Set 10</td>
</tr>
<tr>
<td>25</td>
<td>Set 2</td>
<td>Set 5</td>
<td>Set 8</td>
<td>Set 11</td>
</tr>
<tr>
<td>45</td>
<td>Set 3</td>
<td>Set 6</td>
<td>Set 9</td>
<td>Set 12</td>
</tr>
</tbody>
</table>

3.4 Experimental Set Up

All experimental work was conducted in the construction and materials lab for the construction department at the laboratory of the American University in Cairo. The program is mainly composed of fresh concrete and hardened concrete testing. For the fresh concrete, slump, unit weight and temperature was carried out. For the hardened concrete compression and flexural testing in accordance with the ASTM standards took place. Experiments followed
procedure summarized above, after heating the concrete materials and mixing water, fresh concrete tests were first conducted, then for the hardened concrete respective tests were carried out.

3.4.1 Testing Procedure

For the fresh concrete tests, unit weight was carried out through pouring the concrete mix into the form of set volume, then calculating the net weight of the concrete to finally get the unit weight calculated for every mix design in accordance with ASTM 138. Temperature was tested through the thermocouple apparatus connected by the data logger and computer, where wires embedded inside the concrete beam form recorded the temperature of the concrete for the 8 hours’ span. Slump test shown below in Figure. 21 was carried out in accordance to the ASTM C143 standards measuring the workability of the fresh concrete mixes ahead of hardening and casting. Fresh Concrete Tests Summarized below:
Figure 21: Standard Slump Test Conducted

For hardened concrete, the strengths assessment of the beams after curing was carried out through universal testing machine and the beams flexural strength was conducted through the three-point loading machine in accordance with ASTM C 293/C78 using ELE machine that could be shown in below Figure 21. This standard test was carried out across the 12 mixes beams in scope of the experimental work, whereby three beams were tested in each mix and the average recorded strength from the ELE machine recorded was identified as the flexural test result for this mix. For the beams to the test was carried out at 28- days ahead of casting as the key indicator of the strength of the beams structures under study. In addition,
compressive strength test was carried for cubes sets (three in each test time and average recorded) for 1,3,7 and 28-day strength using universal testing machine.

Figure 22: Beams Flexural Test through 3 ELE Machine
CHAPTER 4: RESULTS AND ANALYSIS

In this chapter, the experimental results obtained will be illustrated and analyzed. This will include key results of the fresh concrete tests; of slump, unit weight and concrete temperature. Following this, hardened concrete test results will be presented under high weather conditions of compressive and flexural strengths for all tested specimens and different concrete mixes poured; summarized below. Whereby, the test specimens after curing in the lab’s curing room were handled and tested in accordance to the test methods illustrated in the methodology and in accordance to the standards. With a total 12 specimens sets of 12 cubes and 2 beams each, all hardened concrete tests were carried out. For the fresh concrete, additional separate amounts of the concrete mixes were used as reference for the tests below.

Table 5: Concrete Tests Summary

<table>
<thead>
<tr>
<th>Tests</th>
<th>Cubes</th>
<th>Beams</th>
<th>Age of Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh Concrete</td>
<td>Slump</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unit Weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardened Concrete</td>
<td>Compressive Strength -</td>
<td>1,3,7 &amp; 28 days</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flexural Strength -</td>
<td>28 days</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>Concrete Temperature -</td>
<td>24 hours</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Monitoring</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.1 Fresh Concrete Results:

Unit weight, Slump results were measured and summarized below for all 12 concrete mixes as per previously illustrated experimental method in below Table 6 as follows;
Table 6: Fresh Concrete Slump & Unit Weight Results

<table>
<thead>
<tr>
<th></th>
<th>Mix 1 (300 kg Cement)</th>
<th>Mix 2 (350 kg)</th>
<th>Mix 3 (450 kg)</th>
<th>Mix 4 (450 kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump (cm)</td>
<td>5 25 45</td>
<td>5 25 45</td>
<td>5 25 45</td>
<td>5 25 45</td>
</tr>
<tr>
<td></td>
<td>4 0 1</td>
<td>5 3 1</td>
<td>20 19.5 18</td>
<td>24 22 22</td>
</tr>
<tr>
<td>Unit Weight (kg/m³)</td>
<td>2477 2323 2496</td>
<td>2436 2371 2508</td>
<td>2460 2372 2413</td>
<td>2347 2390 2339</td>
</tr>
</tbody>
</table>

For mixes 1 & 2 slump and workability was very low ranging between 0-5cm with different mixing water temperatures, however showing an increase in workability and slump with lower temperature water added (5°C). While for mixes 3 & 4 with superplasticizers added a significant increase in slump was seen recording 18 – 24 cm results within the tests carried out. Similar behavior was observed in the 5°C mixing water temperature of relatively higher slump and workability. Unit weight results for all mixes were recorded between 2323 & 2508 kg/ m³ ranges.
Figure 23: Slump Test of Mixes 1-4 from left to right respectively
4.2 Cast Concrete Temperature Analysis

In this test, where the intent is to measure the concrete temperature in the time intervals following its fresh casting in the respective molds; thermocouples inserted into concrete beams and connected to computer data logger was used to monitor the temperature of the concrete casted over a span of 24 hours, and as an indicative of the heat of hydration and exothermic chemical reactions taking place during concrete hardening from the cement material in concrete. Following the temperature recording by the thermocouple nodes inserted in the beams, the data flows directly to the connected data logger, and graphs can be exported and plotted for the concrete temperature progress over the needed time span of the experimental work. Below graphs show the temperature recorded for the different mixes of concrete at different mixing water temperatures.

Figure 24: Mix 1 Temperature Test Results
For the first concrete mix initial recorded temperatures were at 37, 31 and 28°C for the 45, 25 and 5 °C mixes respectively. Results shows a 9 °C drop in the concrete mix temperature with cold water when compared with the highest temperature mix. 5 °C concrete mix was first to reach the minimum temperature in both mixes of 22 °C in mix 3 in 5.25 hrs. 45 °C reached its min ambient temperature in 8 hrs. as summarized in Figure 24.

![Mix 2 Concrete Temperature Results](image-url)

**Figure 25: Mix 2 Concrete Temperature Results**
Mix 2 showed a similar initial recorded temperature behavior with 45, 25 and 5 °C concrete mixes marking 33, 31 and 29 °C temperatures at time 0. 5 °C concrete mix showed highest rate of heat loss and reaching initial plateau of 24 °C after 3.25 hrs. as opposed to 45 °C mix reaching a similar lowest temperature after 20.25 hrs. from initial casting. 25 °C concrete mix should intermediate behavior in comparison reaching same temperature of 24 °C after 15.25 and a total minimum temperature of 23°C after 20 hrs. from casting summarized in Figure 25 below.

![Mix 3 Concrete Temperature Results](image)

**Figure 26: Concrete Mix 3 Temperature Test Results**

Results summarized for mix 3 and the different temperatures in Figure 26 show smaller variation in initial temperatures of 31, 30 & 29 °C respectively after casting and at the start of
temperature monitoring. This is due to a delay in casting after materials preparations which accounts for experimental error in mix 3. Concrete mix of 25 °C showed faster heat loss and reached plateau relatively faster than other mixes reaching a min temperature of 21 °C in 10 hrs. followed by 45 °C mix at 22.5 hrs. and finally 5 °C in 23.75 hrs.

![Mix 4 Concrete Temperature Results](image)

**Figure 27: Mix 4 Concrete Temperature Results**

For mix 4; highest initial concrete temperature was recorded at 40 °C for the 45 °C mix, followed by 33 and 25 °C for the 45, 25 and 5 °C mixes respectively. 5 °C concrete mix was first to reach the minimum temperature in this mix (21°C in 10 hrs.) 45 °C mix reached its min ambient temperature in 10.5 hrs. as summarized in Figure 27.
4.3 Concrete Compressive Test Results

For the hardened concrete test results, cube specimen sets of 3 each were prepared and tested after 1, 3, 7, and 28 days for the 12 different concrete mixes under study. The average compressive strength of the 3 cubes in every time interval was recorded to yield the below results illustrated for every concrete mix.

Table 7: Mix 1 Compressive Test Results

<table>
<thead>
<tr>
<th></th>
<th>Mix 1 (300 kg Cement)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25 °C Temp</td>
<td>45 °C Temp</td>
<td>5 °C Temp</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 D 3 D 7 D 28 D</td>
<td>1 D 3 D 7 D 28 D</td>
<td>1 D 3 D 7 D 28 D</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.7</td>
<td>17.6 28.0 34.3</td>
<td>14.5 29.6 34.8 25.5</td>
<td>13.2 32.2 30.0 49.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.8</td>
<td>16.8 24.9 29.3</td>
<td>14.3 29.8 32.6 46.7</td>
<td>14.0 30.7 32.9 40.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.6</td>
<td>20.0 17.9 33.3</td>
<td>14.7 26.2 21.8 37.8</td>
<td>13.6 29.5 28.9 39.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>12.0 18.1 23.6 32.3</td>
<td>14.5 28.5 29.8 36.7</td>
<td>13.6 30.8 30.6 43.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table-7 showed results of Mix 1 with 300 kg cement, w/c ratio at 0.5 and no admixtures summarized in Figure 28 which showed 21% higher early strength at 45 °C mixing water of 14.5 MPa at Day1 when compared with the 25 °C mixing water control mix. Higher compressive strength of the 45 °C mix is further developed with the 3 and 7 days’ cubes tested when compared with 25 °C, however slightly higher compressive strength is yielded with the lowest water temperature mix of 5 °C. Cold water concrete (5 °C) showed the highest % increase in strength at 3 days Vs. 1 day test with 126% increase in strength reaching 30.8 MPa when compared to 1-day strength of 13.6. For the high temperature water of 45 °C a smaller rate of strength increase is seen of 96% going from 14.5 to 28.5 MPa in 3-day test. An overall lower average compressive strength increase is seen with the day-7ay test Vs. 3 days of only
8% across all different specimens tested, with overall highest Compressive Test recorded at 5 °C mix. Looking at the 28-day compressive test results as indicative of long term performance, cold mixing water (5 °C) scored highest compressive strength at 43.2 MPa at 17.7% and 25% higher strength than 25 °C and 45 °C water temperature mixes respectively.

Table 8: Mix 2 Compressive test Results

<table>
<thead>
<tr>
<th></th>
<th>MIX 2 - Compression Results</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25 Temp</td>
<td>45 Temp</td>
<td>5 Temp</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 D</td>
<td>3 D</td>
<td>7 D</td>
<td>28 D</td>
<td>1 D</td>
</tr>
<tr>
<td>1 D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28 D</td>
<td>17.5</td>
<td>31.5</td>
<td>28.9</td>
<td>42.8</td>
<td>23.5</td>
</tr>
<tr>
<td></td>
<td>18.7</td>
<td>34.5</td>
<td>41.6</td>
<td>44.0</td>
<td>16.3</td>
</tr>
<tr>
<td></td>
<td>23.4</td>
<td>38.0</td>
<td>36.8</td>
<td>37.4</td>
<td>15.6</td>
</tr>
<tr>
<td>Average</td>
<td>15.1</td>
<td>28.4</td>
<td>32.0</td>
<td>42.2</td>
<td>21.9</td>
</tr>
</tbody>
</table>

Figure 29: Mix 2 Compressive Test Results Graph
Table 8 give the results for the second concrete mix studied with 350 kg cement, w/c ratio at 0.4, results of the cubes tested at the different time intervals showed highest early compression at 1-day of 21.9 MPa with the 45 °C mixing water temperature which is 45% higher than the 25 °C temperature water and 35% higher than 5 °C water temperature cubes. For the day-3 and day-7 cubes, compressive strength is further developed across all mixes. Cubes of the 5 °C mix showed the highest % increase in compression between day-1 and day-3 of 127%

Higher compressive strength of the 45 °C mix is further developed with the 3 and 7 days’ cubes tested when compared with 25 °C, however slightly higher compressive strength is yielded with the lowest water temperature mix of 5 °C. Cold water concrete (5 °C) showed the highest % increase in strength at day-3 Vs. day-1 test with 126% increase in strength reaching 30.8 MPa when compared to 1-day strength of 13.6. For the high temperature water of 45 °C a smaller rate of strength increase is seen of 96% going from 14.5 to 28.5 MPa in 3-day test. An overall lower average compressive strength increase is seen with the day-7 test Vs. day-3 of only 8% across all different specimens tested, with overall highest compressive test recorded at 5 °C mix. Looking at the day-28 compressive test results, cold mixing water (5 °C) scored highest compressive strength at 43.2 MPa at 17.7% and 25% higher strength than 25 °C and 45 °C water temperature mixes respectively shown in Figure 29.
Table 9: Mix 3 Compressive Test Results

<table>
<thead>
<tr>
<th>MIX 3 - Compression Results</th>
<th>25 Temp</th>
<th>45 Temp</th>
<th>5 Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 D</td>
<td>3 D</td>
<td>7 D</td>
<td>28 D</td>
</tr>
<tr>
<td>12.9</td>
<td>23.6</td>
<td>27.7</td>
<td>40.7</td>
</tr>
<tr>
<td>14.7</td>
<td>28.3</td>
<td>31.1</td>
<td>41.9</td>
</tr>
<tr>
<td>13.2</td>
<td>23.8</td>
<td>26.7</td>
<td>41.4</td>
</tr>
</tbody>
</table>

Average: 13.6 25.2 28.5 41.3 16.5 31.3 37.1 37.0 16.7 29.2 35.9 38.7

Figure 30: Mix 3 Compressive Test Results Graph
Mix 3 with 450 kg cement showed somehow different trends from the previous two mixes studied. For 1-day compressive strength cubes tested gave comparable strength for the 5 and 45 °C cubes with 16.7 and 16.5 MPa respectively. For the day-3 and day-7 cubes, compressive strength increased significantly across all different temperature water mixes reaching a maximum of 31.3 MPa with 45 °C temperature mix followed by the 5 °C one with 29.2 MPa and overall average 45% Vs. 1-day results across all three mixes. Concrete strength continued to further develop as shown in 7-day results with an overall 16% increase Vs. 3-day results with the highest compressive strength recorded for the 45 °C at 37.1 MPa followed by 5 °C mix at 35.9 MPa. Finally for the 28 compressive test results, 25 °C mix yielded highest compressive results of 41.3 MPa followed by 5 °C mix with 38.7 MPa and minimum compressive strength was recorded for the 45 °C mix at 37 MPa where test specimen is shown in Figure 30 below.

While results of mix 3 showed some inconsistent and different results from the other 3 mixes in scope of this experimental work, some sources of errors could have contributed to this. This could be attributed to a time lag in concrete casting and mixing after constituent materials heating to 45 °C in the oven versus the other mixes. Also, the mix was casted at a lower temperature day that could have also impacted the temperature and material results yielding the results discrepancies vs. the rest of the results data sets.
Figure 31: 45 °C mix 28 days

Table 10: Mix 4 Compressive Test Results

<table>
<thead>
<tr>
<th>25 Temp</th>
<th>45 Temp</th>
<th>5 Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 D</td>
<td>3 D</td>
<td>7 D</td>
</tr>
<tr>
<td>12.5</td>
<td>35.6</td>
<td>46.6</td>
</tr>
<tr>
<td>12.3</td>
<td>32.4</td>
<td>42.5</td>
</tr>
<tr>
<td>14.3</td>
<td>41.2</td>
<td>42.2</td>
</tr>
<tr>
<td>Average</td>
<td><strong>13.0</strong></td>
<td><strong>36.4</strong></td>
</tr>
</tbody>
</table>
Table-10 summarizes the test results of the last concrete mix of 450 kg cement, superplasticizer and silica fumes showed the highest concrete results across the different time intervals. Highest early compressive strength was recorded at 14.3 MPa at 1-day with the 45 °C concrete mix. Followed by the 25 °C mix with 13 °C and finally lowest early strength developed with the low water temperature of 5 °C giving 8.2 MPa only. Similar strength development high rate was seen with the day-3 strength like in previous 3 mixes, giving an overall average 64% compressive strength increase for the 3 different mixes. The strength results of the individual mixes showed comparable results, highest of 36.4 MPa for the 25 °C mix followed by 31.3 MPa for the 5°C one at 31.3 MPa. It is noted that the mix with 5 °C
showed the highest temperature increase from 1-day to 3-day of 282% when compared with 180% increase for the 25 °C and lowest increase of 114% for the hot water mix of 45 °C.

Further strength development is yielded for the day-7 concrete mix with lower rate of strength development that that of 3-day cubes, with average % increase of 28%. For the 28 -day strength cubes, results have shown highest recorded strength of 62.5 MPa shown in Figure 33 below which is also the highest across all 12 concrete nixes in scope of this experimental work.

Figure 33: 5 °C 28 Days Mix

This is followed by mix of 25 °C at 56.3 MPa and finally 50.4 MPa for the 45 °C mix. The relative higher strength developed in mix 4 is attributed to the concrete admixtures and silica fumes used giving high quality concrete mix and compressive test results.
4.4 Concrete Flexural Test Results

Similarly, to further analyze the concrete mixes and structures strength and durability yielded, flexural strength test was conducted on beams specimens for all 12 mixes. Two beam specimens were casted for every concrete mix and tested as per above stated method in the methodology section after 28 days.

The results recorded for the first concrete mix at different mixing water temperatures is recorded in below Table 11 as follows;

<table>
<thead>
<tr>
<th>Specimen</th>
<th>25°C Temp</th>
<th>45 °C Temp</th>
<th>5 °C Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen 1</td>
<td>13.8</td>
<td>10.1</td>
<td>16.3</td>
</tr>
<tr>
<td>Specimen 2</td>
<td>5.4</td>
<td>9.6</td>
<td>17.3</td>
</tr>
<tr>
<td>Average</td>
<td>14.6</td>
<td>9.9</td>
<td>16.8</td>
</tr>
</tbody>
</table>
Figure 34 shows the Flexural beams test results for mix 1 of 300 kg cement giving an average of 9.9, 14.6 and 16.8 MPa for the 45, 25 and 5 °C water respectively. This reflected that with the increase in water temperature long term structural integrity of the beams increase with 70% higher strength in the 5 °C water mix when compared with the 45°C mix. Those results are consistent with the compression results of the cube showing highest 28-days strength for the 5 °C mix as well when compared with both other temperature mixes. This is in addition with less surface cracks observed in this mix in comparison with the two other mixes, also shown in below Figures 35-37.
Figure 35: Mix 1 Beam at 45˚C

Figure 36: Mix 1 Beam at 25˚C

Figure 37: Mix 1 Beam at 5˚C
Table 12: Mix 2 Flexural Results

<table>
<thead>
<tr>
<th>Specimen 1</th>
<th>25°C Temp</th>
<th>45°C Temp</th>
<th>5°C Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen 1</td>
<td>15.4</td>
<td>19.2</td>
<td>18.5</td>
</tr>
<tr>
<td>Specimen 2</td>
<td>15.8</td>
<td>18.4</td>
<td>19.7</td>
</tr>
<tr>
<td>Average</td>
<td>15.6</td>
<td>18.8</td>
<td>19.1</td>
</tr>
</tbody>
</table>

Figure 38: Mix 2 Beams Flexural Test Results

Table 12 and graphs in Figure 38 summarize the test results for mix 2 with 350 kg cement, slightly different data results were projected for the 28 days’ test of the concrete beams under study. Whereby, highest late concrete strength was recorded for the 5 °C temperature mix at 19.1 MPa, followed by the 45 °C temp mix with flexural strength of
18.8 MPa and finally 25 °C temp mid with 15.6 MPa. Results come in line with the compressive test results which gave highest recorded strength for the cubes at the 5 °C however with 25 °C results coming second as opposed to flexural beams results. The overall data however is showing high developed strength for the colder water mix on the long term 28-days test as opposed to hot water mixes. Beams tested are shown in below Figures 39-41 of the failure modes after testing.

Figure 39: Mix 2 Beam at 45°C

Figure 40: Mix 2 Beam at 45 °C
Figure 41: Mix 2 Beam at 5°C

Table 13: Mix 3 Flexural Test Results (MPa)

<table>
<thead>
<tr>
<th>Specimen</th>
<th>25°C Temp</th>
<th>45°C Temp</th>
<th>5°C Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen 1</td>
<td>13.0</td>
<td>18.5</td>
<td>15.9</td>
</tr>
<tr>
<td>Specimen 2</td>
<td>12.4</td>
<td>15.9</td>
<td>15.3</td>
</tr>
<tr>
<td>Average</td>
<td>12.7</td>
<td>17.2</td>
<td>15.6</td>
</tr>
</tbody>
</table>
Table 13 shows the flexural test results for beams of mix 3 with 450 kg cement giving higher average strength among the test results. Mix 1 recorded average of 17.2, 12.7 and 15.6 MPa for the 45, 25 and 5 °C water respectively as shown in Figure 42. Test results however are not consistent in findings with those of the other 3 mixes, giving the highest long term strength (28 days) with the highest temperature mixing water (45 °C), followed by the 5 °C water and finally 25 °C mix. This is however consistent with the compressive test results carried out on the different cubes specimens in the previous section also scoring highest strength at the 45 °C water unlike the rest of results. Similar experimental errors would have contributed to those results, with a time duration lag between heating the water and materials, and mixing and pouring the concrete mix. This is also given that both mixes for the beams and

Figure 42: Mix 3 Beams Flexural Test Results
cubes were prepared and poured at the same time. Failure modes spotted are further illustrated in Figures 43-45.

Figure 43: Mix 3 Beam at 45°C
Figure 44: Mix 3 Beam at 25°C
Figure 45: Mix 3 Beam at 5°C

Table 14: Mix 4 Flexural Test Results (MPa)

<table>
<thead>
<tr>
<th>Specimen</th>
<th>25°C Temp</th>
<th>45 °C Temp</th>
<th>5 °C Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen 1</td>
<td>15.3</td>
<td>16.0</td>
<td>22.6</td>
</tr>
<tr>
<td>Specimen 2</td>
<td>18.4</td>
<td>14.1</td>
<td>20.5</td>
</tr>
<tr>
<td>Average</td>
<td>16.8</td>
<td>15.1</td>
<td>21.5</td>
</tr>
</tbody>
</table>
For mix 4 where results are summarized in table-14 with 450 kg cement, flexural strength data results for the 28-days test of the concrete beams under showed highest late concrete strength for the 5 °C temperature mix at 21.5 MPa, followed by the 25 °C temp mix with flexural strength of 16.8 MPa and finally 5 °C temp with 15.11 MPa as in Figure 46. Results come in line with the compressive test results of this mix which gave highest recorded strength for the cubes at the 5 °C. results of the mix reinforce the different results delivered throughout the test carried out of having higher long term strength when using cold water recording 28% higher than 25 °C mix and 38% higher than hot water mix of 45 °C. Beams tested photos of failure modes are further shown in below Figures 47 – 49.
Figure 47: Mix 4 Beam at 45°C

Figure 48: Mix 4 Beam at 25°C

Figure 49: Mix 4 Beam at 5°C
4.5 Summary of Results in Comparison with Literature and Earlier Research Conclusions

As illustrated in the analysis and results section, the study showed several benefits to the use of cold mixing water in hot weather conditions going hand in hand with the literature review and earlier studies reflecting the need for cold water in elevated temperatures. Results have shown enhanced workability in fresh concrete with higher slump readings and lower concrete temperature by up to 15°C getting the mixes to the required temperatures of not exceeding 35 °C per ACI requirements. For the hardened concrete properties, results showed higher compressive strength on 28-day strength for up to 15MPA, and enhanced flexural strength by up to 6 MPA.

Recent studies carried out on the topic by Magdy et. al. in 2017 further highlighted the enhanced properties of cold mixing water on the compressive strength of the concrete under hot weather conditions, and no significant impact on mild temperatures casting.

Literature and further studies have illustrated that cold water and colder concrete mixtures in hot weather can overcome several negative impacts of hot weather concreting, which included high evaporation rates, high water demand and slump loss, plastic shrinkage and surface cracks that cause a significant deterioration to the concrete. This is in addition to the long term negative impact on the concrete compressive strength and its durability. In addition, to reducing the need for admixtures when transporting concrete with cold water. Research highlighted the urging need to decrease the fresh concrete temperature to avoid those negative impacts while in hot weather this is in many cases not rightly mitigated with
additional water to overcome the workability losses, yielding higher w/c ratio for the concrete and decreasing its compressive strength.
CHAPTER 5 : PRELIMINARY FEASIBILITY ANALYSIS

Considering the experimental results conducted herein, literature review and analysis where cold mixing water used in simulated hot weather conditions yielded higher compressive strength properties, lower cracks and higher workability for the concrete structures. This is in addition to latest studies in 2017 on effect of mixing water temperature on concrete properties by Mady et. al. where cold water in hot mixes was found to increase the compressive strength of concrete by up to 5 MPa. Furthermore, in light of the global warming and prolonged durations and degrees of hot weather year on year, the practical feasibility of using cold mixing water in site or in concrete mixing plant becomes even more eminent to be studied for application in the construction industry. Key parameters to be considered is as follows;

5.1 Applicability

As identified by the ACI 305 and Egyptian code standards fresh concrete temperature should not exceed 35 °C, that can directly result in cracks induced in concrete as it hardens, in addition to a lower strength development in the concrete structures. This is usually the case during hot weather in summer time in Egypt, where the direct sun exposure, humidity in addition to the exothermic reaction of cement and water that further elevates the concrete mix temperature.

5.2 Cooling Methods

In the concrete mixing plant, different cooling methods can be used, summarized below;
1- Water chiller plants for total mixing water

Chiller plants can be used to decrease the concrete temperature from 45°C down to 4°C, they are called containerized cold water plants. Others used to reduce temperature for us to 1°C are called containerized ice water plants which are equipped with special ice bank systems that accumulate ice around tube or plate heat exchangers.

For a daily production up to 180 m³ cold water, they are installed inside of 20-ft. containers which correspond to a daily concrete production between 200 and 1400 m³. Daily production up to 450 m³ cold water, they are installed inside of 40-ft. containers corresponding to a daily concrete production between 1400 and 2800 m³ which depends on the actual water inlet temperature and the possible addition of water.

Figure 46: Water chilling System for Concrete (Concrete Cooling, KTI Website 2017)
From the local market studies, the different capacity chillers prices are as shown in below Table 15. The chillers depreciate on 3 years, and with average 25 working days/month, the distributed cost of chiller per 1m³ of concrete is thus estimated at a range between 5 – 7 LE incorporating their running and maintenance cost.

<table>
<thead>
<tr>
<th>Capacity (Concrete m³/day)</th>
<th>Price (EGP)</th>
<th>Chiller cost / m³ of Concrete (EGP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 – 100</td>
<td>650,000</td>
<td>7</td>
</tr>
<tr>
<td>100 – 160</td>
<td>940,000</td>
<td>6.5</td>
</tr>
<tr>
<td>160 – 250</td>
<td>1,300,000</td>
<td>5.8</td>
</tr>
<tr>
<td>250 – 400</td>
<td>1,800,000</td>
<td>5</td>
</tr>
</tbody>
</table>

2- Cold Water Tanks

Perfectly insulated cold water tanks are ideally suited to support chillers whereby, the size is dependent on the non-production period of the batching plant. There are 3 different possibilities for such tank insulation:

- Concrete cold-water tank and insulated locally – any size possible.
- Steel cold-water tank, installed and insulated inside a 40-ft. Container – maximum size: approx. 58 m³.
- Steel cold-water tank, installed and insulated inside a steel frame – maximum size: approx. 150 m³.
3- Combined Flake Ice / Water Chilling Plants

The main advantage of a combined plant (chiller and ice plant in one unit) is that both systems use one common evaporative condenser. If both plants are 100% in production there is no incremental advantage. However once the flake ice plant has stopped (because the ice storage is full or there is no use for flake ice during the cold season), the chiller runs with an evaporative condenser which has double the capacity than necessary. This brings the discharge pressure down, lowers the power consumption and increases the efficiency. Over the period of one year power savings of up to 30% can be achieved. Furthermore, it increases the life expectancy of the compressors thus reducing the costs for spare parts.

In addition, the production costs of combined plants are lower, so that savings of approx. 5% can be achieved (compared to separate units). Not to mention the savings in transportation, installation and commissioning (Concrete Cooling, KTI Website 2017)
5.3 Case Study

Although cold water is much needed in hot weather concreting, a large percent of construction sites are not employing them towards producing quality concrete. Possibly, this is due to lack of knowledge, quality control as well as initial cost of water cooling devices. This part thus provides an analysis to the feasibility of using cold water in different concrete project sizes.

5.3.1 Large Scale Projects

Different mega projects are to be constructed within Egypt’s new administrative capital and will be the subject of this case study. The new capital is listed as one of the biggest eight urban projects transforming cities across the world by 2030. The project will span a 490-square-kilometer-area with 1,100,000 residential units and housing enough for five million people. According to Egypt Housing Minister Madbouly, the project will have a total cost of $45 billion and should be fully completed by 2022 and construction works began in 2015. The new capital is located in the vicinity of new Cairo, and illustrated in below Figure 47 (The New Capital Website, 2017).
A Chinese Business District will be built inside the new capital project, financed by the Chinese government. The district should span an area of approximately half a million-square meter including, 12 business complexes, two hotels and five residential buildings in addition to 345-meter skyscraper that should be the tallest building in Africa to be completed in the next three and half years (Egyptian Streets 2017).
The use of cold mixing water is to be studied with the benefits anticipated on the quality, strength, concrete properties and cost for the business district with estimated 560,000m² built up area and 320,000 m³ of concrete. Based on latest market research for 25 – 30 MPa the concrete cost is at 750 LE/ m³, and for higher quality concrete it can reach 850 LE/m³ with below breakdown in Table 16. Thus, total concrete budget for this project is estimated at 240 Million LE.
Table 16: Plain Concrete Cost Breakdown

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (LE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (350 Kg)</td>
<td>350</td>
</tr>
<tr>
<td>Coarse Aggregates (0.8m3)</td>
<td>80</td>
</tr>
<tr>
<td>Fine Aggregates (0.4m3)</td>
<td>20</td>
</tr>
<tr>
<td>Labor &amp; overheads Cost</td>
<td>45</td>
</tr>
<tr>
<td>Mixer Cost</td>
<td>35</td>
</tr>
<tr>
<td>Pump Cost</td>
<td>30</td>
</tr>
<tr>
<td>Transportation cost</td>
<td>40</td>
</tr>
<tr>
<td>10% Tax and Insurance</td>
<td>75</td>
</tr>
<tr>
<td>Profit (~10%)</td>
<td>75</td>
</tr>
<tr>
<td><strong>Plain Concrete Cost</strong></td>
<td><strong>750</strong></td>
</tr>
<tr>
<td>With admixtures for slump and additional Strength</td>
<td>80 – 110</td>
</tr>
<tr>
<td><strong>Concrete with admixtures</strong></td>
<td><strong>850</strong></td>
</tr>
</tbody>
</table>

The use of cold mixing water when casting in hot summer weather conditions is studied below with the benefits anticipated on the technical side of concrete and in Table 17 as follows;

Table 17: Technical Study of Cold Mixing Water Use on the different projects

<table>
<thead>
<tr>
<th>Item</th>
<th>Technical Impact</th>
<th>Economic Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concrete Temperature</strong></td>
<td>Ensure concrete temperature lower than 35 °C abiding by ACI codes and Egyptian Code requirements.</td>
<td>Ensure no rework, approval of works by project’s consultant and no delays to the project schedule. In addition to parallel penalties, concrete waste and financial hurts.</td>
</tr>
</tbody>
</table>
Concrete Cracks: Minimize plastic shrinkage cracks as concrete hardens.

Concrete Strength: Achieve higher compressive strength upon using cold mixing water (5 °C).

Workability: Achieve higher slump and concrete workability during transportation and casting.

Reduced Cement: Less cement content will be needed in mix design with the enhanced strength of using cold water when compared with hot mixing water.

The above illustrated benefits translates into direct financial savings on the project’s cost summarized in Table 18 below.

<table>
<thead>
<tr>
<th>Item</th>
<th>Savings/ m³ (EGP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiller additional cost (highest capacity selected)</td>
<td>+5</td>
</tr>
<tr>
<td>50% reduction in admixtures</td>
<td>-50</td>
</tr>
<tr>
<td>Up to 10% reduction in cement</td>
<td>-35</td>
</tr>
<tr>
<td>Total Savings (EGP)</td>
<td>-80</td>
</tr>
<tr>
<td>%Savings on 1 m³ concrete (850 LE)</td>
<td>-9%</td>
</tr>
<tr>
<td>Estimated Savings on Total Project's Concrete Value (LE)</td>
<td>(22,500,000)</td>
</tr>
</tbody>
</table>

The use of cold water as illustrated above yields up to 9% direct cost reduction during construction, on the scale of the Chinese District which gives estimated 22.5 Million LE

89
savings, this is in addition to long term help with much reduced repair costs to the concrete and estimated 20% prolonged service life on the structures constructed given higher durability and less cracking.

### 5.3.2 Medium and Small Scale Projects

For projects up to 250 MM EGP value, and parallel concrete works requiring up to 250 m$^3$ of concrete pouring daily, the BNP Head Quarters with total project value of 240 Million LE, 8,400 m$^3$ of concrete (7 Million LE) in Figure 49 was selected with project data in Table 19. Another Small project with total value under 50 Million EGP is studied which is the Technology Training Center in Marsa Matrouh in Figure 50 of 34 Million LE, 4,800 m$^3$ of concrete (3.6 Million LE) was selected. Further details of the project in Table 20 below.

<table>
<thead>
<tr>
<th><strong>Owner</strong></th>
<th>BNP Paribas.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contractor</strong></td>
<td>Orascom Construction Industries.</td>
</tr>
<tr>
<td><strong>Project Manager</strong></td>
<td>ACE Moharram-Bakhom.</td>
</tr>
<tr>
<td><strong>Build-up Area</strong></td>
<td>16,000 m$^2$.</td>
</tr>
<tr>
<td><strong>Foot Print Area</strong></td>
<td>7000 m$^2$.</td>
</tr>
<tr>
<td><strong>Number of Users</strong></td>
<td>600.</td>
</tr>
<tr>
<td><strong>Total Contract Price</strong></td>
<td>241,200,000 LE.</td>
</tr>
<tr>
<td><strong>Concrete work (m$^3$)</strong></td>
<td>8,400</td>
</tr>
<tr>
<td><strong>Quality</strong></td>
<td>High</td>
</tr>
</tbody>
</table>
Table 20: Technology Center in Matrouh Project

<table>
<thead>
<tr>
<th>Owner</th>
<th>Halliburton.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consultant</td>
<td>ECG-Engineering Consultant Group S.A.</td>
</tr>
<tr>
<td>Build-up Area</td>
<td>10,000 m².</td>
</tr>
<tr>
<td>Foot Print Area</td>
<td>2780 m².</td>
</tr>
<tr>
<td>Number of Users</td>
<td>300.</td>
</tr>
<tr>
<td>Total Contract Price</td>
<td>34,445,000 LE.</td>
</tr>
<tr>
<td>Quality</td>
<td>Low</td>
</tr>
</tbody>
</table>
Following the same technical benefits summarized in Table 17, the direct financial help was estimated on the different projects value. The total concrete cost was assumed at 830 LE (80 LE of admixtures within) and 750 LE (no admixtures) for the medium and small projects respectively. This resulted in estimated 8.3% and 4% for the two projects of direct financial help of 577,000 LE and 135,000 LE.
Table 21: The Economic Study of Cold Mixing Water on Medium and Small Scale Projects

<table>
<thead>
<tr>
<th>Item</th>
<th>Savings/ m³ (LE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BNP PARIBAS</td>
</tr>
<tr>
<td>Chiller additional cost (medium and low capacity selected)</td>
<td>6.5</td>
</tr>
<tr>
<td>50% reduction in admixtures</td>
<td>-40</td>
</tr>
<tr>
<td>Up to 10% reduction in cement</td>
<td>-35</td>
</tr>
<tr>
<td>Total Savings (LE)</td>
<td>-68.5</td>
</tr>
<tr>
<td>% Savings on 1 m³ concrete (830 LE and 750 LE respectively)</td>
<td>-8.3%</td>
</tr>
<tr>
<td>Estimated Savings on Total Project's Concrete Value</td>
<td>(577,000)</td>
</tr>
</tbody>
</table>

From the above drawn simulations and analysis, and given the variable considerations, a general estimation model can be used for the concrete manufacturers to understand the cost benefit of using cold mixing water in their projects studies. This would include, an assumption of 10% reduction in cement requirements, 50% reduction in admixtures used and a range of 5 – 7 EGP additional cost on 1m³ of concrete based on their daily pouring rates shown in Table 15 for the different chillers costs. This is addition to reduction on repairs cost and 20% prolonged service life of the concrete structures with less concrete cracking and enhanced quality.
CHAPTER 6 : CONCLUSIONS AND RECOMMENDATIONS

In this chapter the key study conclusions reached from the experimental work and results are presented and summarized. In addition to future recommendations and further studies proposed on the topic.

6.1 Conclusions

In light of materials and procedures used, illustrated results, experimental work and analysis, the following conclusions can be warranted:

1. The fresh concrete mixes with lower mixing water temperature demonstrated a relative increase in the slump test results as recorded in the mixes studied. Such slump increase reflects a general enhanced workability for the concrete mix.

2. Thermocouple data results showed that decreasing mixing water temperature can induce a notable reduction in initial fresh concrete mix temperature during casting and mixing, making it a key parameter in controlling / influencing concrete mix temperatures; especially in hot weather conditions.

3. Thermocouple data further showed higher heat of hydration developing in higher mixing water temperature of 45°C studied, reaching plateau temperatures in relatively higher times than low temperature water mixes of 5°C.
4. Compressive and flexural test results reflected a clear impact of mixing water temperature on the concrete strength developed for the different stages of concrete strength development.

5. For early compressive strength of 1-day, results suggest that higher early strengths developed when increasing the mixing water temperature. This is likely due to faster exothermic reaction of water with cement material and stronger initial bonding for the different concrete constituents.

6. For 3-day and 7-day compressive test results, results reflected higher rate of strength development with the lower water temperature mix when compared with 25 and 45 °C temperature water mixes. Highest rate of increase is witnessed between 1-day and 3-day strengths.

7. For compressive strength of 28 days, colder mixing water yielded much higher compressive strength for the concrete studied when compared with higher temperature mixing water. This is attributed to more cracks developed due to higher initially yielded heat with higher mixing water temperature affecting concrete properties.

8. Flexural beams strengths are also reflecting higher developed strengths for the lower mixing water temperature when compared with high mixing water of 45°C used in testing, suggesting better properties, strength and durability of concrete structures.

9. Superplasticizers, admixtures and silica fumes can directly enhance workability and strength of concrete when coupled with lower temperature water in concrete mix.
10. Feasibility study investigated highlighted a direct financial help in addition to technical positive impacts on the projects of different scales. Whereby, the use of cold mixing water yields 9%, 8.6% and 4% on large, medium and small scale projects studied.

11. The use of cold mixing water can result in +10% reduction in cement in concrete and 50% reduction in admixtures needed.

### 6.2 RECOMMENDATIONS FOR FUTURE WORK

This experimental work conducted in the work scope herein has identified some areas where recommendations can be made and further studies to be conducted including the following:

1. Increasing water temperature variability for a sensitivity analysis to reach optimal mixing temperature that can be later used as reference for concrete manufacturing in hot weather conditions.

2. Using more controlled temperature simulation throughout the experimental work, possibly constructing an environmental chamber to mimic the heat and sun exposure of concrete during casting in elevated temperatures and severe summer conditions.

3. Monitoring the concrete strength for longer period of time (90 days) to further study the structural behavioral and durability of the concrete structure under analysis.
4. Studying the mixed effect of cooling water in addition to other concrete materials (cement or aggregates) during mixing and casting and see any incremental benefits reflected on concrete properties.

5. Use a wider range of admixtures and concrete mixes proportions with higher variability in w/c ratio in order to study and evaluate the mixed effect of materials temperature control (mixing water, aggregates and cement) with those admixtures, where recommendations can be given to manufacturers on best additives to deploy when pouring and mixing in hot summer conditions. In addition to analytical validation of initial temperatures using analysis equations in literature.

6.3 RECOMMENDATIONS FOR APPLICATORS

With above noted impact of mixing water temperature on concrete developed properties, recommendations for applications in hot weather can be drawn as follows;

1- Use water chillers in hot weather concreting for a direct economic benefit on the concrete cost, properties and durability. In addition to meeting the technical requirements of fresh concrete mix temperatures.

2- Working on mixing and casting at night as feasible to avoid further rise in water temperature used and making it easier to control and influence when compared with morning concreting.

3- Integrate methods to lower mixing temperature of constituent materials of the concrete in addition to water temperature.
4- Special consideration in the mixture design for the materials, water content and constituents for hot weather to avoid slump loss and cracking.

5- Use superplasticizers and admixtures to enhance slump, workability and durability of the concrete structures in hot weather conditions as compared to increasing water content to avoid negatively impacting strength.

6- Consultants to mandate concrete temperature measurement in the job sites ensuring mix is within limits and avoiding the negative impacts of hot weather on concrete structures.
REFERENCES


LABORATORIES FOR MATERIALS AND TESTING), SEPTEMBER 21-25, 1992, TORQUAY, ENGLAND.


