Effect of Extremely Hot and Arid Climate on Concrete Properties

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Abstract—**Temperature, strength, and slump of concrete were investigated under extremely hot and arid climate conditions. It is found that the effect of extremely hot and arid weather on concrete strength is similar to the effect in typical hot weather concreting. This may be due to the fact that precautions to control concrete temperature are taken. The effect of concrete temperature on initial slump is minimal and longer delivery time associated with extremely hot temperature creates the worst effect on slump loss. The compressive strength decreases as the slump increases which implies wrong practice to increase the initial slump in order to account the anticipated slump loss. The variation range of concrete temperature between cold and hot weather conditions in Riyadh city is about 16 °C. Moreover, concrete temperature is about 86% to 95% of the ambient temperature and an increase of the ambient temperature by about 5°C would increase the concrete temperature by 2.2°C.**

Index Terms—**hot weather, arid climate, ambient temperature, concrete temperature, strength, slump**

I. Introduction

There are places around the world that experience extremely hot and dry weather conditions. The climate of Riyadh city, the capital of Saudi Arabia, is one of these places. It is characterized by hot and arid environmental conditions that experiences extreme heat and minimal rainfall all the year round. It goes through an extremely hot summer and temperatures which can reach as high as 50 ℃ (122 ℉), with 45 ℃ (113 ℉) being the common temperature. The monthly mean maximum and minimum temperatures, and monthly mean relative humidity in Riyadh city for 8 years period from 2000 to 2007 [1] are shown in Fig. 1. The climatic factors affecting concrete in hot weather are high ambient temperature and low relative humidity. These effects are considerably pronounced with the increase in wind velocity [2]. The combination of hot dry weather and high winds is the most severe conditions, especially when placing large exposed slabs [3].

A higher temperature of fresh concrete will result in rapid hydration and can lead to accelerated setting. This results in shorter time period for transporting the concrete to the job site. Consequently, it reduces the time required for placement, consolidation, and finishing of the material [2]-[4]. Increased rate of cement hydration at elevated temperatures and the increased evaporation rate of moisture from the freshly mixed concrete are the causes of the most problems associated with hot-weather concreting. The ability of a mix to reach its design strength is determined by the efficiency of the chemical reaction that takes place between water and cement. If water remaining in the mix is not enough to complete the hydration process, the final product would be lower than the optimal economic efficiency with a significant decrease in strength and durability [3], [4].

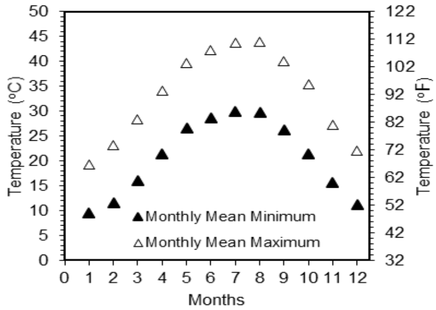

Figure 1. Monthly mean minimum and maximum temperatures for 8 years period from 2000 to 2007.

The higher temperature also leads to a higher water demand in order to maintain the concrete at the specified slump. Quick stiffening and difficulties in handling and finishing the concrete can tempt contractors to undesirably re-temper concrete by adding more water to the mixture. Previous studies state that the strength reduction and other detrimental effects are proportional to the amount of water added for re-tempering [5]-[7]. When concreting is undertaken in Riyadh city during summer which is characterized by extremely hot and arid climate, the temperature of concrete at the time of placing and the ambient temperature during concreting as well as its subsequent curing periods are more severe than the typical hot weather concreting explained by ACI 305R [2]. Therefore, the ultimate goal of this research is to investigate the effect of such harsh environment on some concrete properties based on actual concreting practices.

II. Materials and Experiments

The cement used in ready mix concrete plants was Type I and Type V cement manufactured by local companies and their chemical composition is shown in

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Table I and Table II, respectively. The coarse aggregate is typically a blend of crushed limestone with 20 mm (3/4 in) and 10 mm (3/8 in) sizes. The fine aggregate was a blend of natural silica and manufactured sand obtained from crushed limestone with a blend ratio selected by each ready mix concrete plant to meet the graduation limits specified by ASTM C33 [8]. The municipality of Riyadh city has specified different mix classes to achieve certain strength based on the type of structural member as shown in Table III. Three main concrete tests which are temperature, slump, and compressive strength were conducted. Three samples were taken for each time of testing and the average was calculated. The samples were taken from the transit mixers at the concrete plant that were ready to leave for the job sites. The slump and temperature tests were conducted at the plant according to ASTM C1064 [9] and ASTM C143 [10] respectively. The cubic specimens were casted in rigid molds of dimensions (150 x 150 x 150 mm), cured, and tested for 28 days compressive strength according to BS 1881, part 116 [11].

TABLE I. CHEMICAL COMPOSITION OF TYPE I CEMENT

Chemical composition		% by weight
SILICON DIOXIDE	SiO_2	19.9
ALUMINIUM OXIDE	Al_2O_3	5.24
FERRIC OXIDE	Fe_2O_3	3.78
CALCIUM OXIDE	CaO	63.68
MAGNESIUM OXIDE	MgO	0.71
SULFUR TRI OXIDE	SO_3	2.85
LOSS ON IGNITION	L.O.I.	2.89
INSOLUBLE RESIDUE	I.R	0.78
ALKALIES	(Na_2O+0.658 K_2O)	0.14
TRI CALCIUM ALUMINATE	C_3A	7.47

TABLE II. CHEMICAL COMPOSITION OF TYPE V CEMENT

Chemical composition		% by weight
SILICON DIOXIDE	SiO_2	20.46
ALUMINIUM OXIDE	Al_2O_3	4.13
FERRIC OXIDE	$Fe_2 O_3$	4.47
CALCIUM OXIDE	CaO	64.82
MAGNESIUM OXIDE	MgO	0.74
SULFUR TRI OXIDE	SO_3	2.10
LOSS ON IGNITION	L.O.I.	2.70
INSOLUBLE RESIDUE	I.R	0.52
ALKALIES	(Na_2O+0.658 K_2O)	0.11
TRI CALCIUM ALUMINATE	C_3A	3.38
C_4AF		13.61
$C_4AF + 2(C_3A)$		20.37

III. RESULTS AND DISCUSSION

The results are presented in three sections. The first section explains the effect of ambient temperature on concrete temperature, whilst the second section describes the effect of concrete temperature on compressive strength. The third section presents the effect of concrete temperature on strength and describes the relationship between slump and strength of concrete.

TABLE III. MIX CLASS SPECIFIED BY RIYADH MUNICIPALITY

Mix Class	Cement type	Amount of Cement (Kg/m^3)	Minimum Compressive Strength, MPa	Structural Member	Slump (mm)
M20	Type V	250-300	20	*	100-150
M30	Type I	330-380	30	Slabs and Beams	100-150
M35	Type V Type I	350-380	35	Foundation Columns	75-125
M40	According to the type of the structural member	370-420	40	According to the request of site engineer	75-125

*Beneth of underground strctural members

A. Ambient Temperature

The effect of ambient temperature on the concrete temperature is depicted in Fig. 2. It is clear from the figures that the minimum ambient temperature is in the month of January which increases until the month of August to the highest records. In the cold months the ambient temperature decreases the concrete temperature and vice versa.

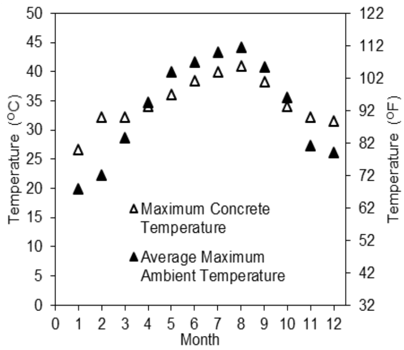

Figure 2. Effect of Ambient temperature on concrete temperature.

Typical effect of ambient temperature on concrete temperature is shown in Fig. 3. The upper peaks in the figure represent the summer months and the lower peaks represent the winter months. The variation range is about 16^{o}C. It is important to mention that the municipality of Riyadh city forces ready mix concrete plants to use precautions during summer season to control concrete temperature including chilled water, sprinkling of aggregate, and shading mix materials.

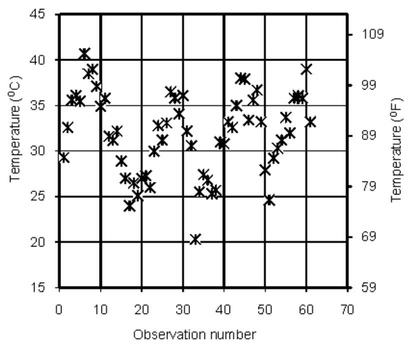

Figure 3. Typical effect of ambient temperature on concrete temperature.

The variation of the ratio of concrete temperature to ambient temperature for each month during year 2000 to 2005 is shown in Fig. 4. It can be seen that the concrete temperature is about 86% to 95% of the ambient temperature during the summer months. The relationship between ambient and concrete temperatures is presented in Fig. 5. It can be stated based on the results that an increase in the ambient temperature by about 5°C (41°F) would increase the concrete temperature by about 2.25°C (36°F). Moreover, it was found that both ambient and concrete temperatures are equal if the ambient temperature is between 31 to 34°C (86 to 93°F).

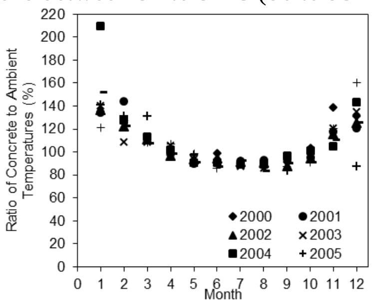

Figure 4. Ratio of concrete maximum temperature to maximum ambient temperature.

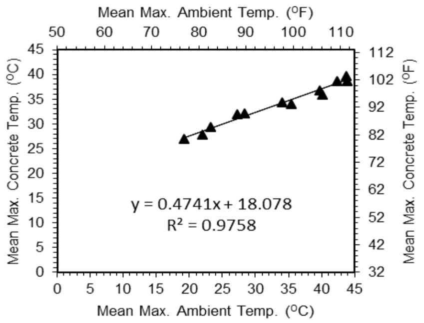

Figure 5. Mean maximum ambient temperature vs. mean maximum concrete temperature for 8 years period from 2000 to 2007.

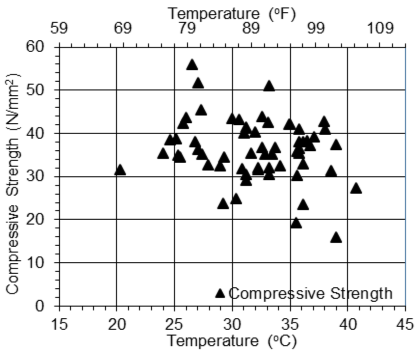

Figure 6. Effect of concrete temperature on compressive strength.

B. Concrete Compressive Strength

The typical effect of concrete temperature on its compressive strength is presented in Fig. 6. It can be observed that the compressive strength decreases as the concrete temperature increases. The results show that the compressive strength for concrete temperatures between 35 to 40°C (95 to 104°F) decreased by about 9% compared to the compressive strength for concrete temperatures between 20 to 25°C (68 to 77°F). This outcome is in line with results reported in the literature for typical hot weather [12]-[15]. In addition, the effect of concrete temperature on the compressive strength was statistically investigated and found not to be significant at $\alpha = 0.05$. The effect of delivery time on compressive strength at summer period in Riyadh city is small as it has been reported that the compressive strength at plant and at site are equivalent [16].

C. Concrete Slump

The typical effect of concrete temperature on slump is presented in Fig. 7. It is found that the effect of concrete temperature on initial slump is minimal. Also, the effect of concrete temperature on the slump was statistically investigated and found not to be significant at $\alpha = 0.05$. However, the effect of delivery time is expected to be high as it has been reported that the delivery slump loss during summer in Riyadh was 37% of the initial slump for an average travel time of 53 minutes [16]. The relationship between slump and compressive strength is depicted in Fig. 8. It is clear from the figure that the compressive strength decreases as the slump increases but found not to be significant at $\alpha = 0.05$. However, this outcome is expected to be due to the wrong practice of increasing the initial slump to account the anticipated slump loss.

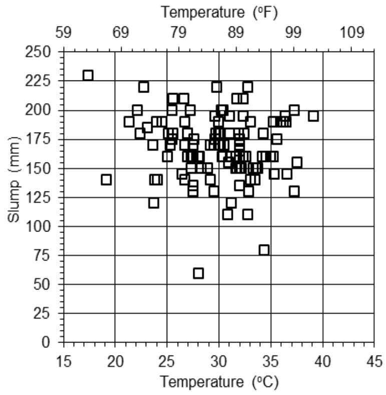

Figure 7. Relationship between temperature and slump.

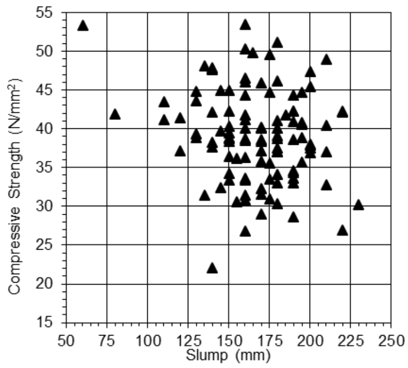

Figure 8. Relationship between slump and compressive strength.

IV. Conclusions

The following conclusions can be drawn from this study:

1. With some precautionary measures, the effect of extremely hot and arid weather conditions on compressive strength could be kept similar to the effect of normal hot weather conditions.
2. The effect of concrete temperature on initial slump is minimal and longer delivery time associated with extremely hot temperature creates the worst effect on slump loss.
3. The compressive strength decreases as the slump increases which implies wrong practice to increase the initial slump in order to account for the anticipated slump loss.
4. The variation range of concrete temperature between cold weather and extremely hot weather with some precautions is about 16°C (61°F).
5. The concrete temperature in extremely hot weather is about 86% to 95% of the ambient temperature when precautionary measures are taken to control the concrete temperature.
6. An increase of the ambient temperature by about 5°C (41°F) would increase the concrete temperature by 2.25°C (36°F).
7. Both ambient and concrete temperatures remain the same if the ambient temperature is between 31 to 34°C (86 to 93°F).

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