Building Tomorrow's Society

Bâtir la Société de Demain

Fredericton, Canada

June 13 – June 16, 2018/ *Juin13 – Juin 16, 2018*

The Effect of Mixing Water Temperature on Concrete Properties in Hot Weather Conditions

Assal, Mennatallah[1] and Abou-Zeid, Mohamed Nagib[1]
[1]Construction Engineering Department, American University in Cairo, Egypt

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 while focusing on curing temperature on overall concrete quality. 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. 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.

1 INTRODUCTION

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 inside the concrete matrix and mix with direct impact on the reinforced concrete causing its deterioration (Nasir et. al. 2016).

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).

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).

2 EXPERIMENTAL PROGRAM

2.1 Materials Selection

The materials used for the concrete mixes under study are mainly sourced from local producers and queries as per below:

Cement: 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).

Coarse Aggregates: Crushed dolomite surface – dry stones for from OCI Crusher, Attakah. The dolomite had a maximum nominal size of 25

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%

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

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: Sourced from Sika to enhance the durability and strength of concrete mixes.

2.2 Concrete Mix Design

Four 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 1 below.

Table 1: Mix Designs Used

Item	Mix 1	Mix 2	Mix 3	Mix 4
Cement (kg)	300	350	450	450

Item	Mix 1	Mix 2	Mix 3	Mix 4
Water (kg)	150	157.5	180	180
w/c	0.50	0.45	0.40	0.36
Fine Aggregates(kg)	681	658	605	594
Coarse Aggregates(kg)	1226	1184	1089	1069
Admixtures	-	2 Liters Plasticizer type "A"	5 Liters Plasticizer type "F"	10 Liters Plasticizer type "F" + 50 kg Silica Fume

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 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)
- 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

2.3 Tests

For the tests; fresh concrete tests of unit weight were carried out for every mix design in accordance with ASTM 138 in addition to slump test as per ASTM C143. 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.

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. 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. Tests carried out summarized in below Table 2.

Table 2: Tests Carried out Summary

Item	Tests	Cubes	Beams	Age of Testing
Fresh Concrete	Slump			
	Unit Weight			
Hardened Concrete	Compressive Strength	X		1,3,7 & 28 days
	Flexural Strength		X	28 days
Other	Concrete Temperature Monitoring		X	24 hours

3 TEST RESULTS AND DISCUSSION

3.1 Fresh Test Results

3.1.1 Slump and Unit Weight

Unit weight, Slump results were measured and summarized below for all 12 concrete mixes as per previously illustrated experimental method in below Table 3 as follows;

Table 3: Slump and Unit Weight Test Results

Mixes	Mix 1 (300 kg Cement)			Mix 2 (350 kg)			Mix 3 (450 kg)			Mix 4 (450 kg)		
Temperature (˚C)	5	25	45	5	25	45	5	25	45	5	25	45
Slump (cm)	4	0	1	5	3	1	20	19.5	18	24	22	22
Unit Weight (kg/m3)	2477	2324	2496	2436	2371	2508	2460	2372	2413	2347	2390	2339

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/ m^3 ranges.

3.1.2 Concrete Temperature Test

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 24 hours time span of the experimental work. Below graphs show the temperature recorded for the different mixes of concrete at different mixing water temperatures.

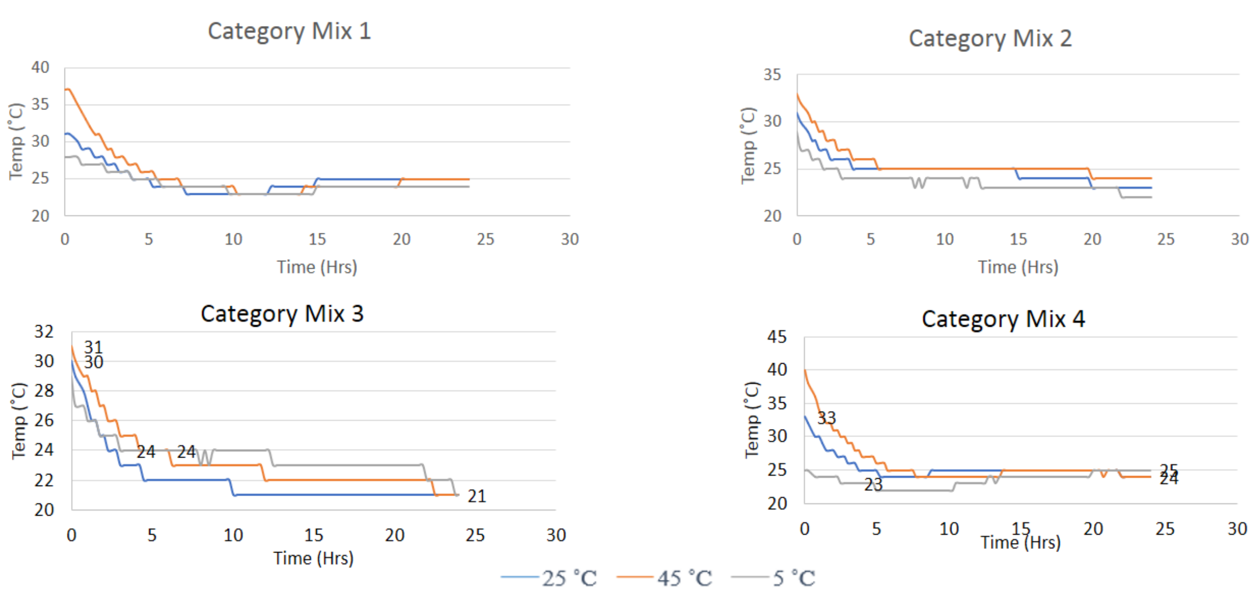

Figure 1: Concrete Temperature Results

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.

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.

Results summarized for mix 3 in Figure 1 showedsmaller 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.

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

3.2 Hardened Concrete Tests

3.2.1 Compressive Strength

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.

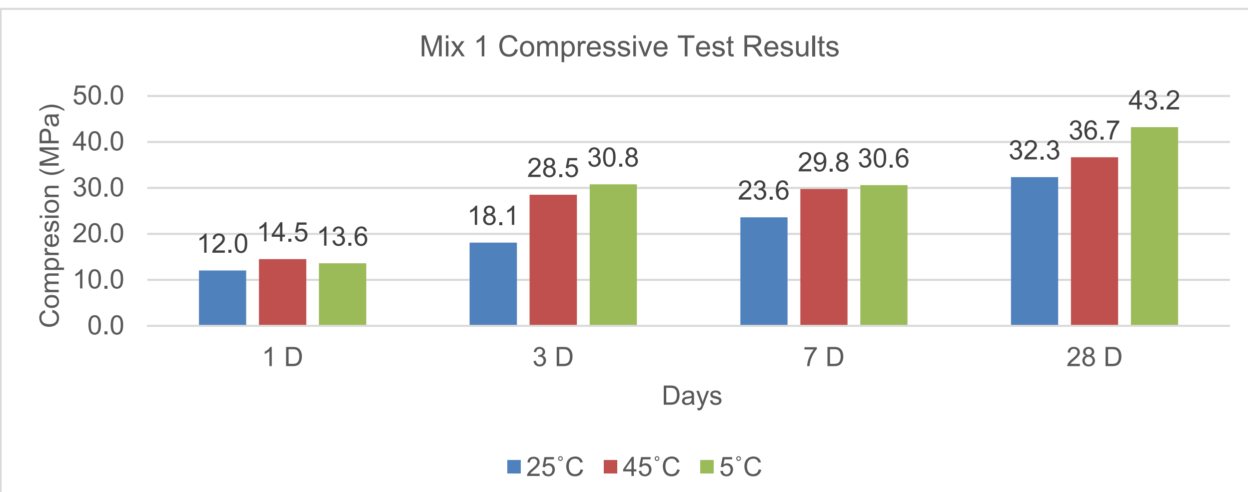

Figure 2: Mix 1 Compressive Test Results

Figure 2 shows results of Mix 1 with 300 kg cement, w/c ratio at 0.5 and no admixtures revealing 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. 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.

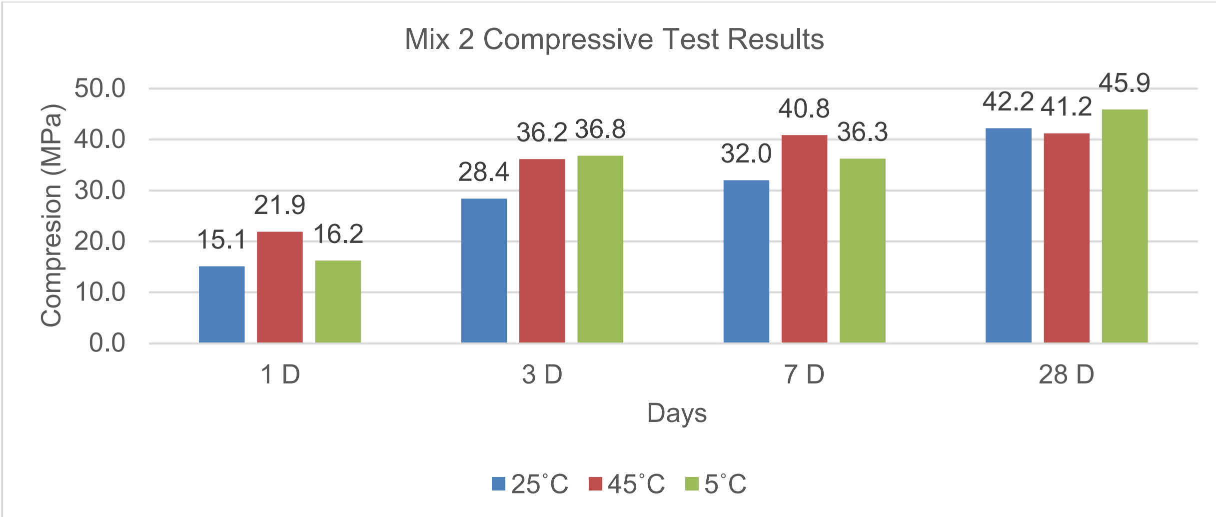

Figure 3: Mix 2 Compressive Test Results

Figure 3 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. 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. 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. 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.

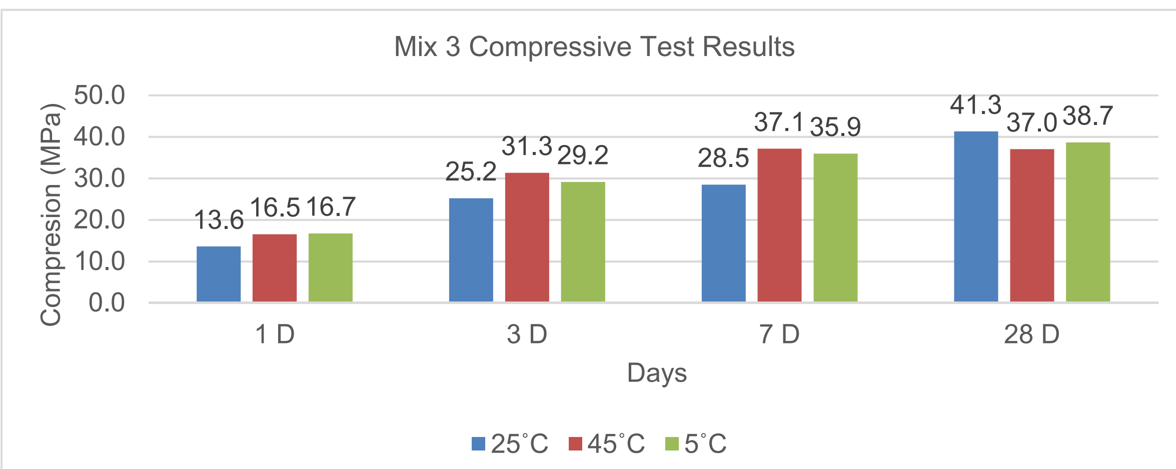

Figure 4: Mix 3 Compressive Test Results

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. 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 4 above.

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.

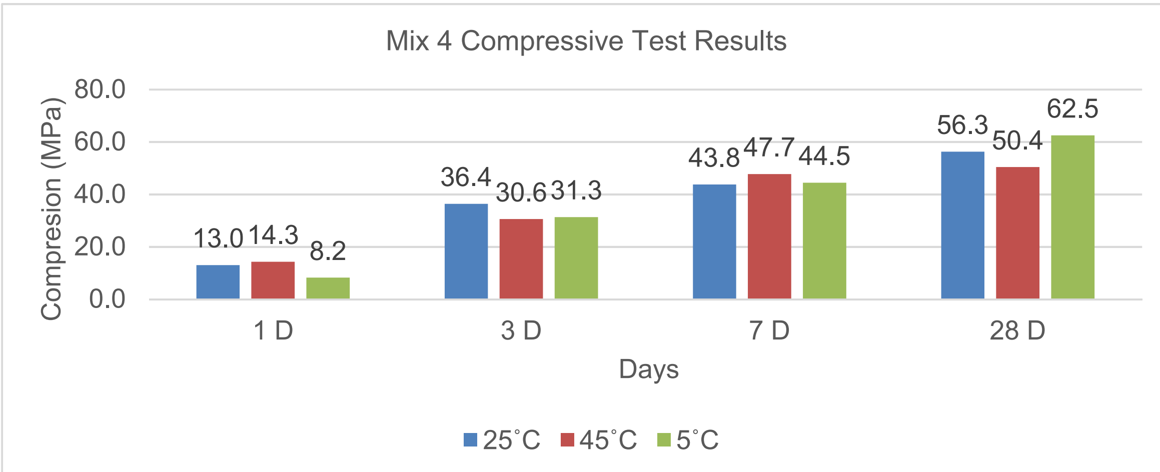

Figure 5: Mix 4 Compressive Test Results

Figure 5 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 which is also the highest across all 12 concrete nixes in scope of this experimental work.

3.2.2 Flexural Test Results

For the flexural test, beams were tested for failure using the three point test machine, though applying loads in the midspan of the beams and testing failure to deliver below results;

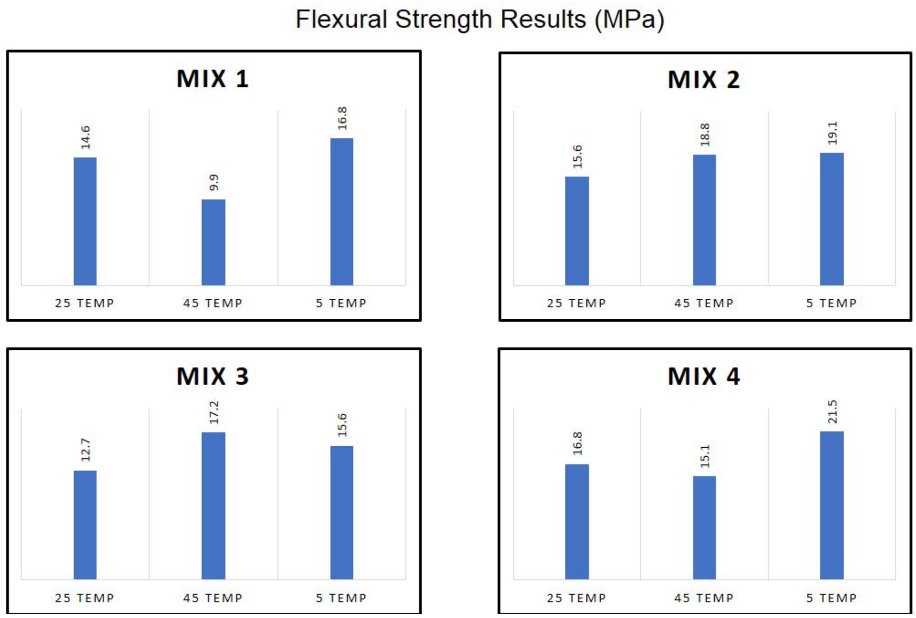

Figure 6: Flexural Test Results

Figure 6 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.

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. 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 .

Mix 3 with 450 kg cement giving higher average strength among the test results. It recorded average of 17.2, 12.7 and 15.6 MPa for the 45, 25 and 5 ˚C water respectively as shown in Figure 6. 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.

For mix 4 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. 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.

4 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 tp faster exothermic reaction of water with cement material and stronger initial bonding for the different concrete constituents.

6. 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.

7. 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.

8. Superplasticizers, admixtures and silica fumes can directly enhance workability and strength of concrete when coupled with lower temperature water in concrete mix.

5 RECOMMENDATIONS

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:

9. 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.

10. 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.

11. 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.

12. 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.

Acknowledgements

This publication is based on the work conducted in the Construction Engineering Materials Lab in the American University in Cairo by Mennatallah Assal and under the supervision of Professor Mohamed Nagib Abou-Zeid.

References

Hover, K. (2005). Hot Weather Concrete. STRUCTURE, 27.

Nasir, M., Al-Amoudi, O. S. B., Al-Gahtani, H. J., &Maslehuddin, M. (2016). Effect of casting temperature on strength and density of plain and blended cement concretes prepared and cured under hot weather conditions. Construction and Building Materials, 112, 529-537.

Neville, A. M. (1995). Properties of concrete (Vol. 4). London: Longman.

Ortiz, J., Aguado, A., Agulló, L., & García, T. (2010). Influence of environmental temperatures on theconcrete compressive strength: Simulation of hot and cold weather conditions. *Cement and concrete research*, *35*(10), 1970-1979.