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THE IMPACT OF MIXING WATER TEMPERATURE ON PORTLAND CEMENT CONCRETE QUALITY

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Abstract: Water is as an essential component in the concrete mix as it has a direct influence on the workability; strength; durability and other performance aspects of concrete together of its indispensible role in reaction with cement. This study aims at assessing and quantifying the impact of mixing water temperature on the performance of fresh and hardened Portland cement concrete. In this work, concrete mixtures were prepared using different mixing water temperatures, 5, 15, 30, and 45°C. The temperature of the aggregates and the cement were controlled throughout the process, where sixteen mixes were poured at room temperature and two mixes were poured at 45°C in order to simulate hot weather conditions. Mineral and chemical admixtures were used, in order to evaluate the impact of mixing water temperature on the properties and the functions of those admixtures. For each mix, two sets of tests were conducted: firstly, fresh tests including measurement of temperature, unit weight, air content and slump retention. Secondly, hardened concrete tests were conducted including compressive and flexural strength tests as well as chemical durability. A separate set of tests were conducted to simultaneously monitor the heat of hydration for concrete samples with time. Results of the study highlight the strong impact of water temperature on concrete performance particularly at early ages. The results well justifies, in a quantitative manner, the need to incorporate cold/chilled water in hot weather conditions. Recommendations are provided for concrete applicators in hot weather conditions.

1 INTRODUCTION

Portland Cement Concrete, the most commonly used construction material, is composed of aggregates, water, and cement. Cement, the binding material in concrete, is a hydrophilic material which means it needs water to react. Water is an excellent tool to control the temperature of concrete, thus during the mixing of concrete, water is sometimes poured as hot water in cold weather conditions, and as cold water in hot weather conditions, or in most cases it is poured at room temperature.

Several problems may arise with hot weather concreting. The first problem that may arise is the formation of cracks due to differential temperature. Differential temperature is caused between the exterior atmosphere temperature, and the high temperature inside the concrete caused by the water, and cement reaction. This differential temperature results in deferential volumetric changes, leading to cracks in the concrete. Another problem that may occur due to hot weather concreting is the excessive evaporation and absorption by the aggregates of the mixing water which can lead to a change in the water to cement ratio leading to problems in the consistency, and workability of concrete. Finally, since the reaction between cement and water is an exothermic reaction, this reaction is sped up when the concrete is hot, as cement consumes the water around the aggregates. When the concrete is hot due to outside temperature, crystals grow around aggregates in a rapid manner but not in a strong manner. So, even though, the concrete gains high early strength, the 28-day strength of concrete suffers greatly.

Naganathan and Mustapha (2015) studied the effect of water temperature during casting and curing of concrete on concrete properties. They concluded that concrete should be prepared by using water temperature in the range between 20ºC to 35ºC to obtain good quality concrete. Etienne (2015) presented the results of an experimental research conducted in Eastern Nigeria to determine the effect of mixing-water temperature on the compressive strength, workability and setting time of concrete. He concluded that the water temperature has significant effect on the compressive strength, workability and setting time of concrete.

The objective of this work is to get a better understanding of the impact of mixing water temperature on the performance of concrete. Different water temperatures will be tested on different sets of concrete mix designs. Four different mixing water temperatures are in the present research namely; 5, 15, 30, and 45°C. These water temperatures are found throughout Egypt, for example according to World Weather Online, temperatures may be as low as 15° C in St. Catherine, South Sinai, and water left in tanks during the day in the middle of summer months could easily reach a temperature of 45°C. Whereas, water with a temperature of 5° C could be found in an upscale project where a concrete plant is installed on site and is equipped with a chiller or a similar device.

Concrete mixtures were prepared with variations mix designs by changing the amount of cement and the type of admixtures in order to gain knowledge about the impact of mixing water temperature on different concrete mixes used in various concrete industries. Testing scheme covers multiple fresh and hardened concrete tests with the aim of hopefully giving recommendations to the concrete industry on controlling mixing water temperature to reach the best quality concrete.

2 EXPERIMENTAL PROGRAM

2.1 Material Properties

Cement: Type I Ordinary Portland Cement Concrete with specific gravity of 3.15.

Fine Aggregates: Natural sand from situ was used; the sand had specific gravity of 2.55 and a fineness modulus of 2.82.

Coarse Aggregates: Well-graded crushed lime stones were used as coarse aggregates. The aggregates had maximum size of 38 mm and an S.S.D specific gravity of 2.62.

Water: Ordinary municipal tap water was used for washing the aggregates as well as the production and curing of the concrete mixtures. Four different mixing water temperatures of 5 °C, 15°C, 30 °C and 45 °C are used.

Plasticizer: Type A, used to reduce the water in the concrete mix, it is locally manufactured with specific gravity of 1.11.

Super Plasticizer: Type F, to acquire low water/cement ratio and cohesive. It shifts the concrete to a new gear. It is locally manufactured.

Silica Fume: A by-product of producing silicon metal or ferrosilicon alloys. It is used because of its chemical and physical properties; it is a very reactive pozzolan. Concrete containing silica fume can have very high strength and can be very durable.

2.2 Concrete mix design

The concrete mixture that was used in the experimental work of this study consists of four different concrete mix designs, with cement content of 300 kg/m^3 and water-to-cement ratio of 0.5, 350 kg/m^3 and water-to-cement ratio of 0.45, 450 kg/m^3 and water-to-cement ratio of 0.4, and 450 kg/m^3 together with 50 kg of Silica Fume and water-to-(cement + silica fume) ratio of 0.36. Each mix was carried out in the lab with four different mixing water temperatures 5 °C, 15°C, 30 °C and 45 °C. Admixtures were used such as Chemical Admixtures Type “A” Plasticizer, and Type “F” Superplasticizer. The four concrete mixes are shown in Table 1. Concrete mixing and casting of specimens were carried out according to ASTM standards.

Table 1:: Mix Design Used

Item	Cement (kg)	Water (kg)	w/c	Fine Aggregates (kg)	Coarse Aggregates (kg)	Admixtures (kg)
Mix 1	300	150	0.5	681	1226	-
Mix 2	350	158	0.45	658	1184	2.2 Plasticizer type “A”
Mix 3	450	180	0.4	605	1089	6 Superplasticizer type “F”
Mix 4	450	180	0.35*	594	1069	12 Superplasticizer type “F” + 50 Silica Fume

* water - to –(cement +silica fume) ratio

2.3 Test Program

The test program consists mainly of two sets, the first set of test is the fresh concrete tests and the other set is the hardened concrete tests. The fresh concrete tests are as follows; unit weight test, air content, fresh concrete temperature, slump and slump retention. While the hardened concrete tests consist of the following; compressive strength tests for the cubes, flexural strength tests for the beams and chemical durability.

The fresh tests were conducted according to the pertinent ASTM standards.

For the hardened concrete tests, the compressive strength tests are done on the 150x150x150 mm cubes and flexural strength tests are done on150x150x750 mm beams. The chemical durability tests are done in the lab using sulphuric acid and sodium sulphate. `

The heat of hydration of the concrete for known time intervals was measured using thermocouples test This test in details is conducted for all the mixes poured at mild temperatures (23°C) using only 5°C and 45°C as mixing water temperatures. In addition,, this test is also conducted on two additional samples using heated Mix 2 with 5°C and 45°C mixing water temperatures, where all components of the mix including cement, fine and coarse aggregates are heated at 45°C. A sample beam from each mix mentioned above is poured where a wire is imbedded in the middle of it at a known depth and width. A data logger connected to a computer in the lab and to the wires imbedded inside the beams, measures simultaneously the temperature versus time for eight hours. These results are done in order to get the heat of hydration of these mixes.

3 TEST RESULTS AND DISCUSSION

3.1 Fresh Concrete Results

The fresh concrete test results are presented in Table 2 and Table 3. The Slump test results were within the acceptable range between 20-100 mm. However, the mixes did not retain the same slump after 10, 20 30, 45 60 and 90 minutes. As for the Air Content results, it varied between 1% - 4%. The initial temperatures for all Mixes that was poured at mild temperature did not exceed 26°C which is close to the ambient temperature in the lab. Concerning the heated Mix 2, where all constituents were heated at 45° C, the initial temperature was 30°C when 5°C mixing water was used and 34°C when 45°C mixing water was used. The sump results were also with the acceptable limits. The slump value dropped slightly after 10, 20 30, 45 60 and 90 minutes.

Table 2: Results for Fresh Tests for all Mixes

Mix No.		Mix 1				Mix 2				Mix 3				Mix 4			
Water Temp.		**5º**	**15º**	**30º**	**45º**	**5º**	**15º**	**30º**	**45º**	**5º**	**15º**	**30º**	**45º**	**5º**	**15º**	**30º**	**45º**
Initial Temp. (°C)		20	21	23	25	20	21	23	25	21	20	23	25	22	24	25	26
Unit Weight (kN/m³)		20	24	24	24	24	24	24	24	25	30	25	24	24	24	24	24
Air Content %		4.0	3.2	3.5	2.5	4	3.3	3.7	3.0	1.5	1.7	2.0	1.8	3.4	4.0	3.5	3.0
Slump (mm.)		20	20	20	20	20	20	50	50	80	80	90	100	20	20	30	30
Slump Retention (mm)	**10 mins**	10	20	20	10	20	20	50	40	70	80	90	80	20	20	20	20
	30 mins	10	10	20	10	20	20	40	40	70	80	80	80	20	20	20	20
	45 mins	10	10	20	10	20	20	40	40	70	70	80	80	20	20	20	20
	60 mins	10	10	10	10	20	20	40	40	70	70	80	80	20	20	20	20
	90 mins	10	10	10	10	20	20	40	40	70	70	80	80	20	20	20	20

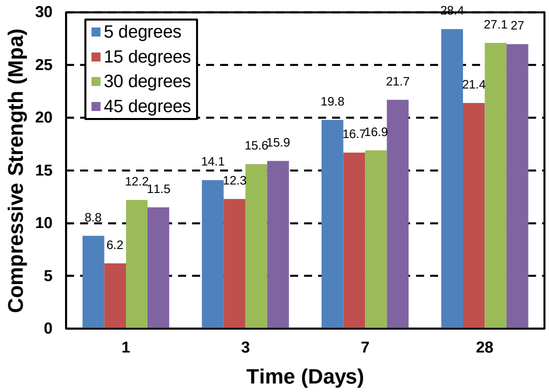
Table 3: Results of Fresh Tests for Heated Mix 2

Water Temp.		15º	45º
Initial Temp. (°C)		30	34
Unit Weight (kN/m³)		23	22
Air Content %		3.9 %	3.2 %
Slump (mm.)		80	70
Slump Retention (mm)	**10 min.**	70	60
	30 min.	70	60
	45 min.	70	60
	60 min.	70	60
	90 min.	70	60

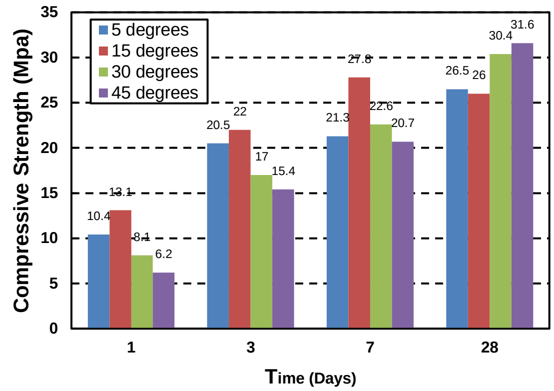
3.2 Hardened Concrete Results

The compressive strength results for all mixes are presented in Figure 1. The figure shows that the maximum compressive strength at 28 day was attained for mixes M1, M2, M3, and M4 for mixing water temperature of 5º C, 45º C, 45º C, and 15º C respectively. There is no clear pattern for change of the compressive strength with the temperature of the mixing water. The temperature at which the maximum strength occurs varies with the age and the constituents of the mix. Comparing the results of Mix 2 without heating the constituents of the mix with that of the heated constituents, it can be seen that heating the mis constituents to 45ºC increased the compressive strength at all tested ages of the concrete mixes for both mixing water temperatures..

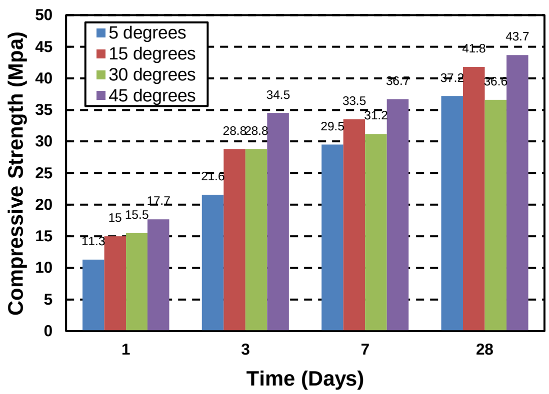
Figure 2, illustrates the flexural strength (MPa) for all mixes. Similar to the results of the compressive strength, there is no specific trend for attaining the highest flexural strength with the mixing water temperature. The highest flexural strength after 28 days was attained for mixes M1 and M2 when the temperature of the mixing water was 5º C, 45º C, respectively which is consistent with the compressive strength results. For Mix M3, The highest flexural strength after 28 day occurred for the mix with mixing water temperature of 15º C while the highest compressive strength occurred with 45ºC mixing water. For mix M4, the highest flexural strength was attained with 5ºC mixing water compared to 15º C for the highest compressive strength



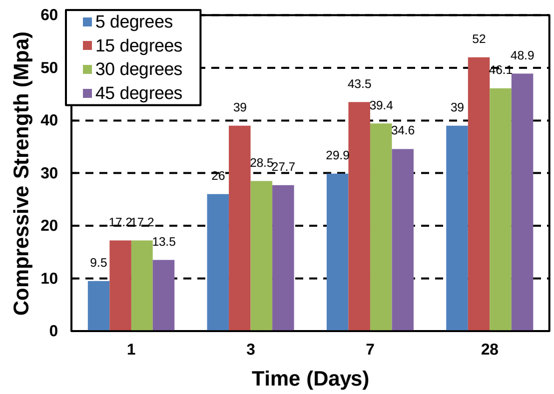
a) Mix 1



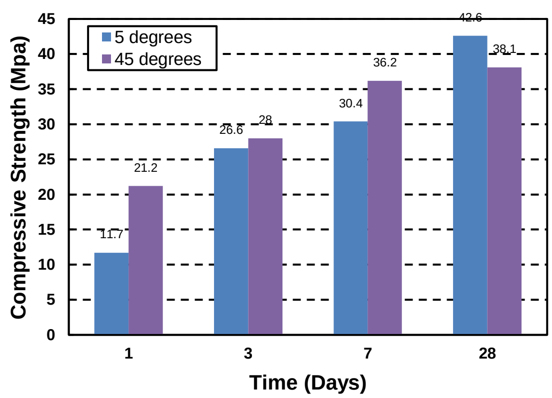
b) Mix 2



c) Mix 3

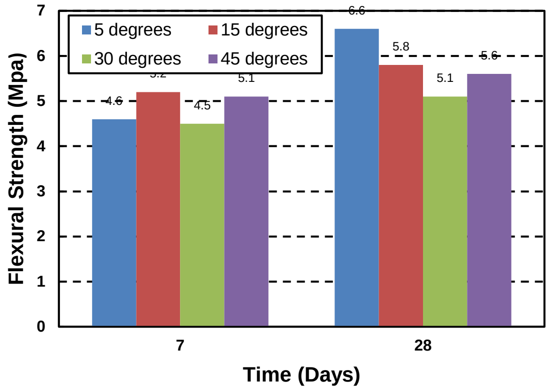


d) Mix 4

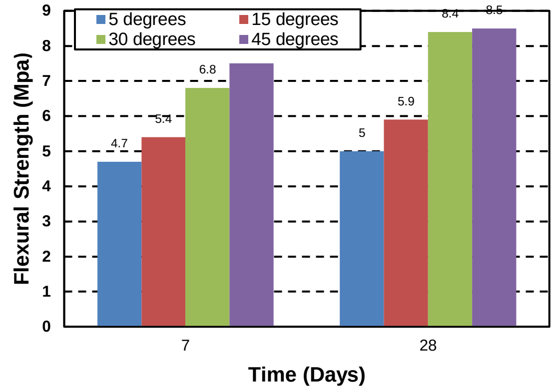


e) Mix 2 with heated constituents

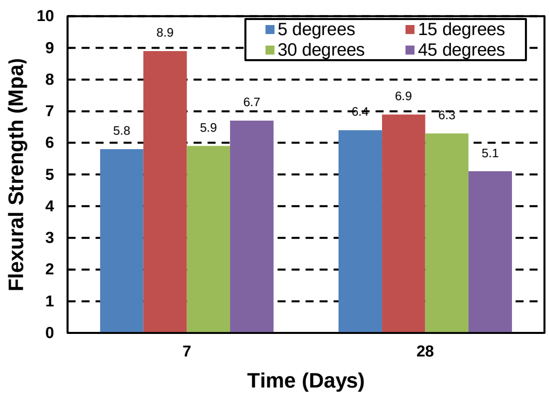
Figure 1: Test results of the compressive strength for all mixex



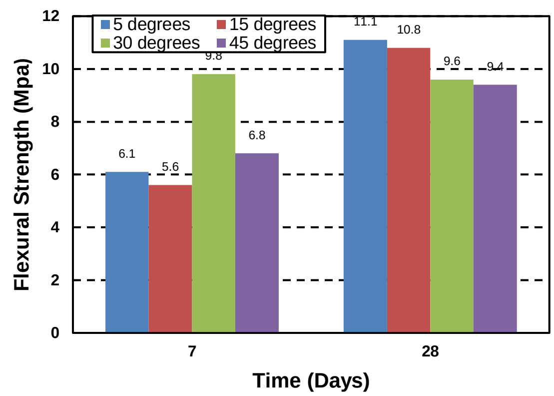
a) Mix 1



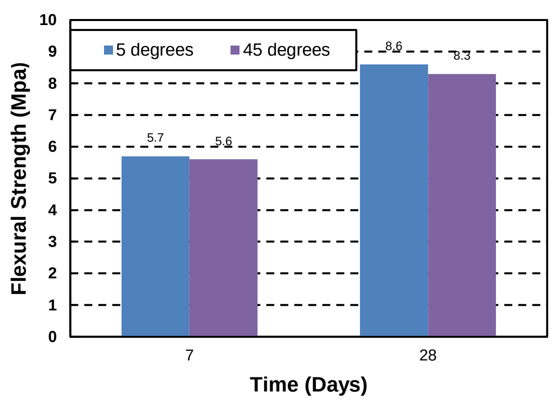
b) Mix 2



c) Mix3



d) Mix 4



e) Mix 2 with heated constituents

Figure 2: A Experimental results of the flexural strength test for all specimens

3.2 Thermocouples Results

The results of the Thermocouple tests are given in Table 4 and sample of the results are illustrated in Figures 3 and 4.

Concrete Mix	Mixing Water Temperature	Ambient Temperature	Time to Reach Plateau	Temperature at reaching the Plateau
M1	5º C	23º C	6 hrs.	23.7 °C
M1	45º C	23º C	3 hrs. 29 min.	24.3 °C
M2	5º C	23º C	1 hr. 33 min.	22.3 °C
M2	45º C	23º C	7 hrs.	22.7 °C
M3	5º C	23º C	1 hr..	21.4 °C/ 22.0 °C
M3	45º C	24º C	5 hrs. 24 min.	23.0 °C
M4	5º C	24º C	4 hrs. 51 min.	24.1 °C
M4	45º C	24º C	5 hrs. 12 min.	26.5 °C
M2 Heated Mix	5º C	24º C	5 hrs.	29.5 °C

Figure 3 illustrates the thermocouples results of mix M3 for the 5°C and the 45°C temperatures of mixing water. The ambient temperature was 23°C. As noted the time for the 5°C temperature to reach a plateau was about 1 hour and it took 4 hours and 56 minutes until the temperature started to noticeably increase again As for the 45°C temperature of mixing water, The ambient temperature was 24°C. As noted the time taken to reach plateau was about 5 hours and 24 minutes.

Figure 4 illustrates the Thermocouples results of 350 kg cement with Plasticizer "A" which is Mix 2, where all constituents were heated at 45°C using 5°C temperature of mixing water. The ambient temperature was poured w 24°C. As noted the time taken to reach plateau was about 5 hours.

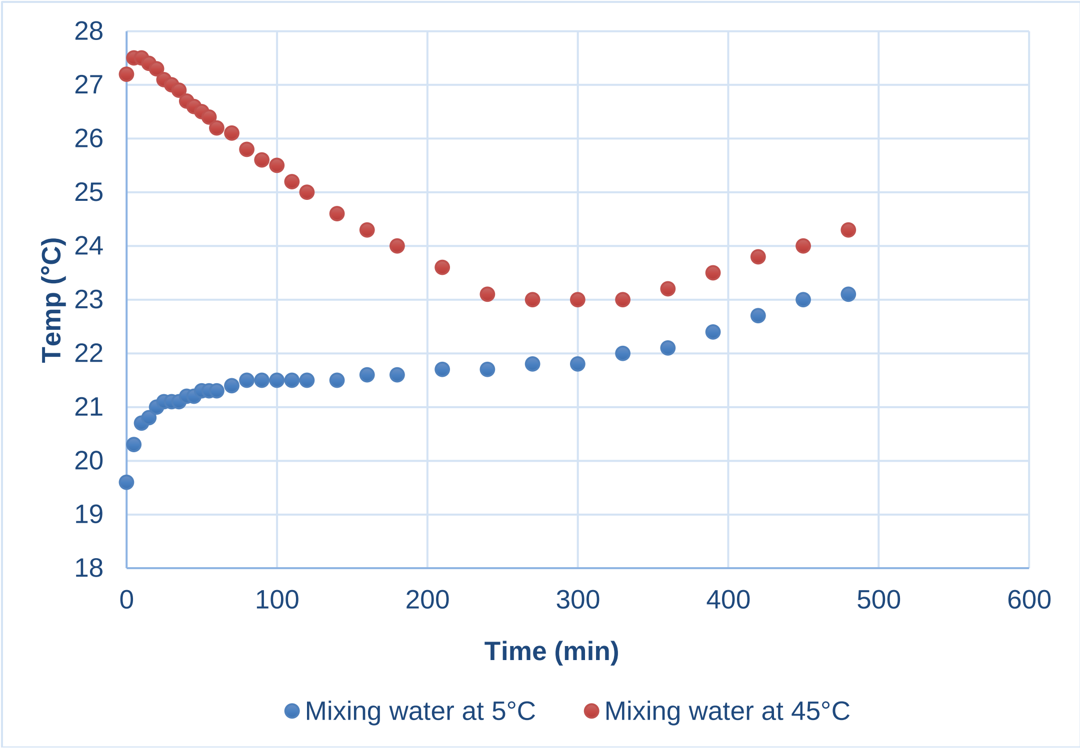


Figure 3: Thermocouple Results for Mix 3

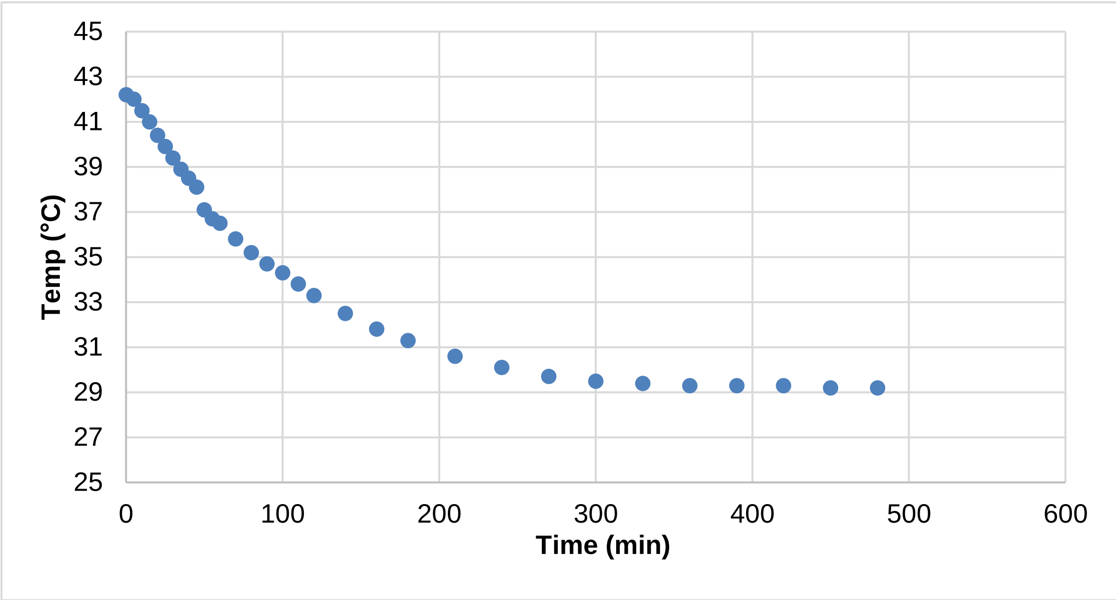


Figure 4: Thermocouple results for Heating all Mix Components and 5°C Mixing Water

When Conducting the Thermocouples test on our 5 different mixes, it was observed that the temperatures at Plateau/ after rise up of the mixes where 45° C mixing water was used, were higher than of the mixes where 5° C mixing water was used.

4 CONCLUSIONS

In light of the experimental work presented herein and the parameters associated with it, the following conclusions could be stated:

- Adding cold water (5°C) to concrete constituents at mild temperatures (23°C) results in a pattern of temperature increase until a plateau. This plateau happens in a window between 3 and 8 hours depending on the concrete mix.
- Adding heated water (45°C) to concrete constituents at mild temperatures (23°C) results in a pattern of temperature decrease until a plateau.
- Mixtures rich in cementitious material with or without Silica Fume seem to have no or short plateau, as the cementitious material continues to hydrate past the termination of test.
- When all constituents of the concrete were at mild temperatures (23°C), close results for compressive and flexural strengths were observed; therefore they were not significantly affected by the different mixing water temperatures.
- When all constituents of the concrete were at relatively hot Temperature (45°C), cooling water to (5°C) contributed to an increase in the 28-day compressive strength that up to 5 MPa.

5 RECOMMENDATIONS

Since drawing a conclusion regarding the impact of mixing water temperature is somewhat limited to our experimental work, the following recommendations can be drawn in light of the relatively limited time for such challenging area of investigation, several recommendations are to be made for future research work

- Larger set of mixtures of various temperatures at longer ages are to be evaluated.
- More moistures are to be performed on heated constancies with various contents
- Other Tests particularly on the long-term properties & durability need to be conducted in future research such as fatigue test, creep test and long term abrasion test.
- In order to validate the thermocouple results obtained in this study, Thermocouple measurements for longer durations need to be resumed up to at least 1 day, using high capacity apparatus.
- Chemical durability tests should be carried out for longer periods using various concentrations.

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