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Effect of Water Temperature on Concrete Properties

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ABSTRACT

This paper describes the effect of water temperature during casting and curing of concrete on concrete properties. The concrete specimens were casted and cured under different water temperatures and then the properties of concrete were tested. The tests include slump, compressive strength, rebound hammer, ultrasonic pulse velocity (UPV) and water absorption. The results of this research show that high water temperature used in concrete production will reduce the strength and quality of concrete. Presence of hot water in concrete mixture leads to defects and failure in the concrete in the hardened state. It is concluded that concrete should be prepared by using water temperatures in the range between 20°C to 35°C in order to obtain good quality concrete.

KEYWORDS: Concrete, Casting temperature, Compressive strength, Rebound hammer, Ultrasonic pulse velocity, Water absorption.

INTRODUCTION

Concrete is a composite construction material, composed of Portland cement and other cementitious materials, aggregate, water and chemical admixtures. Concretes have varied properties based on their formulations. Generally, properties of concrete are divided into two major groups; namely fresh properties and hardened properties. Fresh concrete is the stage of concrete in which concrete can be molded while it's in plastic state, whereas hardened concrete is the stage of concrete in solid state, having developed certain strength. The chemical reaction is continuous from fresh state to hardened state of concrete. In order to produce a good quality concrete, several factors need to be considered, such as controlling the water-cement ratio, suitable temperature, type and amount of aggregates, type and fineness of cement, relative humidity and admixtures (Kosmatka and Panarese, 1988).

Studies conducted by Lerch (1955) showed that to lower the temperature of normal concrete by 1°C, the temperature of the cement must be reduced by 8.2°C, the temperature of the water reduced by 4.9°C, and the temperature of the aggregates lowered by 1.5°C. The reason for this is the intrinsic thermal properties of the concrete materials and mix proportions. Cement usually occupies 7% to 15% of the concrete volume, while water and aggregates occupy 70% to 90% of the concrete volume. By comparing the weight among the mentioned three materials, potential influence from cement is negligible. Moreover, cement has a very low average specific heat capacity of 0.92 kJ/kg.K, which means that it gains and loses heat very readily when exposed to high temperature and similarly, goes to aggregates on average which has an equivalent specific heat capacity to cement. However, water has a very high specific heat of 4.184 kJ/kg.K, indicating that it can store a large quantity of heat (Lerch, 1955).

Generally, concrete provides adequate fire resistance for most normal applications. Unfortunately,

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the strength of concrete decreases at elevated temperatures due to chemical and physical changes (Crozier and Sanjayan, 1999). Water is one of the main ingredients in the production of concrete because it is an agent to form a paste that binds the aggregates together when it's mixed with cement. Water will control the overall strength and workability of the concrete mixture (Richard and Gaynor, 2010). Water reacts with Portland cement in a process known as hydration to form a cementitious paste that hardens with time. This hydration process is a complex chemical reaction which physically alters the character and properties of the matrix (Neville, 1995). The water used for concreting should be clear from any contaminated materials in order to prevent any unwanted reaction that may reduce concrete strength or otherwise interfere with the hydration process. Besides, the temperature of water due to environmental conditions that react with Portland cement may affect the overall quality of concrete production (Berhane 1984). It is necessary to apply water curing on self-compacting concrete for the initial 7 days period to expose pozzolanic activity. Also, full room curing condition (dry curing in lab condition) showed higher mechanical properties than full water curing condition (Zhao et al., 2012).

Nowadays, most of the problems in concreting work are due to the presence of hot water because of hot weather. It is difficult to control the water temperature during concreting work and water has the greatest effect per unit weight on concrete temperature. This is because water has a specific heat about four to five times that of aggregates or cement (ACI 305R-10, 2010). Concrete mixed, placed and cured at elevated temperatures normally will cause a low degree of hydration of cement at later ages and therefore result in a pore structure of cement paste, lower compressive strength and higher permeability of concrete. Despite this, concrete develops higher early strength when casted and cured at elevated temperatures than concrete produced and cured at lower temperatures (Verbeck and Helmuth, 1977). Unfortunately, there is insufficient information or previous findings available on the effect of water temperature on concrete properties.

In this research, several water temperatures were used during the production of concrete to study the effect of water temperature on concrete properties. The behavior of concrete under various water temperatures during casting as well as during curing was investigated. By understanding the effect of heat from surroundings toward water temperature during concrete production, an adjustment of concrete mix and proper concrete handling can be made to maintain high quality standards of concrete production.

METHODOLOGY

The investigation was carried out on a designed concrete mix with target strength of 30 MPa at 28 days of curing by using locally available materials. The mix design was carried out based on the British method (Neville, 1995). The temperature of water added during mixing and curing was controlled. Tests include slump test during fresh state, compressive strength, UPV, rebound hammer and water absorption in the hardened state of concrete up to 28 days.

Materials and Mix Proportions

Type I Portland cement confirming to (ASTM C150, 2011) was used in the concrete mixture. Coarse aggregate with specific gravity of 2.60 was used, whereas the specific gravity of fine aggregate was 2.73. The fineness moduli of coarse and fine aggregates were 5.41 and 2.33, respectively, and the grading of both aggregates was confirming to (BS 882, 1992). Tap water available in the laboratory was used for mixing as well as for curing of concrete throughout the investigation. The mixture proportion used in the investigation is shown in Table 1. Water-cement ratio was kept constant at 0.67. The workability of concrete under room condition is expected to be in the range of 30-60 mm slump.

Table 1. Mixture proportions

Constituent material	Weight (kg/m³)
Water	190
Cement	284
Coarse Aggregate	1002
Fine Aggregate	925

Casting and Curing

In this investigation, the temperature of mixing water was kept at 25°C, 50°C, 75°C and 100°C. The water was heated to the specified temperature and then added to the mixture during casting. The coarse and fine aggregates were transferred into a rotary type concrete mixer and mixed for 2 minutes. About half of the water needed was added and mixed for one minute. Cement was then added into the mix and the contents mixed for 30 seconds.

The remaining water was then added and the contents mixed for 3 minutes. The concrete mixture was then tested for slump. Then, the mixture was filled into the 100 mm cube moulds. The moulds were vibrated via a table vibrator for 10 seconds to eliminate entrapped air. The moulds were kept covered using wet gunny in the laboratory condition for one day and then removed and placed into three different water curing temperature tanks. The temperatures of water in the curing tanks were kept at 20°C, 35°C and 50°C. The cubes were taken out from the tanks before the testing date. Tests on hardened concrete were carried out at 3, 7, 14 and 28 days.

Test Methods

The concrete mixture was tested for slump in its fresh state, as well as compressive strength, rebound hammer, UPV and water absorption at hardened state. The workability and consistency quality of concrete mix can be determined using the slump test. The slump test is prescribed by (BS 1881: Part 102, 1983). This test was carried out to determine the slump value of the concrete mix as an indicator of its workability and quality.

The compressive strength of concrete was tested according to (BS 1881-116, 1983). The test was carried out on three 100 mm cubes using a compression testing machine at 3, 7, 14, and 28 days. The compression machine used in this research was Automatic Compression Tester (50-C4752) having a loading capacity of 2000 kN. Loading on test specimen was applied at a constant rate of stress equal to 0.2 to 0.4 MPa/s. Test for rebound hammer was conducted using Nailik NL4021 Concrete Test Hammer with an impact energy of 2.2 J in accordance to (BS1881-202, 1983). UPV test was carried out as per (BS 1881-203, 1986) using a CMH Ltd. Pundit 6 ultrasonic tester. This test method covers the determination of the propagation velocity of longitudinal stress wave pulses through concrete. Test for water absorption was carried out according to (BS 1881: Part 5, 1970) at 28 days.

RESULTS AND DISCUSSION

This section describes the results of experiments conducted on fresh stage and hardened stage of concrete. Relationship between curing water temperature and each test is illustrated in various figures.

Effect of Water Temperature on Slump

Slump values observed for all the mixtures are indicated as the relationship between casting water temperature and slump in Figure 1. It is indicated that slump decreases when the mixing water temperature increases. Hence, increasing the water temperature during mixing causes a loss in slump value and a decrease in the workability of concrete. During the casting of concrete at higher temperatures, it is found that the rates of water evaporation in concrete which contains high temperature water are higher than for concrete with normal water temperature, because there is more thermal energy available in the concrete to do the work of evaporation (Hassaniain et al., 1989). Generally, water is the main component to control the overall workability of the concrete mix in this research. Rapid slump loss often increases the demand for water, total water content and subsequently increases the potential of drying shrinkage (Klieger, 1958). Hence, more water needs to be added to the concrete mix if the temperature of mixing water is increased. Concrete casted under high water temperature may lead to thermal shrinkage as it subsequently cools down.

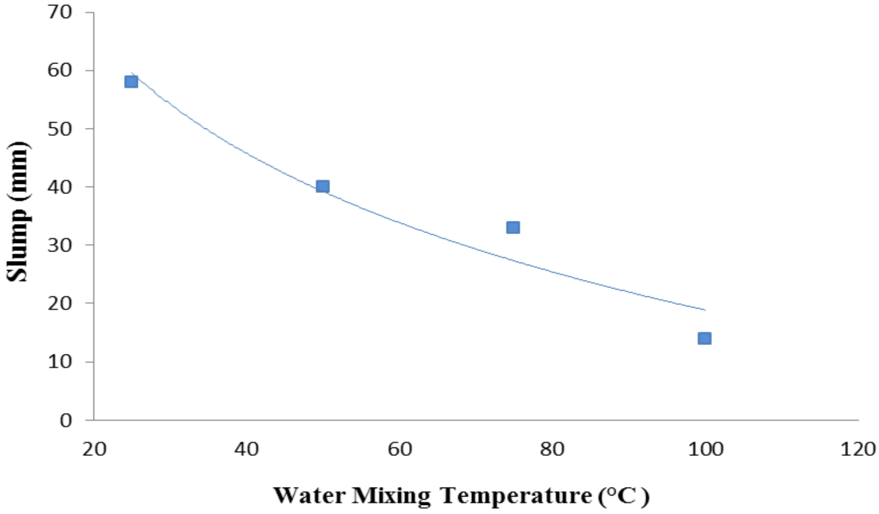

Figure (1): Relationship between slump and water mixing temperature

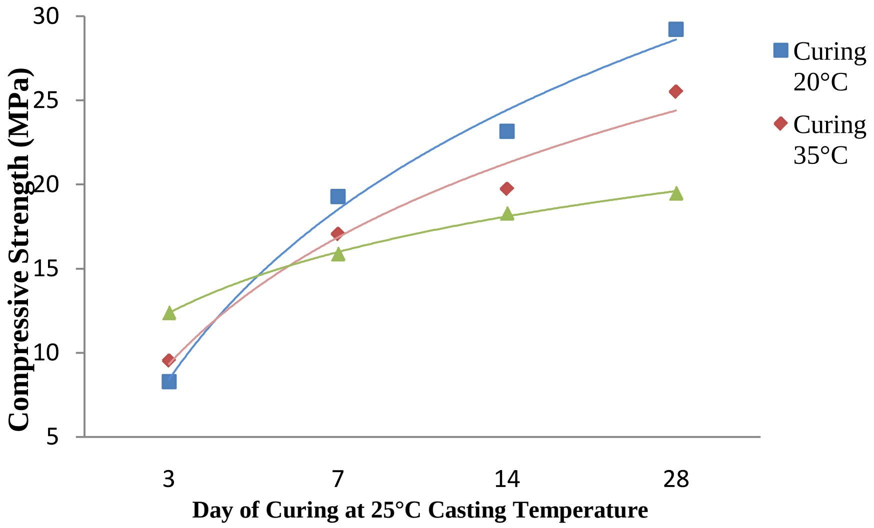

Figure (2): Relationship between compressive strength and age for casting water temperature of 25°C

Compressive Strength

The results of compressive strength of concrete at 3, 7, 14 and 28 days are presented in Figures 2 to 5. The relationship between strength and days for casting water temperature of 25°C is given in Figure 2 and the same relationship for casting water temperature of

100°C is given in Figure 3. Similar relationships were obtained for other casting water temperatures. The relationship between compressive strength at 3 and 28 days for various casting and curing water temperatures is given in Figure 4 and Figure 5. It is clear from Figure 2 and Figure 3 that the strength is lower for mixtures made with casting water temperature of 25°C and strength is larger for higher casting water temperature at 3 days. However, the strength is lower for higher mixing water temperature when tested at 7 days as depicted in Figure 3 and Figure 4.

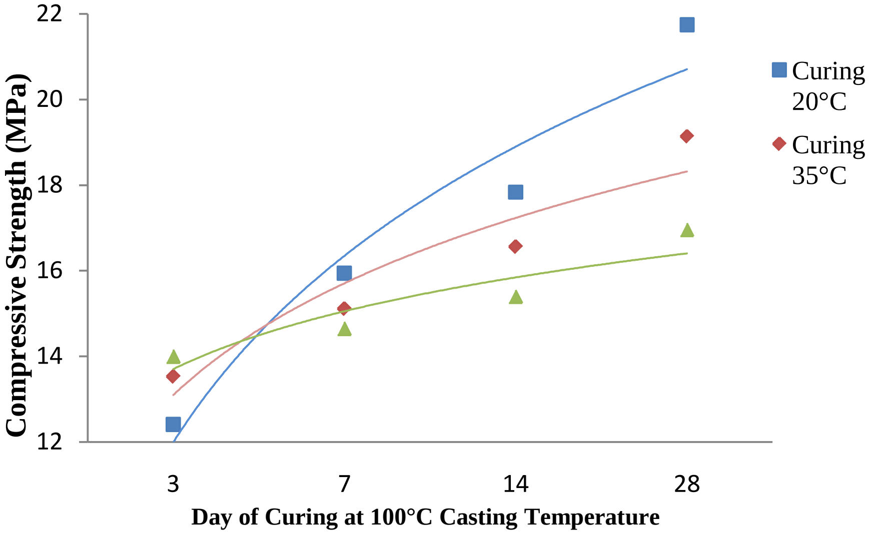

Figure (3): Relationship between compressive strength and age for casting water temperature of 100^{o}C

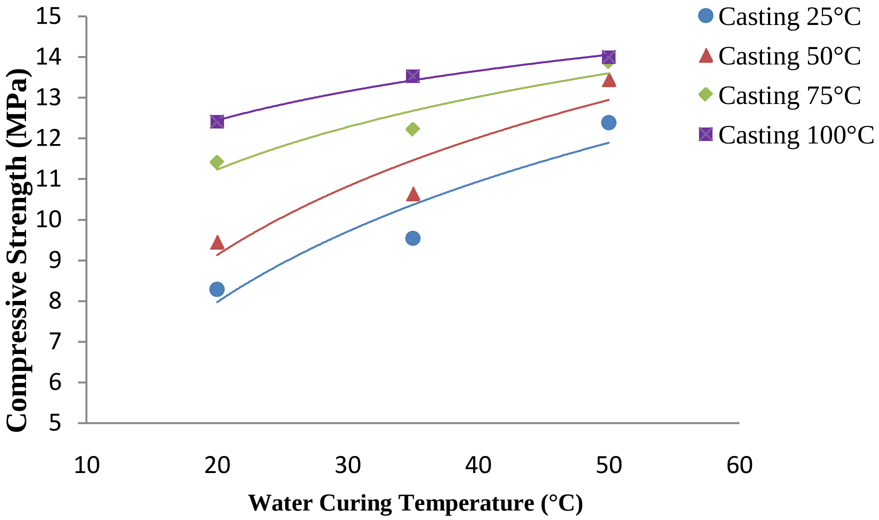

Figure (4): Relationship between 3-day compressive strength and water curing temperature

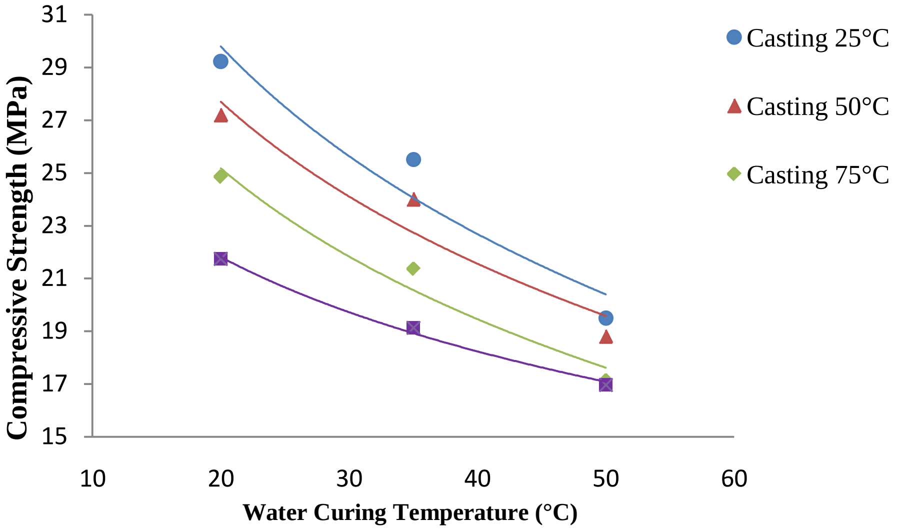

Figure (5): Relationship between 28-day compressive strength and water curing temperature

The compressive strength of concrete at 28 days with 25°C casting water temperature was higher than that of concrete made with a casting water temperature of up to 100°C. It can be seen that as curing temperature increases, the 3-day strength increases, but 7- to 28-day strength decreases as shown in Figure 3. An increase of 30°C in water curing temperature decreases the compressive strength by about 8 MPa as indicated in Figure 3. This phenomenon occurs because higher temperature during the initial contact between hot water and cement reduces the length of dormant period which causes the overall structure of the hydrated cement paste to become established very early. Moreover, a rise in concrete casting and curing temperatures speeds up the rate of hydration and affects beneficially the early strength of concrete. High curing temperature accelerates the early rates of hydration and hence exhibits increase in strength at 3-days. The higher curing temperatures lead to faster hydration rates at early stage (Narmluk and Nawa, 2011). The rapid initial rate of hydration at a high temperatures of concrete retards the subsequent hydration and produces a non-uniform distribution of the products of hydration within the paste. There is insufficient time available for the diffusion of the products of hydration away from the cement particle at a high initial rate of hydration. As a result, a high concentration of products of hydration is built up in the vicinity of the hydrating particles and this delays the subsequent hydration and adversely affects the long-term strength (Verbeck and Helmuth, 1977).

Rebound Number

The rebound value for the concrete samples ranged from 15 to 31 at 28 days. The rebound value for concrete at 28 days for water casting temperature of 25°C is 31 and the same for concrete that was casted with a water temperature of 100°C is 22 at a curing water temperature of 20°C. The normal range of rebound number for concrete at 28 days under room temperature curing is in the range of 31 to 37 (Amasaki, 1991). The effect of water temperature at 3 and 28 days on the rebound number at different water casting temperatures has been presented in Figure 6 and Figure 7. As discussed earlier, when the water curing temperature increases, the 3 day strength increases, but 7-to 28-day strength decreases with the increase in water curing temperature. This phenomenon is also reflected in rebound hammer test. The rebound value was higher for concrete with higher water curing temperature at 3 days; however, the rebound value decreased from 7 days onwards. No abnormalities in the concrete behavior have been observed with regard to the rebound number.

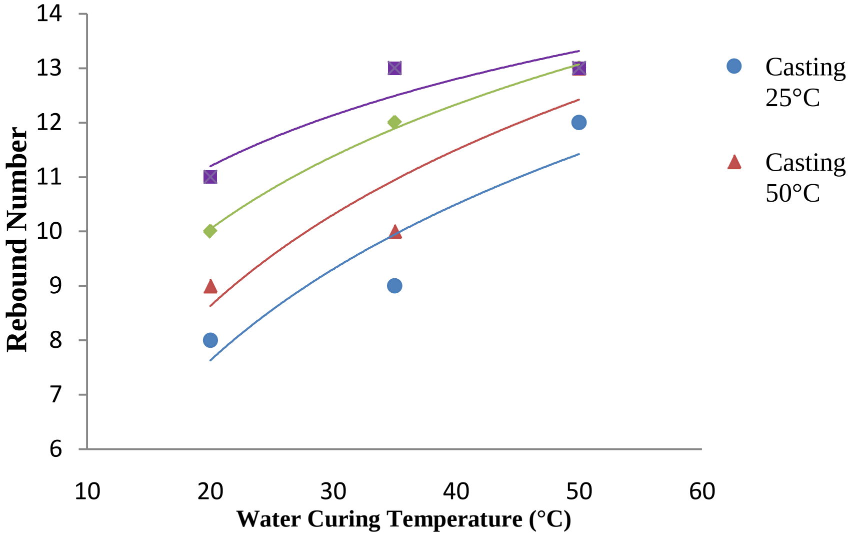

Figure (6): Relationship between rebound number and water curing temperature at 3 days

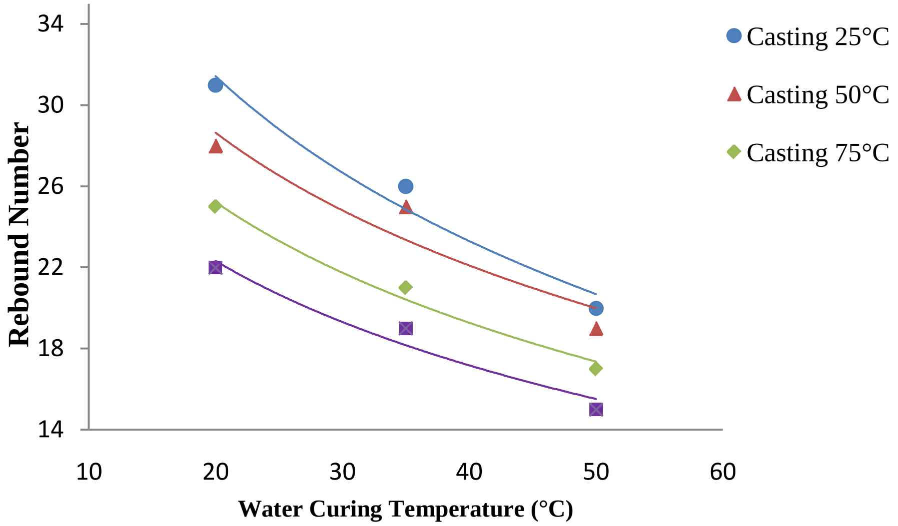

Figure (7): Relationship between rebound number and water curing temperature at 28 days

Ultrasonic Pulse Velocity (UPV)

The denseness of hardened concrete was assessed by measuring the UPV. The relationship between UPV and casting water temperature is indicated in Figure 8 for the curing temperature of 20^{o}C and the relationship between UPV with curing water temperature is shown in Figure 9 for a casting temperature of 25^{o}C. It is clear from Figure 8 that an increase in casting water temperature slightly increases the UPV up to 7 days and decreases the UPV after 7 days. Similar trend is also observed with the curing water temperature as indicated in Figure 9. Moreover, it is found that the difference in UPV values at 28 days between concrete casted at 25°C and 100°C water temperature is only 1.47 km/s.

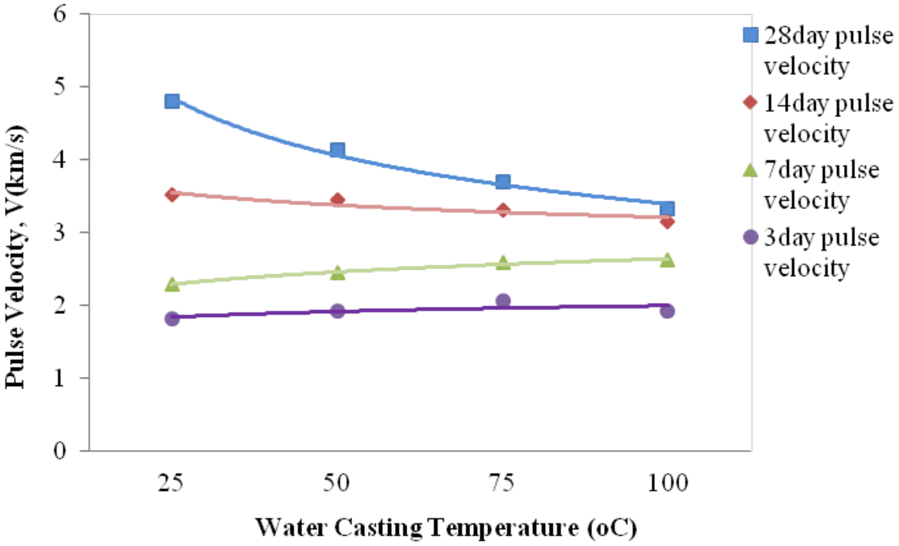

Figure (8): Relationship between UPV and water casting temperature at 20°C

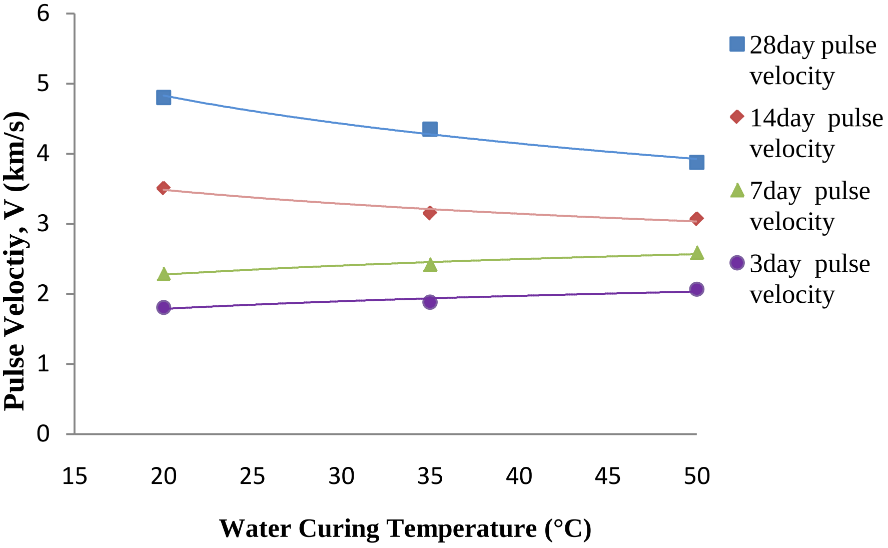

Figure (9): Relationship between UPV and water curing temperature at 25°C

The combination of thermal and drying shrinkage can lead to more cracking than observed for the same concrete casted at lower water temperatures. Reduction in pulse velocity of concrete sample exposed to elevated water temperature may be due to the formation of micro-cracks (Chatterji, 1982). Thermal cracking can occur when the concrete surface is exposed to extreme temperature rapidly which causes the concrete members to expand and contract. Internal and external cracking will occur if the bulk volume change resulting from temperature variations is restrained. Hence, greater cracks and voids presence in concrete specimen required longer travel time of ultrasonic pulse from both contact points of transducer, which decreases the pulse velocity value (Almussallam et al., 1999).

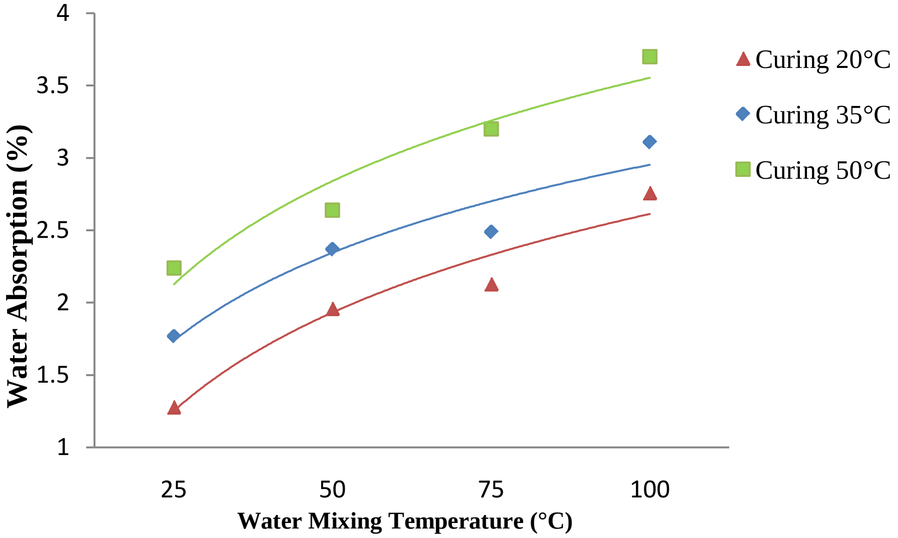

Figure (10): Relationship between water absorption and water mixing temperature

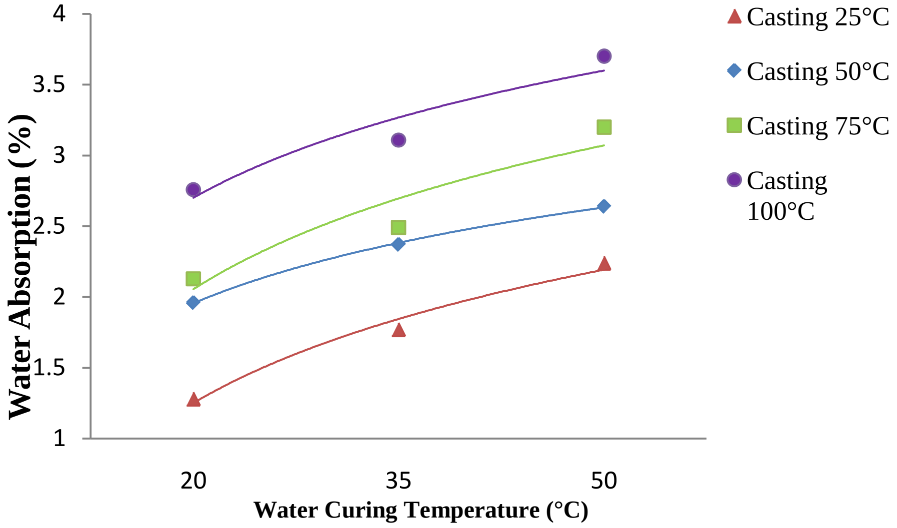

Figure (11): Relationship between water absorption and water curing temperature

Water Absorption

The relationship among water absorption, casting and curing water temperatures is presented in Figure 10 and Figure 11. Higher casting and curing temperature increased the 28-day water absorption. The highest percentage of water absorption in this research was found to be 3.7% for concrete casted at 100°C and cured at 50°C water temperature. This may be attributed to the fact that at low temperatures in concrete, there is sufficient time available for the hydration products to diffuse throughout the cement paste matrix, thereby precipitating uniformly in the hydration. On the other hand, the rate of hydration at high water temperatures is faster than diffusion, which causes the hydration products to remain near the cement grains and leave the interstitial space relatively open (Metha, 1986). Hence, this leads to the presence of pores in the concrete samples which contributes to an increase in the permeability of concrete. When the permeability of concrete increases with increasing rate of hydration, the concrete specimen tends to absorb and trap more water when exposed to wet condition.

CONCLUSIONS

Based on the findings of the investigations, the following conclusions can be drawn:

- An increase in water casting temperature reduces the workability of fresh concrete. Thus, additional water should be added to the mix in order to obtain sufficient workability.
- Increase in water casting temperature leads to increases in hardened properties such as compressive strength, UPV, rebound hammer and water absorption at 3 days. However, further increase in water casting temperature after 7 days of curing reduces the hardened properties of concrete. This phenomenon also occurred when concrete was cured at different water temperatures.
- Higher curing water temperature produces micro-cracking of concrete surface and also diminishes the color of the concrete surface.
- It is recommended that concrete be casted at a temperature of 25°C or less in order to get optimum performance with regard to various properties. Further investigation with many concrete mixtures is suggested to understand the behavior of concrete under various casting and curing water temperatures.

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