EFFECT OF MIXING WATER pH ON CONCRETE

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ABSTRACT

Water is an essential ingredient that largely affects the performance of concrete. pH of the mixing water has a significant impact on the durability of concrete as it affects the reactions of cementitious materials during the hydration process. In this research, the effect of different water pH on the properties of concrete has been studied. Four different pH (i.e. 5, 7, 10 and 13) were selected and water samples containing these pH values were prepared by adding either acid or base solution. The water samples were used as mixing water during the casting of concrete cylinders. Fourteen concrete cylindrical specimens (100mm diameter and 200mm height) were made using the mixing water for each pH and different properties of concrete such as compressive strength, chloride ion penetration, thermal diffusivity, specific heat and thermal conductivity had been tested at the end of different curing period. After analysing the results, it was observed that pH had little effect on 28 days compressive strength of concrete, 90 days strength was varied greatly for different pH values of mixing water. Compressive strength was increased about 25% at 90 days for samples cast with water of pH 13 as compared to pure water (pH 7). Chloride ion penetration was the highest for the samples with mixing water of pH 5. Thermal conductivity which is a function of both specific heat and thermal diffusivity, was increased largely for pH 5 and pH 13 as compared to pH 7 and pH 10. About 28% thermal conductivity was increased for samples cast with water of pH 13 with compared to pH 7.

Keywords: *pH of water, Chloride ion penetration, Thermal diffusivity, Thermal conductivity, Specific heat.*

1. INTRODUCTION

Concrete is composed of inert materials (usually fine aggregate and coarse aggregate), binding material and water. The functioning of binding materials initiates with the addition of water that binds the inert materials. Generally, Portland cement is used as binding materials for the production of concrete in Bangladesh. The process of hydration reactions of cement largely depends on both quality and quantity of mixing water. Therefore, the quantity and quality of mixing water significantly affect the short term as well as long term performance of concrete.

In the past few decades, numerous studies have been conducted to investigate the effect of curing water quality on the performance of concrete. However, the studies regarding mixing water quality is still very limited. In general, potable water is recommended for use in concrete (A. M. Neville, 2012). But in practice it is very difficult to use such water in some regions like coastal area and so on. Adeyemi & Modupeola (2015) tested the compressive strength of concrete cubes prepared and cured with both sea water and fresh water and compared the results. They reported that compressive strength was increased when mixing and curing was done by sea water rather than fresh water. On the contrary, Emmanuel et al. (2012) observed the reverse effect of salt water on reinforced concrete specimens. Strength was found lower for samples cast with salt water as compared to fresh water due to the corrosion of rebar.

Different studies on mixing water quality have been revealed that various impurities of water doesn’t always have adverse impact on concrete performances. The effect of water pH has barely been found in the current literature. pH value indicates the nature of water i.e. either acidic or alkaline. This nature of water affects the properties of concrete. A study on cement properties by using alkaline mixing water (pH 10~ pH 14)was carried out by Çomak (2018). He concluded that alkaline water was effective in increasing the workability of mixture. Compressive strength was also increased with the increasing of pH of mixing water except pH 14. Similar results were reported by Sobhnamayan et al. (2014). They also mentioned that acidic water up to a certain pH level also increased compressive strength of cement mortar. Kucche et al. (2015) concluded that water of pH below 3 decreased concrete compressive strength.

Permeability, thermal diffusivity and thermal conductivity are some important properties of concrete that were evaluated as a function of moisture content, aggregate volume fraction, age, temperature etc. by some researchers (Kim et al., 2003; Taoukil et al., 2013). But the effect of pH of water was not taken into account in that cases. In fact, available research in this regard are very scarce. The aim of this study is to observe how mixing water pH affects different properties such as compressive strength, chloride ion penetration, specific heat, thermal diffusivity and thermal conductivity of concrete.

2. METHODOLOGY

2.1 Materials

In this research, brick broken and river bed sand were used as coarse and fine aggregate respectively. The maximum size, specific gravity and unit weight of coarse aggregate were found 19mm, 2.04 and 1018 kg/m^3 respectively. On the other hand, river bed sand having a fineness modulus of 2.74, specific gravity of 2.50 and unit weight of 1556 Kg/m3 was used. Portland cement (initial setting time 155 minutes and final setting time 290 minutes) was used as binding material. Water samples of different pH (5, 7, 10 and 13) were prepared and then used as mixing water for different concrete specimens.

2.2 Preparation of Different pH Water

Locally available water was collected and pH of the water was determined as 8.38. Then, this water was used to prepare water samples of different pH such as 5, 7, 10 and 13 by adding either acid or base solution. pH 5 and pH 7 of water were achieved by adding sulphuric acid (H_2SO4). On the other hand, water of pH 10 and pH 13 were prepared by adding sodium hydroxide (NaOH). These water of different pH values were used to prepare concrete specimens.

2.3 Mix Ratio and Sample Preparation

A concrete mix ratio of 1 (cement): 1.5 (fine aggregate): 3 (coarse aggregate) having a water cement ratio (w/c) of 0.5 was used to prepare concrete cylinder specimen. The slump of the concrete mixtures was measured and average value was found approximately 40mm. A total 56 nos. of concrete cylinders of size 100mm x 200mm were made with water of different pH. For each pH of water 14 cylinders were casted to evaluate the performance of compressive strength, chloride ion penetration, thermal conductivity, thermal diffusivity and specific heat test. The sample description of the study is summarized in Table 1.

Figure 1: Concrete mix and measurement of slump value

Table 1: Study parameters

Specimen designation	pH of mixing water	Description
P5	5	Acidic water sample
P7	7	Natural water sample
P10	10	Alkaline water sample 1
P13	13	Alkaline water sample 2

2.4 Experimental Program

After casting, the samples were tested at 28 days and 90 days of water curing. The performance of the specimens with different pH of water were evaluated in terms of compressive strength, chloride ion penetration (RCPT), thermal conductivity, thermal diffusivity and specific heat test. The test set ups are described in the following few sections.

2.4.1 Compressive Strength Test

The compressive strength of cylinders was tested at 28 days and 90 days by a Universal Testing Machine (UTM) as shown in Figure 2. The test was conducted in accordance with ASTM C39.

Figure 2: (a) Compression strength test of specimen, (b) Fracture pattern of one of the samples

2.4.2 Rapid Chloride Penetration Test

The test method involves obtaining a 100 mm diameter core or cylinder sample from the concrete being tested. A 50 mm thick specimen was cut from the sample. The side of the cylindrical specimen was coated with epoxy, and after the epoxy was dried, it was put in a vacuum chamber for 3 hours. The specimen was vacuum saturated for 1 hour and allowed to soak for 18 hours. It was then placed in the test device as shown in Figure 3. The left-hand side (Negative-cathode) of the test cell was filled with 3% NaCl solution and the right-hand side (Positive-anode) of the test cell was filled with 0.3N NaOH solution. The system was then connected to a 60-volt potential for 6 hours. At every 30 minutes the amount of charge passed through the specimen was calculated according to AASHTO T 277.

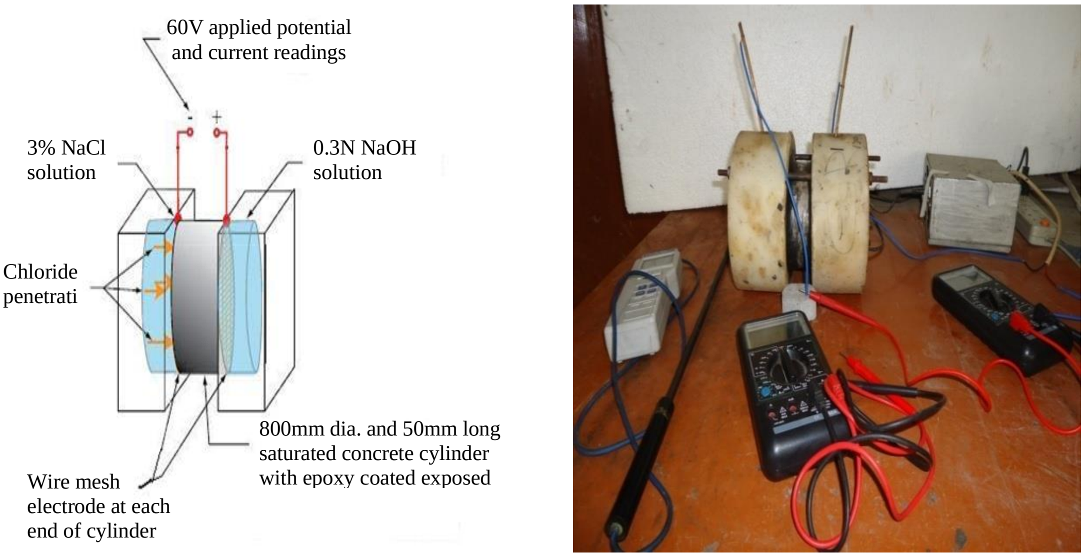


Figure 3: RCPT test setup; (a) Schematic diagram and (b) Image of the test set-up

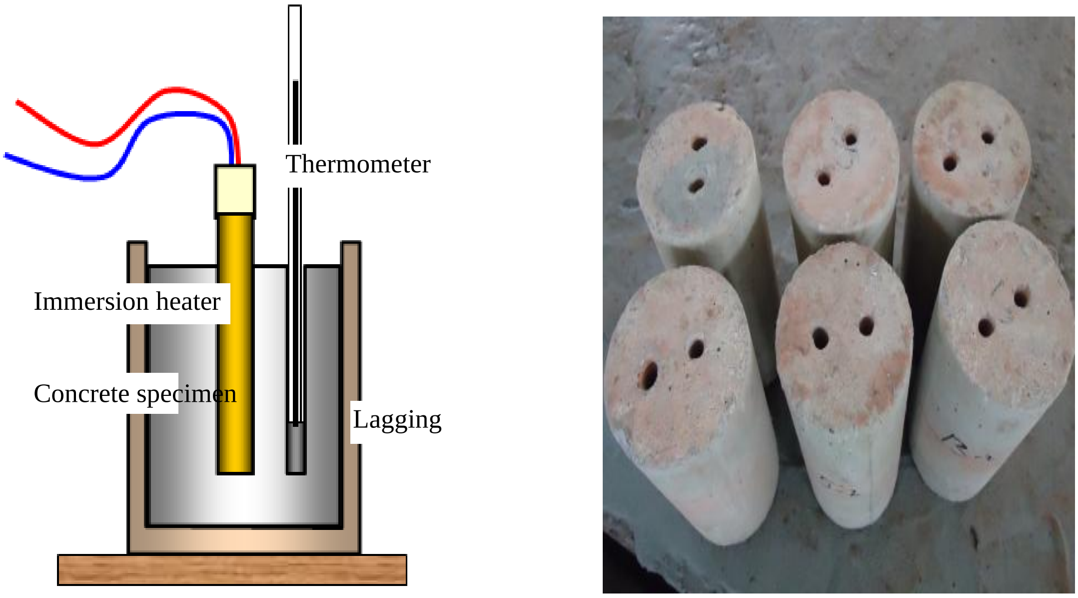
2.4.3 Thermal Diffusivity Test

Thermal diffusivity test was performed according to CRD-C 36-73 method which is one of the most acceptable thermal diffusivity tests for concrete sample. According to the method, a thermocouple was inserted at the centre of mass of the cylinder by axially drilling a 10mm diameter hole. The hole as then subsequently grouted. Diffusivity test as carried out in two phases- one is boiling phase and another is cooling phase as shown in Figure-4. In boiling phase, the specimen was boiled in a steel container (375mm diameter and 500mm in. height) by using a heater of capacity 2000 watt and 220-250 volt. The immersed specimen was heated in the container until the temperature at the center of the specimen reached 100 °C. The specimen was then transferred to a bath of running cold water and cooling phase began. The temperature of cold water was remained constant by providing ice in the bath. The cooling history of the specimen was recorded at every 1-minute interval until the temperature difference between the center of specimen and water dropped to 4°C.

Figure-4: Thermal diffusivity test (a) Boiling Phase and (b) Cooling Phase

2.4.4 Specific Heat Test

Two holes of 10mm diameter as shown in Figure5 were made at the middle third points on each specimen. The mass of each specimen was recorded. A thermometer and an immersion heater were inserted into their respective holes in the block. The thermometer was allowed to reach thermal equilibrium and then the temperature was recorded. A suitable circuit was set up that enabled to measure the energy input of the heater. Current was turned on and the time was noted for measuring energy using an ammeter and a voltmeter to record power.



(a) Schematic diagram b) Samples for specific heat test

c) Image showing inside of the chamber d) Measurement devices of the tests

Figure 5: Specific heat test

2.4.5 Thermal Conductivity Test

Thermal conductivity of specimen was calculated using CRD-C 44-63 method. According to CRD-C 44-63, thermal conductivity can be determined as follow:

Thermal conductivity = Thermal diffusivity × Specific heat × unit weight

3. RESULTS AND DISCUSSIONS

3.1 Compressive Strength

The compressive strength of test samples at 28 days and 90 days are summarized in Table 2. The strength variation percentages as compared to concrete casting with pH 7 water (P7) are shown in Figure 6. It was observed that the strength at 28 days for all specimens were very close. The variation was found within 1~6%. These results indicate that pH of mixing water has very negligible effect on short term compressive strength of concrete.

Table 2: Compressive strength of test samples

Sample ID	**Compressive strength MPa (psi)**	
	28 days	**90 days**
P5	22.5 (3262)	28.2 (4084)
P7	22.9 (3314)	24.5 (3554)
P10	21.4 (3103)	28.9 (4190)
P13	22.7 (3288)	30.5 (4428)

The Compressive strength at 90 days varied largely for all specimens. The compressive strength was increased significantly for concrete prepared with larger pH water that is high alkaline water. About 25% strength increment was observed for sample P13 and 18% was for sample P10. These values indicate compressive strength performs better in alkaline medium. Similar findings were also reported by several researchers (Çomak, 2018; Kucche et al., 2015). The main reason behind the phenomena is that in alkaline media, both the formation of calcium carbonate and calcium silicate hydrate increases with time. These two elements of Portland cement are responsible for hardening of cement composite. Thus, the compressive strength of concrete increases in the long run for all the tested series.

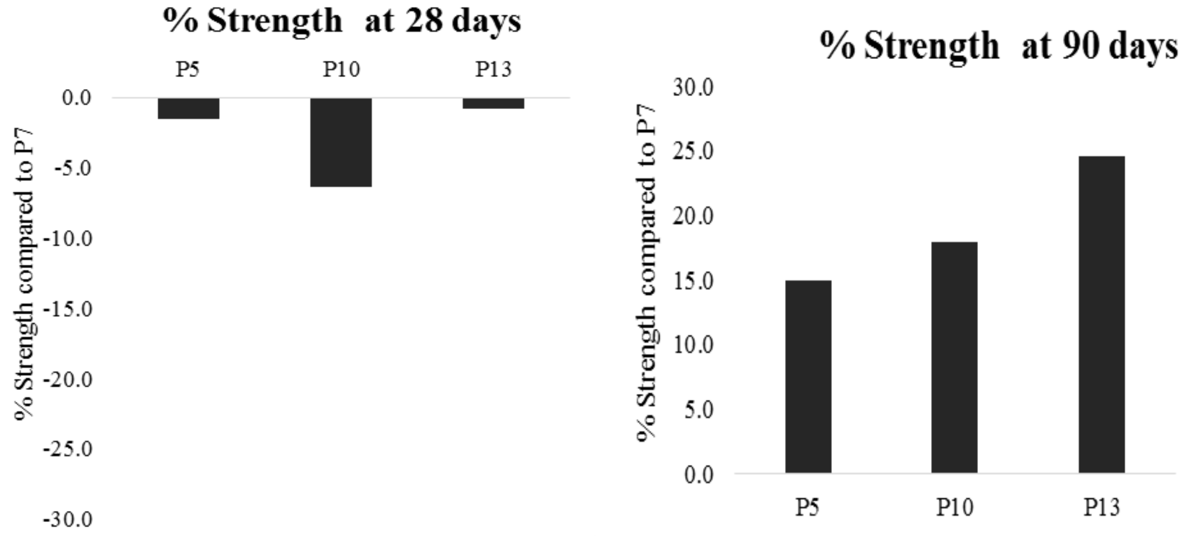


Figure-6: % variation of compressive strength as compared to P7

3.2 Rapid Chloride Penetration Test

The results of the chloride ion permeability of different concrete samples are summarized in Table 3.

Table 3: Average permeability of concrete samples

Time (hr)	**Electrical charge (C)**			
	Sample P5	**Sample P7**	**Sample P10**	**Sample P13**
0.0	0	0	0	0
0.5	432	157	387	243
1.0	1080	558	954	630
1.5	1836	1107	1647	1215
2.0	2664	1944	2376	2016
2.5	3600	2880	3105	2880
3.0	4482	3402	3564	3618
3.5	5040	3717	4095	4095
4.0	5400	3816	4317	4536
4.5	5913	3969	4455	4779
5.0	6300	4050	4590	5130
5.5	6732	4257	4851	5544
6.0	7236	4428	5076	5832

From the permeability result it was found that, the charge passing due to chloride ion was high for concrete prepared with water of pH 5, 10 and 13 than concrete prepared with water of pH 7. The presence of ionic salts increase the amount of coulombs passed. It can be explained as the ionic salts act as an additional transport medium for the charge. The presence of OH- ion at high concentration in concrete increases the charge passed through the concrete. The increase in temperature during the test also causes increase in rate of charge passing.

3.3 Thermal diffusivity test

From the cooling history a graph of temperature difference and elapsed time was plotted as shown in Figure-7. From the graph the elapsed time between temperature 44 °C and 11 °C were obtained. Thermal diffusivity was calculated as follows:

$$\delta = \frac{M}{(t_2 - t_1)}$$

$$\text{Where, } M = \frac{60 \ln\left(\frac{T_1}{T_2}\right)}{\left(\frac{5.783}{r^2} + \frac{\pi^2}{l^2}\right)}$$

$(t_2 - t_1)$ = Elapsed time between temperatures 44 °C and 11 °C
T_1, T_2 = Temperature differences = 44 °C and 11 °C respectively
r = Radius of cylinder
l = Length of cylinder

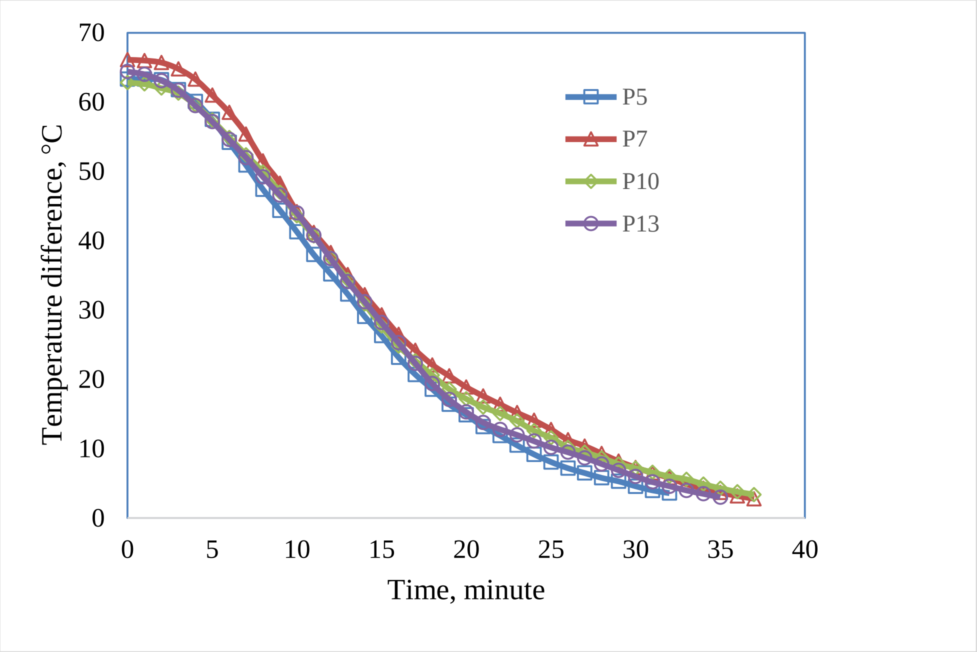


Figure 7: Temperature difference vs. elapsed time during cooling of samples

From the results of thermal diffusivity (shown in Figure 8), it was seen that the thermal diffusivity of concrete was within the typical range. The typical range of thermal diffusivity of normal concrete is 5.2 E-07 m^2/s to 1.5E-06 m^2/s. The diffusivity of concrete casted with water of pH 5, 10 and 13 was 18.14%, 3.09% and 13.72% greater than concrete casted with water of pH 7 respectively.

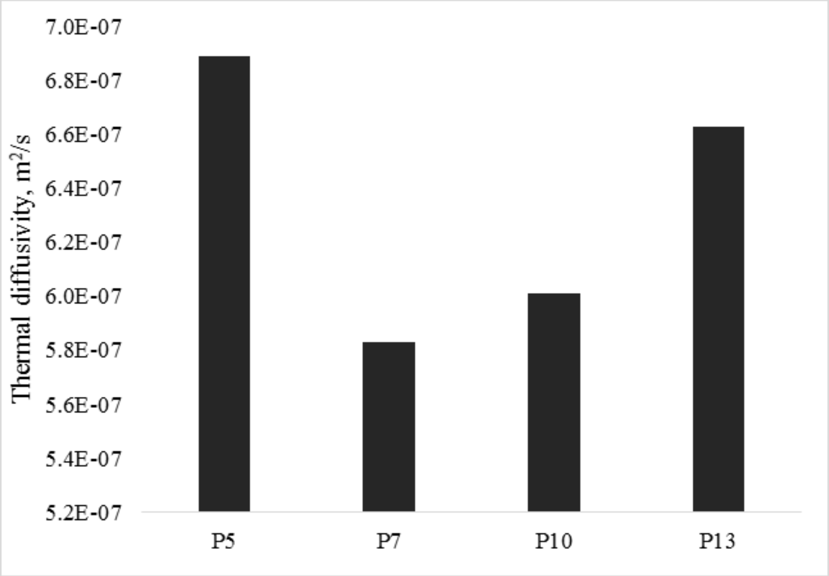


Figure 8: Thermal diffusivity of different samples

3.4 Specific Heat Test

Specific heat test results are illustrated in Figure 9. From the results of specific heat it was found that the specific heat of all concrete samples was found within the typical range 840 and 1800 J/kg °C (Kodur, 2014). It was also found that the Specific heat of concrete cast with water of pH 5, 10 and 13 was 8.39%, 2.11% and 22.6% greater than pH 7 respectively.

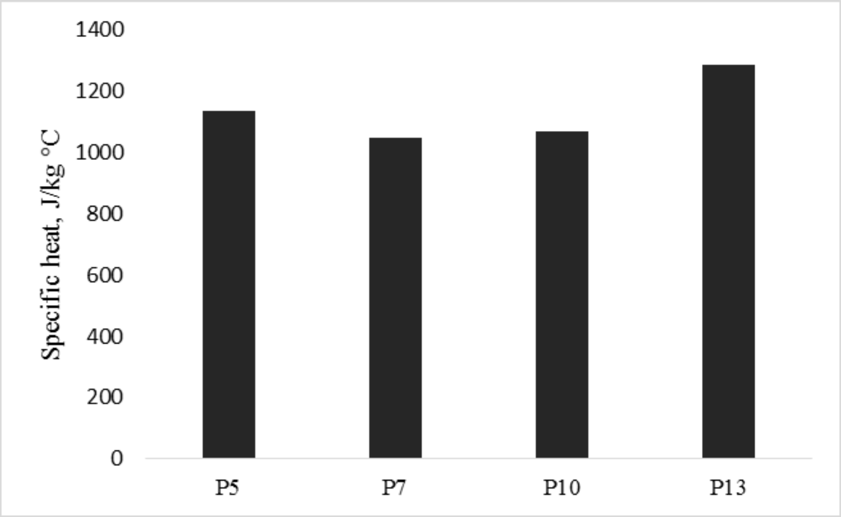


Figure 9: Specific heat of different samples

3.5 Thermal Conductivity

Thermal conductivity of test samples was calculated according to CRD-C 44-63 method shown in Table-4. The thermal conductivity of ordinary concrete ranges generally between 1.4 to 3.6 J/m s °C (Kodur, 2014). The values obtained from sample P7 and P10 are slightly varied from the typical ranges. The thermal conductivity of concrete casting with water of pH 5, 10 and 13 was found 27.84%, 7.05% and 39.70% greater than concrete made with pH 7 respectively.

Table 4: Thermal conductivity of different samples according to CRD-C 44-63 method

Sample ID	Thermal diffusivity (δ), m^2/s	Specific heat (c), J/kg °C	unit weight (ρ), kg/m^3	Thermal conductivity (k = δcρ), J/m-s-°C
P5	6.9E-07	1136.72	2090.63	1.6
P7	5.8E-07	1048.73	2094.16	1.3
P10	6.0E-07	1070.89	2129.48	1.4
P13	6.6E-07	1285.78	2098.40	1.8

4. CONCLUSION

In this research the effect of mixing water pH on concrete performance was studied. From the study it was evident that the pH of mixing water has very little influence on short term compressive strength of concrete. But it has significant impact on long term compressive strength of concrete. It was also found that compressive strength increases with the increase in pH of mixing water. The specific heat and thermal diffusivity values were found incremental for both acidic and alkaline mixing water as compared to neutral water. As thermal conductivity is the product of these two components, similar behaviour was observed for the samples made with different water pH. About 40% thermal conductivity was increased for the sample prepared with mixing water of pH 13 as compared with sample prepared with mixing water of pH 7. The value was also found about 28% incremental for mixing water pH of 5.

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