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INFLUENCE OF MIXING WATER TEMPERATURE ON COMPRESSIVE STRENGTH OF CEMENT GROUT

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ABSTRACT

Grouting plays a very crucial role to develop the bonding among the tendons and surrounding concrete in the pre-stressed members. The performance of grout greatly depends on the mixing temperature of grout. This study mainly focuses on the compressive strength of grout with two type of cement (Ordinary Portland Cement-OPC and Portland Cement Composite-PCC), casting under varing mixing temperature. Seven different miximg temperature (i.e 10°C, 15°C, 20°C, 25°C, 30°C, 40°C and, 50°C) were used to prepare the cement grout. Using the cement grout, 126 nos. of 50 mm × 50mm cube specimens were prepared to find out the mixing temperature effect on the compressive strength of the cement grout. The cubes were tested at three different curing ages (3 days, 7 days and 28 days) of the cement grout. It was found that the compressive strength for OPC grout samples varies from 74% to 110% with respect to 25°C mixing samples. Whereas, for PCC grout samples, the compressive strength ranges from 62% to 122% with respect to 25°C mixing samples. This indicates that PCC grout samples are more susceptible with the mixing temperature than OPC grout samples. Moreover, it can be also observed that the gap between the compressive strength of OPC and PCC is getting closer with respect to the curing of the grout cube specimens.

Keywords: *Post-tensioning, Cement grout, Mixing temperature, Compressive strength*

1 INTRODUCTION

Pre-stressing technology is considered as one of the most significant invention in the field of construction technologies in the recent years. The post-tensioning (PT) technology of the pre-stressed system began widely used for the construction of many bridges, spanning large distances in the United States of America and the Europe in the 1950s. In the last few decades, PT technology has played a significant role in the infrastructure development projects, such as, the construction of warehouses, bridges, dams, nuclear and blast-containment structures, foundations, pavements, stadiums, marine structures, water retaining structures, silos, etc. in the world (Clark, 2013; Corven & Moreton, 2013).

Amin & Okui (2015) outlined in their paper that the pre-stressed concrete technology was first introduced in Bangladesh between 1969 and 1974, through the construction of Tora, Aminbazar and Noyarhat bridges in Dhaka. In recent few years, a huge number of structures including bridges, flyovers, have constructed using pre-stressed technology in Bangladesh. The notable post-tensioned bridges on major rivers in Bangladesh includes Meghna Bridge (1991) in Dhaka, Bangabandhu Bridge (1998) on Jamuna river in Sirajganj, Bhairab Bridge (2002) in Kishoreganj, Gabkhan Bridge (2003) in Jhalakathi, Lalon Shah Bridge (2004) in Bheramara, Khan Jahan Ali Bridge (2005) in Khulna, Muktarpur Bridge (2008) in Munsiganj, Sultana Kamal Bridge (2010) in Dhaka, Shah Amanat Bridge (2010) in Chattogram, Dapdapia Bridge (2011) in Barisal, Kanchpur Bridge (2019) in Dhaka and Gumti Bridge (2019) in Cumilla (Uddin and Mizunoya, 2019).

Moreover, a number of ongoing projects including Mass Rapid Transit (MRT) mega project are employing post-tensioning technology at different locations in the country. However, Kamalakannan et al. (2018) reported that the most commonly used grout materials for post-tensioning system in developing countries do not comply the requirements of the international standards. Therefore, there is a huge scope of research on grouting practices in Bangladesh. The high tensile strand or tendons are used in Post-tensioning to transfer the pre-stressing force and grouts act as the duct filler, to fill the interstitial spaces between the ducts and strands. Main constituents of cementitious grouting material are Portland cement, mineral additives, admixtures, aggregates, and water.

Ordinary Portland Cement (OPC) and Portland Cement Composite (PCC) are used as a cementitious material in the grout mixture. The OPC and PCC are used in accordance with ASTM C 150 and ASTM C595/C595M respectively (Chen & Duan, 2014). Grouting materials primarily provide protection against corrosion in bonded tendons and also form a good bonding with surrounding concrete. Pillai (2018) studied the effect of water/binder (w/b) ratio on various properties of cementitious grout mixes considering varying proportion of OPC, a locally available fly ash and a commercially available Poly Carboxylate Ether based super plasticizer. In the studies, the w/b ratios were varied between 0.30 and 0.44. The flow properties (as per BS EN 445), bleeding resistances (according to ASTM C 940-10a), and retention of flow properties over time of the each grout mixes were determined and compared. The paper reported that the reduction of the w/b ratio improves the flow properties (i.e., low yield stress, low plastic viscosity) of the grout mixes and the use of 25% fly ash produced almost no bleed water of the fresh mixes. He also compared the properties of optimized grout (with 25% fly ash) with a commercially available grout with plasticized expansive grout admixture and a Pre-Packaged Grout (PPG) available in USA.

Moreover, Kamalakkannan et al., (2018) focuses on present state of art on the grouting practices during post-tensioning in India and concluded that optimum mixing speed and ambient temperature significantly influence the performance of PPG and Plasticized Expansive Admixture (PEA) grout. Mirza et al., 2013 performed several laboratory tests of different fresh and hardened state properties of OPC, Type-III Portland Cements and seven others commercially available microfine cementitious grouts. Two different variables such as water-cement ratio (varying between 0.5 and 1.2) and three different temperatures (4°C, 10°C and 20°C) were employed during the laboratory tests.

Several physical properties (i.e. grain size distribution), fresh state properties (i.e. viscosity, bleeding and setting time), and hardened state properties (i.e. Young's modulus, Poisson's ratio, compressive strength, bond strength and change in volume) of the grout were studied in this research. It was concluded that all the rheological and mechanical properties are substantially affected by water-cement ratio and at 10°C temperature compressive strength and Young's modulus were found to be maximum. Several studies reported that the performance of grout is affected by several factors like, mixing time, setting time, viscosity, fineness, ambient temperature (mixing environment, mixing and curing water) and compressive strength of the grout (Bras, Gião, Lúcio, & Chastre, 2013; BS EN 445, 2007; Kamalakannan, Thirunavukkarasu, Pillai, & Santhanam, 2018; Mirza et al., 2013). Bras et al., (2013) concluded that rapid reduction in viscosity of grout mixtures occurs at high temperature. Moreover, Mirza et al., (2013) found that setting time of grout decreases with increasing the temperature of the grout mixtures. This phenomenon occurs as the hydration of cementitious material accelerated at high temperature.

There is very limited research available in the literature on the performance of grouting materials under low temperature. Furthermore, very limited studies are reported the performance of different properties of grout at higher temperatures considering monsoon climatic conditions (Erol and François, 2014). Due to the geographical location of Bangladesh, a warm and monsoon season lasts at most of the time in a year. As a result of the climate change effect, the temperature patterns (i.e. durations, starting time, end time, magnitude of temperature etc.) have been modified globally and fluctuate rapidly within a week. Nasher *et al.* (2013) reported that the lowest temperature was recorded as 3.4°C during winter and highest of 45.1°C temperature was recorded during monsoon over the study period between 1964 and 2012. Thus, it is quite difficult to maintain a constant temperature condition during the mixing of grout materials. This paper will address the most significant mechanical property (compressive strength) of the cement grout material at different mixing temperatures considering OPC and PCC as a cementitious material.

2 EXPERIMENTAL PROGRAM

2.1 Materials

In Bangladesh, OPC and PCC are widely used in preparing cement grout. Therefore, the effect of cement type should also be investigated. In this study, the test specimen were prepared using OPC conforming to ASTM C 150, PCC conforming ASTM C595/C595M and grouting agent (kind of admixture which is commonly used for cement grouting). The chemical characteristics with its composition (% by mass) of OPC, PCC and grouting agent are presented in Table 1. Particle size distribution along with fineness of the cements and the grouting agent can be found in Table 2.

Table 1 Chemical characteristics of materials

Composition (% by mass)	Type-I (OPC)	Type-II (PCC)	Grouting Agent
Silica	19.09	17.6	9.5
Alumina (Al_2O_3)	6.14	3.89	3.47
Ferric Oxide (Fe_2O_3)	3.51	3.42	1.95
Calcium Oxide (CaO)	61.70	52.62	28.05
Magnesium Oxide (MgO)	1.79	2.76	1.92
Sulfur trioxide (SO_3)	2.54	2.40	34.64
Chloride (Cl)	0.03	0.04	0.11
Sodium oxide (Na_2O)	0.13	0.12	0.04
Potassium oxide (K_2O)	0.47	0.65	0.75
Total Alkalis (Na_2O+0.658 K_2O)	0.440	0.554	0.540
Insoluble Residue (IR)	1.60	11.40	12.00
Loss on Ignition (LOI)	2.56	4.55	7.50

Table 2 Physical properties of materials

Parameters	Unit	Type-I (OPC)	Type-II (PCC)	Grouting Agent
Fineness (Blaine method)	cm^2/gm	3074	3455	4758
Particle size (Sieve analysis)	Above 90 µm (%)	0.25	0.37	2.96
	45 µm ~ 90 µm (%)	3.23	3.49	6.84
	Below 45 µm (%)	96.52	96.14	90.20
Moisture Content	(%)	0.75	0.74	1.46

2.2 Mixing Ratio

Test specimens were prepared by mixing OPC/PCC, grouting agent and water. The ratio among cement, grouting agent and water was maintained as 1 : 0.1 : 0.4 which was determined in accordance with ASTM C 938. The properties of the cement grout are provided in Table 3.

Table 3 Properties of the cement grout

Parameters	Unit	OPC Grout Mix	PCC grout Mix	Reference
Initial setting time	mins	570	620	ASTM C953
Final setting time	mins	720	770	ASTM C953

2.3 Preparation of Test Specimens

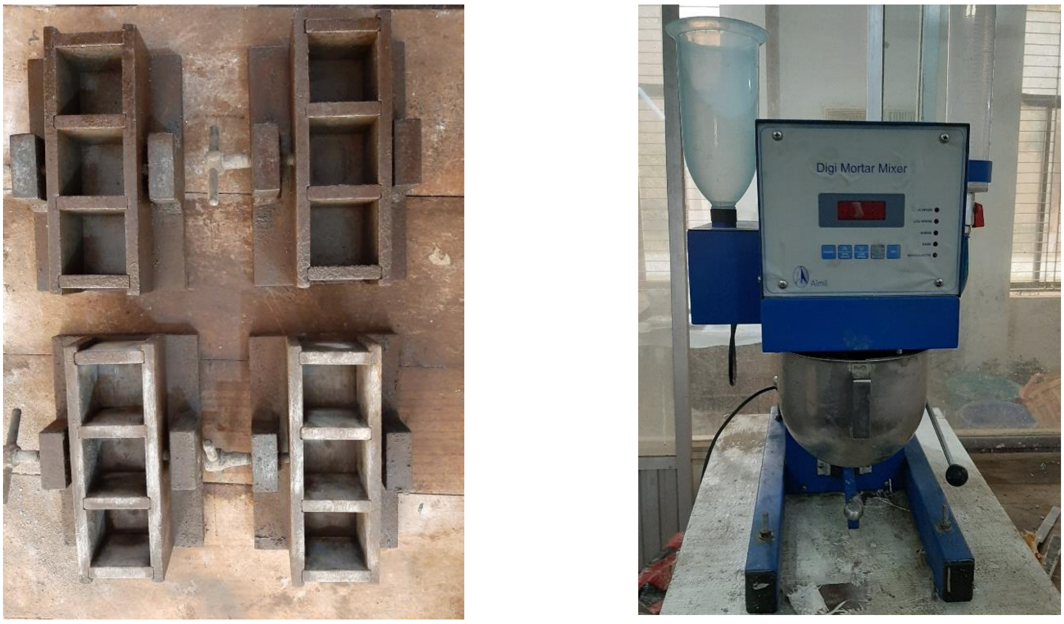
Four different mixing temperatures (20°C, 30°C, 40°C and 50°C) were chosen to determine the mixing temperature effect of the grout. During, preparation of the test specimens these mixing temperatures were maintained by controlling the mixing water temperature. The schedule of grout mixes is given in Table 4.

Table 4: Schedule of Grout Mix

Sample designation	Mixing Temperature (°C)	Cement Type	Sample designation	Mixing Temperature (°C)	Cement Type
10-OPC	10	OPC	10-PCC	10	PCC
15-OPC	15		15- PCC	15	
20-OPC	20		20- PCC	20	
25-OPC	25		25- PCC	25	
30-OPC	30		30- PCC	30	
40-OPC	40		40- PCC	40	
50-OPC	50		50- PCC	50	

To prepare 50mm × 50mm cube specimen for compressive strength test, three gang mold were made ready as shown in figure 1(a), following ASTM C 109. In the beginning, the materials used for the preparation of grout mixes were stored under ambient temperature (20°C) temperature for 24 h prior to mixing. Then, cement and grouting agent were taken in a mixing bowl and hand mixed with a trowel. After that proper amount of mixing water was added with the cement-grout composite. Figure 1(b) illustrates the mechanical mixing machine of the cement grout. Finally, the composition was mixed properly for about 3 minutes with the mixer following the standard mixing method described in ASTM C 938-10. After completion of each mixing step, the temperature of the mixture was measured by means of a thermometer with 0.1°C accuracy. Then the samples were poured in the previously prepared cube mold for finalizing the sampling procedure as shown in Figure 2.

Forty-two batches samples, as mentioned in Table 4, were prepared with different cement types as well as different mixing temperatures. For each batch, three numbers of cube samples were prepared for testing. The desired mixing temperature at every mix was maintained by controlling the mixing water temperature. The temperature was maintained within ±1°C.



(a) (b)

Figure 1: (a) Gang Mold, (b) Mechanical mixing machine

Figure 2: Casting of grout samples

After completion of the molding, the test specimens were placed in a moist room exposed to moist air for minimum of 24 hours. After being finally set the specimens were demolded and each of the samples were given a unique identification mark for further analysis. Then all of the specimens were preserved in a curing chamber as described in ASTM C 109, to obtain desired strength.

2.4 Compressive Strength Test

After completion of desired curing period, compressive strength test of the cube specimens was performed by using a compression testing machine (maximum capacity of 1000 kN) as shown in Figure 3. Compressive strength of the specimens was determined for 3, 7 and 28 days of curing period. The compressive strength tests were conducted as described in ASTM C 109.

Figure 3: Placement of the cube in the testing machine

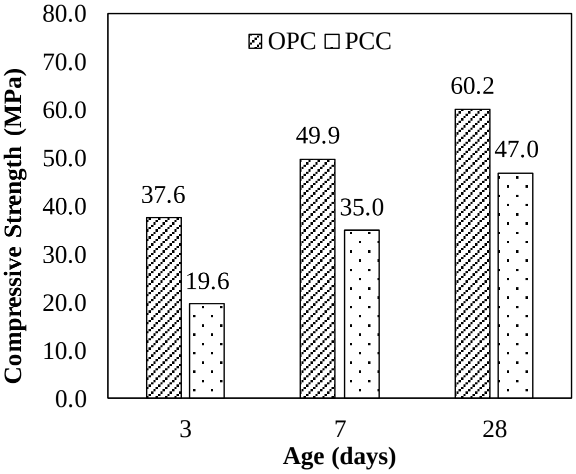
3 RESULTS AND DISCUSSION

The compressive strength of the tested samples was presented in Table 5. It can be seen from the table that the optimum compressive strength among the tested samples was found for 30°C for both types of cement as well as three different curing ages of samples. Specimens, prepared with OPC based grout, showed higher strength than that of prepared with PCC based grout. For OPC based grout, the maximum compressive strength of 67.1 MPa, was found corresponding to 30°C mixing temperature and that of minimum of 35.9 MPa was found at 50°C mixing temperature. Whereas, for PCC based grouts, the maximum (57.3 MPa) was found at 30°C mixing temperature and minimum (19.6 MPa) at 10°C mixing temperature.

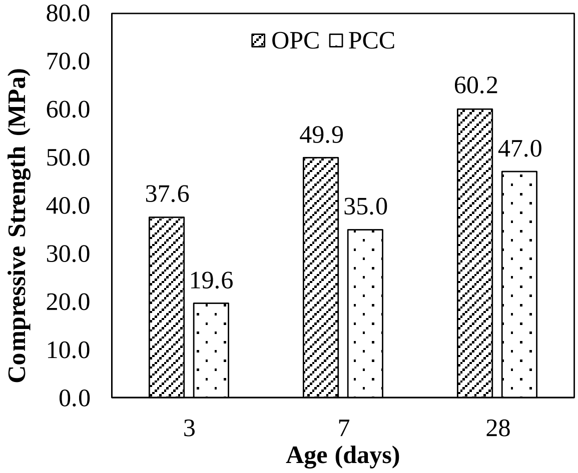
Table 5 Compressive strength of the tested batches of cement grout

Sample ID	Compressive Strength (MPa)			Sample ID	Compressive Strength (MPa)		
	3 days	7 days	28 days		3 days	7 days	28 days
10-OPC	37.58	49.85	60.15	10-PCC	19.6	34.97	46.98
15-OPC	38	50.43	60.04	15- PCC	19.95	36.25	49.25
20-OPC	40	53.09	63.2	20- PCC	21	38.16	50.6
25-OPC	41.2	54.32	63.85	25- PCC	24.26	41.07	55.58
30-OPC	42.9	56.35	67.1	30- PCC	26.1	45.65	57.3
40-OPC	36.8	52.13	58.8	40- PCC	24.2	41.34	52.5
50-OPC	35.9	50.78	57.3	50- PCC	23.3	40.88	51.6

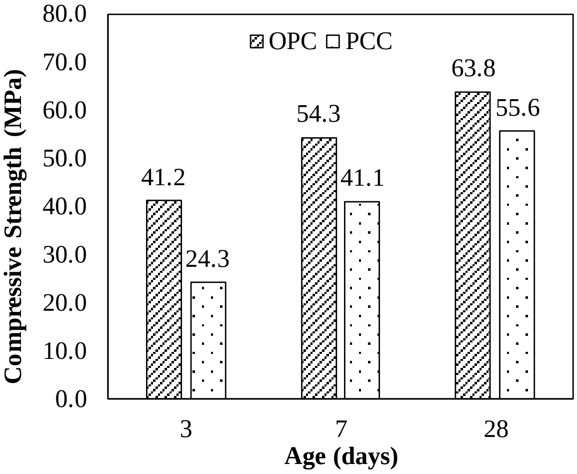
Comparison between compressive strength between OPC and PCC based cementitious grout specimens are represented in Figure 4. It was observed that the specimens made with PCC based grout showed higher strength at early ages than that of in OPC based grout. The compressive strength ratios between PCC based grout and OPC based grout specimens were between 52~66 % for 3 days of samples, between 70~81% for 7 days of samples, and increased up to 78~90% at 28 days curing age. With increasing in curing age, the ratio between the PCC and OPC based grout increases for all mixing temperatures in this study.



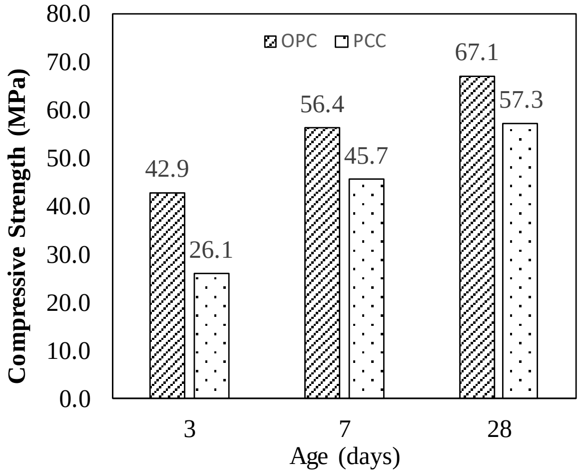
(a) 10°C mixing temperature



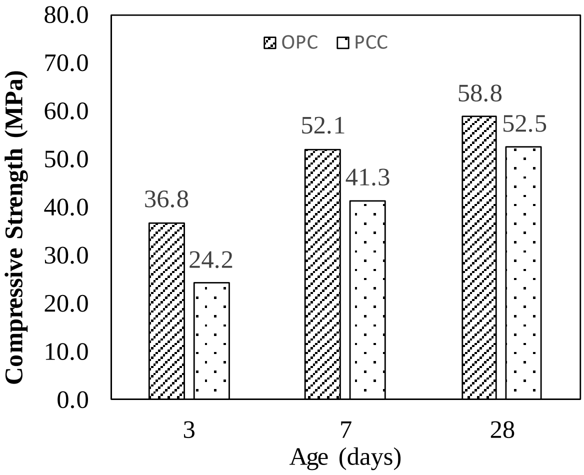
(b) 20°C mixing temperature



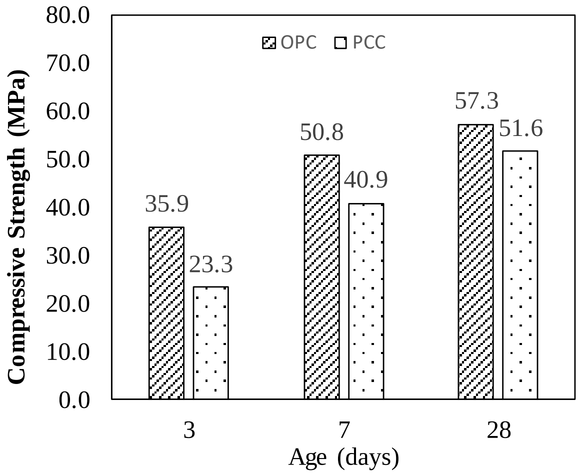
(c) 25°C mixing temperature



(d) 30°C mixing temperature



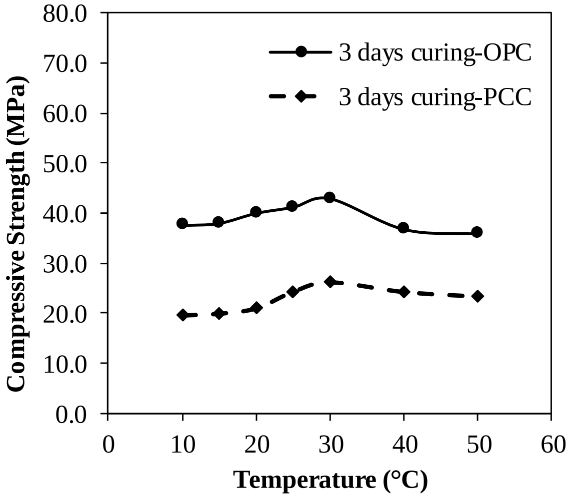
(e) 40°C mixing temperature



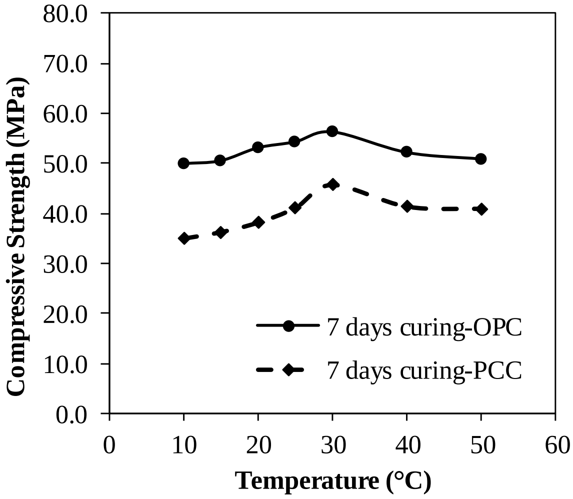
(f) 10°C mixing temperature

Figure 4: Comparison between compressive strength of OPC and PCC based grout sample at different age

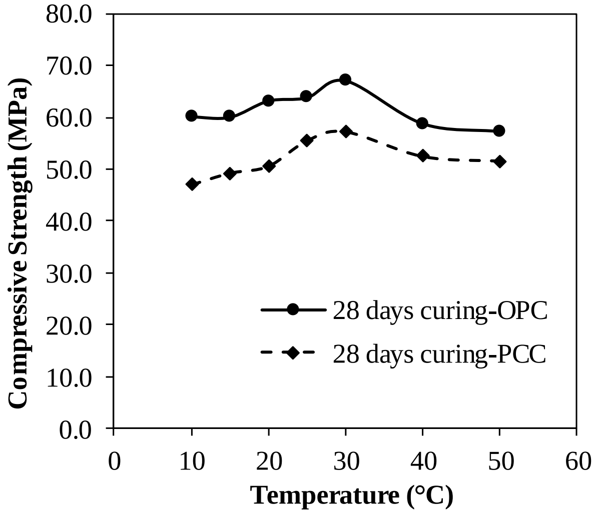
Figure 5 shows the variation of compressive strength of grout (OPC and PCC) with different curing ages at various mixing temperature. The tested results show that the gap between compressive strength between OPC grout and PCC grout for 3 days samples are more than 28 Days samples. This indicate that OPC grout achieve compressive strength faster than PCC grout.



(a) at 3 days curing period



(b) at 7 days curing period



(b) at 28 days curing period

Figure 5: Variation of compressive strength with different mixing temperature

The percentage variation of the tested samples compared with 25°C mixing temperature for both OPC and PCC grout are presented in Table 6. The samples were compared with 25°C mixing temperature as 25°C represents the standard ambient temperature (Wardhono et al, 2015). It has been found that the compressive strength of the OPC grouting sample varies from 74% to 110% relative to the 25°C mixed sample. For PCC grouting samples, the compressive strength ranged from 62% to 122% relative to the mixed sample at 25°C.

Table 6: Percentage variation of the different batches with respect to 25°C samples

	% variation for OPC			% Variation for PCC		
Temperature (°C)	**3 days**	**7 days**	**28 days**	**3 days**	**7 days**	**28 days**
10	82%	84%	88%	62%	70%	69%
15	84%	86%	88%	64%	77%	77%
20	94%	95%	98%	73%	86%	82%
25	100%	100%	100%	100%	100%	100%
30	108%	107%	110%	115%	122%	106%
40	79%	92%	84%	100%	101%	89%
50	74%	87%	79%	92%	99%	86%

4 CONCLUSION

Based on the experimental results, the following conclusions are made:

a) Variation in mixing temperature influences the compressive strength of cementitious grout. The compressive strength of the cement grout decreases with increasing mixing water temperature above 30°C. So, this reduction in the compressive strength of cement grout should be considered while doing the mix design for grout as seasonal variation of temperature is a continuous process in Bangladesh.

b) Cement grout prepared with OPC cement provides higher early strength than that of PCC. When the construction period is very short or it is necessary to complete the pre-stressing work within short period, then OPC based grout might be preferable.

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