AN INVESTIGATION ON CEMENT GROUT PERFORMANCE SUBJECTED TO ITS MIXING TEMPERATURE

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ABSTRACT

Cement-based grout is widely used in construction to protect post-tensioned structures from corrosion and filling the large cracks. It is applied through pumping and injecting. If it lacks sufficient fluidity, proper placement becomes challenging. The environmental and mixing temperature during grout preparation significantly influences its performance. This study employs the Flow Cone Method test, Flow Table test, and compressive strength experiments to examine the rheological and mechanical characteristics of cement-based grout at different mixing temperatures and a constant environmental temperature. The initial mixing temperatures of 45°C, 35°C, and room temperature (28°C) were used to investigate how the grout behaves at higher temperatures. The results indicated a potential loss of fluidity over time. The compressive strength of the grout at lower temperatures showed a higher strength, 28% higher than at 45°C and 25% higher than at 35°C. Additionally, there was higher strength when the admixture of aluminium powder was added at the same temperature. With the addition of the admixture, the strength at 45°C was 1% higher at 0 minutes, 15.7% at 5 minutes, and almost the same at 10 minutes. Water was added again to restore fluidity that exceeded the standard value at different times after mixing, 20 minutes for only grout and 10 minutes for grout with the admixture at 45°C. For 35°C, the time of water addition was found at the same phase, at 10 minutes and 40 minutes after water mixing, and strength was also improved with the addition of the admixture. This study is crucial for the construction materials field as it thoroughly examines the suitability of cement-based grout in dynamic settings. It is anticipated that the results will assist in optimising grout formulations, ensuring stability and reliability in practical applications, especially when exposed to high temperatures.

Keywords: *Cement Based Grout, Initial Mixing Temperature, Compressive Strength, Fluidity, Mixing Time.*

1. INTRODUCTION

The rheology is important for grout injection (Pusch, 2013). According to the findings, low shear rates can close cracks with dynamic injection in materials. Moreover, cement-based substances like grout significantly impact the hydration and chemical reaction of the setting process. It will ultimately affect the rheological properties (Hakansson, 1993). Thixotropic properties explain the complicated behaviour of cementitious materials. This structural breakdown occurs, causing viscosity to drop under low shear stress. Similarly, cementitious materials can regain their rheological properties after shearing. A low water-cement ratio and slag addition can lead to various behaviours in grout (Yahia & Khayat, 2001).

The cement-based grout containing talc or palygorskite has its rheological properties examined in this work, focusing on how it affects injection fluidity and rapid strengthening. Although palygorskite causes early gelation, talc improves fluidity and strength. A statistical analysis shows that these two substances have different impacts on viscosity, with talc having a positive effect on fluidity and palygorskite having a negative effect (Bras et al., 2013).

The experiments consider the flow and mechanical properties of three different types of cement (A, B, and C) in a real tunnel setting and at room temperature. The results express that the rheology, flow, and mechanical behaviour of cement vary significantly. This clarifies how the properties of the grout are affected by temperature, water-cement, and hydration variables (Mohammed et al., 2014).

The effect of mixing water and initial mixing temperature on the compressive strength of OPC and PCC cement-based grout for pre-stressed members was examined in this work. According to the results, the compressive strength difference between OPC and PCC gradually decreases, highlighting the significance of temperature control in maximising grout performance (Molla et al., 2020).

This study deliberates on how cement-sand grouts play an important role in grouting technologies in the construction industry. It investigates how adding a high volume of fly ash to grout can optimise rheological properties and reveals factors that greatly enhance grout fluidity and viscosity for efficient grouting in building and construction projects (Balakrishnan et al., 2020).

The effect of colloidal nano-silica on several properties of cement-based grout, such as plastic shrinkage, heat of hydration, freshness, and rheological properties, is investigated in this study. The effect of mixing water temperature and the dose of superplasticiser and nano-silica significantly varied, and the results were also investigated. Numerical models and iso-response curves were created to identify the trend. The grout's properties critically affect the concentration of nano-silica, mixing water temperature, and the amount of superplasticiser, as revealed in this study. For this work, statistical models were developed to enhance the grout mixture and achieve specific performance goals (Bohloli et al., 2019).

This study investigates optimising the grout injection procedure to enhance compactness and monolithic behaviour in multiple-leaf masonry walls without compromising architectural value. The created models bridge the gap between traditional qualitative assessments and more complex rheometry measurements by predicting and controlling rheological parameters using straightforward flow tests. This allows for developing of practical and affordable grout design tools (Sonebi et al., 2015).

Grout is a widely used construction material that protects post-tensioned strands by filling cracks through pumping and injecting. Pumpability depends on fluidity and the time elapsed after grout preparation. As time passes, the fluidity of grout gradually decreases, affecting pumping. In this paper, the fluidity of cement grout is systematically checked and restored by adding water. The compressive strength of each flow test was also determined.

2. EXPERIMENTAL PROGRAME

2.1 Material

In Bangladesh, two types of cement are available: Ordinary Portland Cement (OPC) and Portland Composite Cement (PCC). OPC-based cement was chosen for its quicker strength gain, intended for use in post-tensioned concrete applications to protect against corrosion. Samples were prepared for this test, confirming compliance with ASTM C 150. The test was conducted following ASTM C 939 standards, and aluminium-based powder was incorporated into the sample preparation to induce expansion in the freshly mixed cement-based grout.

2.2 Mixing Ratio

Initially, test specimens were prepared with an assumed water-cement ratio of 0.40 and various mixing temperatures. Subsequently, a rheological property test was conducted on the freshly mixed grout, following ASTM C 939. The water-cement ratio was determined by the efflux time of the freshly mixed grout, allowing for approximately 3% variations with other samples. The sample ID was created based on the mixing temperature and the addition of aluminium powder. After several trials, the water-cement ratio was fixed. Table 1 outlines the water-cement ratio.

Table 1: Determining w/c of Grout with Efflux Time

Sample	Efflux Time (sec)	Water/Cement Ratio	Reference
28°C	30.89	0.47	ASTM C939
28°C+Admixture	30.88	0.465	ASTM C939
35°C	30.45	0.48	ASTM C939
35°C+Admixture	30.14	0.47	ASTM C939
45°C	31.60	0.495	ASTM C939
45°C+Admixture	31.89	0.48	ASTM C939

2.3 Composition

All cement-based and cement-based with aluminium powder admixture samples of grouts had the same number of mixed solid particles, except for the water-cement ratio, which was chosen to provide approximately the same fluidity.

2.4 Preparation of Samples

Four samples of two different initial mixing temperatures of freshly mixed cement grout samples were prepared (45°C and 35°C with and without aluminium powder). When preparing the sample, the temperature was maintained by heating, mixing water and placing it in a room used to control the initial temperature of the grout. Initially, the water was heated to a temperature higher than that of the freshly mixed grout. The dry cement was then mixed with the appropriate water. The sample was prepared with aluminium powder, and the proper amount of powder was taken with cement and mixed thoroughly by hand with a trowel.

Subsequently, the rheological property flow was determined concerning time (0, 5, 10, 40 minutes), considering field application standards in accordance with ASTM C 939 and ASTM C 1437. If the efflux time of the prepared sample exceeded the standard limit, a sufficient amount of water was added to regain the initial fluidity (efflux time). The flow test was measured at 15 minutes and 30 minutes after the water was added to regain fluidity, and if the standard limit of 35 seconds was exceeded again, water was added again. This process was repeated for one hour after the initial mixing.

For the compressive test, 50 mm × 50 mm cubes were prepared, as shown in figure 5, following ASTM C 109.

2.5 Flow Test

2.5.1 Flow Cone Method Test

Mixing the cement with appropriate water, the cement grout filled in the funnel, closing the bottom orifice. Then, the sample immediately passed through the funnel cone with an orifice of 12.7 mm (shown in Figure 2) in accordance with ASTM C 939, referred to as the 0-minute flow. In this method, approximately 1725 ml of grout filled the funnel and passed through the orifice. According to this method, the efflux time should be less than 35 seconds. For comparison and reliable results, 1725 ml of grout were taken and passed through the funnel. The time required to pass is referred to as the efflux time. Subsequent flow tests for the same sample were conducted after 5, 10, and 20 minutes. If the standard limit was exceeded, water was added, and approximately 15 minutes later, the test was performed using the same procedure as before, as shown in Figure 2. The sample was agitated between the two successive flows with a mechanical agitator with a controlled rotating speed of 30-40 rpm, as shown in Figure 1.

Figure 1: Agitator

Figure 2: Flow Cone and Measuring Jar

2.5.2 Flow Table Test

The flow table test was also conducted alongside the flow cone test in accordance with ASTM C 1437, as shown in Figure 3. In this method, a flow mould specification following ASTM C 230 was filled with grout, and the cone was lifted. During the method, the sample was collected for the marsh funnel test, which was also performed for the flow table test. The blow number was noted to spread over the entire table.

Figure 3: Flow Table Test

2.6 Compressive Strength Test

Following the necessary curing time, the cube specimens underwent a compressive strength test using compression testing equipment (maximum capacity of 1000 kN), as indicated in Figure 4. The compressive strength of the specimens was assessed after 14 and 28 days of curing. The compressive strength tests were carried out per ASTM C 109.

Figure 4: Compressive Strength Test

Figure 5: Preparation of Grout Sample

3. RESULT AND DISCUSSION

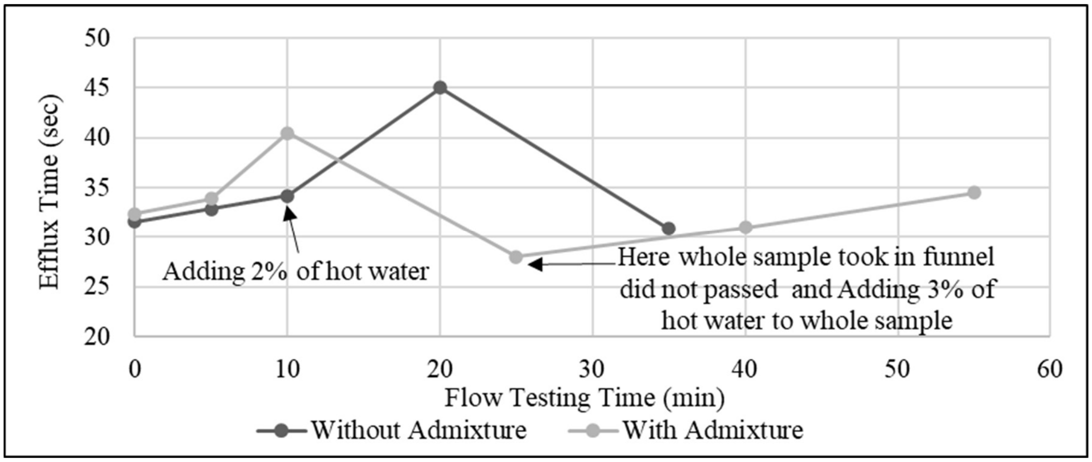
3.1 Findings from Flow Cone Method Test

The fluidity over time is represented in Figure 6. Figure 6(a) shows that at 45°C, the grout without admixture lost its fluidity 20 minutes after the initial mixing, but when adding admixture, the fluidity was lost 10 minutes after the grout mixing. The 45°C grout without admixture taken in the funnel did not pass through it after 20 minutes, and 3% hot water was added to regain its fluidity, demonstrating that with admixture, less water was required to regain fluidity.

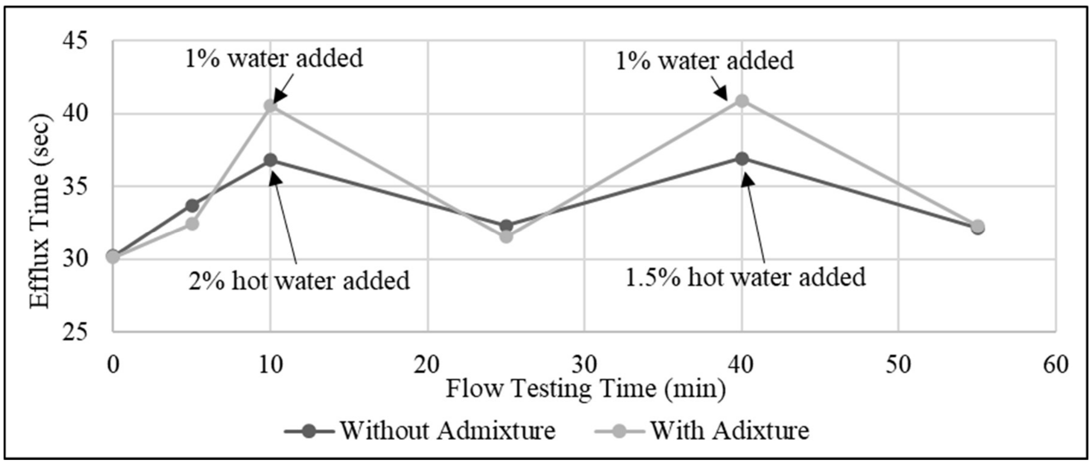
However, it is observed that grout with admixture at the same temperature required less water to regain its fluidity. From Figure 6(b), at 35°C, both types of grout lost their fluidity simultaneously after mixing, but grout with admixture required a smaller amount of water. From Figure 6(c), at room temperature, grout without admixture lost its fluidity at 10 minutes and 40 minutes after mixing grout and took the same amount of water to regain almost the same initial fluidity. In contrast, at 28°C the grout with admixture (aluminium powder) linearly increased and did not lose its fluidity over one hour.

3.2 Findings from Flow Table Test

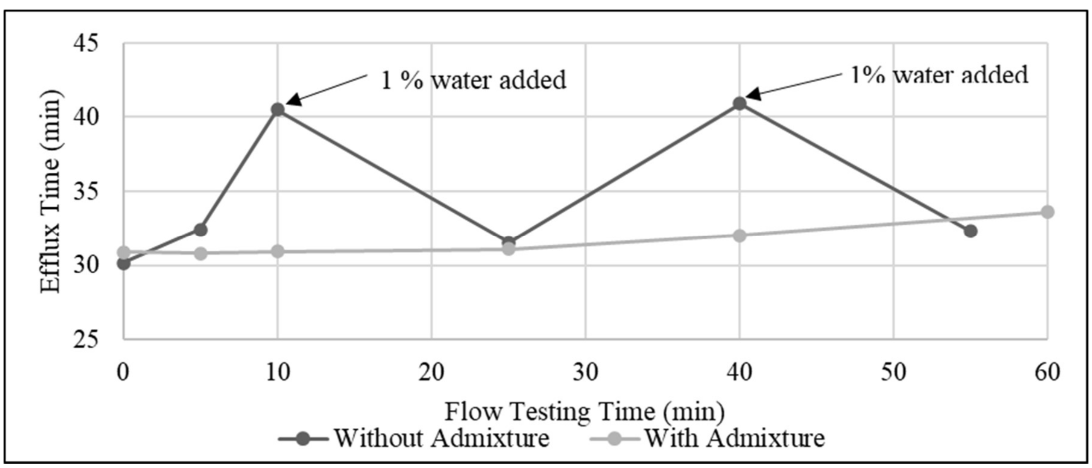
Figure 7 illustrates the blow number of the flow table at different temperatures. The blow number is dependent on the fluidity of the sample. It is observed that at lower fluidity, the blow number was higher. At 35°C, lower fluidity is indicated to be higher than at 45°C but lower than at room temperature, especially when admixture was added, as shown in Figure 7(a), 7(b), and 7(c).



(a)



(b)



(c)

Figure 6: Efflux Time at (a) 45°C, (b) 35°C, and (c) Room Temperature

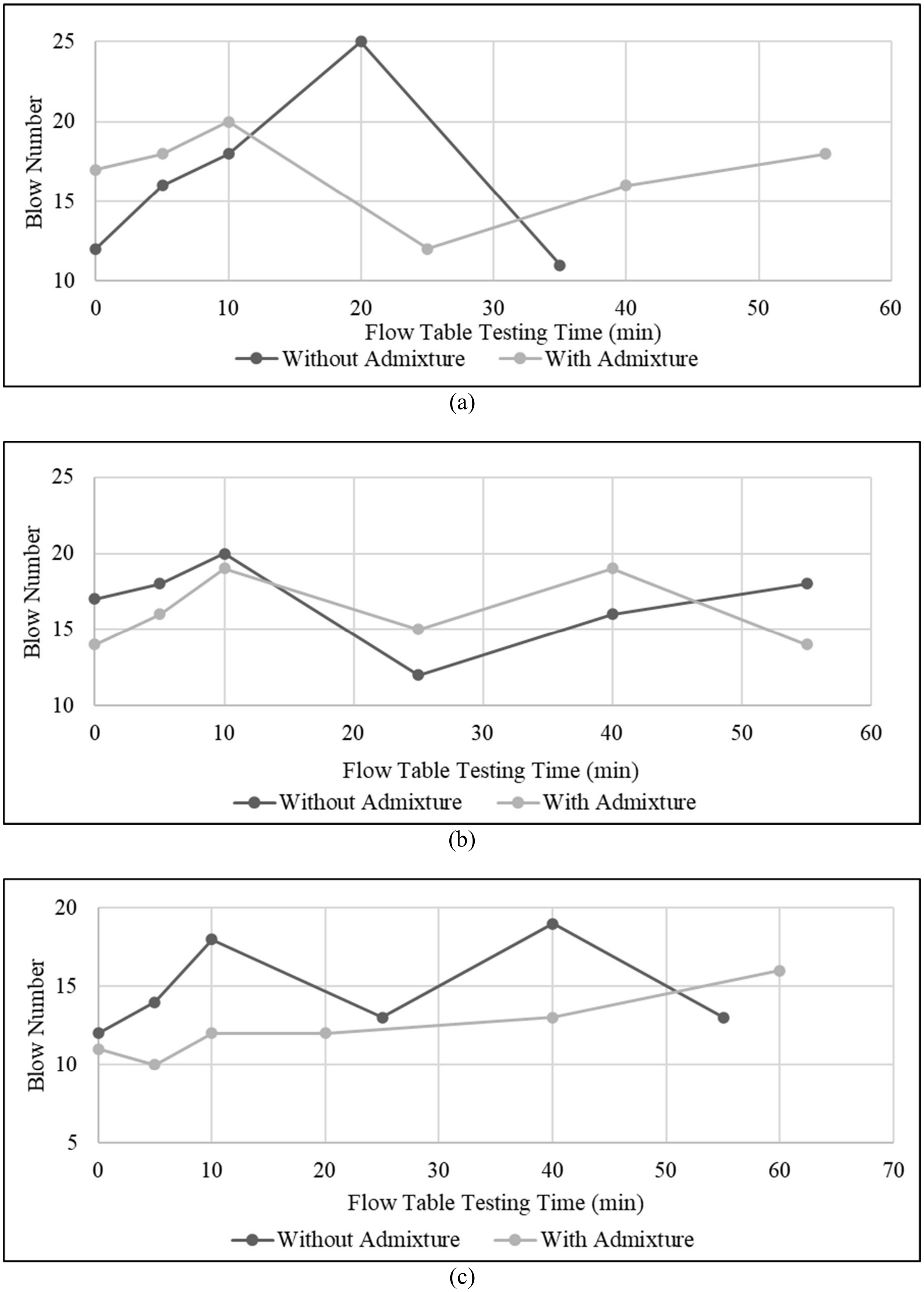


Figure 7: Blow Numbers at Different Flow Table Testing Time at (a) 45°C, (b) 35°C, and (c) Room Temperature

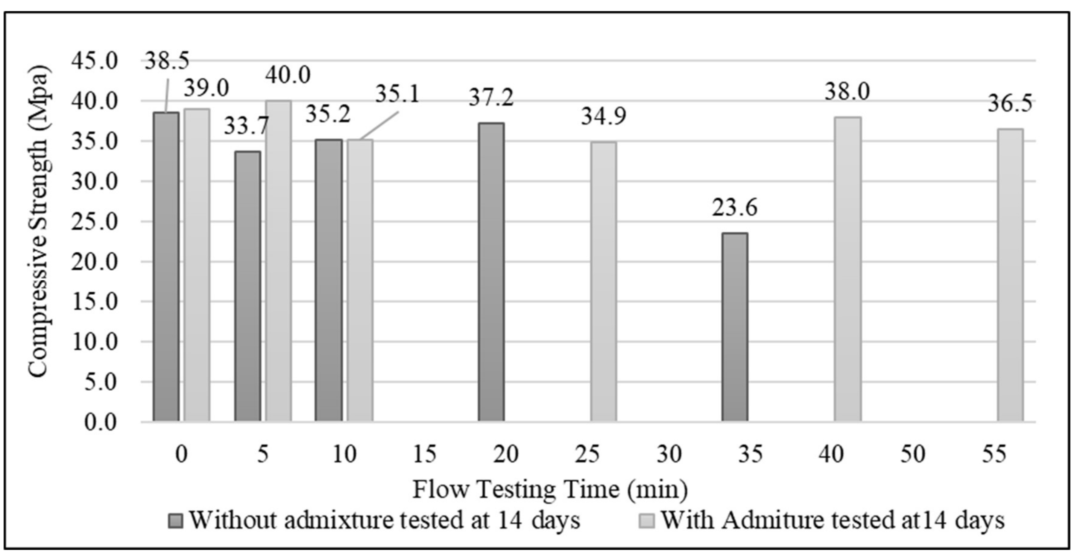
3.3 Findings from Compressive Strength Test

The compressive strength of the tested samples is presented in Table 2 below. It was observed that the optimum compressive strength occurred at 35°C after 40 minutes when admixture was added. The strength was higher at both 45°C and 35°C when the admixture was added. However, it was significantly lower at room temperature than at 45°C and 35°C. The optimum strength was found to be 51.98 MPa at 35°C after 40 minutes.

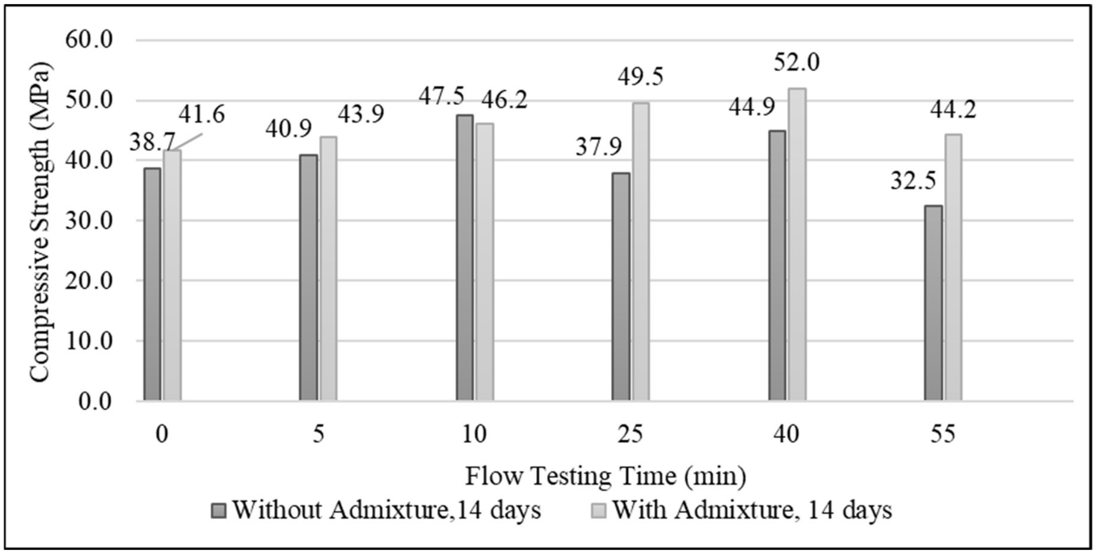
Table 2: Comparison of Compressive Strength with and without Admixture

Flow Testing Time (min)	Compressive Strength (MPa)					
	Room Temperature (28°C)		35°C		45°C	
	Without Admixture	With Admixture	Without Admixture	With Admixture	Without Admixture	With Admixture
0	53.027	35.107	38.72	41.6	38.5	39.013
5	45.88	38.493	40.92	43.85	33.7	40
10	46.4	39	47.53	46.16	35.17	35.133
15	-	-	-	-	-	-
20		32	-	-	37.24	-
25	43.973	-	37.87	49.47	-	34.92
30	-	-	-	-	-	-
35	-	-	-	-	23.58	-
40	46.533	27.307	44.95	51.98	23.58	37.99
45	-	-	-	-	-	-
50	-	-	-	-	-	-
55	44.733	-	32.45	44.21	-	36.54
60	-	42.8	-	-	-	-

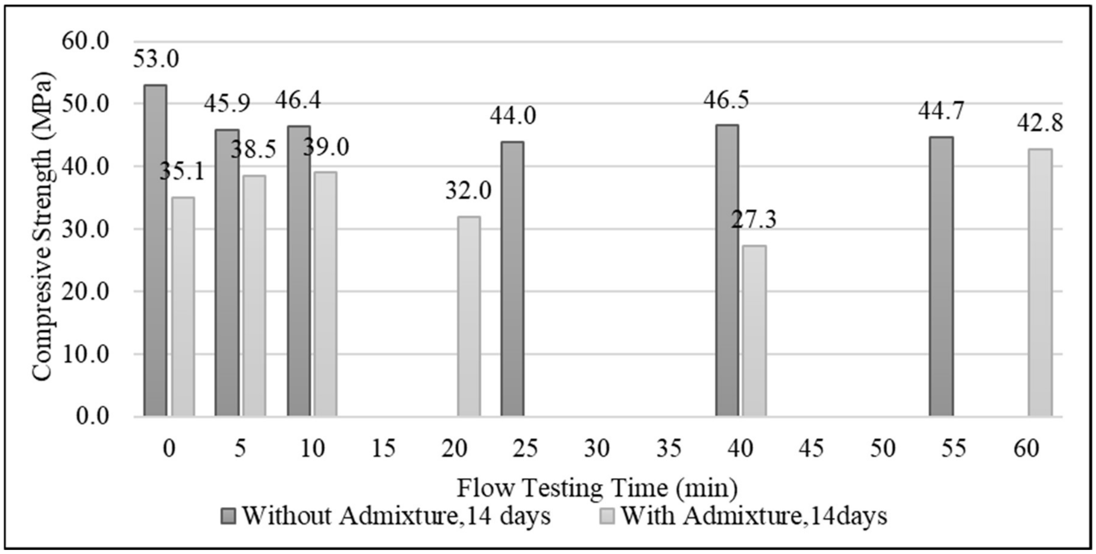
In Figure 8(a), at 45°C, the optimum strength was 3.75% greater when admixture was added to the grout than when the grout was without admixture. It is also observed that every sample exhibited higher strength when admixture was added at higher temperature. Figure 8(b) displays a 13.53% increase in strength at 35°C when admixture was added to the grout. For every sample of flow testing at 35°C, higher strength was observed when admixture was added, with percentages ranging from 6.92% to 26.6%. However, in room temperature grout, as shown in Figure 8(c), the strength was higher when admixture was not added, and the optimum strength found here was 53.027 MPa, which is 2% higher than at 35°C and 24% higher than at 45°C.



(a)



(b)



(c)

Figure 8: Compressive Strength at (a) 45°C, (b) 35°C, and (c) Room Temperature

3.4 Analysis of Results

The flow characteristics of cement grout and compressive strength with time and temperature have been determined through flow cone tests and flow table tests according to ASTM C 939 and ASTM C 1437 for fluidity, respectively. The main purpose of this work is to observe the fluidity of grout for one hour after the addition of water and the variation of compressive strength with the fluidity of grout. Two types of grouts were used, with and without admixture. The water-cement ratio of each grout was determined to ensure the same efflux time for each samples. The fluidity of the grout was restored by adding a certain amount of water after a specified time when the efflux time exceeded the standard limit. This process was repeated for one hour.

To investigate the effect of temperature on fluidity, 45°C and 35°C were selected due to the hot weather in Bangladesh. The initial mixing temperature of the grout was set at 45°C by adding hot water, and a room was created to maintain the initial temperature where the sample was placed. For the grout at 45°C without admixture, the fluidity at 0-minute efflux time was 31.6 seconds, and at 5 minutes after mixing, the efflux time was 32.89 seconds, within the standard limit. However, fluidity was lost at 20 minutes, and to regain the initial efflux time (fluidity), 3% of hot water was added. In contrast, the grout with admixture lost fluidity at 10 minutes, and 2% of water was added to regain the initial fluidity. The compressive strength was also determined for each flow cone test, showing that the compressive strength at 45°C was higher when admixture was added to each sample.

For the grout at 35°C, without and with admixture, efflux times followed a similar pattern; both types lost their fluidity at 10 and 40 minutes. However, 2% and 1.5% of water were required without admixture at 10 minutes and 40 minutes, respectively, after mixing with water and cement, which was higher than the grout with admixture, which required 1% at both times. The compressive strength was higher when admixture was added.

At room temperature (28°C), the compressive strength of the grout was higher when admixture was not added. Since grout is widely used for post-tensioned structures to protect strands from corrosion and fill cracks, the findings suggest that when grout is used at higher temperatures, admixture will be helpful in terms of workability for one hour and compressive strength. However, at 35°C, it is even more helpful as it requires less water to regain fluidity and exhibits higher strength than the initial grout temperature of 45°C.

4. CONCLUSIONS

From the findings of the studies, several conclusions can be drawn:

- The grout without admixture required more water to regain fluidity than the grout with admixture at both 45°C and 35°C initial temperatures.
- Both grout with and without admixture at 45°C required more water to regain fluidity compared to 35°C.
- The ability to regain fluidity for one hour is crucial for the pumping and injecting of grout during field placement over time.
- The compressive strength of grout with admixture increases when hot water is added, demonstrating higher strength at both 45°C and 35°C initial temperatures.
- The compressive strength of grout without admixture at 35°C is higher than at 45°C initial temperature.
- When the initial temperature of grout is 28°C without admixture, it exhibits higher compressive strength than any other type of grout.
- At 28°C initial temperature, the compressive strength of grout with admixture is reduced.
- It is found that in hot weather exceeding 30°C, the use of admixture is helpful due to the increased compressive strength, especially at 35°C.
- At lower temperatures, when normal water is added to the grout, the compressive strength without admixture shows an increase.

In summary, the temperature sensitivity of the grout with admixture plays an important role in its fluidity, strength, and water requirements. Understanding and optimising these factors can provide valuable insights for applications requiring specific performance characteristics under varying environmental conditions.

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