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Physical and Strength Properties of Cements Manufactured in Bangladesh: A Case Study

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ABSTRACT

This study investigates the physical qualities and strength properties of representative cements manufactured by different brands in Bangladesh. The physical and strength properties such as normal consistency, initial and final setting time, density, specific gravity, fineness, and compressive strength of cement mortars as well as concrete cylinders were investigated experimentally. Using CEM II/B-M type cement, a total of 300 test specimens are prepared to determine those parameters. In this case study, specimens were prepared from ten different representative cement industries of Bangladesh and tested as per ASTM specifications. The experimental result shows that the physical and strength parameters of nearly all the representative cement samples are within the ASTM recommended ranges that ultimately proofs the quality of Bangladeshi Cement. The relationship between mortar and concrete strengths from the same batch of cement has also been investigated. Besides, a regression analysis has been conducted to find relationships between the concrete strength and their age of curing. The influence of initial and final setting times on concrete strength is also investigated. This study also provides the relationships between compressive strengths, between mortar and concrete cylinders at different ages. These age dependencies of concrete strength will help to predict the actual concrete strength at the early age of curing which may ensure faster construction work.

1. INTRODUCTION

The increased demand for cement in the construction industry gains interests of researchers, engineers, and practitioners to understand their quality and standards. Several industries produce cement not only to meet the local demand but also to export cement all over the world. It is said that cement-made concrete consumption in the world is second only to the consumption of water (Goldstein, 1995). Cement is a major ingredient of concrete structures and plays a key role in the construction industry (Ali, 2010; Amin & Ali, 2009). To address the sustainability concern of any concrete structure, the quality of the raw materials of construction has to be ensured. Hence, it becomes imperative to understand the physical and mechanical properties of cement for concrete construction in real-life projects.

Concrete strength and durability are very important factors in construction which depend on various parameters including the quality of cement (Mohammed et al., 2012). Due to a huge demand for cement in concrete structures, the enormous growth of the cement industry can be noticed in the last two decades. The application of cement and its growth depends on the rate of urbanization and the number of development projects undertaken in the country. The per capita cement consumption of Bangladesh is increasing rapidly in the last decade as shown in Figure 1(a). Keeping pace with the infrastructure development of Bangladesh, the consumption of per capita cement almost doubled from 95 kg in 2011 to 187 kg in 2018 during the seven years (EBL Securities Ltd., 2017). It is observed from the figure that the cement consumption was doubled in just 7 years of span time. They have already started to export cement in many places of the world. The growth of cement export is sharply increasing as presented in Figure 1(b).

The demand is growing geometrically due to the mega projects such Dhaka Mass Rapid Transit (DMRT), Padma Multipurpose Bridge, elevated expressways in several cities, nuclear power plants, and so on. The economical effectiveness in building infrastructures depends on the quality of the cement used in the concrete. Though high-quality cements have a higher cost, it is proved to be economical in the long term (Rafi & Nasir, 2014). To ensure the sustainability of the structure, the ingredients of the construction must meet certain qualities established by standards (Soltani et al., 2019; Hani, 2011; ASTM, 2001). These standards allow us to conduct various tests, compare the cements obtained from different manufacturers with different sets of established parameters and review the quality of the binding material (Mangi et al., 2019b; Mangi et al., 2019a). Furthermore, numerical analysis can also be applied to correlate the results to predict the quality parameters of casted concrete such as ultimate strength, porosity, etc. (Hasan & Kabir, 2011; Iffat, 2015).

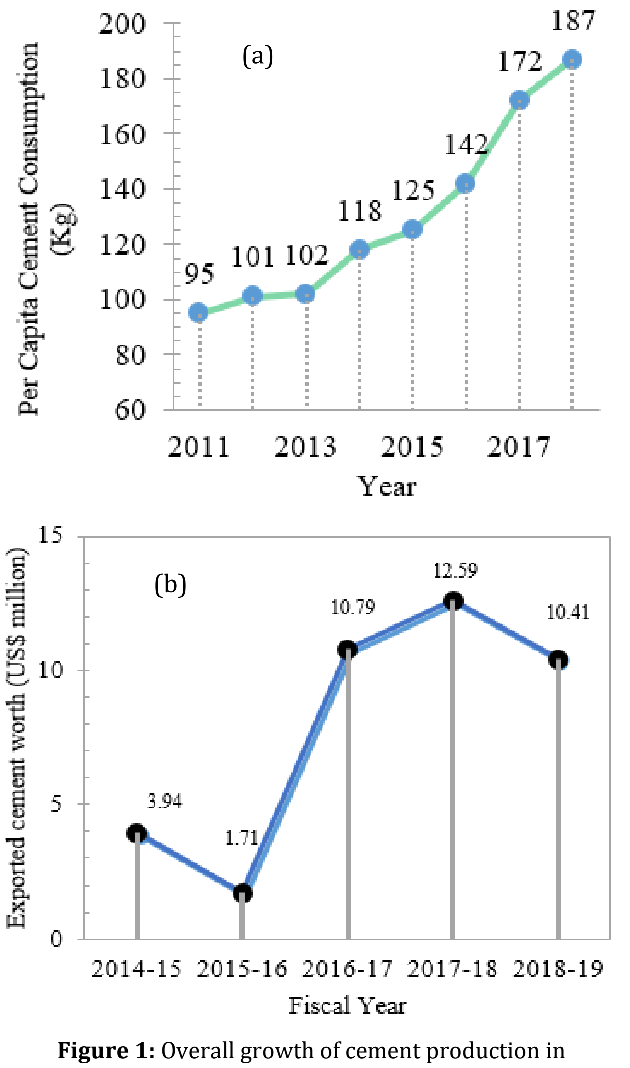


Figure 1: Overall growth of cement production in Bangladesh, (a) per capita cement consumption of Bangladesh over the past decade, (b) growth of cement export of Bangladesh (EBL Securities Ltd., 2017)

dAs most of the infrastructure development relies on locally produced cements for the construction of concrete structures, the in-depth investigation of the physical and mechanical properties of locally produces cements is of great concern. Most of these cement brands produce blended cements with a maximum of 35% admixtures mixed with clinker, which has become a global trend because of the availability of natural pozzolans and reduced environmental effects (Mohammed et al., 2011; Pourkhorshidi et al., 2010). Certain parameters such as setting time, fineness, specific gravity, and strength are largely influenced by the admixtures present in the cement (Barnett et al., 2007). Mohammed (2007) carried out research on investigation on factors related to sustainable development of concrete technology in Bangladesh. The objectives of their research work were the causes of deterioration of concrete structures, quality of cement brands, properties of concrete, recycling of demolished concrete as coarse aggregate for new construction, recycling of demolished concrete as fine aggregate for new construction.

There are 34 active different industries currently manufacturing cement in Bangladesh. However, the market is dominated by the ten to twelve leading brands because of their quality as well as cost-effectiveness. Mohammed et al. (2011), carried out research on the investigation of different cement brands commonly used in Bangladesh. They studied the common causes of deterioration of concrete structures in Bangladesh, common problems at construction sites that cause early deterioration of concrete structures in Bangladesh. However, the research was conducted more than a decade ago and important parameters like fineness and correlation between strength properties were not determined.

This case study aims to present the ASTM standard test results that can demonstrate the quality of the cements manufactured by ten of the leading industries dominating the capital market. The study also correlates different physical parameters and age dependencies to predict the concrete strength based on mentioned parameters.

2. EXPERIMENTAL INVESTIGATIONS

To determine the physical properties of cement such as normal consistency, initial and final setting time, density, specific gravity, and fineness of cement, standard tests were performed on test specimens prepared from the representative cements as per ASTM specifications. For strength properties like compressive strength of cement mortars and compressive strength (cylindrical), ASTM standards were followed in each step of the test preparation and test conduction. Based on the cement production, 10 different cement brands manufactured by 10 different industries were collected from the market to prepare 300 samples to conduct those tests. This section includes sample collection, major composition, test plan, test set-up, sample preparation, and experimental procedure.

A. Representative Sample Collection

According to Bangladesh Standard, BDS EN 197-1:2003, cements are mainly classified into five major categories according to their composition, namely CEM-I, CEM-II, CEM-III, CEM-IV, and CEM-V. CEM-II is Portland Composite Cement (PCC). CEM-II cement is sub-divided into different groups depending on the contents of mineral admixture and limestone powder, i.e., CEM II/A-M, CEM II/B-M, CEM II/A-S, CEM II/A-L. Quality assessment of CEM II/B-M type cement is justified in this analysis. Among the 34 active and recognized cement manufacturers in Bangladesh, samples of 10 major cement brands from CEM II/B-M category were collected from the market for experimental specimen preparation. These cement industries are considered the main stakeholder of the current cement industries of Bangladesh based on the production capacities. During the collection of the samples, the manufacturing dates were observed very carefully so that the date of manufacturing for all cements were close to each other (±3 days). All cements investigated in this study were manufactured in the 13-16th June of 2019. Each cement bag was kept in an air-tight plastic bag to prevent unwanted hydration with the moisture which is normally prominent in local weather conditions.

B. Composition of Cements of Different Brands

According to Bangladesh Standard (BDS EN 197-1:2003), CEM-II is Portland Composite Cement. CEM-II is sub-divided into different groups depending on the contents of mineral admixture and limestone powder, i.e., CEM II/A-M, CEM II/B-M, CEM II/A-S, CEM II/A-L. Quality assessment of CEM II/B-M type cement is used as the sample in this case study. The composition of each representative cement sample (RCS) was recorded. The cement industries of Bangladesh that follow BDS EN 197-1:2003 and recommend that CEM II/B-M type cement contains clinker 65% - 79%, blast furnace slag, fly ash, and limestone 21% - 35%, and minor additional constituents 0% - 5%. The strength class of this cement is 42.5N. All cement bags leveled approximately the same ingredient as per BDS guideline. Since the variation of the ingredients contains a wide range, there is a chance to possess different physical properties even the different industries keep them in the range value. CEM II is widely used with any types of rebars including high strength rebars (Ahmed et al., 2021b), stainless steels (Ahmed et al., 2021a; Islam et al., 2020) and also applicable for retrofitting and strengthening of existing structures such as column jacketing (Mahmud & Ahmed, 2020).

C. Specimen preparation and test setup

A schematic view of sample preparation and test setup is presented in Figure 2. In this study, normal consistency (ASTM C187) (ASTM, 2016), initial and final setting time (ASTM C191) (ASTM, 2019), compressive strength of cement mortar (ASTM C109) (ASTM-C109, 2013), fineness of cement (ASTM C204) (Testing and Materials, 2007), density and specific gravity (ASTM C188) (Standard, 2009) and compressive strength (cylindrical) (ASTM C39) (ASTM, 2012b) were tested in the laboratory following all the designated standards. Locally obtained fine and coarse aggregates which conform to the ASTM standards were used for the preparation of cement mortar and concrete. The compressive strength of cement mortar was tested at the age of 3, 7, and 28 days and cylindrical concrete specimens were tested at 7,14, and 28 days. The number of the samples tested in this study are shown as matrix in Table 1.

(a) Weighing cement (b) Pouring required water (c) Test set-up for setting time test

(d) Blaine air permeability apparatus (e) Test set-up for density test (f) Casted concrete cylinders

Figure 2: Sample preparation and experimental setup for the tests

Table 1
Test matrix of the specimens

Designation (Representative Cement Samples)	Density & Specific Gravity	Fineness	Normal Consistency	Setting Time	Compressive strength (mortars)			Compressive strength (cylindrical)			Total Tested Sample
					3 days	7 days	28 days	7 days	14 days	28 days	
RCS-1	2	4	5	1	3	3	3	3	3	3	30
RCS-2	2	4	5	1	3	3	3	3	3	3	30
RCS-3	2	4	5	1	3	3	3	3	3	3	30
RCS-4	2	4	5	1	3	3	3	3	3	3	30
RCS-5	2	4	5	1	3	3	3	3	3	3	30
RCS-6	2	4	5	1	3	3	3	3	3	3	30
RCS-7	2	4	5	1	3	3	3	3	3	3	30
RCS-8	2	4	5	1	3	3	3	3	3	3	30
RCS-9	2	4	5	1	3	3	3	3	3	3	30
RCS-10	2	4	5	1	3	3	3	3	3	3	30
Total	20	40	50	10	30	30	30	30	30	30	300

3. RESULTS AND DISCUSSIONS

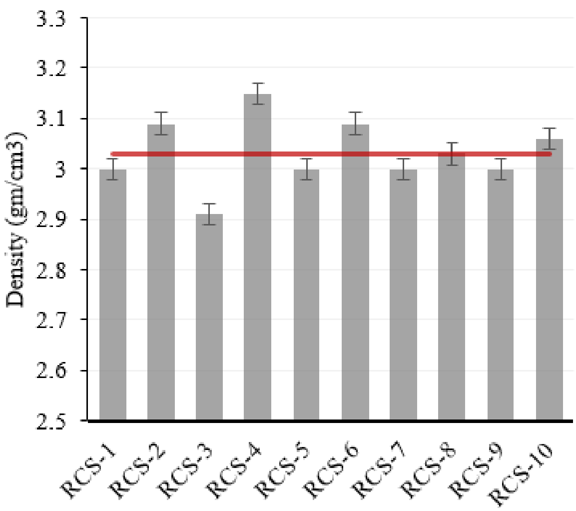
All specimens were tested following ASTM standards. All pieces of equipment used in this study were calibrated before conducting the tests. The test results of the physical properties of cement are presented as follows.

A. Density and Specific Gravity Test

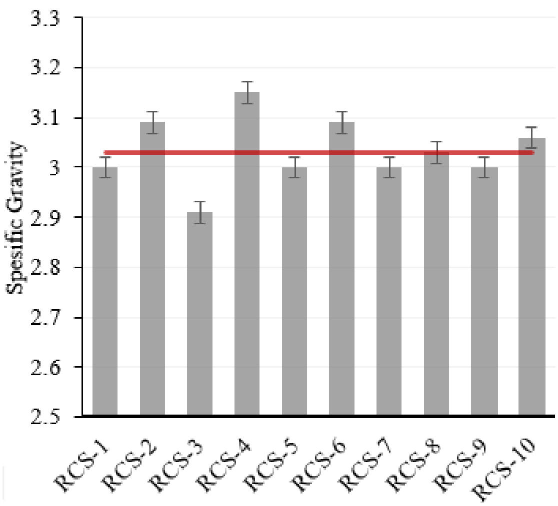
The density and specific gravity of the representative cement samples (RCSs) are shown in Figures 3(a) and 3(b), respectively. The values are very close to each other varying within the range of 2.91g/cc to 3.15g/cc regarding density and 2.91 to 3.15 regarding specific gravity. Only one out of ten RCS namely RCS-3 has shown the value of specific gravity below 3. However, the range is fairly close to the commonly used value of 3.15 (ASTM C188), with the highest deviation being 7.61% in the case of RCS-3. Therefore, it can be concluded that the Bangladeshi manufacturers maintain the ASTM C 188 standard.

B. Fineness Test

The fineness test of cement samples was conducted by Blaine air permeability apparatus as per ASTM C204. Figure 4 shows the results of the fineness test which varies within the range 241-364m2/kg with a mean value of 303m2/kg. According to ASTM C150(ASTM, 2001), the standard Blaine fineness range is 260-430 m2/kg. Though 80% of RCSs concur with this standard, the fineness for RCS-1 and RCS-3 were below the lower limit of ASTM standard. However, the deviation from the lower limit of the standard is 3.8% and 7.3% respectively, which are very reasonable for this test's perspective.



(a)



(b)

Figure 3: (a) Density comparison of RCSs, (b) Specific gravity of RCSs

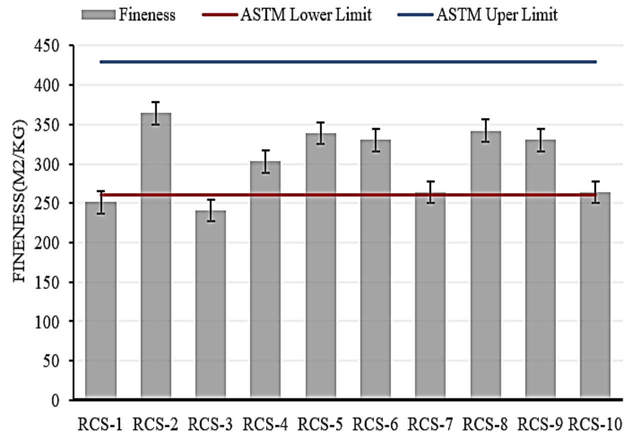


Figure 4: Fineness comparison of the RCSs

C. Normal Consistency Test

Figures 5a and 5b present the compiled data from the normal consistency test conducted as per ASTM C187. The relation between the percentage of water and penetration is shown in Figure 5a, whereas the normal consistency of the RCSs is shown in Figure 5b. It is observed from figure 5a that all the specimens follow a similar trend except for RCS-7. The value of normal consistency for Bangladeshi RCSs varies within 28-32% though the ASTM standard for normal consistency of cement is 22-30%.

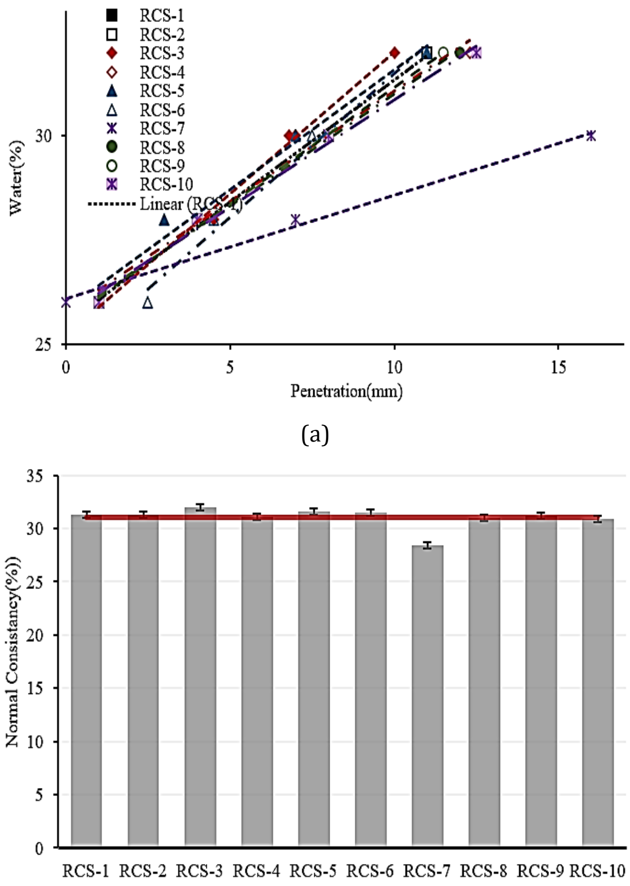


Figure 5: (a) Percentage of water vs penetration, (b) Normal Consistency of RCSs

D. Setting Time Test

Figure 6 shows the relationship between setting time and penetration for all RCSs. It is evident from the graph that all of the RCSs start to set within the range of 120-180 min and they reached their final setting points within 195-240mins. Figure 7 exhibits the initial and final setting times of the RCSs. As per ASTM C 150 standard, the standard requirement of initial setting time should not be less than 45 minutes and the final setting time should not be more than 375 minutes. As per ASTM Standard, all of the RCSs fall within the acceptable limit.

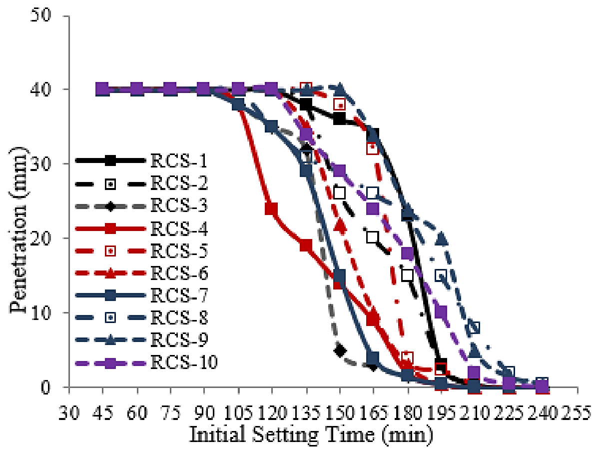


Figure 6: Penetration vs Initial setting time of RCSs

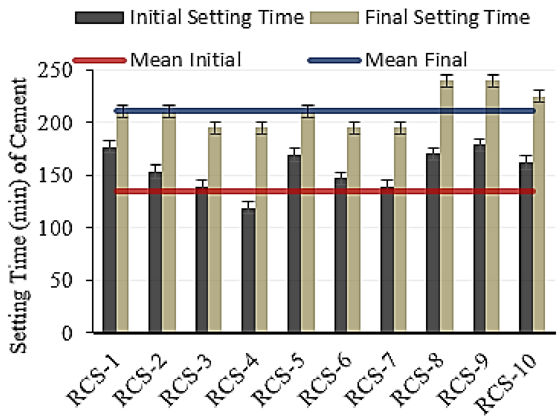


Figure 7: Initial and final setting times (min) of the RCSs

Interestingly, the RCS-7 that showed low consistency also shows relatively low setting time because consistency affects the setting time of the cement. The result also shows that the final setting time of RCS 8, 9 and 10 are comparatively higher. This can be described by the fact that those three cements hydrates slower than the others or may be due to the increased w/c ratio in the mixing process.

E. Compressive Strength of Mortars

A total of 90 samples were tested from 10 categories on 3 different dates (every 30 samples after 3,7 and 28 days). The test results are shown in Figure 8. According to ASTM C595-12, standard requirements of compressive strength are 13 MPa, 20 MPa and 25 MPa at 3 days, 7 days and 28 days, respectively. Among the ten RCSs, 9 meet the requirements of ASTM standard of 3 days, 6 meet the requirement of 7days and 8 specimens meet the requirement of 28 days compressive strength. The samples which do not concur with the ASTM range are also very close to the standard value. It is interesting to highlight that the compressive strength of RCS7 is lower than six other representative samples which matches well with its consistency. However, its higher than that of some cement specimens due to the low precisions in manufacturing.

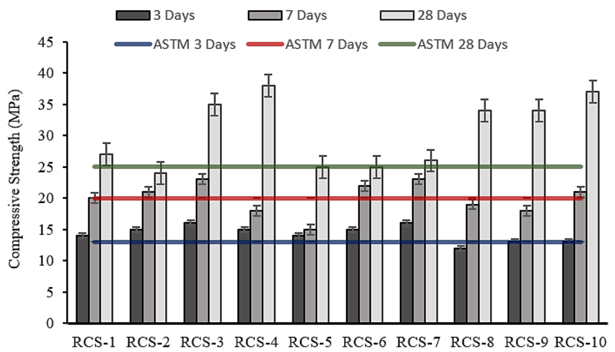


Figure 8: Compressive strength of cement mortars of RCSs at different ages

F. Regression Analysis for Compressive Strength of Mortar

Regression analysis was performed on the test results of the compressive strength test of the mortar samples to predict the strength of mortar from the data of 3days and 7days compressive strength of the mortar. For prediction of ultimate strength from 3days compressive strength, the regression equation is y = a + bx. From the regression relationship between 28-days compressive strength of cement mortar and 3-days compressive strength of cement mortar the coefficient of determination, R2 is 0.956 which is close to 1.0 that reflects a very good correlation. This implies that 95.6% of the variation in y is explained by x and 4.4% is not explained. In this case, y-intercept a= 0 and slope b= 2.102. Therefore, it can be concluded from the regression relationship between 28-days compressive strength of cement mortar and 3-days compressive strength of cement mortar that the following regression equation can be written. The regression relationship between the 28-days and 3-days compressive strength of cement mortar is shown in Figure 9 (a).

$$f'_{c\,(28d)} = 2.20f'_{c\,(3d)} \qquad (1)$$

From the regression relationship between 28-days compressive strength of cement mortar and 7-days compressive strength of cement mortar it can be understood that the coefficient of determination, R2 is 0.952. y-intercept were found to be a= 0 and slope b= 1.489. Therefore, from the regression relationship between 28-days compressive strength of cement mortar and 7-days compressive strength of cement mortar, the following regression equation can be written. The regression relationship between 28-days and 7-days compressive strength of cement mortar is shown in Figure 9(b)

$$f'_{c(28d)} = 1.49f'_{c(7d)} \qquad (2)$$

The combined regression relationship among 28-days compressive strength of cement mortar and 3 and 7-days compressive strength of cement mortar shows that adjusted R2 is 0.826. Adjusted R2 is used for multiple regression instead of R2. y-intercept a= 0 and slope or coefficient for 3-days b1= 1.489 and coefficient for 7-days b2= 0.437. Therefore, from the regression relationship between 28-days compressive strength of cement mortar and 3 & 7-days compressive strength of cement mortar, the following regression equation can be written. The regression relationship among 28-days and 3 & 7-days compressive strength of cement mortar is shown in Figure 10.

$$f'_{c(28d)} = 1.49f'_{c(3d)} + 0.44f'_{c(7d)} \qquad (3)$$

Figure 11 represents the predicted 28-days compressive strength of cement mortar against 3-days, 7-days and a combination of 3 & 7-days compressive strength of cement mortar. From the regression relationship among f'c 28 days and f'c 3 days, f'c 28 days and f'c 7 days and fc 28 days and fc 3 & 7 days we can get the predicted 28-days compressive strength.

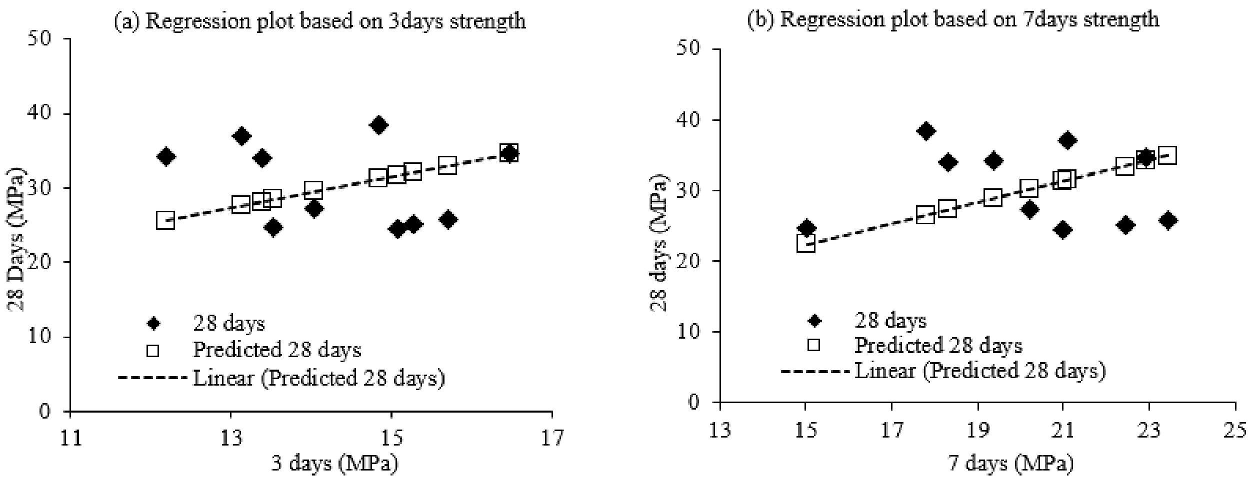


Figure 9: Regression analysis plots for the strength of cement mortar at different ages, (a) 3 days to 28 days relationship; (b) 7 days to 28 days relationship

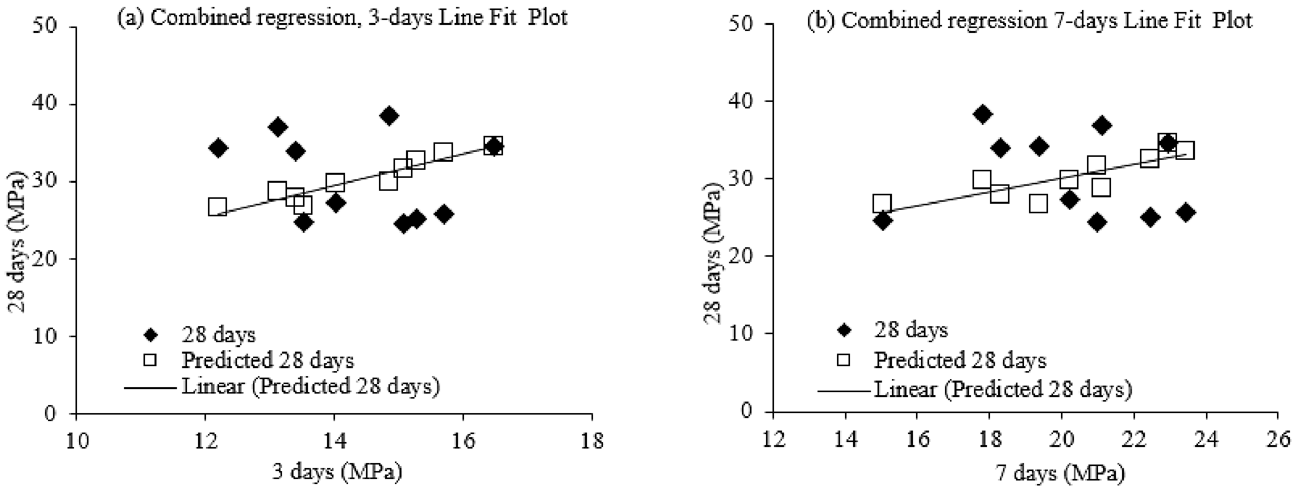


Figure 10: Concrete cylinder strength at 3 to 28 days and 7 to 28 days

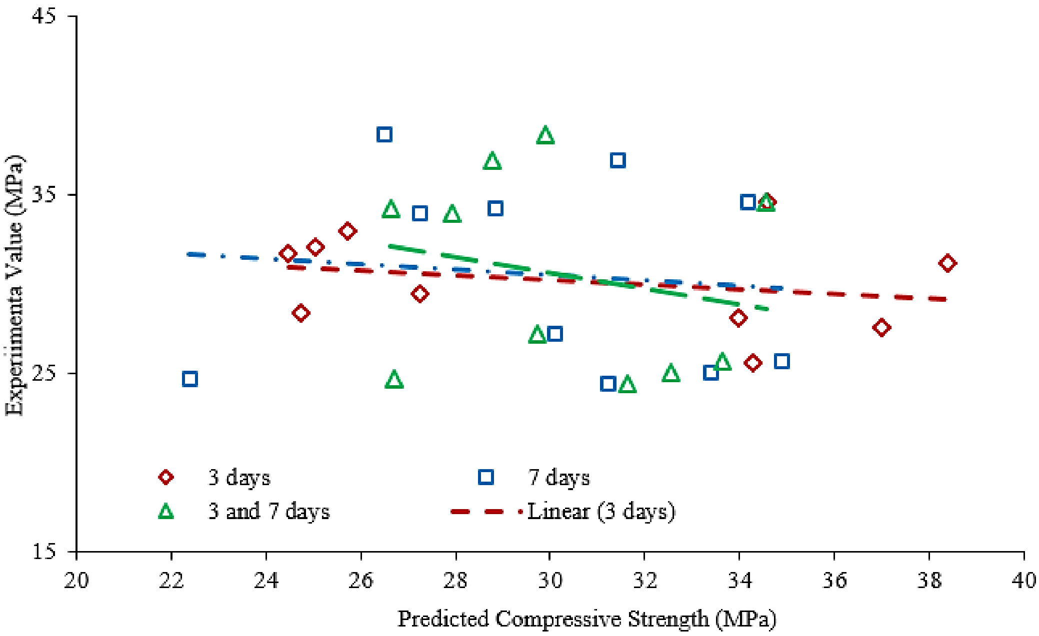


Figure 11: Experimental to predicted compressive strength of concrete at 3 days and 7 days

G. Variation of Compressive Strength of Mortar with Setting Time and Fineness

Figures 12(a) and 12(b) represent the relationship between compressive strength of mortar and initial and final setting time respectively. Though the increase in initial setting time resulted in decreased ultimate strength, the reversed trend was observed for final setting time where strength increased with the increase of final setting time. The relationship between the fineness of cement and the compressive strength of mortar is shown in Figure 13. Though all the strength values show a negative trend with the increase of fineness value of cement, the rate of decrease in strength was found to be increasing with the maturity of the mortar specimen.

H. Compressive Strength of Concrete

The variation of compressive strength of cylindrical concrete specimens is shown in Figure 14. Mix ratio for concrete was 1: 1.5: 3 and W/C ratio was 0.45. The target strength of the concrete mix was 24MPa. According to the ASTM standard, the minimum rates of strength gaining are 7 days 65%, 14 days 90%, and 28 days 99%. Compressive testing ages are 7 days, 14 days and 28 days and minimum strengths are required 15.6 MPa, 21.6 MPa and 23.76 MPa respectively. It was observed that 8 representative cement samples satisfy the 7-days requirement, only 3 representative cement samples satisfy the 14-days requirement and all representative cement samples satisfy the 28-days ASTM requirement of strength. Mean values are 17.07 MPa for 7-days, 20.8 MPa for 14-days and 36.5 MPa for 28-days. The average strength gaining rate 70.74% for 7-days, 86.26% for 14-days and 151.28% for 28-days.

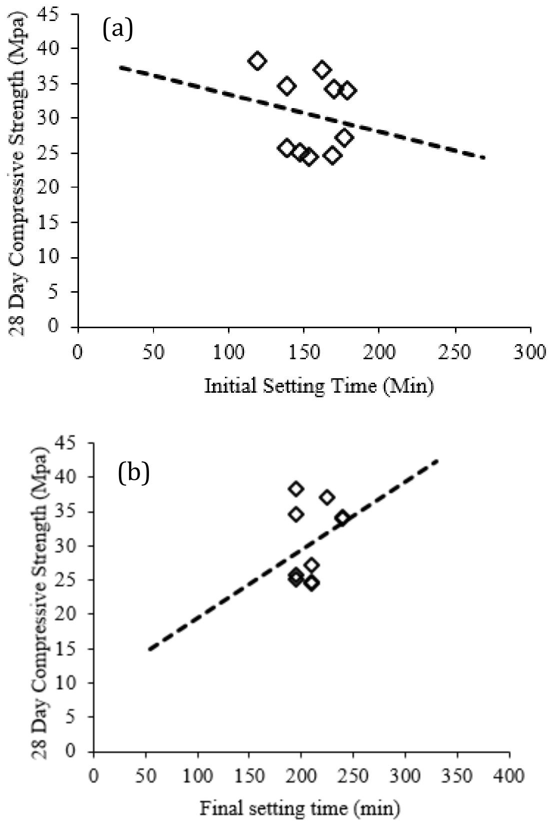


Figure 12: Variation of concrete strength with setting time

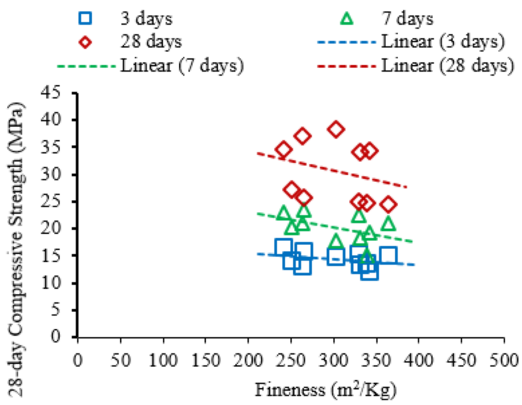


Figure 13: Relationship between the fineness of cement and compressive strength of mortar

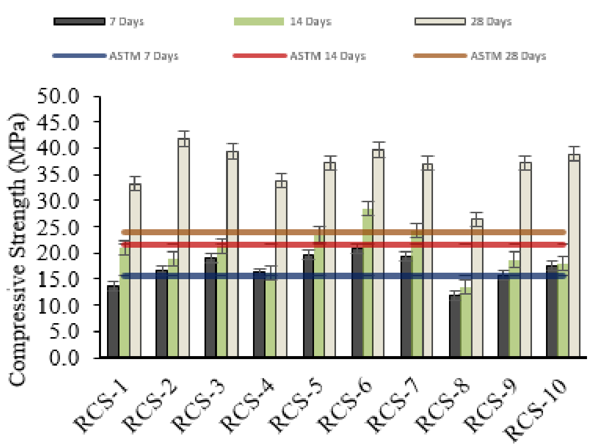


Figure 14: Compressive strength of concrete cylinder specimens at different age

I. Regression Analysis

A series of regression analysis was also performed on the test results the compressive strength test of the cylindrical specimens to predict the strength of concrete from the data of 7 days and 14 days compressive strength of the mortar. For prediction of ultimate strength from 7days compressive strength, the regression equation is $y = a + bx$. From the regression relationship between 28-days compressive strength of concrete cylinders and 7-days compressive strength of cement mortar it can be seen that the coefficient of determination, R2 is 0.989. This implies that 98.9% of the variation in y is explained by x and 1.1% is not explained. In this case, y-intercept a= 0 and slope b= 2.115. Therefore, from the regression relationship between 28-days mortar strength to that of 7-days, the regression equation can be written as presented in Eq. (4).

$$f'_{c\,(28d)} = 2.12 f'_{c\,(7d)} \tag{4}$$

The relationship obtained from the regression analysis shows that 7days strength is 47% of the 28days strength which is very much close to the ASTM recommended minimum values and also matches well with the results observed by (Hasan & Kabir, 2011).

The regression relationship between 28-days and 7-days compressive strength of cement mortar is shown in Figure 15(a). From the regression relationship between 28-days compressive strength of cement mortar and 14-days compressive strength of concrete it is evident that the coefficient of determination, R2 is 0.976. y-intercept were found to be a= 0 and slope b= 1.7138. Therefore, from the regression relationship between 28-days compressive strength of cement mortar and 14-days compressive strength of cement mortar, the regression equation can be written as presented in Eq. (5). The regression relationship between 28-days and 14-days compressive strength of cement mortar is shown in Figure 15(b)

$$f'_{c(28d)} = 1.71 f'_{c(14d)} \tag{5}$$

The relationship indicates that the strength gained in 14 days are roughly 60% of the strength gained in 28 days which is also suggested by the ASTM.

The combined regression relationship among 28-days compressive strength of concrete cylinders and 7 and 14-days compressive strength of concrete cylinders show that adjusted R2 is 0.864. Adjusted R2 is used for multiple regression instead of initial R2. y-intercept a = 0 and slope or coefficient for 7-days b1= 2.392 and coefficient for 14-days b2 = -0.227. So from the regression relationship between 28-days compressive strength of concrete cylinders and 7 & 14-days compressive strength of the specimens, the following regression equation can be written. The regression relationship among 28-days and 7 & 14-days mortar strength is shown in Figure 16.

$$f'_{c(28d)} = 2.39 f'_{c(7d)} - 0.23 f'_{c(14d)} \tag{6}$$

Figure 17 represents the predicted 28-days compressive strength of concrete against 7-days, 14-days and a combination of 7 & 14-days compressive strength of concrete. From the regression relationship among f'c 28 days and f'c 7-days, f'c 28 days and f'c 14 days and fc 28 days and fc 3 & 7 days we can get the predicted 28-days compressive strength of concrete.

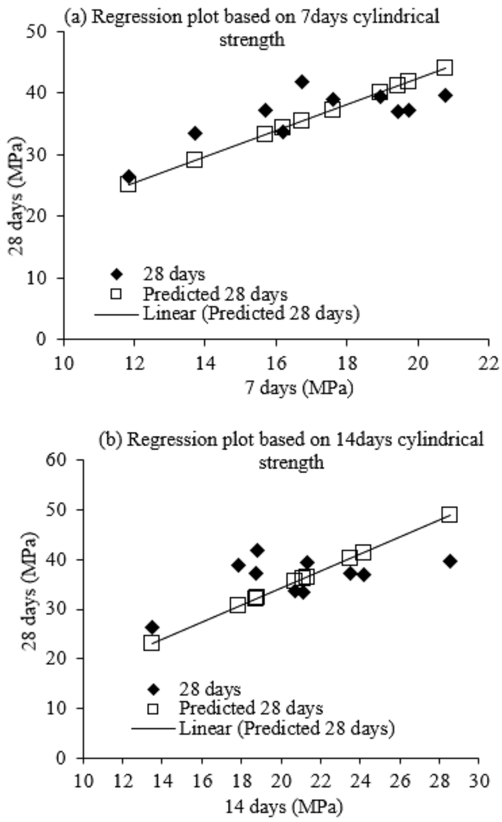


Figure 15: Regression analysis plots for concrete cylinder strength

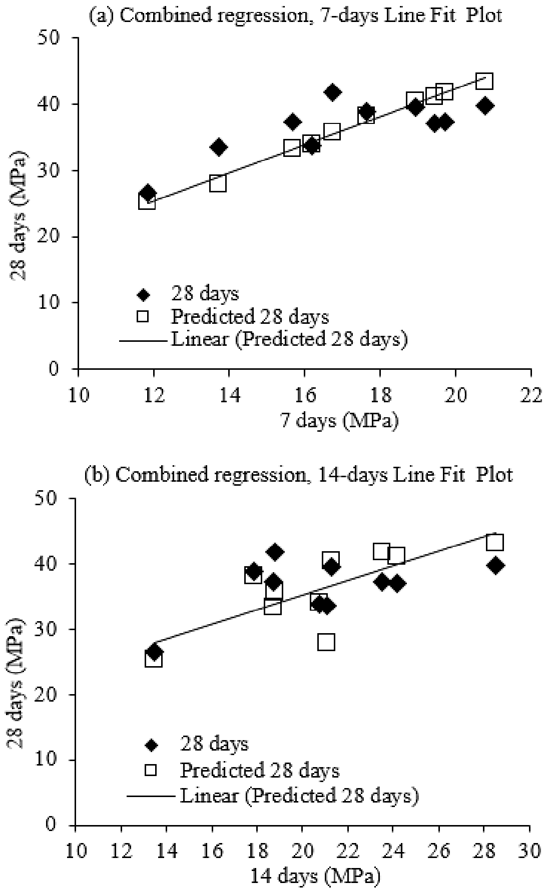


Figure 16: Combined regression analysis plots for cylindrical strength

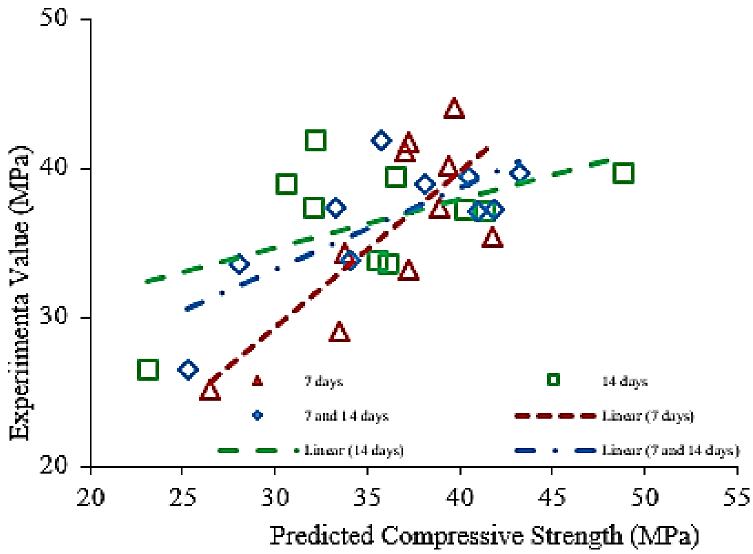


Figure 17: Experimental result to predicted compressive strength

4. CONCLUSIONS

In Bangladesh, the demand for cement is increasing day by day due to the ongoing extensive construction work and mega projects. Besides national demand, local industries are exporting cement to other countries. In a view to understanding the cement quality, this study investigates the physical and strength properties of concrete by performing a total of 300 tests on 10 different representative cement brands of Bangladesh. The key findings of this study are presented as follows.

The experimental results on density and specific gravity showed that the mean density of all tested samples is 3.023

whereas the ASTM range of specific gravity of such type cement varies in the range of 3.12-3.19. Since the mean value is very close to the ASTM range, it can be concluded that the specific gravity of Bangladeshi cements follows the guideline quite accurately.

The experimental result showed that the fineness of more than 80% of the tested cement samples is in the ASTM recommended range (2600-4300 m2/kg). The mean value of fineness of all the samples is 3028 m2/kg that satisfies the ASTM standard.

As per ASTM C187, the standard for normal consistency of cement is 22~30%. However, the Bangladeshi cements showed a bit higher consistency than the ASTM range. 90% of the representative cement samples showed quite similar behavior. All the samples showed consistency in the range of 28.0~32% rather (22-30%) with a mean value of normal consistency as 31 %.

All representative cement samples satisfy the ASTM C 595-12(ASTM, 2012a) requirements of the limit of initial setting time and final setting time. It is found that there is a tendency of achieving lower strength for the representative cement samples with a longer initial setting time and a higher level of strength for the cement with a longer final setting time.

The result showed that the compressive strength of cement increases with age as expected. According to ASTM C 595-12, the standard requirements of compressive strength of cement mortars are 13 MPa in 3 days, 20 MPa in 7 days, and 25 MPa in 28 days. It is found that 90% of representative cement samples satisfy the 3-days requirement, 60% of representative cement samples satisfy the 7-days requirement and 80% of representative cement samples satisfy the 28-days requirement. Mean values of compressive strength at different ages satisfy the ASTM requirements.

According to the ASTM standard of compressive strength of cylindrical concrete specimens, the minimum rates of strength gaining are 3 days 40%, 7 days 65%, 14 days 90%, and 28 days 99%. The test results indicated that they conform with the guideline with very few exceptions.

Based on regression analysis of the experimental results the following relations were derived to predict both the ultimate strength of the cement mortar and cylindrical strength. For mortar samples predicted 28-days strength from 3- and 7-days strength is formulated by,

$f'_{c(28d)} = 1.49f'_{c(3d)} + 0.44f'_{c(7d)}$, where R2=0.826

For cylindrical samples predicted 28-days strength from 3- and 7-days strength is formulated by,

$f'_{c(28d)} = 2.39f'_{c(7d)} - 0.23f'_{c(14d)}$, where R2=0.864

The values of the coefficient of determination reflect that the proposed equations are quite accurate to predict the concrete strengths at 28 days. Those correlations may be used to predict the 28 days concrete strength at the early age of concrete. Therefore, the construction industries may take the benefit in decision making and plan accordingly to ensure faster construction.

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