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Adverse Curing Conditions and Performance of Concrete: Bangladesh Perspective

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***Abstract*—**Concrete is the predominant construction material in Bangladesh. In large projects, stringent quality control procedures are usually followed under the supervision of experienced engineers and skilled labors. However, in the case of small projects and particularly at distant locations from major cities, proper quality control is often an issue. It has been found from experience that such quality related issues mainly arise from inappropriate proportioning of concrete mixes and improper curing conditions. In most cases external curing method is followed which requires supply of adequate quantity of water along with proper protection against evaporation. Often these conditions are found missing in the general construction sites and eventually lead to production of weaker concrete both in terms of strength and durability. In this study, an attempt has been made to investigate the performance of general concreting works of the country when subjected to several adverse curing conditions that are quite common in various small to medium construction sites. A total of six different types of adverse curing conditions were simulated in the laboratory and samples were kept under those conditions for several days. A set of samples was also submerged in normal curing condition having proper supply of curing water. Performance of concrete was evaluated in terms of compressive strength, tensile strength, chloride permeability and drying shrinkage. About 37% and 25% reduction in 28-day compressive and tensile strength were observed respectively, for samples subjected to most adverse curing condition as compared to the samples under normal curing conditions. Normal curing concrete exhibited moderate permeability (close to low permeability) whereas concrete under adverse curing conditions showed very high permeability values. Similar results were also obtained for shrinkage tests. This study, thus, will assist concerned engineers and supervisors to understand the importance of quality assurance during the curing period of concrete.

***Keywords*—**Adverse, concrete, curing, compressive strength, drying shrinkage, permeability, tensile strength.

I. Introduction

THE construction sector of Bangladesh is in blooming phase due to enormous economic growth of the country. As a result, a large number of infrastructural development works has been proliferating around the country. The types of construction ranges from huge multi-span bridges to small single-story structures. Most of these structures are made up of reinforced concrete (RC). The overall performance of any RC structure largely depends on proper proportioning of materials and strict quality control (QC). The mechanical properties of concrete are not its' intrinsic characteristics. Certain conditions need to be maintained during preparation of concrete to ensure adequate strength and durability. Therefore, appropriate QC protocol during construction is extremely important for any concrete work. Although a significant number of research has been conducted around the globe to produce advanced high performance cementitous composites using different types of nano and micro fibers [1]-[7], the construction practices in Bangladesh are still quite rudimentary in a number of instances [8].

In the case of large projects in the country, it has been observed that proper quality control procedures are usually followed under the supervision of experienced engineers and skilled labors. However, small projects, particularly at distant locations from major cities, often suffer from poor QC issues. From experience, it can be said that such quality related problems mainly arise from inappropriate proportioning of concrete mixes and improper curing conditions [8], [9]. The primary reason behind curing related problems is the lack of awareness and knowledge among the unskilled and semi-skilled construction supervisors and workers of the country [10], [11].

Typical external curing method is mainly followed in small to medium constructions works. Such curing process requires supply of sufficient amount of water from external sources as well as proper protection against evaporation. It is beyond doubt that stringent supervision is necessary to ensure these two conditions. Unfortunately, due to absence of proper supervision which arises from unaware construction supervisors, general concreting works frequently experience durability issues. Also, in some cases scarcity of supply of water poses an issue where retention of curing water is essential. It is widely known that improper curing results in weaker concrete both in terms of strength and permeability. However, quantification of deterioration due to curing related problems is extremely important to compel construction workers and supervisors to be responsive to this issue. An intensive literature review reveals that very limited number of significant study is available on effect of adverse curing conditions, that are quite common in various small to medium construction sites of Bangladesh, on concrete properties. Few recent studies are available on durability characteristics of some commonly used concrete mix proportions of the country under normal curing conditions [12], [13].

Therefore, an attempt has been made in this study to investigate the performance of general concreting works of Bangladesh when subjected to several prevailing harsh curing conditions. Locally manufactured cement and locally available stone chips and sand were used as coarse and fine aggregates respectively. A total of six different types of adverse curing conditions were simulated in the laboratory and samples were kept under those conditions for several days. All simulated curing conditions had no or insufficient supply of external curing water. In addition, three of the six simulated curing conditions had no protective covering. A set of samples was also submerged in normal curing condition with adequate supply of curing water. Performance of concrete under different curing conditions was evaluated in terms of compressive strength, tensile strength, chloride permeability and drying shrinkage. Chloride permeability was measured through rapid chloride permeability test (RCPT). It has been found that curing condition has significant impact on overall performance of concrete. Concrete without adequate supply of external curing water and proper covering showed considerable reduction in strengths and augmentation of permeability and shrinkage values. The author believes that findings of this study will be helpful for general site engineers and supervisors to understand the importance of quality assurance during the curing period of concrete.

II. Experimental Program and Materials Used

Locally produced Ordinary Portland Cement (OPC) was used in this study along with locally available stone chips as coarse aggregate and sand as fine aggregate. All required properties of cement, sand and stone chips were determined in the laboratory following relevant ASTM standards. Gradation of coarse aggregate (stone chips) was measured according to ASTM C136 method [14] and is shown in Fig. 1. Bulk specific gravity and absorption capacity of both fine and course aggregates were obtained following ASTM C128 [15]. Bulk specific gravity of stone chips was found to be 2.601 and 2.629 on Oven Dry (OD) and SSD basis, respectively. Bulk specific gravity of sands on OD basis and SSD basis was obtained as 2.606 and 2.634, respectively. Absorption capacity of stone chips and sand was found as 1.1% and 0.95% respectively. Unit weight of stone chips and sand were obtained as 1545kg/m^3 and 1610kg/m^3, respectively as per ASTM C29 [16]. The normal consistency of the cement was measured as per ASTM C187 [17] and found to be 25.5%. The 7 and 28 days compressive strength of cement mortar were determined according to ASTM C109 [18] and obtained as 12.7 MPa and 29.3 MPa, respectively. All samples were prepared using one of the most commonly used mix ratios of 1: 1.5: 3 on volume basis with a water cement ratio of 0.40.

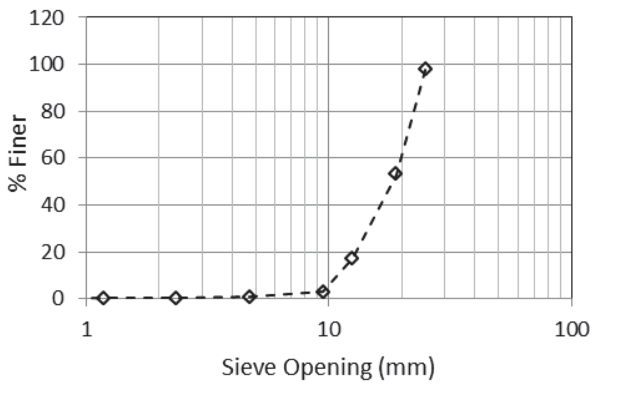

Fig. 1 Gradation curve of - stone chips (SC) used as coarse aggregate

A total of six curing conditions were considered in this study to simulate adverse curing conditions of different degree. In one curing condition, samples were kept in exposed condition just after casting both with and without polythene sheet covering, termed as C1 and C2 curing condition, respectively. In cases of C3 and C4 curing conditions, samples were kept submerged under water for 3 days and then kept under exposed condition with and without polythene cover, respectively. For C5 and C6 conditions, the samples were submerged under water for 7 days and then placed outside, with and without cover, respectively. Samples were also kept under normal external curing condition (termed as NCC) for comparison.

Performance of concrete under different simulated adverse curing conditions was evaluated in terms of compressive strength, split tensile strength, chloride permeability and drying shrinkage. The compressive and tensile strength tests were performed according to ASTM C39 [19] and ASTM C496/C496M [20], respectively. Permeability of concrete specimen was measured through rapid chloride permeability tests (RCPT) following ASTM C1202 [21]. A test setup has been built to perform the test as shown in Fig. 2 [22]. Drying shrinkage test was conducted according to ASTM C157/C157M [23] procedures. Changes in length of concrete bars at different days were measured to evaluate linear shrinkage of the samples as shown in Fig. 3.

Fig. 2 RCPT test setup

Fig. 3 Shrinkage measurement

III. Results and Analysis

Effect of different curing conditions on compressive strength of concrete at 7, 29 and 90 days is shown in Fig. 4.

Concrete under proper normal curing condition (NCC) showed the highest compressive strength at all ages. Concrete under NCC achieved compressive strength of about 17.5, 28 and 33.7 MPa at 7, 28 and 90 days, respectively. Samples under C2 condition exhibited the minimum strength. In this condition, samples were exposed to ambient condition just after casting without any covering. C2 samples produced around 25.5%, 37% and 38% reduced strength as compared to samples under NCC conditions at 7, 28 and 90 days, respectively.

It is also evident from Fig. 4 that samples without covering experienced considerable reduced strength as compared to covered samples under similar curing condition particularly at later ages. For example, samples under C2 showed about 26% lower strength than that of C1-samples at 28 days. Similarly, C4-samples achieved about 16% lesser strength than C3-samples at 28-days. Samples under exposed condition with covering after 7 days of submergence (C5) showed relatively superior performance as compared to samples subjected to other harsh curing conditions. It has been observed that C5 samples showed about 6.5% and 7% lesser strength than that of NCC-samples at 28 and 90 days, respectively. As compared to C2-samples, C5-samples showed about 33% higher strength both at 28 and 90 days.

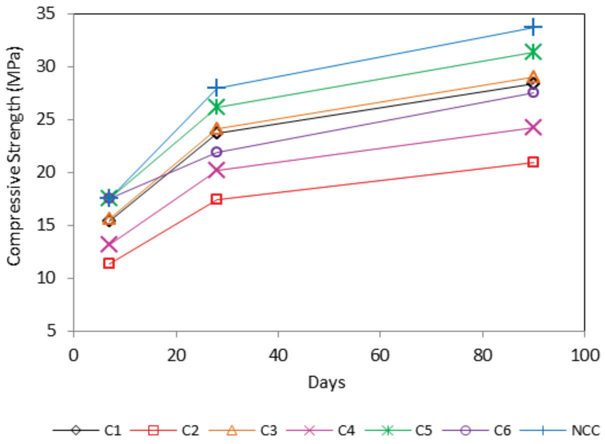

Fig. 4 Compressive strength of samples under different curing conditions

Split tensile strengths of concrete samples at 28 days under different curing conditions are shown in Fig. 5. C2-samples experienced the lowest split tensile strength (about 25% less than NCC-samples) as compared to all other samples considered in the study. Samples under adverse curing conditions with covering (C1, C3 and C5) exhibited almost equal tensile strength values with tensile strength of C5-samples being the highest. C5-samples showed about 6.5% lesser strength than that of NCC-samples. As compared to C2-samples, C5-samples showed about 20% higher tensile strength at 28 days. C1-samples produced about 15% higher tensile strength than C2- samples.

Fig. 6 shows the RCPT test results. As per ASTM C1202 [21], if less than 4000 coulomb charge passes through concrete samples, then it can be termed as "moderate chloride permeable". On the other hand, if a concrete sample allows more than 4000 coulomb to pass through, then it can be termed as "high chloride permeable". It is evident from Fig. 6 that samples under NCC condition showed moderate chloride permeability having the lowest amount of coulomb passed through it. Samples with polythene covering (C1, C3 and C5) also exhibited moderate permeability values. However, C1, C3 and C5 samples experienced about 85%, 84% and 81% higher coulomb charge passing through them as compared to NCC-samples, respectively. Similar to the previous two cases, C2-samples exhibited the highest permeability among all samples tested in the study. It is also obvious from Fig. 6 that all samples under adverse curing conditions without covering (C2, C4, and C6) showed significantly high chloride permeability.

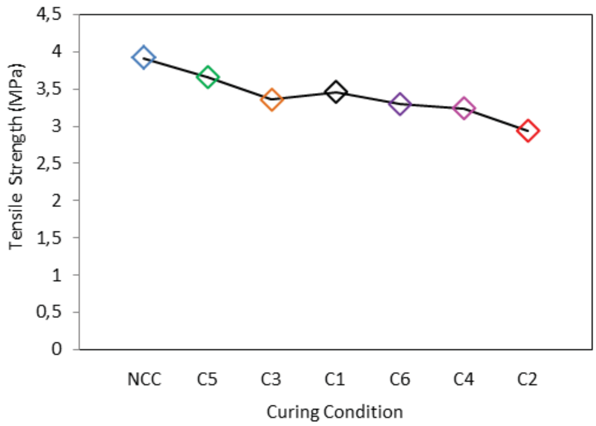

Fig. 5 Split tensile strength of samples under different curing conditions

Shrinkage values of concrete samples under different curing conditions are shown in Fig. 7. For shrinkage test, samples having dimension of 10” by 10” by 2” were made and submerged under lime saturated water for 30 minutes just after removal from the sample preparation molds. After 30 minutes of submergence under lime water, initial readings (length of samples) were taken. After initial readings, samples were kept under six different simulated adverse curing conditions. NCC-samples were kept under water for 28-days and then kept in contact with air. Shrinkage readings were taken up to 56 days (84 days from the initial reading) at an interval as per ASTM C157/C157M [23]. All samples, except NCC, showed shrinkage strain from day one. In case of NCC-samples, initial swelling effect was observed since these samples were kept submerged under water for first 28 days that protected the samples from evaporation. C2-samples experienced the maximum shrinkage strain at all ages. Like previous cases, all samples under polythene sheet covering experienced relatively lesser strain than that of covered sampled for the same curing conditions. For example, C1-samples showed about 31% lesser strain as compared to C2-samples at 56 days from the initial reading. Similarly, at 56 days, C5-samples exhibited about 30% reduced strain as compared the C6-samples.

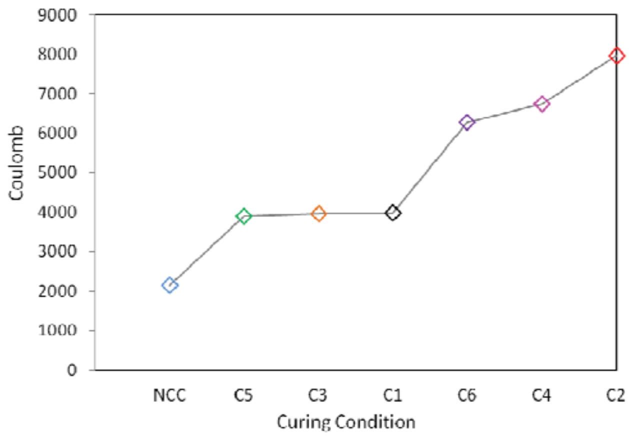

Fig. 6 RCPT results of samples under different curing conditions

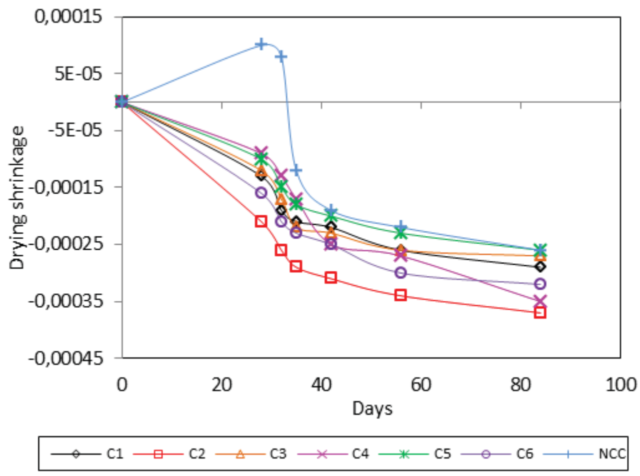

Fig. 7 Shrinkage results of samples under different curing conditions

It is, therefore, obvious from the above discussion that absence of proper curing has significant adverse effect on concrete properties. Compressive strength of concrete could be as low as one third of the required/design strength due to improper curing conditions. Permeability and shrinkage of concrete can also be severely affected by inappropriate curing conditions. A concrete mix, proportioned as moderately permeable concrete, could become highly permeable concrete if required curing conditions cannot be maintained. It is also evident that covering of concrete improves concrete properties even under adverse curing conditions. Covering of samples prevented water loss through evaporation and eventually resulted in concrete with relatively better performance. Such polythene covering is a simple process to execute and also inexpensive. However, this requires proper attention from workers and supervisors.

IV. Conclusion

In this study, the effect of adverse external curing conditions that are quite common in Bangladesh on concrete properties is discussed with a view to make construction workers and supervisors more aware about this issue. Six adverse curing conditions were simulated in the laboratory without supply of any external water. It has been found that external curing conditions with insufficient supply of water has significant detrimental effect on concrete properties. Compressive strength of concrete could be reduced by 35% or more as compared to the desired value if left without supply of any external water and covering. If proper normal curing conditions cannot be maintained, the permeability of concrete could increase by more than 3 times. Similar phenomena were also observed for drying shrinkage of concrete. It is, thus, evident that deficient curing conditions severely affect the design life of a concrete structure. However, it has been observed that polythene sheet covering can significantly improve the strength and permeability of concrete even without supply of additional water for curing. It is also evident that proper external curing for 7 days can result in relatively better performance concrete if polythene sheet covering is provided for up to 28 days. Finally, an attempt has been made in this study to provide a clear quantitative depiction of importance of proper curing on concrete strength and durability characteristics. A good quality control protocol and awareness among workers and engineers can ensure the fulfillment of necessary conditions required for concrete curing and eventually can produce robust concrete. Findings of this article, therefore, will assist concerned engineers and supervisors to understand the importance of quality assurance during the curing period of concrete.

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References

[1] Parveen, S., Rana, S., and Fangueiro, R. "A Review on Nanomaterial Dispersion, Microstructure, and Mechanical Properties of Carbon Nanotube and Nanofiber Reinforced Cementitious Composites," *Journal of Nanomaterials, Hindawi Publishing Corporation,* 2013. (DOI: 10.1155/2013/710175)

[2] Manzur, T. and Yazdani, N. "Effect of Different Parameters on Properties of Multiwalled Carbon Nanotube Reinforced Cement Composites," *Arabian Journal for Science and Engineering,* 2016. (DOI:10.1007/s13369-016-2181-8)

[3] Manzur, T., Yazdani, N. and Emon, A. B. "Potential of Carbon Nanotube Reinforced Cement Composites as Concrete Repair Material," *Journal of Nanomaterials, Hindawi Publishing Corporation,* 2016, Article ID 1421959. (DOI: 10.1155/2016/1421959)

[4] Manzur, T., and Yazdani, N. "Optimum Mix Ratio for Carbon Nanotubes in Cement Mortar," *KSCE Journal of Civil Engineering*, 19(5), 2015, pp. 1405-1412. (DOI: 10.1007/s12205-014-0721-x)

[5] Manzur, T., Yazdani, N. and Emon, M. A. B. "Effect of Carbon Nanotube Size on Compressive Strengths of Nanotube Reinforced Cementitious Composites," *Journal of Materials*, *Hindawi Publishing Corporation*, 2014, Article ID 960984. (DOI: 10.1155/2014/960984)

[6] Manzur, T., and Yazdani, N. "Importance of Flow Values in Qualitative Evaluation of Carbon Nanotube Reinforced Cementitious Matrix," *Malaysian Journal of Civil Engineering,* 25(1), pp. 71-80.

[7] Emon, M. A. B., Manzur, T., and Yazdani, N. "Improving performance of light weight concrete with brick chips using low cost steel wire fiber," *Constr. Build. Mater.*, vol. 106, 2015, pp. 575-583.

[8] Afroz, S., Rahman, F., Iffat, S., and Manzur, T. "Sorptivity and Strength Characteristics of Commonly Used Concrete Mixes of Bangladesh,"

International Conference on Recent Innovation in Civil Engineering for Sustainable Development, DUET, Gazipur, Bangladesh, December 2015.

[9] Bosunia, S. Z., and Chowdhury, J. R. "Durability of Concrete in Coastal Areas of Bangladesh," *Journal of Civil Engineering, IEB*, vol. CE 29, No. 1, pp 41-53, 2001.

[10] Manzur, T., Iffat, S., and Noor, M. A. "Efficiency of Sodium Poly-Acrylate to Improve Durability of Concrete Under Adverse Curing Condition," *Advances in Materials Science and Engineering, Hindawi Publishing Corporation*, 2015, Article ID: AMSE 685785. (DOI: 0.1155/2015/685785)

[11] Iffat, S., Manzur, T., and Noor, M. A. "Durability of Internally Cured Concrete Using Locally Available Low Cost Light Weight Aggregate," *KSCE Journal of Civil Engineering*, 2016. (DOI: 10.1007/s12205-016-0793-x)

[12] Rumman, R., Kamal, M. R., Manzur, T., and Noor, M. A. "Durability Performance of Locally Produced OPC and PCC Cement Concretes," *International Conference on Recent Innovation in Civil Engineering for Sustainable Development*, DUET, Gazipur, Bangladesh, December 2015.

[13] Rumman, R., Kamal, M. R., Manzur, T., and Noor, M. A. " Comparison Of CEM I and CEM II Cement Concretes in Terms of Water Permeability," *The 3rd International Conference on Civil Engineering for Sustainable Development (ICCESD2016),* KUET, Khulna, Bangladesh, February 2016.

[14] ASTM C136-06, *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates,* ASTM International, West Conshohocken, PA, 2006.

[15] ASTM C128-12, *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate*, West Conshohocken, PA, 2012.

[16] ASTM C29-09, *Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate*, West Conshohocken, PA, 2009.

[17] ASTM C187–11e1, *Standard Test Method for Normal Consistency of Hydraulic Cement.* West Conshohocken, PA, 2011.

[18] ASTM C109/C109M-13, *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or (50-mm) Cube Specimens)*. West Conshohocken, PA, 2013.

[19] ASTM C39–14a, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*, West Conshohocken, PA, 2005.

[20] ASTM C 496/C496M-11, *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens,* ASTM International, West Conshohocken, PA, 2011.

[21] ASTM C 1202-12, *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*, West Conshohocken, PA, 2012.

[22] Iffat, S., Emon, A. B., Manzur, T., and Ahmad, S. I. "An Experiment on Durability Test (RCPT) of Concrete According to ASTM Standard Method using Low-Cost Equipments," *Advanced Materials Research,* vol. 974, 2014, pp. 335-340.

[23] ASTM C157/C157M-08(2014)e1, *Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete*, West Conshohocken, PA, 2014.