Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Sustainable Development of Concrete Construction Works in Bangladesh: Key Issues

Mohammed Tarek Uddin

Professor, Department of Civil Engineering, University of Asia Pacific, Bangladesh
House No. 8/A, Road No. 7, Dhanmondi R/A, Dhaka-1205, tarek@uap-bd.edu

ABSTRACT

This paper presents the summary of some research works carried out with an objective of Sustainable Development of Concrete Construction Works in Bangladesh. The scope of research work include: (1) causes of deterioration of concrete structures in Bangladesh, (2) problems at construction sites that causes early deterioration of concrete structures in Bangladesh, (3) quality of various cement brands commonly used in Bangladesh, (4) properties of concrete made with various aggregates commonly used in Bangladesh, (5) recycling of demolished concrete as coarse and fine aggregate for new construction works, (6) development of permeable concrete for special applications, (7) carbonation rate of concrete structures in the Capital City, Dhaka, and (8) applications of recycled and permeable concrete in real structures. Several important conclusions were drawn based on these studies that will play a vital role for sustainable development of concrete construction works in Bangladesh.

Keywords: Concrete, Sustainable Development, Recycling, Carbonation, Deterioration.

INTRODUCTION

Due to the large demand of housing and infrastructures, a huge number of construction works can be seen in the capital city as well as other cities in Bangladesh. Therefore, it is essential to take necessary steps for the sustainable development of concrete construction works in Bangladesh. At the beginning of thinking of sustainable concrete construction works, it is necessary to understand the causes of deterioration of concrete structures; it is also necessary to understand the general construction practices at site that accelerate the deterioration process of concrete structures. Therefore, these issues are included in the scope of this topic.

To meet the demand of cement for construction projects more than sixty cement manufacturing industries were established in Bangladesh. It is necessary to understand the quality of these cements. Due to the lack of good quality stone aggregates, brick chips obtained from crushing clay burned bricks (using Hofman Kiln or Clamp) are commonly used for making concrete. In addition to the stone chips and brick chips, shingles (round shaped stones) and jhama brick chips (over burned bricks) are also used. Studies are necessary to understand the mechanical behavior and durability of concrete made with these aggregates. Studies related to recycling of demolished concrete as coarse aggregate and fine aggregate in new construction works are also necessary. To increase infiltration of rain water into the ground, it is also necessary to conduct studies related to the development of permeable concrete for specific applications.

Due to high humidity and temperature in Bangladesh, concrete structures are damaged by carbonation induced corrosion of steel in concrete. A detailed study is necessary to determine the carbonation coefficient of concrete in natural exposures of different cities. Applications of recycled aggregate and permeable concrete are necessary to make examples of utilization of these useful and environmentally friendly materials. Also, long-term exposure tests (100 years or more) are necessary to understand deterioration rate of concrete structures in Bangladesh.

With the above-mentioned background, a comprehensive research project was commenced at the Department of Civil Engineering of University of Asia Pacific (UAP) in 2004. The following main topics were taken into account in this research project for sustainable development of concrete construction works in Bangladesh:

1. Causes of deterioration of concrete structures,
2. Problems at construction sites that causes early deterioration of concrete structures,
3. Quality of cement brands,
4. Properties of concrete made with various aggregates,
5. Recycling of demolished concrete as coarse and fine aggregate for new construction,
6. Use of recycled fine aggregate (less than 5 mm in size) for making concrete blocks,
7. Development of permeable concrete for special application,
8. Determination of carbonation coefficient in natural exposure conditions, and
9. Application of recycled and permeable concrete and long-term exposure tests.

In this report, key results of the above-mentioned research topics are summarized. Detailed results of these investigations can be obtained in References (Rashid et al, 2005; Siddique et al, 2005; Hasan et al, 2006; Sutradhar, 2012).

EXPERIMENTAL RESULTS AND DISCUSSION

Causes of Deterioration of Concrete Structures in Bangladesh

To understand the possible causes of deterioration of concrete structures in Bangladesh, a detailed survey of some buildings in several districts were carried out. Based on the survey results, the main causes of deterioration of concrete structures in Bangladesh are:

1. Carbonation induced corrosion of steel bars,
2. Chloride induced corrosion of steel bars,
3. Drying shrinkage,
4. Mud in aggregate,
5. Efflorescence in bricks,
6. Sulphate attack/ Chemical attack,
7. Leakage through joints,
8. Heat of hydration,
9. Thermal expansion,
10. Differential settlement,
11. Lack of reinforcement in structural members,
12. Lack of cover thickness of structural members,
13. Leakage of water through roof,
14. Leakage of water from plumbing pipes embedded in walls, and
15. Lack of maintenance.

Due to the high humidity (60% ~95%) and high temperature (40°C in summer), a high rate of carbonation is found in concrete structures of Bangladesh. The use of low strength concrete (less than 20.7 MPa) as well as poor quality concrete works at the construction site also accelerates the process of carbonation. Concrete floors, beams, and columns are severely damaged due to the carbonation induced corrosion of steel bars after 10 ~ 15 years of construction. It is found as the most common cause of deterioration of concrete structures in Bangladesh. Investigations were also conducted to determine carbonation coefficient of concrete in Dhaka city. These results are summarized in this report.

In the coastal areas, the concrete structures are damaged due to the combined action of chloride and carbonation-induced corrosion of steel bars in concrete. Investigations related to the chloride ingress into concrete at the coastal areas of Bangladesh are necessary.

Cracks on the walls are found due to the drying shrinkage at the early age of the structure. A lime concrete coat on the roof of the buildings is applied to reduce the heat flow in summer. Unfortunately, the lime concrete soaks water in rainy seasons for long time and it accelerate the deterioration of the roof slab. Storage of the materials on the roofs as well as water logging on the roof is also found to be the causes of deterioration of roof slab. Efflorescence is found in the partition wall due to the presence of salts in the brick. Leakage of water through the plumbing pipes embedded in walls is also found. Soaking of water and quick damage of paints on wall are found. Generally, patch type repair is carried out but it is found to be ineffective after a short time of repair.

Problems at Construction Sites that Causes Early Deterioration of Concrete Structures in Bangladesh

Several construction sites were visited to identify the causes associated with the early deterioration of concrete structures at service. The followings are identified:

1.Un-sieved poorly graded aggregates,
2.Unwashed aggregates,
3.Mud in mixing water,
4.Rusted reinforcement,
5.Excess water in mix,
6.Higher W/C,
7.Excess sand,
8.Excess coarse aggregate,
9.Poor mixing/ mixture proportion,
10.Problems associated with volumetric mix proportions,
11.Lack of cover concrete ,
12.Problems associated with formwork (leakage of mixing water),
13.Placing of concrete from a large height by labors,
14.Inappropriate compaction,
15.Inappropriate curing,
16.Brick efflorescence,
17.Poor workmanship,
18.Unskilled workers, and
19.Inappropriate storage of construction material.

Volumetric mix proportions are generally used for most of the construction works except ready mix concrete industries. Generally mix proportions for concrete are set at 1:1.5:3 (compressive strength 20.7 ~ 27.6 MPa) or 1:2:4 (compressive strength 17.2~20.7 MPa) for most of the construction works. The amount of water for concrete works is recommended to be 25 liter per bag of cement as per Bangladesh National Building Code (BNBC).

Unfortunately, at the construction sites, water is added till the mix become workable without any measure. For this reason, in actual construction, the strength of concrete becomes lower than the target strength. The use of a high W/C makes concrete relatively porous and consequently creates easy paths for ingress of harmful constituents into concrete and thereby early deterioration of structures.

The concrete cover is not maintained adequately due to the lack of knowledge of durability based design of civil engineers. Generally, in the four-year curriculum of B. Sc. Eng. (Civil) program, a four credit hour theory course is taught on engineering materials, a part of which covers concrete (roughly 25% of syllabus). Another 1.5 credit-hour laboratory course is also taught on concrete technology which mainly covers different tests related to concrete and its ingredients. Some more credit hours are necessary to include in the undergraduate curriculum covering microstructures of concrete, the process of deterioration of concrete structures, durability based design, repair and maintenance of concrete structures, quality control at construction sites, life cycle management of concrete structures, sustainability of concrete structures, etc. Generally, unskilled workers are involved at construction works. It is necessary to create skilled workers through professional organizations.

Quality of Different Cement Brands Commonly Used in Bangladesh

The quality of cement is one of the important factors related to the strength and durability of concrete. In Bangladesh, there are more than 60 cement companies those are producing cements with different composition and supplying to the market with different brand names. However, no comparative study has been made to check the quality of the cement brands available in the market. For investigation, cement bags were collected from thirty different companies with different brand names. The composition of the cement has been recorded from the cement bags.

According to BDS EN 197-1 : 2003, cements are mainly classified into five categories according to their composition, namely CEM I, CEM II, CEM III, CEM IV, and CEM V. CEM II cement is sub-divided into different groups depending on the contents of mineral admixture and limestone powder as indicated in Table 1. CEM I is the ordinary portland cement (OPC). Based on the ingredients of cement collected from the cement bags, it is found that the collected cement bags belong to CEM I and CEM II only. CEM III, CEM IV, and CEM V cements are absent in the samples. Out of the thirty cement bags collected from the market, two samples fall in the group of CEM I (Sample No. 1 and 2), 15 samples fall in the group of CEM II/A-M (indicated as Sample No. 3 to 17), 9 samples fall in the group of CEM II/B-M (Sample No. 18 to 26), 3 samples fall in the group of CEM II/A-S (Sample No. 27 to 29), and one sample fall in the group of CEM II/A-L (Sample No. 30). It indicates that CEM I and CEM II cements are commonly used for construction works. Among the blended cements, CEM II/A-M, i.e., cement with less amount of mineral admixture (<20%) is commonly available in the market compared to CEM II/B-M which contains more amount of mineral admixture (20~35%). Concrete users are afraid of using cement with large amount of mineral admixture due to lack of advanced knowledge and low quality mineral admixtures imported from abroad.

All cements satisfy the ASTM requirement related to the normal consistency of cement (ASTM C187). It can also be seen that for the brands of blended cement, the normal consistency is lower. It indicates that for a certain degree of softness of these cements, less amount of water will be required. Initial setting time of blended cement is higher than the initial setting time of OPC cement. Final setting time of the blended cement is also found slightly higher than the OPC cement.

The variation of compressive strength of cement mortar made with different brands of cement is shown in Figure 1. It is found that compressive strength of cement is increased with age irrespective of the type of cement. OPC cement (CEM I) shows relatively higher strength compared to the other cements (CEM II/A-M, CEM II/B-M, CEM II/A-S, CEM II/A-L). At the early age, the strength of mortar specimen is lower for other cements compared to OPC cement. But this difference of strength is reduced with time. The difference of strength becomes larger with higher amount of mineral contents in cement. It is expected that the strength of blended cement will increase with time further and will compete with the strength of OPC cement and exceed the strength of OPC cement in the long run. The data of compressive strength at 51 and 90 days were not recorded.

The variations of initial setting time and final setting time with 28-day compressive strength of cement mortar are shown in Figure 2(a) and Figure 2(b). It is found that there is a tendency of having lower level of strength for the cement with longer setting time (both initial and final). Correlations between the setting time and compressive strength of cement mortar can be used to predict the strength of cement from the setting time data that can be quickly determined in the laboratory. The variation of average compressive strength of cement mortar with age up to 28 days is shown in Figure 3. It is found that the compressive strength of mortar specimens is increased with time. The rate of increase in strength is higher for CEM I cement as expected due to the faster rate of hydration of cement particles. CEM II/A-S and CEM II/A-L cements shows faster strength development compared to CEM II/A-M and CEM II/B-M cements. At the early age, CEM II/B-M cement brand shows relatively lower strength than CEM II/A-M due to the more content of mineral admixtures, however, no significant different is observed at 28 days. Correlations between the compressive strength and age of the cement mortar are proposed and can be used to predict strength at 28 days from early age data.

Properties of Concrete Made with Various Aggregates Commonly Used in Bangladesh

Brick chips are commonly used in Bangladesh for making concrete since long ago due to lack of availability of stones. Stone chips are also used but the quality of stone chips is questionable. Shingles (round shaped stone) are also used in construction for its better workability. Jhama brick chips are also found in the market which is used rarely in construction. A detailed study was carried out to compare the properties of concrete made with these aggregates. The properties of aggregates are summarized in Table 2. Brick chips were also investigated with the variation of moisture content (SSD-Saturated Surface Dry Condition, AD-Air Dry Condition, CAD-Controlled Air-Dry Condition, and OD-Oven Dry Condition). Concrete cylinder specimens (15 cm diameter and 30 cm height) were made with water-to-cement ratio of 0.55. Cement content of the mix was 340 kg/m^3. Sand to aggregate volume ratio of the concrete was set at 0.44. FM of coarse aggregates was 6.69. FM, specific gravity, and absorption capacity of sand was 2.64, 2.61, and 3.9% respectively. For comparison of brick and stone aggregates, the brick aggregates with similar abrasion of stone aggregate were selected. The absorption of brick aggregates (11.5%) and jhama brick chips (12.2%) is higher than the stone aggregates (0.8%) and shingles (2%). The abrasion value of brick chips was 26.3%, and for stone chips was 25%. The abrasion value of shingles and jhama brick chips were 20.78 and 37.16% respectively.

The workability of concrete made with different aggregates is shown in Figure 4. Concrete made with brick chips shows the lowest workability due to the more internal friction between the brick aggregates as well as higher absorption capacity. Due to its round shape, shingles shows the highest workability. In construction sites, it was found that water is added to the mix as long as the mix becomes workable, therefore it is likely that more water is added in brick aggregate concrete for improving workability. The strength of concrete at 7, 14, and 28 days are shown in Figure 5(a) for concrete made with different aggregates. Interestingly, brick aggregates give higher strength compared to the stone aggregates. It is happened due to the development of strong interfacial transition zone around brick aggregates compared to the same with stone aggregate.

The compressive strengths of concrete with the variation of moisture condition of brick aggregates (NB) are shown in Figure 5(b). In all cases, the amount of water in concrete is kept same (amount of water to make SSD sample plus amount of water required from W/C) except NBEW55 case. In the case of NBEW55 (Normal brick aggregate with excess water and w/c=.55), the aggregates with surplus amount of water on the surface were used. The compressive strength of concrete remains same with the variation of moisture condition. But, the presence of excess water on the surface leads to the reduction of strength due to the increase of the amount of water in the system. In addition to these factors, dust contaminated aggregates, pre-heated aggregates, and cement paste-coated aggregates were also investigated. These results will be incorporated in the future reports.

Table 1: Classification of Cement as Per BDS EN 197-1 (CEM I and CEM II)

<table>
<tr><th rowspan="2">Composition (%)</th><th colspan="5">Type of Portland Cement</th></tr>
<tr><th>CEM I</th><th>CEM II/A-M</th><th>CEM II/B-M</th><th>CEM II/A-S</th><th>CEM II/A-L</th></tr>
<tr><td>Clinker</td><td>95-100</td><td>80-94</td><td>65-79</td><td>80-94</td><td>80-94</td></tr>
<tr><td>Blast-furnace Slag</td><td>-</td><td rowspan="6">6-20</td><td rowspan="6">21-35</td><td>6-20</td><td>-</td></tr>
<tr><td>Silica Fume</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Pozzolana</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Fly Ash</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Burnt Shale</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Limestone</td><td>-</td><td>-</td><td>6-20</td></tr>
<tr><td>Additional Constituents</td><td>0-5</td><td>0-5</td><td>0-5</td><td>0-5</td><td>0-5</td></tr>
</table>

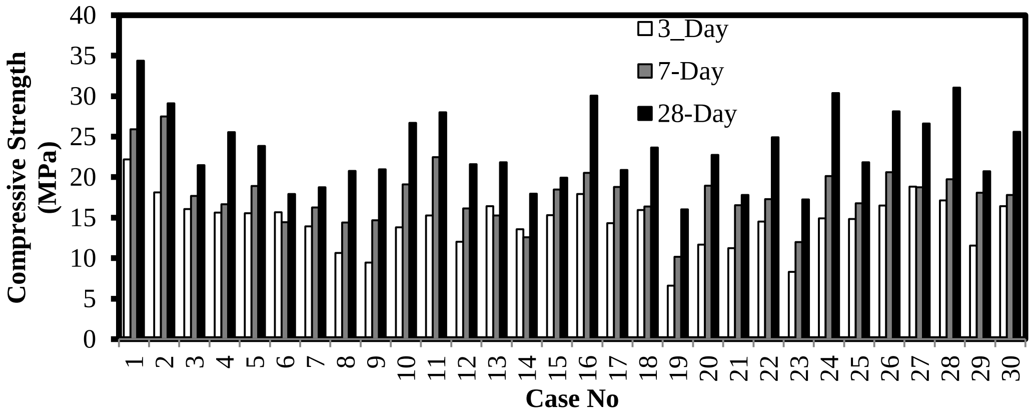


Figure 1. Variation of compressive strength with age

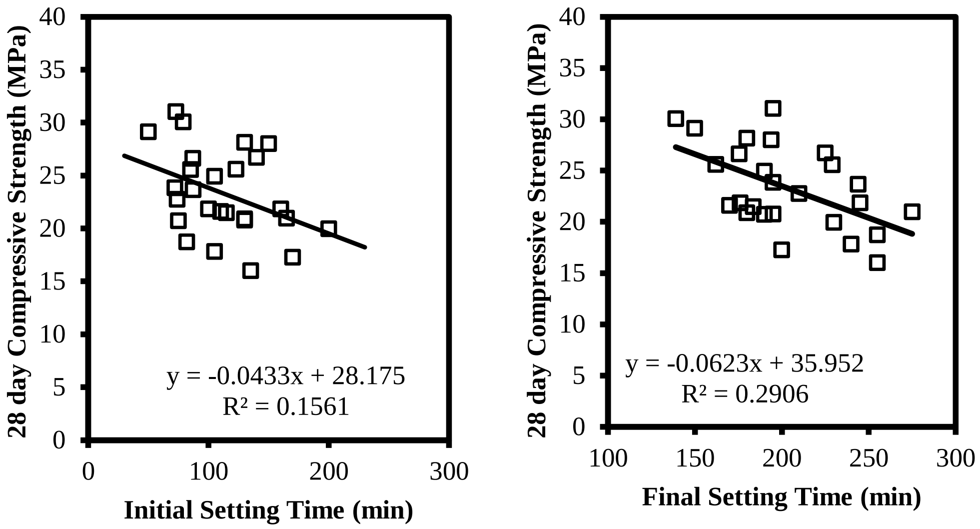


Figure 2. Variation of compressive strength with (a) initial setting time (left), (b) final setting time (right)

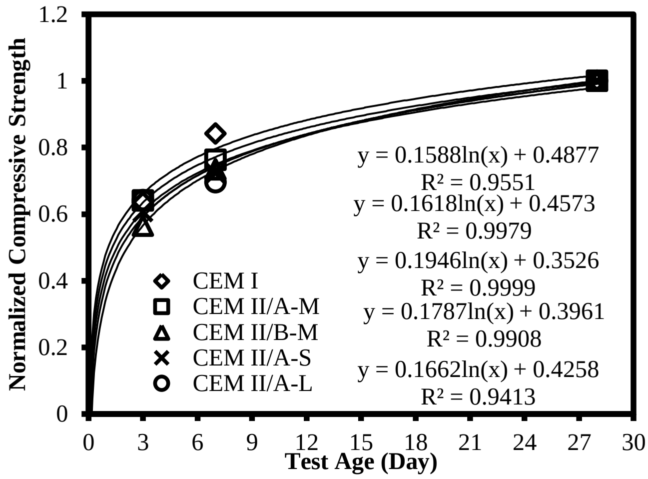


Figure 3. Variation of normalized compressive strength with age

Table 2. Properties of Aggregates Investigated

Type of Aggregates	Notations	FM	Bulk unit weight (kg/m3)	Water content (%)	% of Wear
Brick Chips	NB-SSD	6.69	2000	11.5*	26.3
	NB-AD		1961	7.6	
	NB-CAD		1939	5.4	
	NB-OD		1885	0	
	NB-SW		2040	15.5	
Crushed Stone	CS		2650	0.8*	25
Shingles	SG		2800	2*	20.78
Jhama Brick Chips	JB		1500	12.2*	37.16

* Absorption capacity

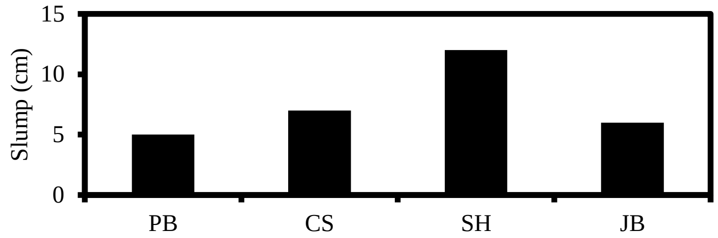


Figure 4. Workability of concrete made with different aggregates (W/C=0.55)

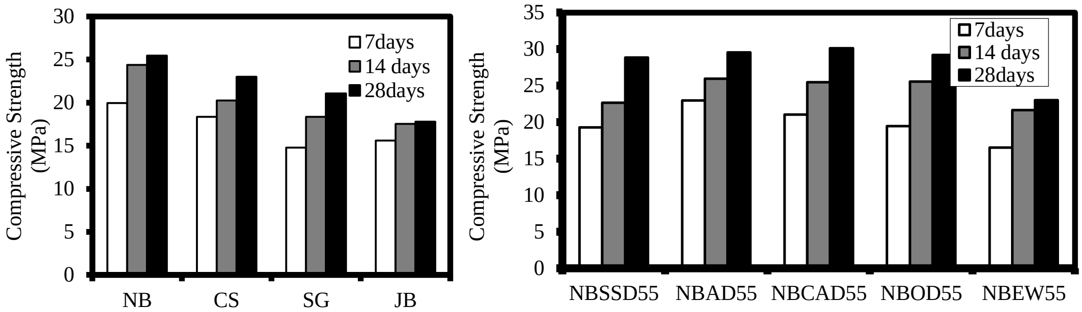


Figure 5. Compressive strength of concrete made with (a) different aggregate (left) (b) different moisture condition (right)

Recycling of Demolished Concrete as Coarse Aggregate

The global consumption of concrete is estimated at 17.5 billion tons (@ 2.5 tons/capita/year for 7 billion of world's population). To make this huge volume of concrete, 2.62 billion tons of cement, 13.12 billion tons of aggregate, and 1.75 billion tons of water are necessary. At present, the global production of demolished concrete is estimated at 2~3 billion tons per year. In the next ten years, the global production of demolished concrete will be raised to 7.5~12.5 billion tons. If it is possible to recycle the total amount of demolished concrete, there will be no need for production of new aggregates by destroying mountains or burning clay. The volume of demolished concrete in Bangladesh is also increasing day by day due to the aging of infrastructure as well as replacement of low rise buildings by relatively high rise buildings due to the booming of real estate business. Therefore, an attempt was made to find out the possible ways for recycling of demolished concrete for new construction as coarse aggregates. The properties of recycled aggregates collected from 33 different sites are summarized in Table 3. 1-Year old recycled brick and stone samples were collected by crushing cylinder specimens tested at the concrete laboratory. The age of the recycled aggregate is varied from 1 to 60 years. In most of the cases, the absorption capacity of the recycled aggregates is lower than the normal brick aggregates. Also, in most of the cases, no significant difference is found between the abrasion values of normal brick aggregate and recycled brick aggregate. The results indicate that the quality of recycled brick aggregate (old brick aggregate with old adhered mortar) is very similar to the quality of the normal brick aggregate commonly used in Bangladesh. Cylinder concrete specimens (150 mm diameter) are made for 58 separate cases as summarized in Table 4.

The compressive strength of concrete with the variation of aggregate and W/C is shown in Figure 6 (a). For W/C= 0.55, a reduction in strength of concrete is found for recycled brick aggregate concrete compared to the normal brick aggregate concrete. But for W/C=0.45, the compressive strength of recycled aggregate concrete is higher than the normal brick aggregate concrete. The results indicate that by reducing W/C, compressive strength of recycled aggregate concrete can be improved to the level of the normal aggregate concrete. The variation of tensile strength of recycled aggregate concrete with the compressive strength of recycled aggregate concrete is shown in Figure 6 (b). The relationship shown in Figure 6 (b) can be used to calculate the tensile strength of recycled aggregate concrete from the compressive strength of recycled aggregate concrete.

The variation of compressive strength of recycled aggregate concrete with the wear value of recycled coarse aggregate is shown in Figure 7 (a). It is observed that with an increase of wear value, the compressive strength of recycled aggregate concrete is reduced. Using these relationships (as shown in Figure 7 (a)), the expected strength of recycled aggregate concrete with a known wear value of recycled aggregate and W/C of concrete (0.45 or 0.55) can be judged.

Table 3. Properties of Aggregate

Type	Age (Years)	Sp. Gr.	Absorption Cap. (%)	Abrasion (%)	Type	Age (Years)	Sp. Gr.	Absorption Cap. (%)	Abrasion (%)
NB	-	2.20	21.10	47.80	RB	36	2.09	14.24	49.80
RB	1	2.35	10.00	46.90	RB	37a	2.06	19.10	48.20
RB	1.5	2.10	17.17	46.03	RB	37b	2.06	18.50	48.32
RB	15	2.15	9.03	40.96	RB	38a	2.20	18.50	47.68
RB	16	2.03	10.91	37.17	RB	38b	2.15	15.90	47.36
RB	20	2.20	17.92	49.55	RB	38c	2.06	10.04	42.29
RB	28	2.50	15.85	40.33	RB	40	2.14	15.0	47.00
RB	29	2.27	18.30	53.18	RB	41	2.11	18.60	48.6
RB	30	2.32	9.12	47.26	RB	43	2.22	15.15	50.94
RB	31	2.22	16.70	48.06	RB	44	2.02	14.92	45.60
RB	32	2.22	18.40	43.82	RB	45a	2.10	22.70	50.58
RB	33	2.22	15.80	47.16	RB	45b	2.00	17.76	48.32
RB	34	2.11	15.47	45.88	RB	46	2.00	19.80	52.32
RB	35a	2.00	19.76	49.04	RB	50	2.34	10.70	57.00
RB	35b	2.06	17.86	48.45	RB	52	2.20	18.80	46.16
RB	35c	2.07	15.30	45.43	RB	55	2.10	23.15	43.44
RB	35d	2.09	12.87	42.40	RB	60	2.10	13.40	44.80

Table 4. Cases Investigated (58 Cases)

Case No.	Symbol	Explanation
1 ~ 29 (W/C=0.55)	NBWC55, RBY1WC55, RBY1.5WC55, RBY15WC55, RBY28WC55, RBY29WC55, RBY30WC55, RB31WC55, RBY32WC55, RBY33WC55, RBY34WC55, RBY35aWC55, RBY35bWC55, RBY35cWC55, RBY36WC55, RBY37aWC55, RBY37bWC55, RBY38aWC55, RBY38bWC55, RBY40WC55, RBY41WC55, RBY43WC55, RBY44WC55, RBY45WC55, RBY46WC55, RB60WC55.	NB –Normal Brick Aggregate, the digit after NB indicates W/C. RB – Recycled Brick Aggregate, The digit after RB indicates age and the digit after the age indicates W/C. To separate the cases made with recycled aggregate of same ages a, b, c or d are used accordingly.
30 ~ 64 (W/C=0.45)	NBWC45, RBY1WC45, RBY1.5WC45, RBY20WC45, RBY28WC45, RBY29WC45, RBY30WC45, RBY31WC45, RBY32WC45, RBY33WC45, RBY34WC45, RBY35aWC45, RBY35bWC45, RBY35cWC45, RBY35cWC45, RBY35dWC45, RBY36WC45, RBY37aWC45, RBY37bWC45, RBY38aWC45, RBY38bWC45, RBY40WC45, RBY41WC45, RBY43WC45, RBY44WC45, RBY45aWC45, RBY45bWC45, RBY46WC45, RBY50WC45, RBY52WC45, RBY55WC45, RBY60WC45.	

**The age of the demolished concrete buildings from which the concrete blocks were collected and later broken into pieces as recycled aggregate (as coarse aggregate).*

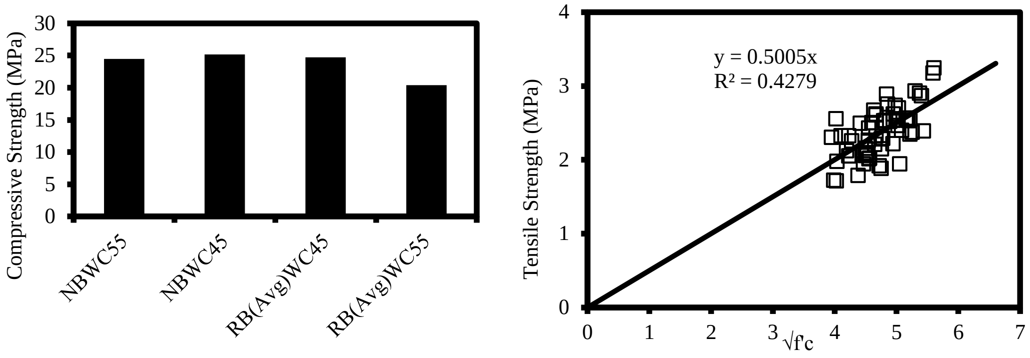


Figure 6.(a) Compressive strength of concrete with the variation of w/c (left) (b) tensile strength versus compressive strength of concrete (right)

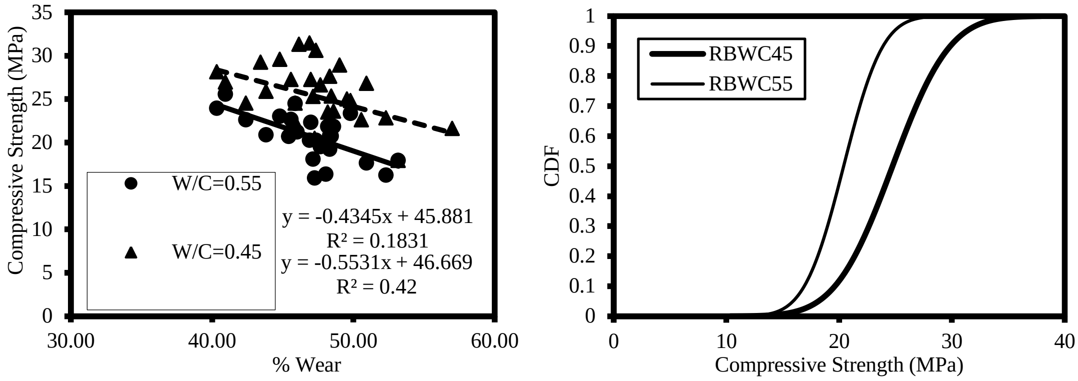


Figure 7.(a)Compressive strength of concrete versus wear (left), (b) cumulative probability distribution of compressive strength of recycled aggregate concrete for w/c=0.55 and 0.45 (right)

The cumulative probability distribution function (CDF) of 28-day compressive strength of recycled aggregate concrete is shown in Figure 7 (b) using normal distribution. The average compressive strength (with cumulative probability = 0.5) for W/C=0.55 is found at 20.7 MPa and the same for W/C=0.45 is found at 25.5 MPa. The standard deviation was 2.6 MPa for W/C=0.55 and 3.5 MPa for W/C=0.45. The ten percentile values (with cumulative probability = 0.1) of 28-day compressive strength of recycled aggregate concrete is found at 17.2 MPa and 20.7 MPa for W/C=0.55 and W/C=0.45 respectively. It is important to note that similar strength of concrete is generally found for concrete made with normal brick aggregates. The results indicate that the recycled brick aggregate can be utilized for new construction works with design compressive strength of 20.7 MPa to 25.5 MPa.

Recycling of Recycled Fine Aggregate

Demolished concrete blocks from eight different demolished building sites were collected and then manually crushed into aggregate (recycled aggregate). The concrete of the demolished buildings was made with brick aggregate. Therefore, the scope of investigation will cover only the recycling of fine aggregate obtained from brick made demolished concrete for making mortar blocks. The ages of the demolished buildings were 30, 35, 37, 44, 45, 45 (denoted as 45a), 50, and 60 years. During the production of coarse aggregate, smaller sizes aggregate less than 5 mm (passing through #4 sieve) is produced as a by-product. The portion of the by-product aggregate passing through #4 sieve and retained on #16 sieve are collected during breaking of demolished concrete block. Similar portions of aggregate are also collected during crushing of brick and stone for making coarse aggregate. It was done as aggregate portion passing through #4 sieve and retained on #16 sieve is found in small proportion in fine aggregate commonly used in Bangladesh. The coarse portion of the collected fine aggregate was mixed with natural coarse sand (FM 2.6) and natural fine sand (FM 1.8) in different proportions. Here, recycled fine aggregate (RFA) indicates the fine aggregate combined with the portion of the fine aggregate collected during production of recycled coarse aggregate plus natural coarse sand plus natural fine sand in different proportions as explained later. In the similar way, stone fine aggregate (SFA) and brick fine aggregate (BFA) can be defined.

Mortar block specimens were made with different fine aggregates as explained before with different grading as listed in Table 5. RFA45-40-30-30 indicates recycled fine aggregate(RFA) of age 45 with 40% of recycled aggregate plus 30% of coarse sand and 30% of fine sand. W/C ratios were 0.55 and 0.45. The mixture proportions were made based on the absolute volume method explained before with constant FA/C = 5. Also, some cases were made with lower values, such as 4.5, 4, 2.5, and 2 to increase the strength of the mortar blocks. CEM II/B-M was used throughout this study.

Mortar blocks of size 100 mm in length, 100 mm in width, and 70 mm in height were made for investigations which are half of a standard brick used in Bangladesh to measure compressive strength. Compressive strength of the mortar blocks was determined at 28 days after making of the specimens. The compressive strength of mortar block is shown in Figure 8 (a)for all cases of recycled fine aggregate made with W/C=0.55 with fine aggregate (FA) to cement ratio is 5. It can be seen that with the increase of amount of finer portion of sand, the strength of mortar block is reduced irrespective of the ages of recycled fine aggregate (say 45 and 50 years). The compressive strength of mortar block is shown in Figure 8 (b) for the cases W/C=0.45, and fine aggregate to cement weight ratio is 5.0. As in W/C=0.55, it is found that with the increase of finer portion of aggregate, the compressive strength of mortar block is reduced. Therefore, it can be concluded that the finer portion in fine aggregate plays a vital role in compressive strength of mortar blocks. The proportion of 50:25:25 gives the maximum compressive strength. Similar observations are also found for W/C=0.45. By reducing the FA/C ratio, compressive strength of RFA mortar block can be increased up to 31 MPa. Recycled fine aggregate gives higher strength compared to the brick fine aggregate. The data are not included in this report.

Table 5 Grading of Different Fine Aggregate

Sl No.	Case	Fine Aggregate (%)	Coarse Sand (%)	Fine Sand (%)
1	RFA45-40-30-30	40	30	30
2	RFA45-30-40-30	30	40	30
3	RFA45-50-25-25	50	25	25
4	RFA45-40-40-20	40	40	20
5	RFA45-30-30-40	30	30	40
6	RFA50-40-30-30	40	30	30
7	RFA50-30-40-30	30	40	30
8	RFA50-50-25-25	50	25	25
9	RFA50-40-40-20	40	40	20
10	RFA50-30-30-40	30	30	40

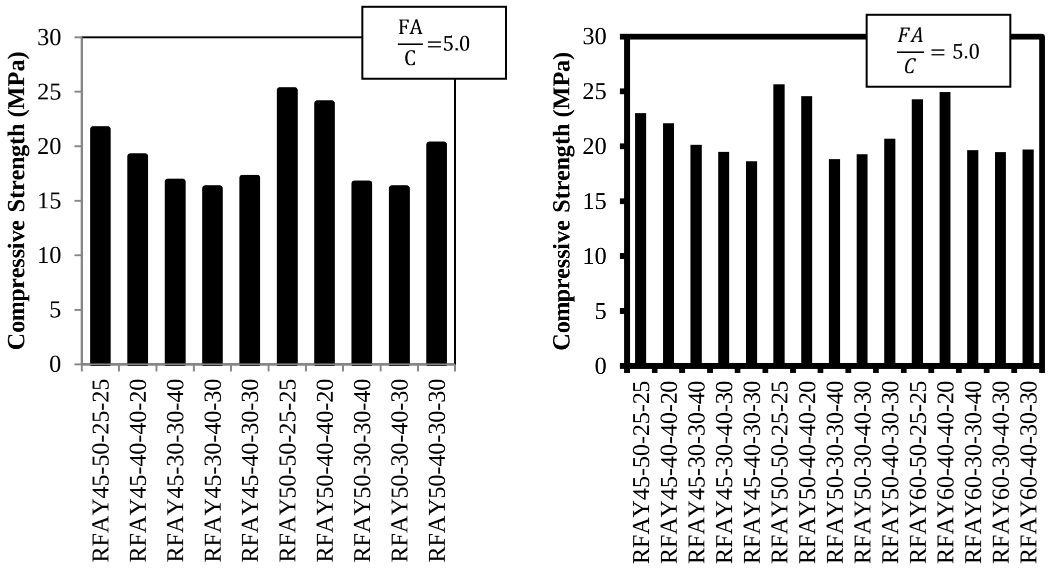


Figure 8. Compressive strength of recycled mortar block (a) w/c=0.55 (left) (b) w/c=0.45 (right)

Development of Permeable Concrete for Special Applications

Due to the construction of buildings and other infrastructures in the major cities in Bangladesh, it is found that the uncovered ground area for infiltration of rain water to ground water reservoir is reduced significantly. On the other hand, continuous sucking of ground water from underground reservoir results in depletion of ground water level year by year. This environmental problem can be reduced by application of porous concrete on parking areas, walkways, and roads for light vehicles, etc. With this background, this study on pervious concrete has been planned. Cylinder concrete specimens of diameter 100 mm and height 200 mm were made with locally available coarse aggregates (1st class brick aggregate, crushed stone aggregate, and recycled brick aggregate). Variables include type of aggregate and gradation of aggregate. Cement content was 300 kg/m^3 and water-to-cement ratio was 0.33. Test items include void in aggregate, unit weight of aggregate, specific gravity of aggregate, compressive and tensile strength of pervious concrete at 28 days and permeability of water through the pervious concrete.

Three types of locally available aggregate ((1st class brick (FB), crushed stone (CS), and recycled brick aggregate (RB)) were used in this study. The properties of these aggregate are summarized in Table 6. Pervious concrete used in this study was prepared using 10 different aggregate gradations. The cement used in this study was CEM II/A-M as per BDS EN 197-1. Tap water was used for all mixture. All mixture had water-to-cement ratio 0.33 and cement content 300 kg/m^3. The mixture proportions are summarized in Table 7. Thirty different cases were investigated by varying type of aggregate (CS, FB, and RB) and gradation of coarse aggregate. Mixture ID 100#3/8 indicates 100% of coarse aggregate (CA) is retained on 3/8″ sieve. Similarly mixture ID 50#4 50#8 indicates 50% of CA is retained on #4 sieve and 50% on #8 sieve.

Unit weight of concrete for different mix proportions are shown in Figure 9.The results revealed that the unit weight of pervious concrete varied with respect to the gradation of CA and the type of aggregate. It is observed that pervious concrete made with CS shows higher unit weight with an average of 1885 kg/m^3 compared to FB and RB pervious concrete. Unit weight of pervious concrete made with FB varied from 1380 kg/m^3 to 1730 kg/m^3 with an average value of 1520 kg/m^3. Pervious concrete made with RB varied from 1450 kg/m^3 to 1600 kg/m^3 with an average value of 1510 kg/m^3.

Table 6. Summary of Aggregate Properties

Items	ASTM Specifications	Type of Aggregate		
		FB	CS	RB
Specific gravity (SSD)	C127	2.02	2.67	2.20
Absorption capacity (%)	C127	25.81	7.35	18.82
Loss Angeles abrasion (%)	C131 (Grade B)	41.6	36.8	41.0

Table 7. Mixture Proportions of Pervious Concrete

Mixture ID	Aggregate Type											
	FB				CS				RB			
	Unit Content (kg/m^3)*			TV * %	Unit Content (kg/m^3)*			TV* %	Unit Content (kg/m^3)*			TV* %
	C	W	CA		C	W	CA		C	W	CA	
100 #3/8	300	99	1064	27.1	300	99	1553	21.6	300	99	992	34.7
100#4			1042	28.2			1470	24.7			895	39.1
100#8			967	31.9			1452	25.4			1010	33.8
75#3/8 25#4			1125	24.1			1657	17.7			1085	30.4
75#4 25#8			1071	26.7			1528	22.5			981	35.2
25#3/8 75#8			1068	26.9			1585	20.4			1082	30.6
25#4 75#8			1014	29.6			1484	24.2			1010	33.8
50#3/8 50#4			1082	26.2			1567	21.1			981	35.2
50#3/8 50#8			1093	25.7			1578	20.7			1103	29.6
50#4 50#8			1039	28.3			1499	23.6			996	34.5

** C=Cement, W=Water, CA=Coarse aggregate, and TV=Theoretical void.*

Percentage void of pervious concrete with different type of aggregate is shown in Figure 10(a). The percentage void of pervious concrete varied widely. It is observed that, pervious concrete with large size aggregate shows more interconnected void than other mixes. It is also observed that, pervious concrete made with RB shows higher interconnected pores, it is due to blunt edge of the RB. Further research is necessary to give a conclusion with this respect. Percentage void of pervious concrete made with CS is varied from 10% to 27%, from 12% to 28%for FB, 12% to 31%for RB. According to ACI 522-06 the typical void content of pervious concrete can range from 15% to 35% . Most of the mix proportions (Table 7) satisfy the ACI specification.

Permeability of pervious concrete made with different type of aggregate is shown in Figure 10(b). Similar to percentage void, permeability of pervious concrete made with RB is higher in most of the cases. Permeability of pervious concrete is varied from 15 mm/sec to 59 mm/sec for CS, 16 mm/sec to 51 mm/sec for FB, from 17 mm/sec to 49 mm/sec for RB.

Compressive strength of pervious concrete made with different type of aggregate is shown in Figure 11(a). For the investigated cases, compressive strength of pervious concrete made with CS varied from 5.2 MPa to 12.0 MPa, from 4.3 MPa to 6.9 MPa for FB, from 5.5 MPa to 6.9 MPa for RB. Pervious concrete made with CS shows higher compressive strength compared to FB and RB. RB shows higher average compressive strength compared to FB. It is due to the rough and porous texture of recycled aggregate which gives good bonding with cementecious matrix (Jiusu, 2011).

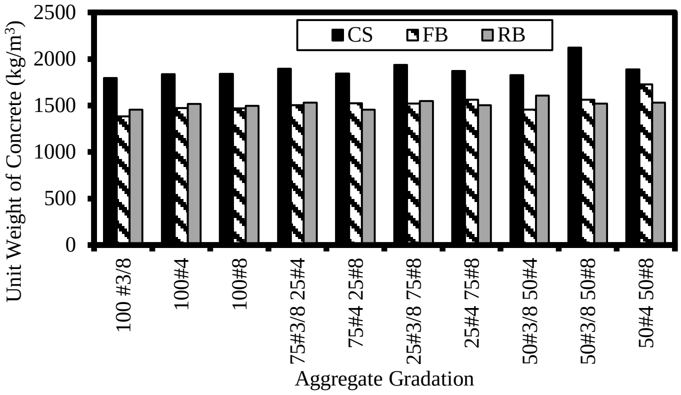
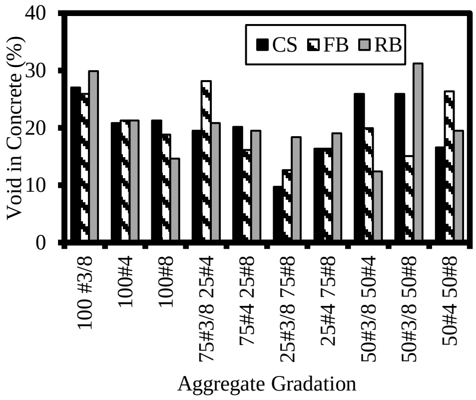


Figure 9. Unit weight of pervious concrete made with different aggregates



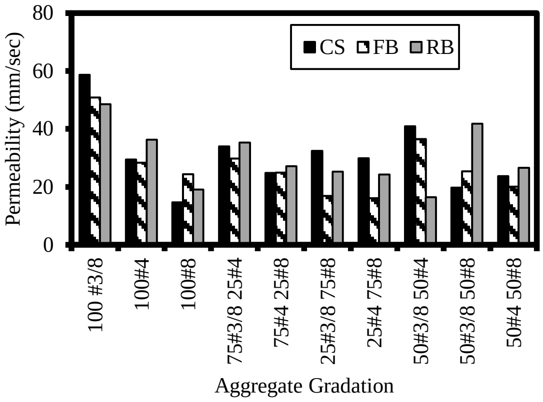


Figure 10. Pervious concrete made with different aggregates (a)percentage void (left), (b) permeability (right)

Same as compressive strength, pervious concrete made with CS shows higher tensile strength compared to other two aggregates (FB and RB) as shown in Figure 11(b). Tensile strength of pervious concrete made with CS varied from 1.03 MPa to 1.69 MPa, from 0.90 MPa to 1.45 MPa for FB, from 0.86 MPa to 1.38 MPa for RB.

Determination of Carbonation Coefficient of Concrete

To determine carbonation coefficient of concrete, carbonation depth of concrete in real structures was determined for different structural elements, such as beams, columns, stairs, and slabs. Exposure environments were separated as indoor and outdoor. Carbonation depths were measured by spraying phenolphthalein solution on freshly broken surface of concrete or on powder sample collected from different depths of concrete by using a concrete drill. The results are shown in Figure 12. The average carbonation coefficient was found to be 3.36 and 4.16 in indoor and outdoor exposures, respectively. The results indicate that, for 100 years of service life, minimum cover of concrete in indoor and outdoor exposure condition is to be 34 mm and 42 mm respectively. In general, for slabs cover concrete is specified to be 20 mm. Also, relative low strength concrete is used for slabs. Therefore, within a short period of time, spalling of cover concrete for slab is found due to carbonation induced corrosion. Cover thickness of slab is to be increased from the currently specified value in the design code. The detailed results can be obtained from (Sutradhar, 2012).

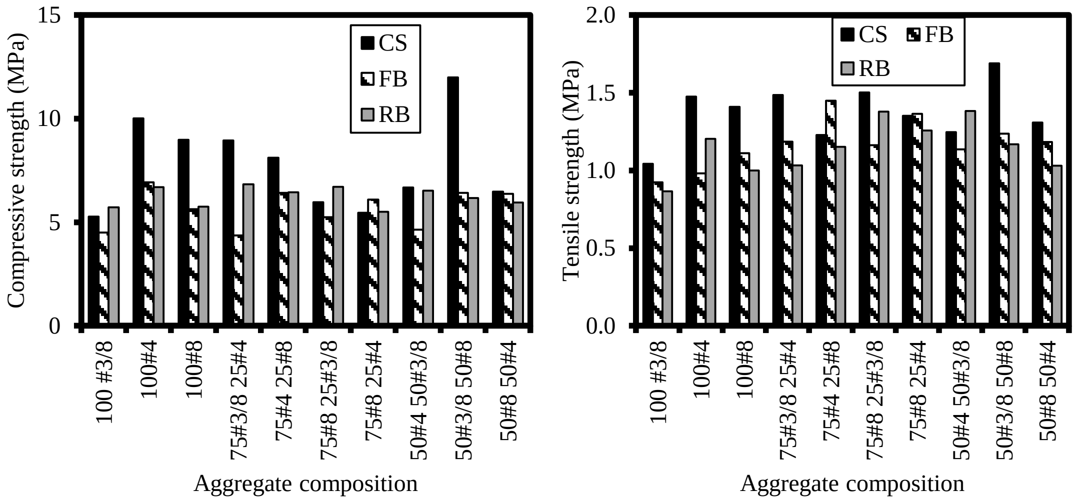


Figure 11. Pervious concrete made with different aggregates (a) compressive strength (left), (b) tensile strength (right)

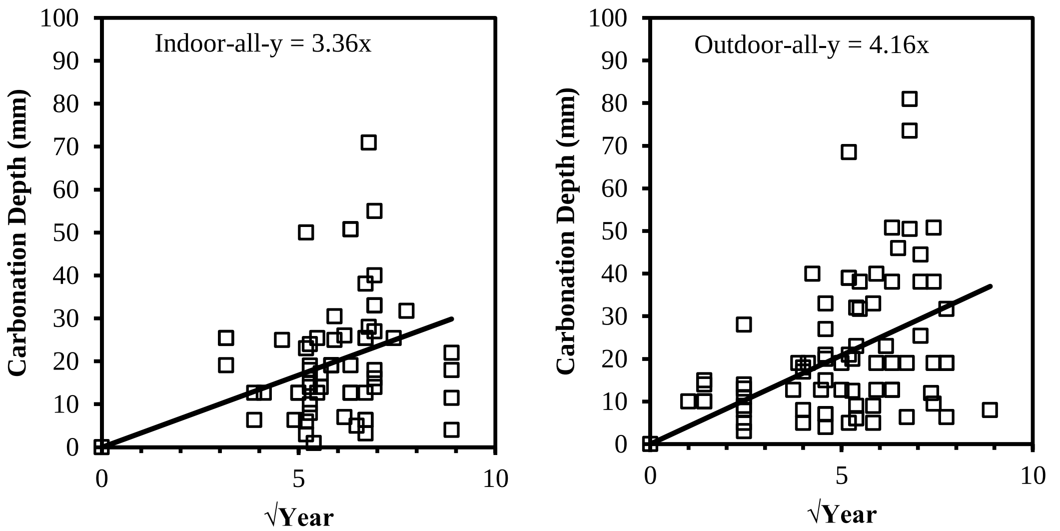


Figure 12. Relationship between depth of carbonation and age of structure for indoor exposure (left) and outdoor exposure (right)

Applications of Recycled Aggregate and Permeable Concrete

The roof-top community hall (columns, beams, and slab) of a six-storied building at Mirpur, Dhaka was constructed with recycled aggregate. Concrete was made with 1:1.5:3 volumetric mix ratio. Aggregate types include brick recycled aggregate, stone recycled aggregate, picked recycled aggregate, and re-recycled brick aggregate. Also, 100 mm diameter and 200 mm height cylinder specimens were made and exposed on the roof of the community hall for investigation at 28 days, 5 years, 10 years, 20 years, and 50 years of exposure. In addition to the compressive strength, carbonation depth of the specimens will also be recorded with time. A walkway of a spinning mill in Chittagong, Bangladesh was constructed with permeable concrete. More applications are necessary for wider acceptance of these environmentally friendly materials.

CONCLUSIONS

Based on the field and laboratory investigations, the following conclusions are made:

1. Durability based design of concrete structures is necessary to prevent early deterioration of concrete structures. Careful detailing of structural elements and also close supervision of construction works are necessary,

2. Technical discussions on cement with mineral admixtures are necessary to make these cements widely acceptable,

3. With similar abrasion value, brick aggregate concrete gives higher strength compared to the same with stone aggregate concrete,

4. Concrete strength from 20.7 ~ 25.5 MPa can be obtained using recycled brick coarse aggregate,

5. To improve the grading of fine aggregate, recycled fine aggregate (passing through #4 sieve and retained in #16 sieve) can be used,

5. In undergraduate program, more courses on concrete technology are to be included,

6. Skilled workers are to be produced through professional organizations,

7. Cover thickness of slab is to be increased from the currently specified value in design code to avoid early deterioration of slab,

8. More seminars and symposium are to be organized to discuss the knowledge related to the sustainable development of concrete construction works in Bangladesh.

REFERENCE

ACI 522-R(2006). American Concrete Institute, Farmington Hills, USA.

Hansen, E.J., and Saouma, V.E.(1999). "Numerical Simulation of Reinforced Concrete Deterioration – Part I : Chloride Diffusion." *ACI Materials Journal*, 96(2),173-180.

Hasan et al.,(2006). " Investigation on Factors Related to Sustainable Development of Concrete Technology in Bangladesh-Part III" Undergraduate Thesis, Department of Civil Engineering, University of Asia Pacific, Dhaka, Bangladesh.

Jiusu, L. (2011). "Theoretical compressive strength of pervious recycled aggregate concrete". *Energy Procedia*, Vol. 11, pp. 3547-3552.

Rashid et al., (2005). " Investigation on Factors Related to Sustainable Development of Concrete Technology in Bangladesh-Part I" Undergraduate Thesis, Department of Civil Engineering, University of Asia Pacific, Dhaka, Bangladesh.

Richardson, M. G., (2002) *Fundamental of durable reinforced concrete,*Spoon Press, London and New York.

Siddiqui et al.,(2005). " Investigation on Factors Related to Sustainable Development of Concrete Technology in Bangladesh-Part II" Undergraduate Thesis, Department of Civil Engineering, University of Asia Pacific, Dhaka, Bangladesh.

Sutradhar, S. K., (2012)."Determination of carbonation coefficient of concrete in Dhaka city "Graduate Thesis, Department of Civil Engineering, University of Asia Pacific, Dhaka, Bangladesh.