# BANGLADESH –

# SUSTAINABLE DEVELOPMENT OF CONCRETE TECHNOLOGY

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ABSTRACT**:** This paper presents a summary of some recent research closely associated with the sustainable development of concrete technology in Bangladesh. The research projects 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) the quality of various cement brands commonly used in Bangladesh, (4) the properties of concrete made with various aggregates commonly used in Bangladesh, and (5) recycling of demolished concrete as coarse aggregate for new construction.

## 1. INTRODUCTION

Recently, a huge number of building construction projects (from six-storied to twenty-storied) have been undertaken in the major cities of Bangladesh. To meet the demand of cement for construction projects, more than sixty cement manufacturing industries have been established in Bangladesh. Cements are also imported from other countries. Huge numbers of brick manufacturing industries were established around the major cities. Generally, clay burned bricks are very popular due to the lack of stone aggregates. Bricks are also often broken manually or by uusing a brick crusher into coarse aggregate for concrete works. Stone chips and shingles are also used in construction. Unfortunately, the deterioration of some concrete structures occurs within several years of construction due to the lack of durability considerationa during the design, construction, and maintenance of civil infrastructures. Therefore, with an aim of sustainable development of concrete technology in Bangladesh, a research project was started in the Department of Civil Engineering at The University of Asia Pacific (UAP) in April 2004. The following main topics were taken into account in this research project:

- Causes of deterioration of concrete structures in Bangladesh
- Problems at construction sites that cause early deterioration of concrete structures in Bangladesh
- Quality of cement brands commonly used in Bangladesh
- Properties of concrete made with various aggregates commonly used in Bangladesh
- Recycling of demolished concrete as coarse aggregate for new construction

In this paper, key results from the above-mentioned research are summarized. Detailed results of these investigations can be obtained in References [1–4].

## 2. DETERIORATION OF CONCRETE STRUCTURES

To understand the possible causes of deterioration of concrete structures in Bangladesh, a detailed survey of some buildings in several districts was carried out. The survey included photographing the distressed regions in the structures and identifying the possible causes of the distress.

Typical photographs of the deterioration of concrete structures are shown in **Figure 2.1**. Based on the survey results, the following were found to be the main causes of deterioration of concrete structures in Bangladesh:

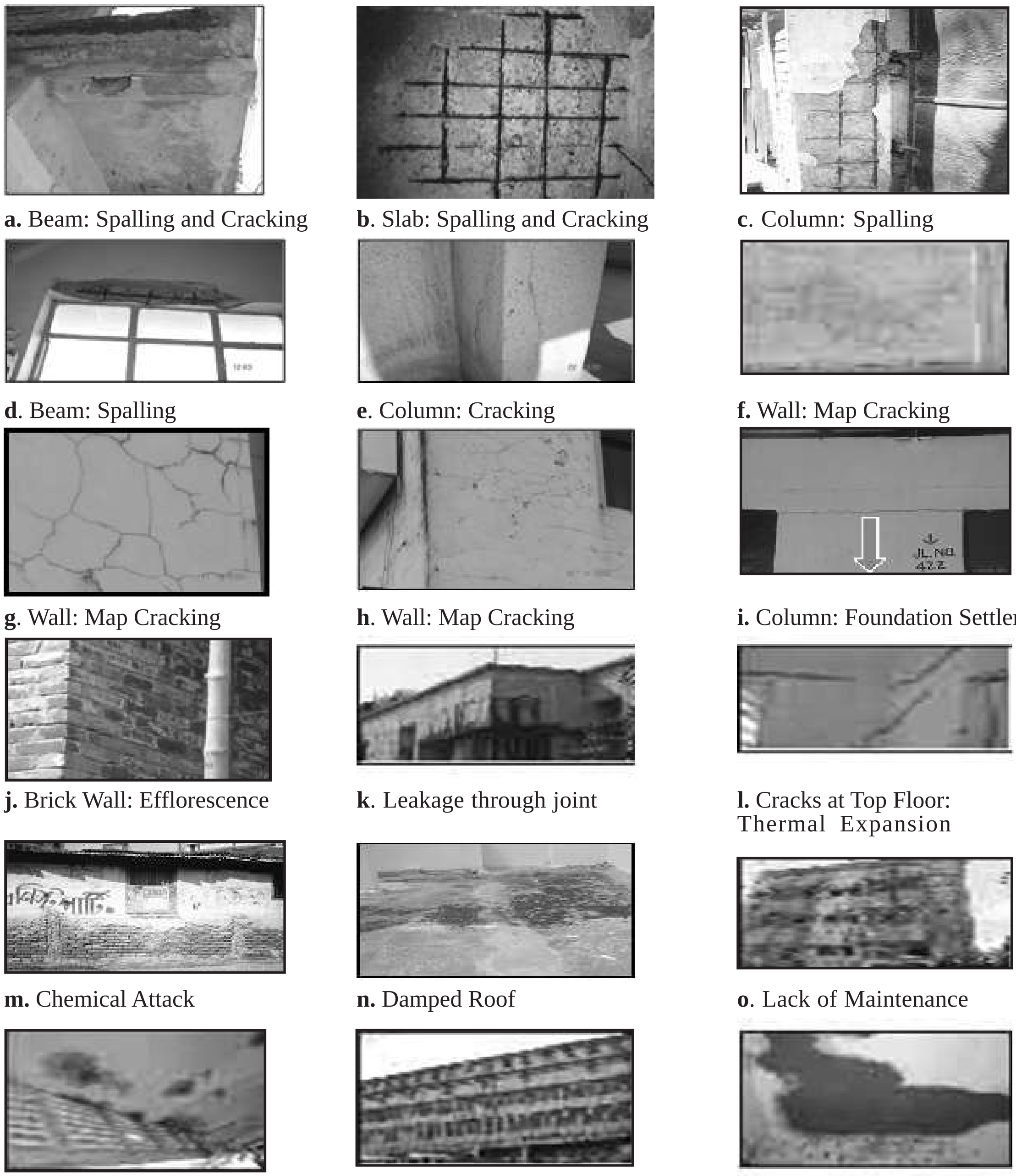
1. Carbonation induced corrosion of steel bars (**Figure 2.1a,b,c**)
2. Chloride induced corrosion of steel bars (**Figure 2.1d,e**)
3. Drying shrinkage (**Figure 2.1f,g,h**)
4. Mud in aggregate
5. Efflorescence in bricks (**Figure 2.1j**)
6. Sulphate attack/Chemical attack (**Figure 2.1m**)
7. Leakage through joints (**Figure 2.1k**)
8. Heat of hydration
9. Thermal expansion (**Figure 2.1l**)
10. Differential settlement (**Figure 2.1i**)
11. Lack of reinforcement in structural members
12. Lack of cover thickness of structural members
13. Leakage of water through the roof (**Figure 2.1n and 2.1p**)
14. Lack of maintenance **(Figure 2.1o, p, q and 2.1r**)

Due to the high humidity (60% ~100%) and high temperature (40$^{o}$C in summer) in Bangladesh, a high rate of carbonation is expected in concrete structures. The use of low strength concrete as well as poor quality concrete works at the construction stage also accelerates the process of carbonation. Many concrete floors, beams, and columns are severely damaged due to the carbonation induced corrosion of steel bars 10–15 years after construction. It is the most common cause of deterioration of concrete structures in Bangladesh.

Generally, the depth of carbonation is expressed by the following equation [5]:

$$D = K\sqrt{t} \qquad (1)$$

where, D is the depth of carbonation in mm, k is carbonation coefficient in mm/year $^{0.5}$, and t is time in years. Experimental investigations are necessary to find the value of the carbonation coefficient.



**a.** Beam: Spalling and Cracking
**b**. Slab: Spalling and Cracking
**c**. Column: Spalling
**d**. Beam: Spalling
**e**. Column: Cracking
**f.** Wall: Map Cracking
**g**. Wall: Map Cracking
**h**. Wall: Map Cracking
**i.** Column: Foundation Settlement
**j.** Brick Wall: Efflorescence
**k**. Leakage through joint
**l.** Cracks at Top Floor: Thermal Expansion
**m.** Chemical Attack
**n.** Damped Roof
**o**. Lack of Maintenance
**p**. Damped Roof
**q.** Lack of Maintenance
**r**. Patch Repair

**Figure 2.1** Photographs of some typical types of deterioration observed in concrete structures in Bangladesh.

In the coastal areas, concrete structures are damaged due to the combined action of chloride and carbonation-induced corrosion of steel bars in concrete. Investigations related to chloride ingress into concrete in the coastal areas of Bangladesh are necessary. Fick's Second Law of diffusion is commonly used to determine the chloride profile in concrete due to the diffusion of chloride into the concrete from the outside environment. The closed form solution for pure diffusion of chloride ions into concrete is expressed as [6]:

$$C(x,t) = C_o\left(1 - erf\left[\frac{x}{2\sqrt{D_{ac}t}}\right]\right) \quad (2)$$

where, $C(x,t)$ is the chloride ion concentration at a depth $x$ (mm) and time $t$ (year), $C_o$ is the chloride ion concentration at the surface (here it is assumed to be equal to the chloride ion concentration at a mean sampling depth of 1 cm) as weight percentage of cement, $D_{ac}$ is the apparent diffusion co-efficient in $mm^2$/year, and *erf* is the standard error function. Investigations are necessary to determine the diffusion coefficient of chloride into concrete exposed to the marine environment in Bangladesh.

Cracks in the walls are found due to drying shrinkage of the structure at an early age, as shown in **Figure 2.1f**. A lime concrete coat is applied to the roofs of the buildings to reduce the heat flow in summer (**Figure 2.1n**). Unfortunately, the lime concrete soaks water in rainy seasons for long time and thus accelerates the deterioration of the roof slab. Storage of materials on roofs as well as water logging on roofs are also found to be causes of deterioration of roof slabs. Efflorescence is found in the partition wall due to the presence of salts in the brick. Generally, patch type repairs are carried out, but they are found to be ineffective after a short time (**Figure 2.1r**).

## 3. CONSTRUCTION SITES – EARLY DETERIORATION

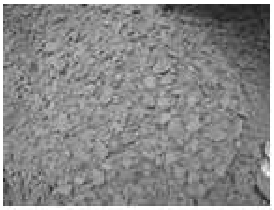
Several construction sites were visited to identify the causes associated with the early deterioration of concrete structures during service. The following were identified:

1. Un-sieved aggregates (**Figure 3.1a**)
2. Unwashed aggregates (**Figure 3.1 b**)
3. Overly Wet sand (**Figure 3.1c**)
4. Mud water for mixing (**Figure 3.12d**)
5. Rusted reinforcement (**Figure 3.1e, 2h, and 2i**)
6. Excess water in mix (**Figure 3.1f**)

7. Higher w/cm
8. Excess fine aggregate (sand)
9. Excess coarse aggregate
10. Poor mixing/ mixture proportion (**Figure 3.1 g**)
11. Problems associated with volumetric mix proportions
12. Lack of cover concrete (**Figure 3.1 h and 3.1 i**)
13. Problems associated with formwork (leakage of mixing water)
14. Placing of concrete from a large height by labors
15. Inappropriate compaction
16. Inappropriate curing
17. Brick efflorescence
18. Poor workmanship

Volumetric mix proportions are generally used for most construction except for the ready mix concrete industries. Generally, mixture proportions for concrete are set at 1:1.5:3 (strength range of concrete 3,500~4,000 psi, 24.5 MPa – 28 MPa) or 1:2:4 (strength range of concrete 2,500 – 3,000 psi, 17.5 MPa – 21 MPa) for most construction work. For concrete works, the Bangladesh National Building Code (BNBC) recommends 25 liters of water per bag of cement. Unfortunately, at construction sites water is added until the mixture become workable without any measuring. For this reason, in actual construction the strength of concrete becomes 2500 – 4000 psi (17.5 MPa – 28 MPa). The use of a high W/C ratio makes concrete relatively porous, and consequently easy paths for the ingress of harmful constituents are developed.

The concrete cover is not maintained adequately due to the lack of knowledge of durability-based design by civil engineers. Generally, in the four-year curriculum of B. Sc. Eng. (Civil) program, a three-credit hour theory course is taught on engineering materials including concrete. A 1.5 credit-hour laboratory course is also taught on concrete technology. More credit hours are necessary to teach students about the 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, etc. At many construction sites, unskilled workers are involved. It is necessary to create skilled workers through professional organizations.

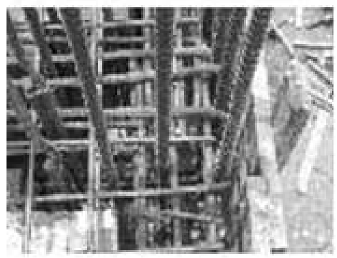


**a**. Unsieved aggregate

**b**. Unwashed aggregate

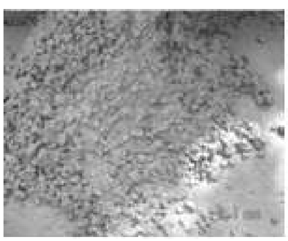
**c**. Overly wet sand

**d**. Turbid water

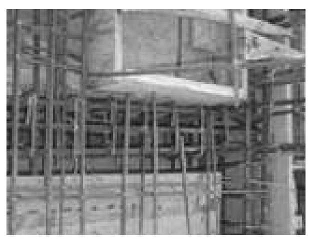


**e**. Rusted reinforcement

**f**. Much bleeding



**g**. Segregated concrete



**h**. Lack of clear cover

**i**. Lack of clear cover

**Figure 3.1** Photographs depicting typical construction conditions contributing to the potential distress of structures during their service life.

## 4. QUALITY OF VARIOUS CEMENT BRANDS

More than sixty cement brands are available in Bangladesh. Among them, thirty commonly used cement brands were investigated to determine their initial setting time, final setting time, consistency, bleeding, bulk unit weight, and strengths at 7, 14, and 28 days. The ingredients of the cement (as specified on the cement bags) are listed in **Table 1**. Cement ingredients varied widely. Brands 11 and 12 contain only clinker (about 95%) and gypsum (about 3%). In other brands, some portion of the clinker is replaced by fly ash, slag, or limestone. A maximum of 35% replacement is found. It is understood that most of the cements available in Bangladesh are blended cement. More seminars and symposiums are necessary to discuss the technology associated with blended cements.

**Table 1** Ingredients of cement brands investigated

| Brand | Clinker (%) | Gypsum (%) | S, FA, LS (%) | FA, LS (%) | FA (%) | S (%) | LS (%) | MAC (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 79 | - | - | | | 17 | | 4 |
| 2 | 80-94 | 0~5 | | 6~20 | | | | |
| 3 | 80~94 | 0~5 | 19 | | | | | |
| 4 | 65~79 | 0~5 | 21~35 | | | | | |
| 5 | 80~90 | 1~5 | 5~19 | | | | | |
| 6 | 80~94 | 5 | 6~20 | | | | | |
| 7 | 78 | 2 | | | | 17 | 3 | |
| 8 | 78 | 3 | 19 | | | | | |
| 9 | 65~79 | 0~5 | 21~35 | | | | | |
| 10 | 75 | 3 | | | 3 | 15 | 4 | |
| 11 | 95~100 | 0~5 | | | | | | |
| 12 | 95 | 5 | | | | | | |
| 13 | 80~94 | | | 6~20 | | | | |
| 14 | 65~79 | 0~5 | 21-30 | | | | | |
| 15 | 80~94 | 0~5 | 21~35 | | | | | |
| 16 | 80~94 | 1~5 | 5~19 | | | | | |
| 17 | 65~79 | 5 | 6~20 | | | | | |
| 18 | 65~79 | 2 | | | | 17 | | |
| 19 | 80~94 | 3 | 19 | | | | | |
| 20 | 80~94 | 0~5 | 21~35 | | | | | |
| 21 | 65~79 | 0 ~ 5 | 21 ~ 35 | 17 | | | | |
| 22 | 79 ~90 | | | | | | | |
| 23 | 80~94 | 0 ~ 5 | 6 ~ 20 | | | | | |
| 24 | 80~94 | 0 ~ 5 | 6 ~ 20 | | | | | |
| 25 | 80 ~ 94 | 0 ~ 5 | 6~20 | | | | | 4 |
| 26 | 70 ~79 | 0~5 | | | | | 6 ~ 20 | |
| 27 | 80~94 | | 6 ~ 20 | | | | | |
| 28 | 80~ 94 | 0~ 5 | 6~ 25 | | | | | |
| 29 | 70 ~ 94 | 0 ~ 5 | 6 ~ 20 | | | | | |
| 30 | 70~79 | 3 | | 21~30 | | | | |

S: Slag, FA: Fly Ash, LS: Limestone, MAC: Minor Additional Constituents

Consistency of the cement brands falls within 22–30% as specified by ASTM C 187. The initial and final setting times of the cement brands are shown in **Figures 4.1 and 4.2.** It can be seen that all cement brands satisfy the ASTM C 150 for both initial (not less than 45 minutes) and final setting times (not more than 375 minutes). Two inch cement mortar cubes were made to measure the strength of cement as per ASTM C 109. Instead of Ottawa white sand, standard graded sand was used for making the specimens.

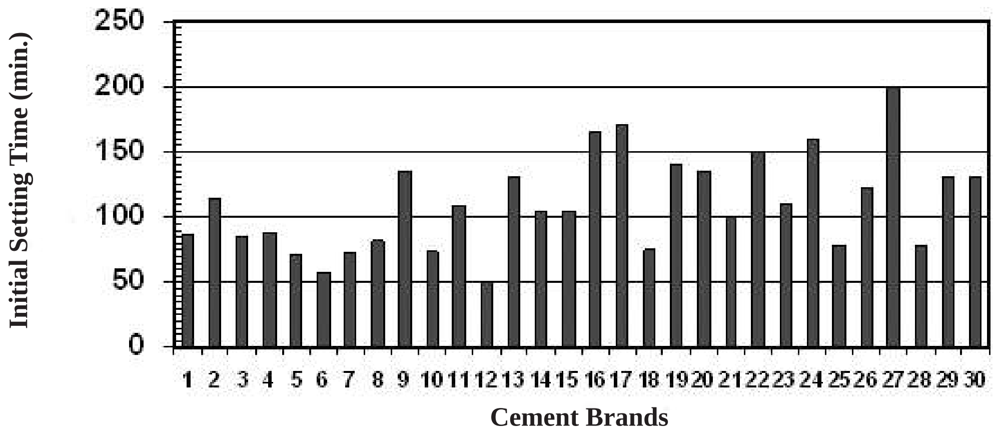



**Figure 4.1** Initial setting time of cement brands.

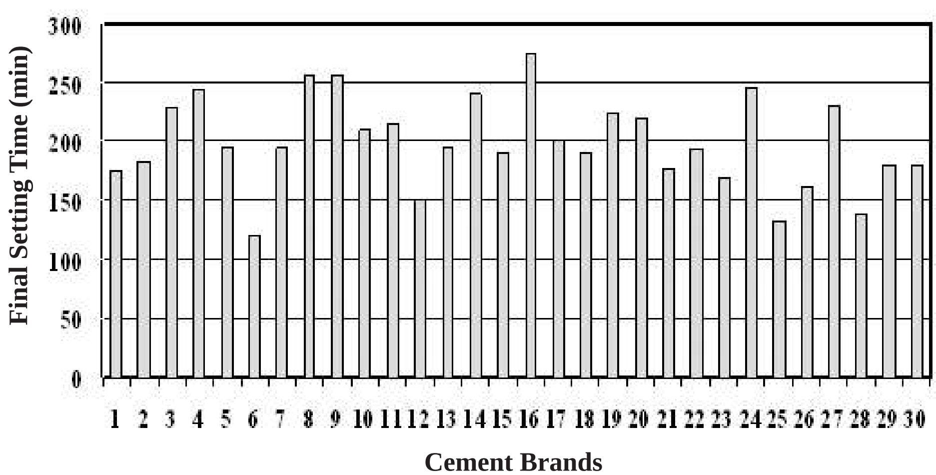



**Figure 4.2** Final setting time of cement brands.

The strength of the cement mortar at 3, 7, and 28 days is shown in **Figure 4.3**. Most of the cement satisfies the ASTM C 150 strength requirements for 3 days (1800 psi), and 7 days (2800 psi) strengths. Only seven cement brands (out of 30), however, satisfy the ASTM C150 requirements for strength at 28 days (4000 psi). Based on the experimental results, it was found that a cement brand that shows more bleeding has less strength as well as that a cement brand that has a later final setting time has less strength. The data associated with fineness and bleedings are not explained here.

**Figure 4.4** shows the normalized strength with time. The following empirical equation is proposed for estimating the 28-day strength from the 3, 7, and 14 day strengths:

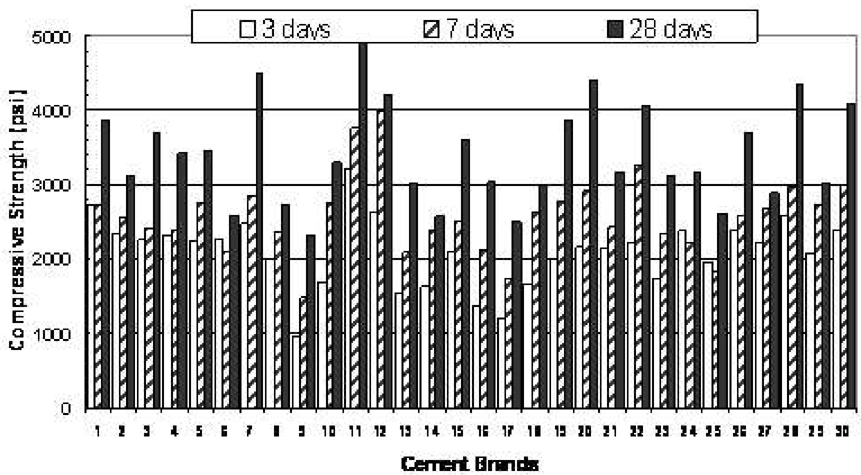



**Figure 4.3** Strength at 3, 7, and 28 days.

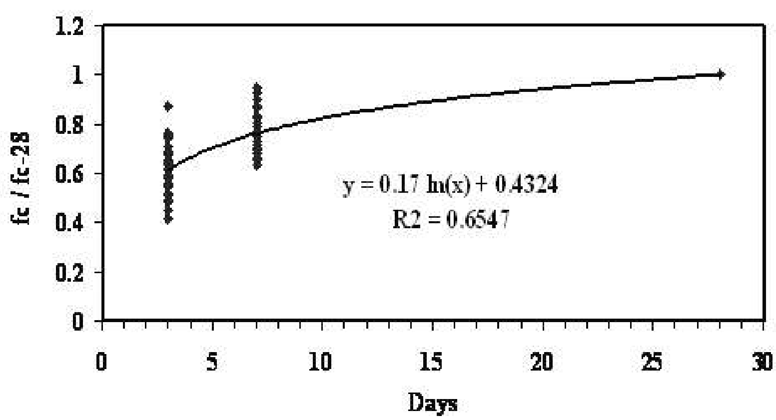



**Figure 4.4** Normalized strength-time relationship.

## 5. CONCRETE PROPERTIES WITH VARIOUS AGGREGATES

Brick chips have been commonly used in Bangladesh for making concrete since long ago. Stone chips are also becoming popular. Shingles (round shaped stones) are also used in construction due to their better workability. Jhama brick chips are also found on the market but are used rarely in construction. A detailed study was carried out to compare the properties of concretes made with these aggregates. The properties of the aggregates are summarized in **Table 2**. Brick chips were also investigated with variation in the 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 a water-to-cement ratio of 0.55. The cement content of the mix was 340 kg/m$^3$. The sand to aggregate volume ratio of the concrete was set at 0.44. The FM of coarse aggregates was 6.69. The FM, specific gravity, and absorption capacity of the sand were 2.64, 2.61, and 3.9% respectively. For comparison of brick and stone aggregates, brick aggregates with similar abrasions as stone aggregates were selected. The absorption of brick aggregates (11.5%) and jhama brick chips (12.2%) is higher than that of stone aggregates (0.8%) and shingles (2%). The abrasion value of the brick chips was 26.3%, and for stone chips it was 25%. The abrasion values of the shingles and jhama brick chips were 20.78 and 37.16%, respectively.

The workability of concrete made with different aggregates is shown in **Figure 5.1**. Concrete made with brick chips shows the lowest workability due to the internal friction between the brick aggregates. Due to their round shape, shingles shows the highest workability. At construction sites it was found that water is added to the mixture until the mixture becomes workable, therefore, it is likely that more water is added to brick aggregate concrete to improve workability. The strength of concrete at 7, 14, and 28 days is shown in **Figure 5.2** for concrete made with different aggregates. Interestingly, brick aggregates give higher strengths as compared to the stone aggregates. This happens due to the development of a stronger interfacial transition zone around brick aggregates as compared to stone aggregates.

**Table 2** Properties of aggregates

| 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

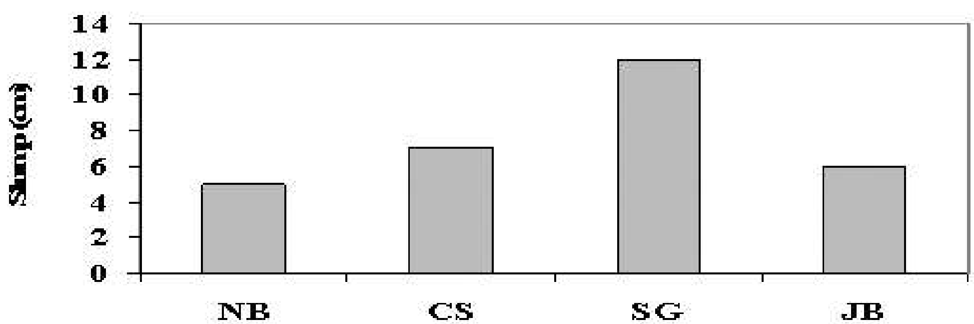



**Figure 5.1** Workability of concrete made with different aggregates (w/cm =0.55).

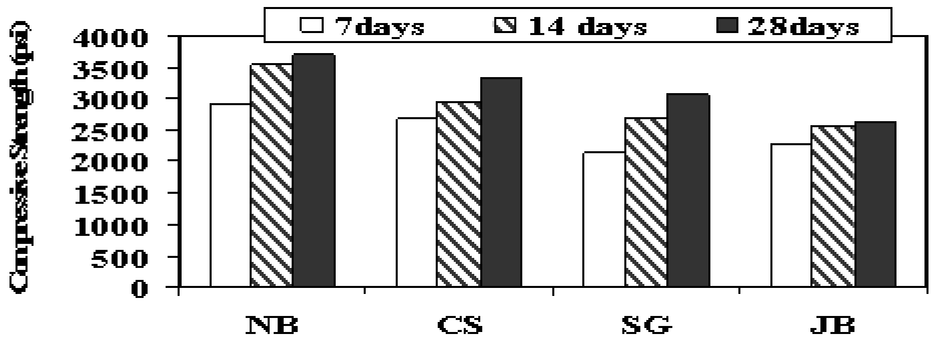



**Figure 5.2** Compressive strength of concrete made with different aggregates.

The compressive strengths of concrete made with brick aggregates (NB) and variable moisture conditions are shown in **Figure 5.3**. In all cases, the amount of water in the concrete is kept the same (the amount of water to make the SSD sample plus the amount of water required from w/cm) except for the NBEW55 case. In the case of NBEW55, aggregates with a surplus amount of water on the surface were used. The compressive strength of concrete remains the same as the moisture conditions are changed. However, the presence of excess water on the surface leads to a reduction in strength due to the increase in the amount of water in the system. In addition to these factors, dust contaminated aggregates, pre-heated aggregates, and cement paste-coated aggregates were investigated. These results are not presented here.

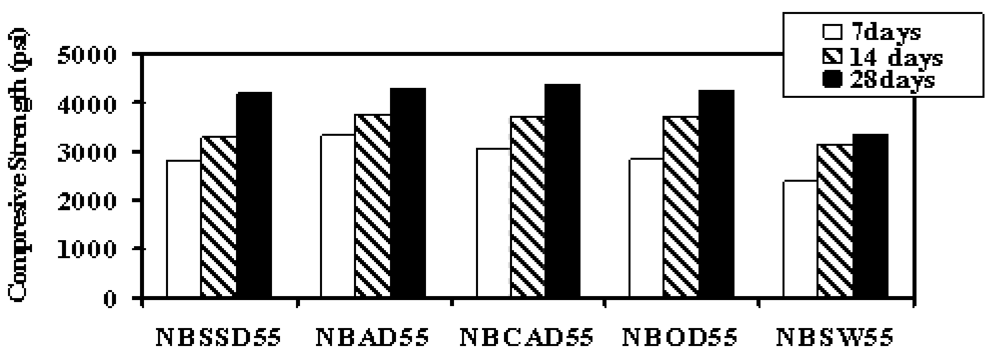



**Figure 5.3** Compressive strength of concrete made with aggregates with different moisture conditions.

## 6. RECYCLED COARSE AGGREGATE - NEW CONSTRUCTION

The global consumption of concrete is estimated at 12 billion tons (@ 2 tons/capita/year). To make this huge volume of concrete, 1.5 billion tons of cement, 9.3 billion tons of aggregate, and 1.2 billion tons of water are necessary. The global production of demolished concrete is estimated at 2–3 billion tons per year. In next ten years, the global production of demolished concrete will rise to 7.5–12.5 billion tons. If it is possible to recycle the total amount of demolished concrete, there will be no need to produce 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 the replacement of low rise buildings by relatively high rise buildings due to the booming real estate business. Therefore, an attempt was made to determine possible ways to recycle demolished concrete for new construction as coarse aggregates. The properties of the recycled aggregates investigated in this study are summarized in **Table 3**.

One-year year old recycled brick and stone samples were collected by crushing cylinder specimens tested at the concrete laboratory. Thirty-year and 50-year-old recycled aggregates were collected by crushing oconcrete collected from demolished building sites. It can be seen that abrasion value of both stone and brick aggregates increases sharply due to the presence of mortar surrounding the virgin aggregates. The absorption capacity of the aggregate is also increased for this reason. Concrete samples (15 cm diameter and 30 cm height) were made and tested accordingly. The results of the following nine cases were incorporated in this report:

- NB-55 (Normal Brick Aggregate, w/cm=0.55)
- NS-55 (Normal Stone Aggregate, w/cm =0.55)
- RBY1-55 (Recycled 1-Year Old Brick Aggregate, w/cm =0.55)
- RBY1-45 (Recycled 1-Year Old Brick Aggregate, w/cm =0.45)
- RSY1-55 (Recycled 1-Year Old Stone Aggregate, w/cm =0.55)
- RSY1-45 (Recycled 1-Year Old Stone Aggregate, w/cm =0.45)
- RBY50-45 (Recycled 50-Year Old Brick Aggregate, w/cm =0.45)
- RBY50-55 (Recycled 50-Year Old Brick Aggregate, w/cm =0.55)
- RBY30-45 (Recycled 30-Year Old Brick Aggregate, w/cm =0.45)

**Table 3** Properties of recycled aggregates

| Age | Aggregate | FM | Sp.Gr. | Absorption (%) | Abrasion (%) |
|---|---|---|---|---|---|
| - | Normal Brick | 6.69 | 2.1 | 9.5 | 26.13 |
| - | Normal Stone | 6.71 | 2.50 | 2.89 | 25 |
| 1 Year | Recycled Brick | 6.7 | 2.35 | 10 | 46.9 |
| 1 Year | Recycled Stone | 6.72 | 2.6 | 3 | 46 |
| 30 Year | Recycled Brick | 6.71 | 2.32 | 9.12 | 47.26 |
| 50 Year | Recycled Brick | 6.71 | 2.34 | 10.7 | 57 |

The workability of concrete is shown in **Figures 6.1** and **6.2** for w/cm =0.55 and 0.45 respectively. The workability of recycled aggregate concrete is lower than that of normal aggregate concrete. To improve the workability of the recycled aggregate concrete, cement paste coated recycled aggregates were investigated. A significant improvement in the workability of concrete was found due to the application of a cement paste coat around the recycled aggregates. These data were not incorporated in this report.

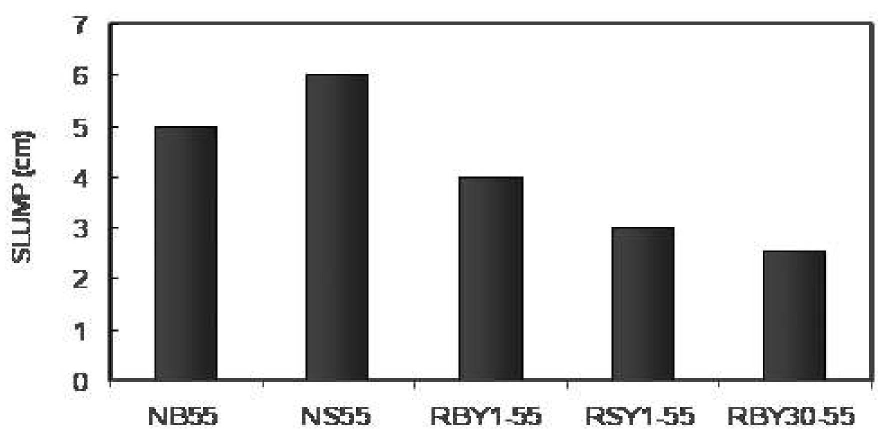



**Figure 6.1** Workability of concrete (w/cm =0.55).

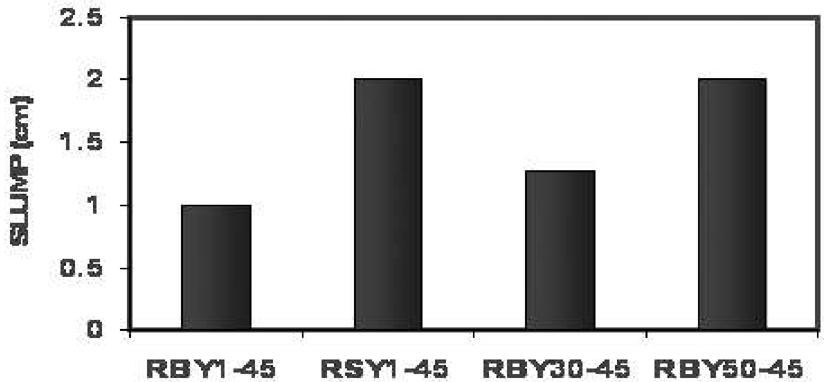



**Figure 6.2** Workability of concrete (w/cm =0.45).

The compressive strength of normal and recycled aggregate concrete at 7, 14, and 28 days is shown in **Figures 6.3** and **6.4**. For the same w/cm, the strength of recycled aggregate concrete is about 10~20% lower than that of normal aggregate concrete. If the w/cm is reduced to 0.45, the strength of the concrete becomes similar to or higher than that of normal aggregate concrete made with w/cm =0.55. It is easily understood that a concrete strength of 3000 – 4000 psi can be obtained by using recycled aggregate concrete. Cement content of all concrete was set at 340 kg/m$^3$. The strength of recycled aggregate concrete with higher cement content was also investigated. These data will be summarized in the near future.

Young's modulus for normal aggregate concrete and recycled aggregate concrete are shown in **Figures 6.5 and 6.6**. For w/cm =0.55, a 20% a reduction in Young's modulus is found for recycled aggregate concrete compared to normal aggregate concrete. The reduction of w/cm to 0.45 improves the Young's modulus to a value similar to that of the normal aggregate concrete at w/cm = 0.55 for good quality recycled aggregate. Typical stress-strain curves for concrete made with recycled and normal aggregates are shown in **Figure 6.7**. It can be seen that for good quality recycled aggregates the stress-strain curves becomes stiffer (w/cm =0.45) compared to the normal aggregate concrete (w/cm =0.55), but for relatively poor quality (higher abrasion value) recycled aggregate no significant improvement of Young's modulus is found for w/cm =0.45. The variation in the strength of recycled aggregate concrete (W/C=0.45) with the abrasion value of the aggregate is shown in **Figure 6.8**. The recycled aggregates with higher abrasion values give less strength. This indicates that concrete that is to be recycled after demolition at the end of its service life should be a good quality concrete. If a good quality concrete is made with care, it is expected that its strength will increase forever, but if it is made without care (less strength, porous system, paths for harmful constituents), the reverse results are possible, as schematically explained in **Figure 6.9**. Reduction of the strength of good quality concrete is generally not found after long-term exposure [7 and 8].

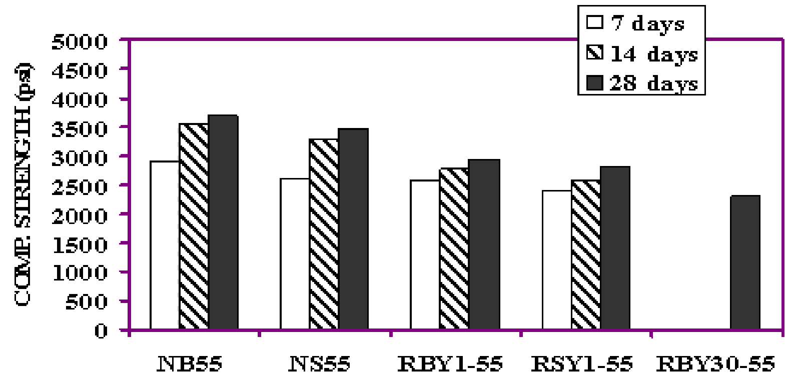



**Figure 6.3** Compressive strength of concrete (w/cm =0.55).

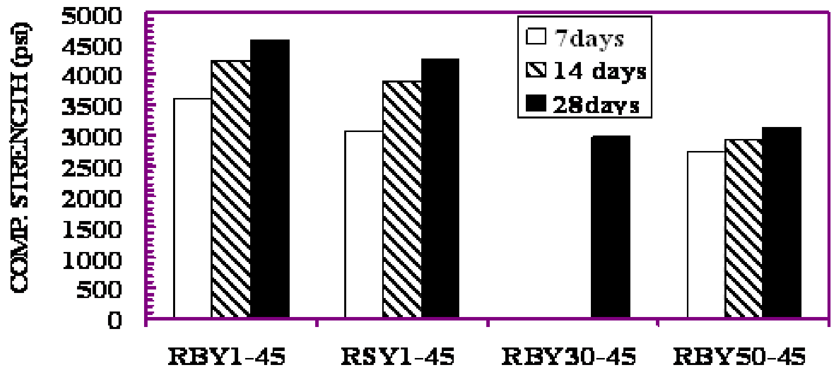



**Figure 6.4** Compressive strength of concrete (w/cm =0.45).

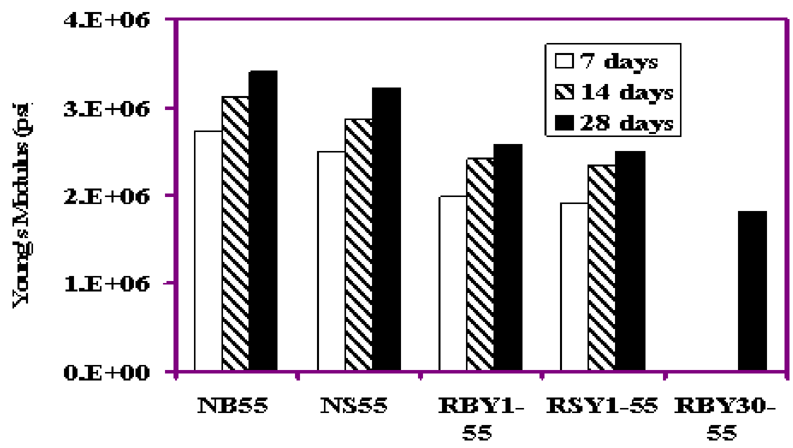



**Figure 6.5** Young's modulus of concrete (w/cm =0.55).

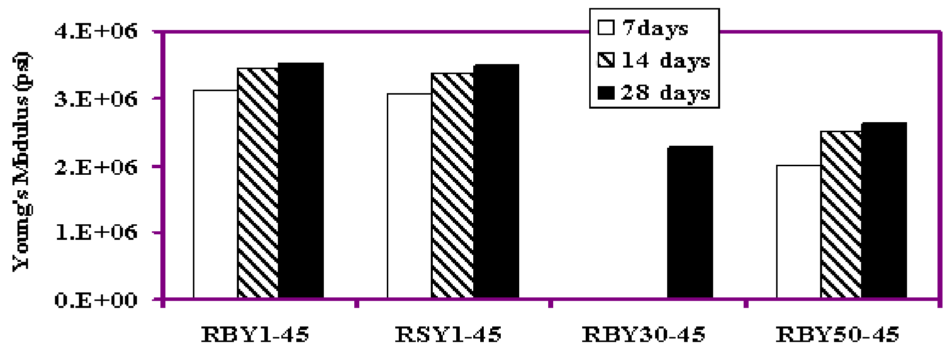



**Figure 6.6** Young's modulus of concrete (w/cm =0.45).

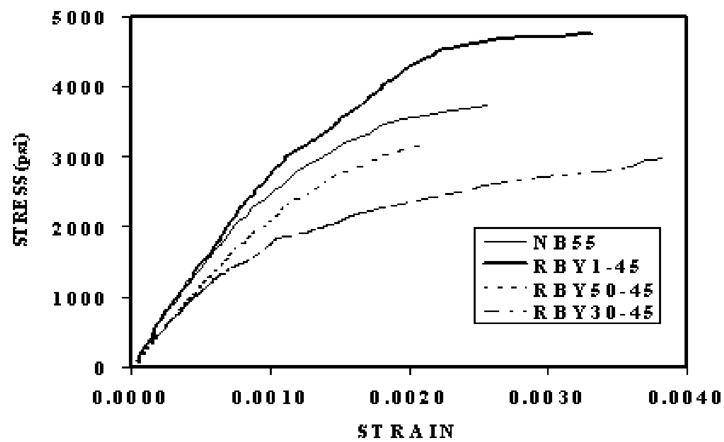



**Figure 6.7** Stress-strain curves of concrete.

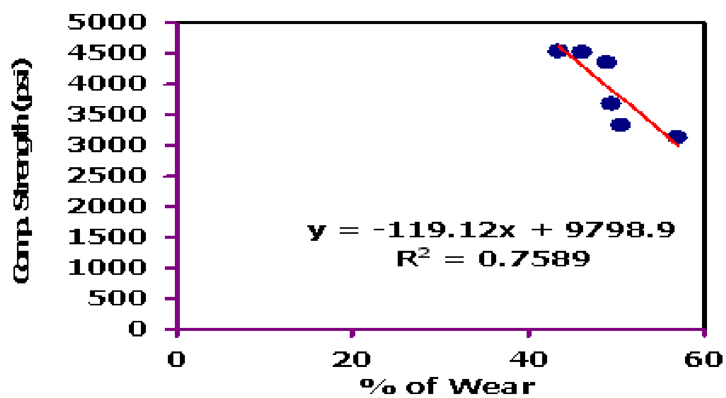



**Figure 6.8** Compressive strength versus abrasion value.


**Figure 6.9** Schematic of strength of concrete versus time.

## 7. CONCLUDING REMARKS

This paper summarizes some recent research closely associated with the sustainable development of concrete technology in Bangladesh. The following concluding remarks are made:

1. To avoid early deterioration of concrete structures, the durability design of the structures must be taken into account.
2. More research on the durability of concrete structures in Bangladesh needs to be carried out to understand deterioration processes in our hot and humid country.
3. The quality of cement brands must be controlled for the sustainable development of concrete technology.
4. When they have similar abrasion values, brick aggregate concrete gives higher strengths as compared to stone aggregate concrete.
5. Recycling of demolished concrete is possible for concrete in the strength range 3,000 – 4,000 psi.
6. More courses are to be incorporated in the undergraduate program on concrete technology.
7. Skilled workers are to be produced through professional organizations.
8. More seminars and symposia are to be arranged to discuss the knowledge related to the sustainable development of concrete technology in Bangladesh.

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## REFERENCES

[1] Rashid et al., Investigation on Factors Related to Sustainable Development of Concrete Technology in Bangladesh, Part I, Undergraduate Thesis, Spring 2005, Department of Civil Engineering, The University of Asia Pacific, Dhaka, Bangladesh.

[2] Siddiqui et al., Investigation on Factors Related to Sustainable Development of Concrete Technology in Bangladesh, Part II, Undergraduate Thesis, Fall 2005, Department of Civil Engineering, The University of Asia Pacific, Dhaka, Bangladesh.

[3] Hasan et al., Investigation on Factors Related to Sustainable Development of Concrete Technology in Bangladesh, Part III, Undergraduate Thesis, Spring 2006, Department of Civil Engineering, The University of Asia Pacific, Dhaka, Bangladesh.

[4] Miah et al., Investigation on Factors Related to Sustainable Development of Concrete Technology in Bangladesh, Part IV, Undergraduate Thesis, Fall 2006, Department of Civil Engineering, The University of Asia Pacific, Dhaka, Bangladesh.

[5] Richardson, M. G., Fundamentals of Durable Reinforced Concrete, Spoon Press, London and New York, 2002, pp. 86-87.

[6] Hansen, E.J., and Saouma, V.E., Numerical Simulation of Reinforced Concrete Deterioration – Part I : Chloride Diffusion, ACI Materials Journal, Vol. 96, No. 2, 1999, pp. 173-180.

[7] Mohammed, T.U., Yamaji, T., and Hamada, H., Chloride Diffusion, Microstructure, and Mineralogy of Concrete after 15 Years of Exposure in Tidal Environment, ACI Materials Journal, 2002, Vol. 99, No. 3, pp. 256-263.

[8] Mohammed, T.U., Yamaji, T., and Hamada, H., Microstructures and Interfaces of Concrete after 15 Years of Exposure in Tidal Environment, ACI Materials Journal, 2002, Vol. 99, No. 4, pp. 352-360.