ReCAP

Research for Community Access Partnership

UKaid from the British people

# Climate Resilient Concrete Structures in Marine Environment of Bangladesh

## Interim Field and Laboratory Testing Report 2 – Phase 1 study


**Mott MacDonald Ltd.**


*BAN2077A*

**March 2017**

MOTT MACDONALD

Cover Photo: Photo showing concrete trial mixing at LGED Central Laboratory

| *Quality assurance and review table* | | | |
|---|---|---|---|
| Version | Author(s) | Reviewer(s) | Date |
| 1.0 | Sudarshan Srinivasan | Ian Gibb | 23/03/17 |
| | | | |
| | | | |
| | | | |

Mott MacDonald,
Mott MacDonald House,
8-10 Sydenham Road,
Croydon CR0 2EE,
United Kingdom
T +44 (0)20 8774 2000
F +44 (0)20 8681 5706
W www.mottmac.com

ReCAP Project Management Unit
Cardno Emerging Market (UK) Ltd
Oxford House, Oxford Road
Thame
OX9 2AH
United Kingdom

## Project Summary

Bangladesh has a vast coastal infrastructure seriously affected by climate change and associated extreme environmental conditions. Reinforced concrete structures in the coastal regions can deteriorate rapidly (within 5-10 years of construction) due to exposure to aggressive marine environment, issues related to poor workmanship, limited availability of good quality materials and lack of awareness on good construction practices.
LGED maintains around 380,000 linear metres of concrete bridges/culverts in the rural coastal areas and are planning to build more than 200,000 linear metres during the next ten years. In order to construct durable concrete structures to withstand the aggressive coastal environment for the intended design life, there is a need to study the local factors that influence the durability of reinforced concrete structures. This project will examine the major factors that contribute to premature deterioration of concrete structures, develop cost effective concrete mix design to enhance the durability of future structures and make recommendations on improvements in construction practice and workmanship considered necessary to improve service life.

## Interim Field and Laboratory Testing Report 2

Following the approval of Inception report, Condition survey report and Interim Field and Laboratory Testing Report 1, this Interim Field and Laboratory Testing Report 2 is submitted to fulfil the objectives of milestone 4 agreed in the terms of reference of the contract. This report describes and discusses the phase I experimental work undertaken as part of field and laboratory testing. The outcome of the phase I testing results suggest that the material optimisation and inter-relationship between various factors studied helps in the design of concrete mixes planned for phase II laboratory testing. The study on coated brick aggregates has showed a potential scope for improvement of concrete strength as compared with uncoated brick aggregates.

## Key words

Condition survey, Testing, Concrete durability, Corrosion, Carbonation, Bangladesh, Chloride content, Coastal infrastructure, Marine structures

## Acknowledgements

The project team would like to greatly acknowledge the continuous support provided by LGED engineers through the tenure of the project.
The kind contribution of cement products supplied by Basundhara cement, Bangladesh and corrosion inhibitor supplied by Yara Intl ASA, Norway are greatly acknowledged.

## Acronyms, Units and Currencies

| | |
|---|---|
| £ | British Pound |
| RECAP | Research for Community Access Partnership |
| UK | United Kingdom (of Great Britain and Northern Ireland) |
| UKAid | United Kingdom Aid (Department for International Development, UK) |
| LGED | Local Government Engineering Department |
| DFID | Department of International Development |
| MML | Mott MacDonald Ltd. |
| BDT | Bangladesh Taka |
| BNBC | Bangladesh National Building Code |
| SCM | Supplementary Cementitious Material |
| CI | Corrosion Inhibitor |
| SSD | Saturated Surface Dry |
| W/C | Water/Cement or Water/Cementitious ratio |

## RESEARCH FOR COMMUNITY ACCESS PARTNERSHIP (ReCAP)

***Safe and sustainable transport for rural communities***

ReCAP is a research programme, funded by UK Aid, with the aim of promoting safe and sustainable transport for rural communities in Africa and Asia. ReCAP comprises the Africa Community Access Partnership (AfCAP) and the Asia Community Access Partnership (AsCAP). These partnerships support knowledge sharing between participating countries in order to enhance the uptake of low cost, proven solutions for rural access that maximise the use of local resources. The ReCAP programme is managed by Cardno Emerging Markets (UK) Ltd.

**See www.afcap.org**

## Contents

# 1 Introduction

## 1.1 Background

Following a competitive tendering process, Mott MacDonald Limited was awarded the contract to undertake the Research for Community Access Partnership (ReCAP) project, "Climate Resilient Reinforced Concrete Structures in the Marine Environment of Bangladesh" (the Project). The ReCAP programme is funded by the Department for International Development (DfID) and managed by Cardno Emerging Markets (UK) Ltd.

The original tender documentation set out the context of the Project, describing how Bangladesh is seriously affected by climate change. In particular, excessive intrusion of seawater, air borne chlorides and the high humidity of the coastal belt cause the rapid deterioration of concrete structures within 5 to 10 years of construction.

LGED maintains around 380,000 linear metres of concrete bridges/culverts at the rural coastal areas, with plans to build more than 200,000 linear metres during the next ten years. This has created an urgency to undertake a study on the durability of concrete structures in the marine environment of Bangladesh.

## 1.2 Inception report

The outcome and deliverables for each phase of the project is presented in the form of technical reports as agreed in terms of reference in the contract. An Inception Report was submitted to Cardno on 22$^{nd}$ Aug 2016, which provided a comprehensive review of background information on locally available concrete materials, durability of concrete, workmanship issues and gaps identified in literature review. The inception report also provided an outline of the plan of work for the condition survey phase and a research matrix for the mix design development and laboratory testing phase.

### *1.2.1 Identified gaps in literature review*

Although information on environment, materials and performance of concrete structures are available from the coastal regions of Bangladesh, the following major gaps were identified, which needed to be addressed to enable the design and assessment of concrete structures:

- Very little information on the benefits of locally available fly ash and slag as cement replacement on long-term strength and corrosion resistance of concrete.
- Numerous studies on the comparison of stone aggregates vs brick aggregates mainly focussed on the strength characteristics, however limited information was available on the variability in quality of brick aggregates, measures to improve quality of brick aggregates and corrosion resistance of brick aggregate concrete.
- Some of the previous surveys of concrete structures in the coastal regions identified that corrosion of reinforcement and workmanship issues are the major reasons for deterioration of concrete structures based on visual observations, however no testing data is available. No condition survey of concrete structures that involved information related to local exposure conditions, extent of chloride and carbonation levels in concrete, extent of corrosion activity by half-cell surveys and in-situ strength and condition of concrete.
- Most of the available literature on durability studies of concrete using locally available materials focussed on influence of strength; very little on permeation properties of concrete and no information/data on corrosion resistance of concrete and steel type.

- Chloride induced corrosion models are widely used as a tool to predict the service life of concrete structures in marine environment. These models need crucial information on the durability properties such as chloride migration coefficient, maturity/strength development characteristics, surface chloride and climatic information of local environment. This information obtained at different exposure zones in the coastal regions of Bangladesh will be invaluable for the design and service life assessment of concrete structures in the region.

### 1.3 Condition survey

The Condition survey report submitted to Cardno on 21st Nov 2016, provided a factual information on the condition of various concrete structures surveyed in identified coastal districts viz., Bagerhat, Noakhali, Gopalganj and Cox's Bazar. Based on the observations from the condition survey of concrete structures it is believed that the major causes of deterioration of concrete in coastal regions are as follows:

- exposure to aggressive marine environment,
- poor workmanship
- Use of brick aggregates
- use of chloride contaminated aggregates and water in construction
- limited availability of good quality materials
- lack of awareness on good construction practices.
- Lack of quality control mechanism for small construction projects

A mix design programme was planned to explore the possibility of developing cost effective mix design(s) that will enhance the durability of concrete used in the rural marine environment. While it is easy to recommend that only clean aggregates or clean water be used, in some areas these materials are simply not available. Bangladesh has little natural resources with most cement and aggregates being imported. While major infrastructure projects are able to use the imported aggregate, much of the smaller, rural market relies on crushed bricks. The mix design programme needs to gauge the effect of using bricks and contaminated water, assess whether there are opportunities to enhance durability with these materials and contrast potential service life improvements if quality materials can be sourced.

## 2 Laboratory testing phase

The mix design and laboratory testing phase of the project has been planned based on the gaps identified in the Inception stage of the project and findings obtained in the condition survey stage of the project. The experimental programme for the laboratory testing has been divided in two phases; the Phase-I deals with optimisation of the concrete mix to enhance its durability performance and phase-II focusses on studying the corrosion resistance characteristics and service-life assessment of reinforced concrete elements. The research matrix and the factors considered for the study has been established and reported in the Interim Laboratory report 1. In this Interim Laboratory report 2, the progress on the phase-I laboratory testing is reported.

## 3 Phase-I Experimental plan

The phase-I study involves various trial mixes for optimising the concrete mix constituents to produce workable, good strength and low permeable concrete. The experimental research matrix for phase I study is shown in Table 1, which mainly focuses on establishing relationships between W/C ratio, Cement content and compressive strength; increasing the SCM proportion in concrete, improving the properties of brick aggregates; and identify optimum proportions of combined graded stone and brick aggregates.

The study to establish relationship between W/C ratio, Cement content and compressive strength, mainly focusses on understanding the performance of materials in producing a workable concrete. The relationship established in this study will help to identify appropriate cement content for a given W/C ratio in the Phase-II testing of concrete.

The study to increase the proportion of SCMs in concrete deals with optimising the locally available fly ash and/or slag proportion in blended cement in the coastal regions of Bangladesh. The increased dosage of composite cement is tested for 28 days and 56 days strength and an optimum SCM content for the cement is obtained by taking into consideration the later age strength development (56 days strength). The increased dosage of SCMs in cement should improve the durability of concrete and produce more economical cement.

One of the novel features of phase-I study is feasibility trials on improving the properties of brick aggregates by pre-treating them with thin cement slurry mix. A recent research study by Sarkar and Pal, 2016, suggests that addition of cement coating in over burnt brick aggregate has reduced the impact value, LA Abrasion value, water absorption and increased the specific gravity of aggregates. This study shows a potential scope for improving the properties of brick aggregates, which can be tried in cement concrete mixes to check the improvement in durability properties of concrete.

**Table 1 Experimental Research Matrix**

| Study | Variables | Techniques of analysis |
|---|---|---|
| To establish relationship between W/C ratio, Cement Content and Strength | Stone aggregates vs Brick Aggregates<br><br>No Chemical Admixture vs Chemical Admixture | Fresh properties of concrete (slump, cohesion of mix and density)<br>Strength (7 and 28 days) |
| To increase the proportion of SCMs in concrete | Binder content and W/C ratio: Approximate binder content 350, and 400 corresponding to 0.5 and 0.4 W/C ratio<br>Flyash (30-40% cement replacement)<br>Slag (30-50% cement replacement)<br>Combination of flyash and slag (>30% cement replacement) | Fresh properties of concrete (slump, cohesion of mix and density)<br>Strength development (7, 28 and 56 days) |

| Study | Variables | Techniques of analysis |
|---|---|---|
| Feasibility study on improving the properties of brick aggregates | Coated vs uncoated brick aggregates | Preliminary Testing:<br>Specific Gravity<br>Absorption Capacity (%)<br>Unit Weight (kg/m3)<br>Los Angles Abrasion (%)<br><br>Secondary Testing:<br>Fresh properties of concrete (slump, cohesion of mix and density of concrete)<br>Compressive Strength (7, 28 and 56 days) |
| To study the effect of Calcium Nitrate Corrosion inhibitor on fresh and hardened properties of concrete | Dosage of Corrosion Inhibitor:<br>3%, 3.5% and 4%<br>W/C ratio:<br>0.4, 0.5 and 0.6 | Cement Testing:<br>Setting time<br>Normal consistency<br>Compressive strength<br>Concrete testing:<br>Slump loss<br>Compressive strength |

# 4 Material Selection and Testing

This part of the study involves testing representative materials that will be used in the study in accordance with the list of testing specified in Table 2.

Table 2 Specification for material sampling and testing

| Material | Comparison of samples | Laboratory testing of chosen sample |
|---|---|---|
| Cement | At least 3 no popular selling cement – CEM I | • Chemical analysis<br>• Blaine fineness<br>• Setting time (Initial & Final)<br>• Specific Gravity<br>• Compressive Strength (3, 7 and 28 days) |
| Fly ash | At least 3 no from most popular cement companies in coastal region | • Chemical analysis<br>• Blaine fineness<br>• Specific Gravity |
| Slag | At least 3 no from most popular cement companies in coastal region | • Chemical analysis<br>• Blaine fineness<br>• Specific Gravity |
| Aggregates | Locally available sand, brick chips, 'Machine Made' aggregates and stone aggregates should be sampled at Bagerhat, Noakhali, Gopalganj and Cox's Bazar | • Specific Gravity<br>• Absorption Capacity (%)<br>• Unit Weight (kg/m3)<br>• Los Angles Abrasion Value (%)<br>• Ten Percent fines value (%)<br>• Flakiness Index (%)<br>• Elongation Index (%) |

| Material | Comparison of samples | Laboratory testing of chosen sample |
|---|---|---|
| | | • Fineness Modulus<br>• Chloride content |
| Water | Locally available drinking water and untreated water at Bagerhat, Noakhali, Gopalganj and Cox's Bazar | All the samples shall be tested to EN 1008 or ASTM equivalent |

### 4.1.1 Cement, Flyash and Slag

Two types of cement are in widespread use in Bangladesh, CEM I Ordinary Portland Cement and CEM II/B-M Portland Composite Cement with slag and/or flyash. Given that the most likely outcome of the research is to increase blend levels, it is necessary to consider all cements with at least two addition levels. CEM I is perceived as the "quality" cement and is often specified on major government contracts, whereas European specifications and standards[1] would use blended cements in more aggressive environments, particularly when exposed to chlorides.
The local market information and discussions with LGED suggested that Bashundhara cement company is the most popular cement used in the country. Therefore, as a representative cement sample of the market, Bashundhara cement products are used in this study. The Cement (CEM I), Flyash and Slag used in this study was a kind contribution of Bashundhara cement company. The local CEM II/B-M cement did not offer different control of SCM contents so instead, flyash and slag were blended in the concrete mix with CEM I.

**The chemical testing of the cement was done at testing facility of Bashundhara Cement and the results are presented in Table 3. The physical testing of the cement was conducted at LGED laboratory and the test results are presented in**

Table 4.

**Table 3: Chemical characteristics of OPC (CEM I) cement**

| Chemical parameter | Result (% mass) | BS EN 197-1:2011 requirements |
|---|---|---|
| Loss on Ignition (LOI) | 0.48 | ≤ 5.0% |
| Magnesium Oxide (MnO) | 1.68 | - |
| Sulphuric Anhydrate (SO3) | 2.40 | ≤ 4.5% |
| Insoluble Residue | 0.40 | ≤ 5.0% |
| Free Lime | 0.45 | - |
| Sodium Oxide ($Na_2O$) | 0.07 | - |
| Pottasium Oxide ($K_2O$) | 0.53 | - |
| Total Alkalies | 0.42 | - |
| Chloride (Cl-) | 0.019 | ≤ 0.1% |

[1] BS 8500-1:2015+A1:2016. Concrete – Complementary British Standard to BS EN 206. Part 1: Method of specifying and guidance for the specifier. Tables A4 and A5. The British Standards Institution 2016

**Table 4: Physical characteristics of OPC (CEM I) cement**

| Physical parameter | Result | BS EN 197-1:2011 requirements |
|---|---|---|
| Specific Surface ($m^2/kg$) | 385 | - |
| Setting time (mins) | | |
| Initial Setting Time | 102 | ≥ 60 |
| Final Setting Time | 250 | - |
| Soundness (mm) | 0.50 | ≤ 10 |
| Compressive Strength (MPa) | | |
| 3 days | 24.48 | - |
| 7 days | 27.88 | - |
| 28 days | 45.38 | ≥ 42.5 |

The flyash sample supplied by Bashundhara cement was imported from India, the physical and chemical characteristics of the flyash are given in Table 5.

**Table 5 Chemical and Physical characteristics of flyash**

| Elements | Result (% mass) | BS EN 450-1: 2012 requirements |
|---|---|---|
| Calcium Oxide (CaO) | 1.25 | ≤ 1.5% |
| Silicon dioxide (SiO2) | 59.60 | SiO2+Al2O3+Fe2O3 ≥ 70% |
| Aluminium oxide (Al2O3) | 28.70 | SiO2+Al2O3+Fe2O3 ≥ 70% |
| Iron Oxide (Fe2O3) | 6.64 | SiO2+Al2O3+Fe2O3 ≥ 70% |
| Magnesium Oxide (MgO) | 0.97 | ≤ 4.0% |
| Sulphuric Anhydride (SO3) | 0.11 | ≤ 3.0% |
| Loss of Ignition (LOI) | 1.12 | ≤ 5.0% by mass (Cat A) |
| Moisture | 0.32 | - |
| Blaine Surface area | 283 | - |
| Bulk Density | 0.806 | - |

The slag sample supplied by Bashundhara cement was imported from Japan, the physical and chemical characteristics of the sample are presented in Table 6. The test results show that the moisture content of the slag is higher than the limits specified in EN 15167-1:2006.

Table 6 Chemical and Physical characteristics of Slag

| Elements | Result (% mass) | EN 15167-1:2006 requirements |
|---|---|---|
| Loss on Ignition (LOI) | 0.09 | ≤ 3.0% |
| Insoluble Residue (IR) | 0.14 | - |
| Sulphur trioxide (SO3) | 0.05 | ≤ 2.5% |
| Calcium oxide (CaO) | 42.60 | - |
| Iron oxide (Fe2O3) | 0.91 | - |
| Alluminium oxide (Al2O3) | 16.30 | - |
| Silicon dioxide (SiO2) | 34.10 | - |
| Magnesium oxide (MgO) | 5.53 | ≤ 18.0% |
| Moisture | 7.81 | ≤ 1.0% |

### *4.1.2 Coarse Aggregate*

Most of the stone aggregates used in infrastructure projects are imported from neighbouring countries. The source of these stone aggregates is quite variable depending on the availability and cost of transporting to the construction location. Although locally quarried stone aggregates are available in some regions of the country, the quality of the aggregates were observed to be variable. For example, some of the samples of local aggregates collected from Gaptoli in Dhaka had LA abrasion value varying between 35 and 50 (well above maximum LA limit of 30 as per LGED standard).

The stone aggregates used in this study were a combination of local aggregates (10 mm nominal size) and imported Vietnam aggregates (20mm nominal size) collected from Gaptoli in Dhaka.

The brick aggregates were also collected from Gaptoli in Dhaka, where a combination of first class bricks and picked Jhama brick were selected and machine crushed, such that the combined aggregates has an LA Abrasion value close to LGED limit of 40.. The physical properties of all the sampled aggregates were tested at LGED Central Laboratory. The physical characteristics of the stone aggregates and brick aggregates are presented in Table 7 and Table 8.

Table 7 Physical characteristics of stone aggregates

| Test Parameter (units) | Result |
|---|---|
| Specific Gravity | |
| 20 mm | 2.74 |
| 10mm | 2.65 |
| Water Absorption (%) | |
| 20 mm | 0.40 |
| 10 mm | 0.73 |
| Unit weight (kg/m$^3$) | |
| 20 mm | 1667 |
| 10 mm | 1472 |

| Test Parameter (units) | Result |
|---|---|
| LA Abrasion<br>Combined aggregates (50% of 20 mm and 50% of 10 mm) | 30.0 |
| Ten percent fines (%)<br>Combined aggregates | 9.96 |
| Flakiness Index (%)<br>20 mm<br>10 mm | <br>14.84<br>36.22 |
| Elongation Index (%)<br>20 mm<br>10 mm | <br>33.33<br>41.22 |

Table 8 Physical characteristics of brick aggregates

| Test parameter (units) | Result |
|---|---|
| Specific Gravity | 2.06 |
| Water Absorption (%) | 14.99 |
| Unit weight (kg/m$^3$) | |
| LA Abrasion | 42.26 |
| Ten percent fines (%) | 12.19 |
| Flakiness Index (%) | 23.03 |
| Elongation Index (%) | 44.34 |
| Fineness modulus | 7.03 |

### 4.1.3 Fine Aggregate

The fine aggregate used in this study was Sylhet sand collected from Gaptoli in Dhaka. The physical properties of the fine aggregate are presented in Table 9.

Table 9 Physical characteristics of fine aggregate

| Test parameter (units) | Result |
|---|---|
| Specific Gravity | 2.57 |
| Water Absorption (%) | 1.28 |
| Unit weight (kg/m$^3$) | 1587 |
| Silt content (%) | awaiting |
| Fineness modulus | 2.98 |

### 4.1.4 Water

The water used in the study was tap water available at LGED central laboratory.

### 4.1.5 Water-reducing admixture (Superplasticiser)

Sikament 2002 NS, which is a high range water reducing chemical admixture manufactured by Sika India Ltd was used in this study. This is a modified Naphthalene Formaldehyde Sulphanate (SNF) based water reducing admixture that has a relative density of 1.17 kg/l and pH greater than 6.

### 4.1.6 Corrosion Inhibitor

Corrosion of reinforcement due to chloride ingress in concrete is one of the major deterioration mechanisms identified from the Inception phase and condition survey phase of the project. Corrosion inhibitors are often used to prolong the initiation period of corrosion of reinforcement in concrete. In the context of this project, while corrosion inhibitors are unlikely to be added on-site in rural infrastructure projects, it is considered that there could be an opportunity to can be incorporate them in the bagged cement products. While calcium nitrite (commonly used CI) is an expensive constituent, which would preclude it from widespread application, there is evidence[2] that the significantly cheaper calcium nitrate can be effective at extending the propagation period of the corrosion process. Moreover, calcium nitrate based corrosion inhibitors are available in granules, which can be easily inter-grounded with clinker/cement to produce bagged cement product.

In the phase-I stage of laboratory testing, concrete trial mixes using corrosion inhibitors are tested to study the influence of this admixture on fresh and hardened concrete properties. The calcium nitrate corrosion inhibitor used in this study was kindly contributed by Yara Intl ASA, Norway. The chemical and physical characteristics of calcium nitrate corrosion inhibitor as given in the manufacturer's test certificate is provided in Table 10.

**Table 10 Chemical composition and density of Calcium Nitrate Corrosion Inhibitor**

| Test parameter | Result (%) |
| --- | --- |
| Total Nitrogen | 2.57 |
| Ammonium-N | 1.28 |
| Nitrate-N | 1587 |
| Total CaO | 2.98 |
| Chlorine | 0.0 |
| Iron | 0.03 |
| Water insoluble >3µm | 500 ppm |
| Bulk density | 1.10 kg/l |

# 5 Concrete mix design and testing – Phase I Study

## 5.1 To establish relationship between free W/C ratio, Cement content and Strength

This part of the phase-I study involves trial mixes to determine free W/C ratio and cement content for a constant slump, ensure mixes are cohesive and yield 1.0m3. The study focusses on establishing relationship between free W/C ratio, cement content and strength of concrete at a target slump of 75-100mm for both stone and brick aggregate concretes. To get a good correlation curve between the free W/C ratio and cement content of concrete, concrete mixes with four different cement content was tested. In the trial testing, the final free W/C ratio of each concrete mix with given

[2] Baghabra Al-Amoudi OS, Maslehuddin M, Lashari AN, Almusallam AA. "Effectivenss of corrosion inhibitors in contaminated concrete. Cement and Concrete Composites 25 (2003) 439-449

cement content was determined based on total amount of water added to the mix to attain target slump of 75-100mm. The free total water in the mix is determined after moisture correction compensating for the water contributed by wet aggregates or water absorbed by dry aggregates. The final saturated surface dry (SSD) batch weights of concrete mixes tested with stone aggregates are given in Table 11.

Table 11 Mix proportions of concrete mixes with stone aggregates

| Mix Ref | Free w/c ratio | Cement (kg) | Coarse Aggregate (60%) (kg) | | Total Coarse Aggregate (60%) (kg) | Sand (40%) (kg) | Water (kg) | Slump (mm) | Plastic Density (kg/m³) |
|---|---|---|---|---|---|---|---|---|---|
| | | | 20 mm (50% of CA) | 10 mm (50% of CA) | | | | | |
| T-01 | 0.84 | 250 | 555.83 | 555.83 | 1111.66 | 741.11 | 211 | 90 | 2337.72 |
| T-02 | 0.63 | 350 | 542.17 | 542.17 | 1084.34 | 722.89 | 219 | 80 | 2384.64 |
| T-03 | 0.51 | 450 | 522.43 | 522.43 | 1044.86 | 696.57 | 231 | 90 | 2360.86 |
| T-04 | 0.46 | 500 | 491.26 | 491.26 | 982.52 | 655.02 | 229 | 75 | 2389.46 |
| T-05 | 0.44 | 550 | 460.1 | 460.1 | 920.2 | 613.47 | 241 | 90 | 2375 |

In the case of concrete mixes with brick aggregates, the aggregates were pre-soaked for a period of 1 hour such that the brick aggregates do not absorb any additional water at the time of mixing and testing of concrete for slump. The moisture content of pre-soaked aggregates was measured prior to the trial mixing and the batch weights for each mix were corrected for moisture contributed by the aggregates to the mix. The final SSD batch weights of concrete mixes with brick aggregates are given in Table 12.

Table 12 Mix proportions of concrete mixes with brick aggregates

| Mix Ref | w/c ratio | Cement (kg) | Coarse Aggregate (50%) (kg) | Sand (50%) (kg) | Water (kg) | Slump (mm) | Plastic Density (kg/m³) |
|---|---|---|---|---|---|---|---|
| T-07 | 0.93 | 250 | 855 | 856 | 232 | 70 | 2087 |
| T-08 | 0.65 | 350 | 790 | 791 | 227 | 90 | 2084 |
| T-09 | 0.52 | 450 | 748 | 749 | 180 | 100 | 2018 |
| T-10 | 0.47 | 500 | 708 | 709 | 236 | 80 | 2119 |
| T-11 | 0.45 | 550 | 667 | 668 | 248 | 95 | 2123 |

### *5.1.1 Use of water reducing admixture*

The water reducing chemical admixtures are quite widely used in larger infrastructure projects in Bangladesh and less predominant in rural projects. The major benefit of using these chemical admixtures will help in improving the workability and homogeneity of concrete mix, however it needs stringent quality control practices at sites. The increased workability of the mix will also help in better compaction of concrete at site. It is envisaged that for the next ten years in Bangladesh there will be high amount of construction activity and it is more likely that chemical admixture will be predominantly used in concrete.

In this part of the study, high range water reducing admixture was used in four different concrete mixes containing stone aggregates. Similar to the methodology adopted in T01 to T05 mixes, the W/C ratio of the mixes was determined such that the concrete mix attains a target slump of 75-100mm. The final SSD batch weights of the concrete mixes are given in Table 13.

**Table 13 Mix proportions of concrete mixes with stone aggregates and superplasticiser**

| Mix Ref | w/c ratio | Cement (kg) | Coarse Aggregate (60%) (kg) | | Sand (40%) (kg) | Sikaplast 2002NS (1%) | Water (kg) | Slump (mm) | Plastic Density (kg/m³) |
|---|---|---|---|---|---|---|---|---|---|
| | | | 20 mm (50% of CA) | 10 mm (50% of CA) | | | | | |
| T-15 | 0.74 | 250 | 616.65 | 616.65 | 822.21 | 2.825 | 185 | 70 | 2339 |
| T-16 | 0.49 | 350 | 570.55 | 570.55 | 760.74 | 3.955 | 173 | 90 | 2365 |
| T-17 | 0.38 | 450 | 540.67 | 540.67 | 720.9 | 5.085 | 171 | 90 | 2433 |
| T-18 | 0.42 | 400 | 569.81 | 569.81 | 759.74 | 4.52 | 169 | 90 | 2407 |

The relationship between W/C ratio and cement content was determined for the three-different type of concrete mixes viz., stone aggregates, brick aggregates and stone aggregates with superplasticiser (SP) as shown in Figure 1.

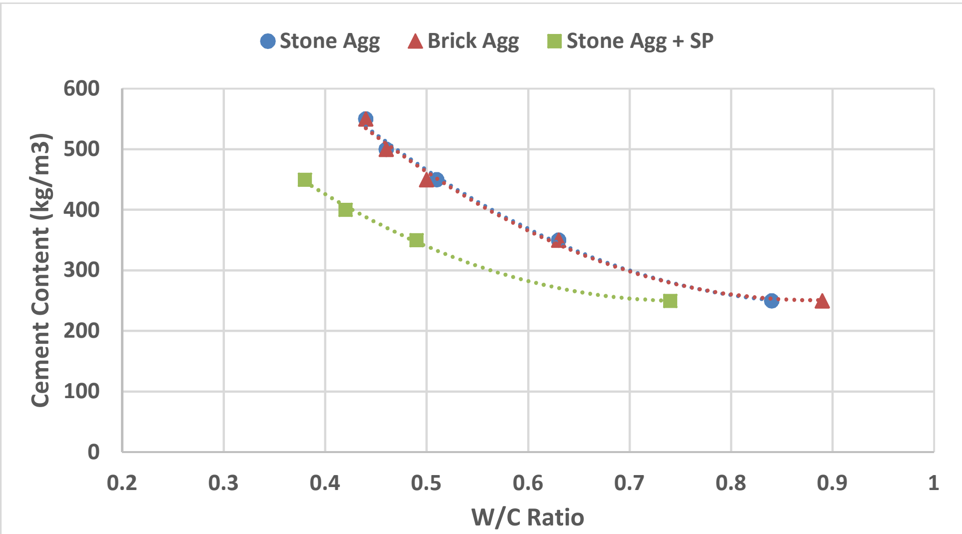


**Figure 1 The relationship between W/C ratio and cement content of concrete**

It can be observed from Figure 1 that the free W/C ratio required by brick aggregate concrete to produce constant slump concrete was higher than the stone aggregate concrete at 250 kg/m3 cement content, however the relationship curve between free W/C ratio and cement content of the concrete mix almost overlapped.  On the other hand the concrete mixes with stone aggregate and superplasticiser required less cement in the mix to produce similar workability. The relationship presented in Figure 1 helps to identify the required cement content for a given free W/C ratio and can therefore be used in mix design of concrete for phase II laboratory testing.

Table 14 Compressive strength results of concrete mixes with stone and brick aggregates

| Mix Ref | Free W/C ratio | Cement (kg) | Variable | Compressive Strength (MPa) | |
|---|---|---|---|---|---|
| | | | | 7 days | 28 days |
| T-01 | 0.84 | 250 | Stone Aggregate | 17.49 | Awaiting |
| T-02 | 0.63 | 350 | Stone Aggregate | 26.69 | Awaiting |
| T-03 | 0.51 | 450 | Stone Aggregate | 38.13 | Awaiting |
| T-04 | 0.46 | 500 | Stone Aggregate | 39.95 | Awaiting |
| T-05 | 0.44 | 550 | Stone Aggregate | 42.28 | Awaiting |
| T-07 | 0.93 | 250 | Brick Aggregates | 12.343 | 17.24 |
| T-08 | 0.65 | 350 | Brick Aggregates | 20.813 | 26.78 |
| T-09 | 0.52 | 450 | Brick Aggregates | 28.387 | 37.46 |
| T-10 | 0.47 | 500 | Brick Aggregates | 30.057 | 37.82 |
| T-11 | 0.45 | 550 | Brick Aggregates | 34.66 | 39.97 |
| T-15 | 0.74 | 250 | Stone Agg + SP | 18.5 | 22.76 |
| T-16 | 0.49 | 350 | Stone Agg + SP | 36.48 | 43.79 |
| T-17 | 0.38 | 450 | Stone Agg + SP | 46.4 | 53.67 |
| T-18 | 0.42 | 400 | Stone Agg + SP | 42.44 | 46.01 |

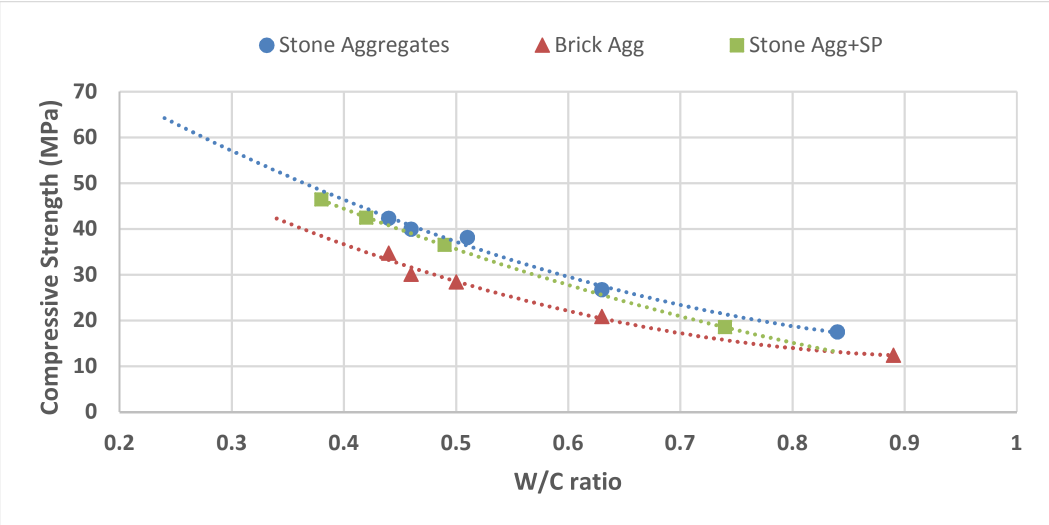


Figure 2 Relationship between W/C ratio and 7 days compressive strength of concrete

The 7-day and 28-day compressive strength results of the concrete mixes with stone and brick aggregates are presented in Table 14. Although 28-day strength results for stone aggregate concrete mixes are still awaited, a general trend in variation of strength of concrete at different W/C ratio can be observed from the 7-day strength results as plotted in Figure 2 and presented in Figure 3. The curve showing the relationship between W/C ratio and 7-day compressive strength of concrete for stone and brick aggregate concrete suggest that at similar cement content and workability, the 7-day strength of brick aggregate concrete mixes are around 20% less than the stone aggregate concrete mixes. The 28-day compressive strength results are presented in Figure 4, which suggests that the rate of strength gain with increase in cement content is low in the case of brick aggregate concrete as compared with stone Agg + SP concrete mixes. This suggests that the concrete with brick aggregates is reaching its strength limit due to the use of low strength brick aggregates. It can also be observed from Figure 2 that the concrete mixes with stone aggregates and stone aggregates+SP show a similar W/C ratio and strength relationship.

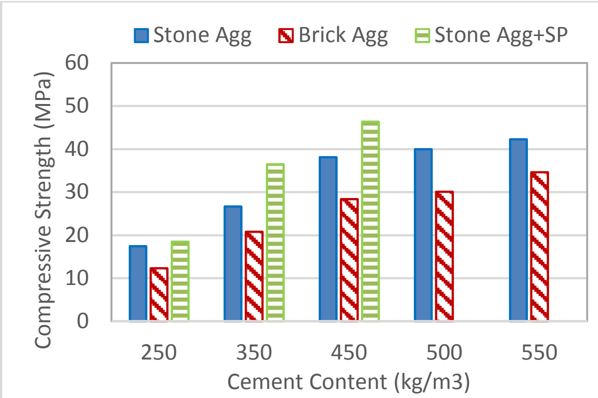


**Figure 3 Comparison of 7 day compressive strength between brick and stone aggregate concrete**

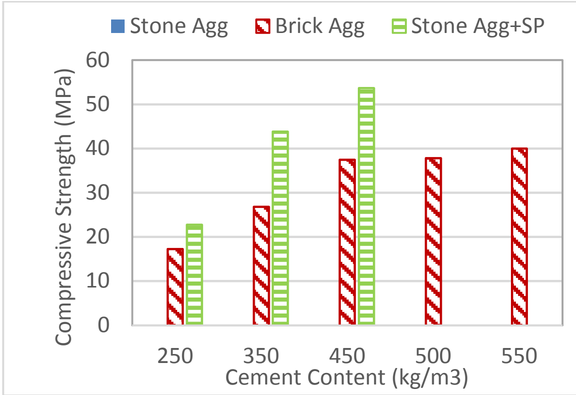


**Figure 4 Comparison of 28 day compressive strength between brick and stone aggregate concrete**

### 5.2 To increase the proportion of SCMs in concrete

The focus of this study is to increase the current levels of cement replacement in Portland Composite Cement (21-30%) to ≥ 30% replacement by fly ash or slag. Based on the literature review at the inception stage and discussions with local cement manufacturers, it is understood that the quality of flyash and slag available in Bangladesh are lower than those available in Europe and therefore optimum replacement levels are expected to be lower.

In this study three flyash replacement levels viz., 20%, 25% and 30% and four slag replacement levels viz., 20%, 30%, 40% and 50% were investigated. The influence of flyash/slag on the strength development of concrete are studied at target slump of 75-100mm, 0.5 W/C ratio and 450 kg/m$^3$ cementitious content. The mix details of concrete trial mixes with different replacement levels of flyash and slag is given in Table 15 and Table 16 respectively.

**Table 15 Mix details of concrete with different proportions of flyash**

| Mix Ref | w/c ratio | Cem I (kg) | Flyash (kg) | Coarse Aggregate (60%) (kg) | | Sand (40%) (kg) | Water (kg) | Slump (mm) | Plastic Density (kg/m³) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 20 mm | 10 mm | | | | |
| T-12 (70% Cem I + 30% Flyash) | 0.50 | 315 | 135 | 489 | 489 | 652.37 | 225 | 100 | 2328 |
| T-13 (75% Cem I & 25% Flyash) | 0.47 | 337.5 | 112.5 | 492 | 492 | 655.68 | 225 | 100 | 2341 |

| Mix Ref | w/c ratio | Cem I (kg) | Flyash (kg) | Coarse Aggregate (60%) (kg) | | Sand (40%) (kg) | Water (kg) | Slump (mm) | Plastic Density (kg/m³) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 20 mm | 10 mm | | | | |
| T-14 (80% Cem I & 20% Flyash) | 0.47 | 360 | 90 | 494 | 494 | 659 | 225 | 70 | 2332 |

Table 16 Mix details of concrete with different proportions of slag

| Mix Ref | w/c ratio | Cem I (kg) | Slag (kg) | Coarse Aggregate (60%) (kg) | | Sand (40%) (kg) | Water (kg) | Slump (mm) | Plastic Density (kg/m³) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 20 mm | 10 mm | | | | |
| T-19 (80% Cem I & 20% Slag) | 0.50 | 360 | 90 | 501 | 501 | 668 | 223 | 90 | 2389 |
| T-20 (70% Cem I & 30% Slag) | 0.50 | 315 | 135 | 500 | 500 | 667 | 223 | 80 | 2356 |
| T-21 (60% Cem I & 40% Slag) | 0.49 | 270 | 180 | 499 | 499 | 665 | 220 | 85 | 2350 |
| T-22 (50% Cem I & 50% Slag) | 0.50 | 225 | 225 | 497 | 497 | 663 | 226 | 85 | 2325 |

The results of compressive strength tests of concrete with different replacement levels of flyash and slag are presented in Table 17 and shown in Figure 5. As for most of the concrete mixes the 28-day and 56-day strength results are still awaiting and therefore the optimum replacement levels cannot be concluded at this stage.

Table 17 Compressive strength results of concrete mixes with different proportions of flyash and slag replacements

| Mix Ref | w/c ratio | Cement (kg) | Cement composition | Compressive Strength (MPa) | |
|---|---|---|---|---|---|
| | | | | 7 days | 28 days |
| T-12 | 0.50 | 450 | 70% Cem I + 30% Flyash | 17.97 | 25.28 |
| T-13 | 0.47 | 450 | 75% Cem I & 25% Flyash | 20.54 | 24.82 |
| T-14 | 0.47 | 450 | 80% Cem I & 20% Flyash | 22.91 | 27.90 |
| T-19 | 0.50 | 450 | 80% Cem I & 20% Slag | 27.15 | awaiting |
| T-20 | 0.50 | 450 | 70% Cem I & 30% Slag | 32.09 | awaiting |
| T-21 | 0.49 | 450 | 60% Cem I & 40% Slag | 26.44 | awaiting |

| Mix Ref | w/c ratio | Cement (kg) | Cement composition | Compressive Strength (MPa) | |
|---|---|---|---|---|---|
| | | | | 7 days | 28 days |
| T-22 | 0.50 | 450 | 50% Cem I & 50% Slag | 24.40 | awaiting |

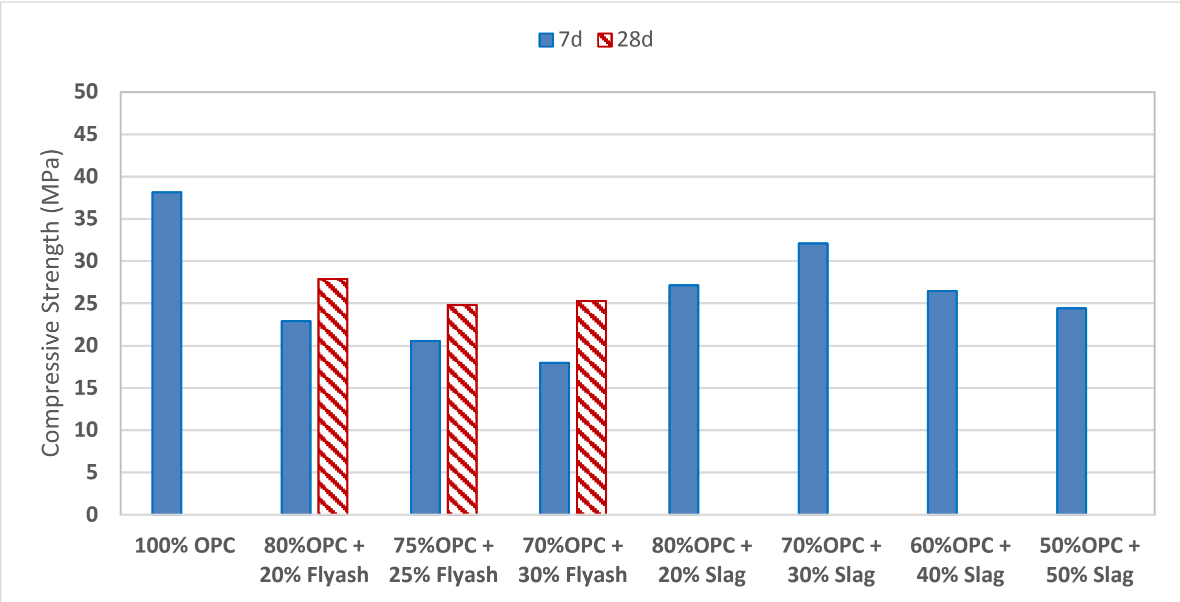


Figure 5 Comparison of strength development in concrete with different replacement levels of flyash and slag

### 5.3 Feasibility study on improving the properties of brick aggregates

This feasibility study deals with improving the properties of brick aggregates by cement coating. The preliminary testing involved coating of brick aggregates with cement paste containing 4%, 6% and 8% cement (by weight of aggregate) at 0.50 and 0.40 W/C ratio. The cement used for coating the brick aggregates was varied with two different proportions of flyash replacements. For each mix, the brick aggregates were initially conditioned to saturated surface dry and coated with cement paste in a laboratory concrete mixer for a period of 2-3 mins. The coated brick aggregates were cured for a period of 7-day and the aggregates were tested for specific gravity and water absorption. The results of testing of brick aggregates with varied proportions of cement paste coating are presented in Table 18. The specific gravity and water absorption results presented in Table 18 suggests that the cement paste coating has increased the water absorption of brick aggregates. The specific gravity of coated brick aggregates did not change much in comparison to uncoated brick aggregates. Although no clear explanation on the increase of water absorption of coated brick aggregates could be made due to the limited testing data, it can be assumed that one possible reason for this increased water absorption would be caused due to un-hydrated cement particles on the surface of brick aggregates. Among the varied proportions of cement coating tests, the 8 % cement coating mix at 0.4 W/C ratio was observed to have the lowest water absorption value.

Table 18 Physical properties of brick aggregates with varied coating proportions

| Coating proportions | | | Specific gravity | Water absorption (%) |
|---|---|---|---|---|
| **Cement content (% by weight of aggregates)** | **Cement** | **W/C ratio** | | |
| Uncoated | - | - | 2.06 | 15.0 |
| 4% | 100% OPC | 0.5 | 2.05 | 17.3 |
| 6% | 100% OPC | 0.5 | 2.04 | 17.0 |
| 6% | 100% OPC | 0.4 | 2.04 | 17.2 |
| 8% | 100% OPC | 0.4 | 2.02 | 15.8 |
| 6% | 60% OPC + 40% Flyash | 0.5 | 2.01 | 16.3 |
| 6% | 80% OPC+20% Flyash | 0.5 | 2.00 | 16.6 |
| 8% | 100% OPC | 0.5 | 2.01 | 17.3 |

Although a clear improvement in brick aggregate properties has not been observed with coated bricks, however the 100% OPC mixed coated bricks were further tested in a concrete mix at two different cement content and W/C ratios. The mix proportions of concrete mix with three different coated brick aggregates are presented in Table 19.

Table 19 Mix proportion of concrete with different types of cement coated brick aggregates

| Coating Type | Trial No. | w/c ratio | Cement (kg) | Coated Brick Aggregate (50%) (kg) | Sand (50%) (kg) | Water (kg) | Slump (mm) | Plastic Density (kg/m³) |
|---|---|---|---|---|---|---|---|---|
| 4% CC (100%-OPC), w/c-0.5 | T-23 | 0.6 | 350 | 766.29 | 766.29 | 211 | 65 | 2097 |
| | T-24 | 0.44 | 450 | 712.6 | 712.6 | 199 | 70 | 2117 |
| 6% CC (100%-OPC), w/c-0.4 | T-25 | 0.55 | 350 | 764.2 | 764.2 | 192 | 85 | 2110 |
| | T-26 | 0.43 | 450 | 710.65 | 710.65 | 192 | 80 | 2131 |
| 8% CC (100%-OPC), w/c-0.4 | T-27 | 0.59 | 350 | 759.98 | 759.98 | 205 | 70 | 2095 |
| | T-28 | 0.47 | 450 | 706.73 | 706.73 | 211 | 90 | 2134 |

The 7-day strength results of concrete mixes with three different types of coated brick aggregate are compared with uncoated brick aggregate and stone aggregate as shown in Figure 6.

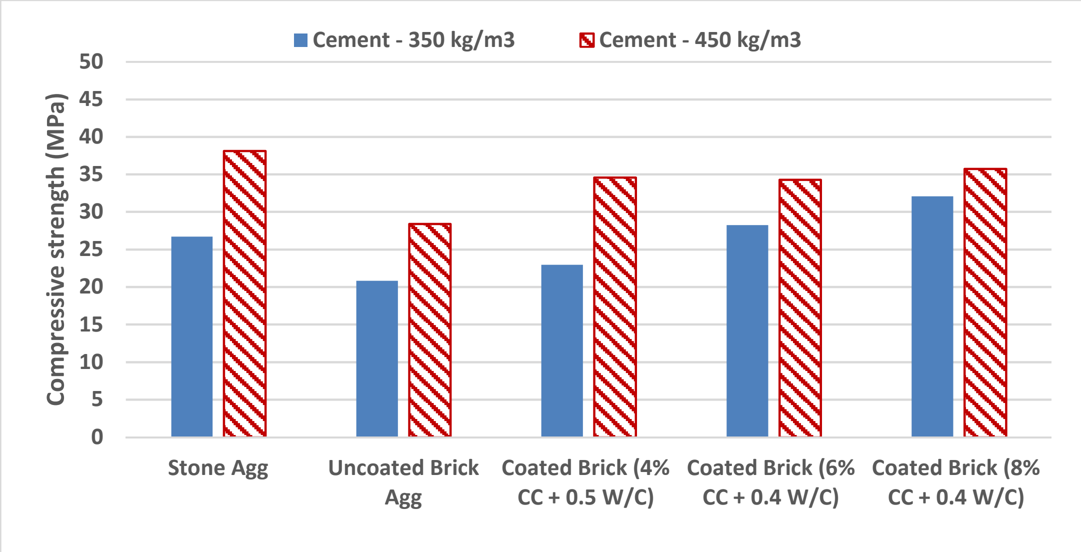


**Figure 6 Compressive strength (7-day) of stone aggregate vs uncoated brick aggregate vs coated brick aggregate**

The comparison of early strength results as shown in Figure 6 suggest that the concrete strength increased with increase in cement coating. The coated brick aggregates with 8% cement content and 0.4 W/C ratio produced concrete with compressive strength similar to stone aggregate concrete. This suggests that there is potential in improving the strength of concrete by use of coated brick aggregates. However, further testing is needed to get clear conclusions on the enhancement of strength properties of concrete with coated brick aggregates.

## 5.4 To study Influence of Calcium Nitrate Corrosion inhibitor on fresh and hardened properties of concrete

Previous studies on Calcium nitrate corrosion inhibitor suggests that it acts as a set accelerator at lower dosage (1-3%) and as corrosion inhibitor (CI) at higher dosage (3-4%). The accelerating effect of calcium nitrate CI affects the fresh concrete properties such as slump and setting time of concrete. Therefore in order to counter the set acceleration of calcium nitrate, additional set retarding admixture needs to be added to the concrete mix. The effect of calcium nitrate CI on setting properties are initially studied on cement paste by testing normal consistency, Initial setting time and final setting time of cement with varied proportions of CI. The optimum dosage of set retarding admixture to counter the set acceleration of CI is determined by testing the delay in setting time at different dosages of retarder. The results of testing of cement with different proportions of corrosion inhibitor and different dosages of retarder are presented in Table 20. It can be observed from the results shown in Table 20 that the incorporation of CI at 3-4% (by weight of cement) considerably reduces the setting time of the cement. The cement testing results with CI and various dosages of retarder suggests that the optimum combination of 3.5% CI and 1.8% retarder extends the setting time of cement to acceptable limits. Trial concrete mixes with this optimum combination of CI and retarder is currently being tested and this report will be updated as and when the results of the concrete testing are available.

**Table 20 Comparision of setting time of cement with different proportions of CI and retarder dosages**

| Cement composition | Normal consistency | Setting time | |
|---|---|---|---|
| | | Initial Setting Time (mins) | Final Setting Time (mins) |
| 100% OPC | 0.27 | 102 | 250 |

| Cement composition | Normal consistency | Setting time | |
|---|---|---|---|
| | | Initial Setting Time (mins) | Final Setting Time (mins) |
| 97% OPC + 3% CI | 0.26 | 33 | 60 |
| 96.5% OPC + 3.5% CI | 0.26 | 32 | 60 |
| 96% OPC + 4% CI | 0.26 | 34 | 60 |
| 97% OPC + 3% CI + 1.2% Retarder | 0.23 | 39 | 75 |
| 97% OPC + 3% CI + 1.5% Retarder | 0.23 | 58 | 120 |
| 97% OPC + 3% CI + 1.8% Retarder* | 0.22 * | 126* | 225* |
| 96.5% OPC + 3.5% CI + 1.8% Retarder | 0.215 | 78 | 180 |
| 96% OPC + 4% CI + 1.8% Retarder | 0.21 | 37.5 | 105 |

* High Air voids observed in the cement paste

# 6 Conclusions

This report describes the experimental work and outcome of the phase-I mix design and laboratory testing. As described in the previous sections, most of the work planned for phase-I testing has been successfully completed. The outcome of the various experimental studies pursued in phase-I testing gives the following conclusions:

- The relationship between W/C ratio, cement content and strength of concrete containing three different variables viz., stone aggregates, brick aggregate and stone aggregate + superplasticiser has been established. This relationship helps in identifying appropriate cement content for a given W/C ratio and target slump, which is needed for the mix design of concrete mixes planned for phase II.
- The study to increase the proportion of flyash and slag used in composite cements suggests that the concrete mixes produced with varied proportions of flyash and slag produced homogenous and cohesive concrete. The comparison of 100% OPC concrete mix with flyash and slag mixes suggest that at a given cementitious content and target slump of 75-100mm, the required W/C ratio was almost similar between the mixes. The 7-day strength of different concrete tested in this study suggests that the strength drops with increase in flyash/slag levels in concrete. However, it is a well-established fact that due to slower pozzalanic and hydration reactions in flyash/slag based concretes, strength development more than 100% OPC mix will be observed in later age (>56 days).
- The feasibility study on improving the brick aggregate properties by coating them with cement paste suggest that the specific gravity of aggregate has not changed much and the water absorption of coated brick aggregates has slightly increased as compared with uncoated aggregates. However, the early age strength results of concrete containing coated brick aggregates has showed increase in strength with increase in coating proportions. The 7-day strength of 8% cement coated brick aggregate with 350 kg/m3 cement content was higher than equivalent stone aggregate concrete. Therefore, the initial results suggest that there is a potential for improving the strength of brick aggregate concrete by using pre-coated brick aggregates. However more testing is needed to get a better evidence on the improvement of strength properties of concrete with coated brick aggregates.
- The study on use of calcium nitrate corrosion inhibitor suggests that at recommended 3-4% dosage of corrosion inhibitor has accelerated the setting time of cement drastically. However, with the use of set retarders, the accelerating effect of calcium nitrate corrosion

inhibiter can be counter acted. The experimental trials at different dosages of corrosion inhibitor and set retarder suggested optimum combination at 3.5% corrosion inhibitor and 1.8% set retarder resulted in acceptable setting time results in cement samples.

Based on the outcome of the phase-I testing, the following changes in phase-II testing has been suggested:

- The use of manual broken brick aggregates was initially proposed as a variable to be tested in the research matrix for phase-II laboratory testing. However, after finding positive results with the use of coated brick aggregates, the research matrix is modified by replacing manual brick aggregate with coated brick aggregate as a variable to be tested.

# 7 Phase-II Laboratory testing

This section provides an update on planning and arrangements for phase-II testing

- The new laboratory concrete mixer has been delivered to LGED laboratory and ready to be used for phase-II testing
- All the materials viz., cement, flyash, slag, stone aggregate, brick aggregate, superplasticiser and corrosion inhibitor are sufficiently stocked enough for phase-II experiments
- The slab moulds required for salt ponding tests to study corrosion of reinforcement have been ordered in January 2017, but due to delay in manufacturing the slab moulds will be delivered in end of March 2017.
- The durability instrument – NT Build 492 is available in stock in China and ready to be ordered, but due to issues in dealing with Bangladesh customs, delays are being experienced in ordering and delivering this instrument. Based on the initial enquiries, it needs importer licence to be able to import equipment from outside the country. As Mott MacDonald do not have this licence we have been negotiating with local dealers to import the durability instrument from China. Although we got few quotations from import and customs handling dealers, some of the quotations have quoted twice the cost of the instrument. We have recently identified a dealer who has quoted a reasonable price and we are negotiating with this dealer to order the instrument as soon as possible. As this instrument is crucial for the phase II laboratory testing, we are unable to start the work before the delivery of NT Build 492.
    - Based on the negotiations with the import dealer, it is expected that the durability instrument will be delivered around mid of April 2017.
    - Due to delay in start of phase II testing, the timetable of work for the remaining milestone reports is modified as shown in Table 21

**Table 21 Revised Time table of work for remaining activities of the Project**

| Milestone | Task | Revised Deadlines |
|---|---|---|
| Milestone 5 | Hold workshop<br><br>Issue Stakeholder workshop report | 30th June 2017<br><br>15th July 2017 |
| Milestone 6 | Final Field and Laboratory Testing Report | 11th August 2017 |
| Milestone 7 | Final Report | 15th September 2017 |