Semi-Annual Progress Report

Project Number and Title: C7.2018: Alternative Cementitious Materials (ACMs) For Durable and Sustainable Transportation Infrastructures
Research Area: New Materials for Longevity and Constructability
PI: *Warda Ashraf, Ph.D., University of Maine.*
Graduate Student: *Rakibul I. Khan, University of Maine.*
Reporting Period: *06/01/2019 – 09/30/2019*
Date: *09/30/19*

Overview:

Alternative cementitious systems (ACM), specifically, carbonation activated binders provide the opportunity to sequester CO_2 and to use higher volume of industrial by-products in concrete. The overall carbon footprint of carbonation activated concrete can be up to 50% lower compared to the traditional concrete depending on the mix design and curing condition. The goal of this project is to evaluate the performance of carbonation activated binder for transportation infrastructure applications.

The project began on June 1, 2019. The first phase of this project was to recruit a graduate student (Rakibul I Khan), to give him some basic training, to procure raw materials and to collect information from MaineDOT on common practices and current challenges of concrete infrastructure in the state of Maine. Based on MaineDOT information and comprehensive literature reviews, 120 grade Ground Granulated Blast Furnace ladle slag (GGBFS) was selected for the initial phase of the project to be used as a partial replacement of Ordinary Portland Cement (OPC).

The initial challenges of this phase were selecting the percentage of Fine aggregate content and coarse aggregate content in the mix design, selecting the best combination of OPC replacement by slag (GGBFS) and setting the carbonation setup.

To determine the best ratio of fine aggregate and coarse aggregate content in the mix design, different batches of concrete cylinders (100 mm by 200 mm) were cast with varying proportions of coarse aggregate and fine aggregate content. Based on the results of compressive strength after 7 days of hydration, 38% fine aggregate content and 62% coarse aggregate content in the mix design provided the highest compressive strength compared to the other combinations. In this study, river sand was used as fine aggregate and gravel was used as a coarse aggregate.

Using the selected the fine aggregate and coarse aggregate content, six concrete batches were prepared containing GGBFS based on different weight percent of OPC replacement. 0%, 20%, 45%, 65%, 80% and 100% (by weight) of OPC were replaced by GGBFS in the concrete batches. For each batch, concrete cylinders (100 mm by 200 mm) were cast for three different curing conditions. These curing conditions were pure hydration, carbonation followed by hydration and hydration followed by carbonation. Concrete cylinders were kept in sealed condition for pure hydration curing in a moisture-controlled room. For carbonation followed by hydration curing, concrete cylinders were stored in a humidity-controlled room for 3 days (72 hours) and then kept for 4 days in a carbonation chamber (99.9% CO_2 purged at room temperature in atmospheric pressure). The cylinders were preserved in a moisture-controlled room after 4 days of carbonation. In the case of hydration followed by carbonation curing, the concrete cylinders were kept in the carbonation chamber for 7 days for carbonation and then kept in a humidity-controlled room. Compressive strengths of the cylinders were tested for all three curing conditions after 3, 7 and 28 days of curing. In addition to compressive strengths, moisture contents of the concrete cylinders and CO_2 stored were also monitored.

Compressive strength test results of all curing conditions are shown in Figure *1*. In the case of pure hydration (Figure *1* (a)), a decrease in strength was observed after 45% (by weight) of OPC replacement by slag. Whereas in the case of carbonation (Figure *1* (b), (c)) an increase of strength was noted until 65% (by weight) OPC replacement by slag. It has also been noticed that the compressive strength of hydration curing for 28 days can be accomplished by carbonation curing within 7 days.

Figure *1* (d) to Figure *1* (f) illustrate the variability of the cylinder's compressive strength of the different curing conditions with respect to pure hydration of 0% OPC (by wt.) replacement by slag. Figure *1* (d) showed up to 20% OPC substitution by slag within 3 days, providing 5% more strength than the control batch (0% OPC substitution) in carbonation curing condition. As slag is slow reactive, it remained inert initially. Figure *1* (e) postulates that 65% OPC replacement by slag in carbonation curing provides 13% higher compressive strength than the control batch within 7 days. Figure *1* (f) showed that 65% OPC replacement gave 30% more compressive strength than the control batch within 28 days.

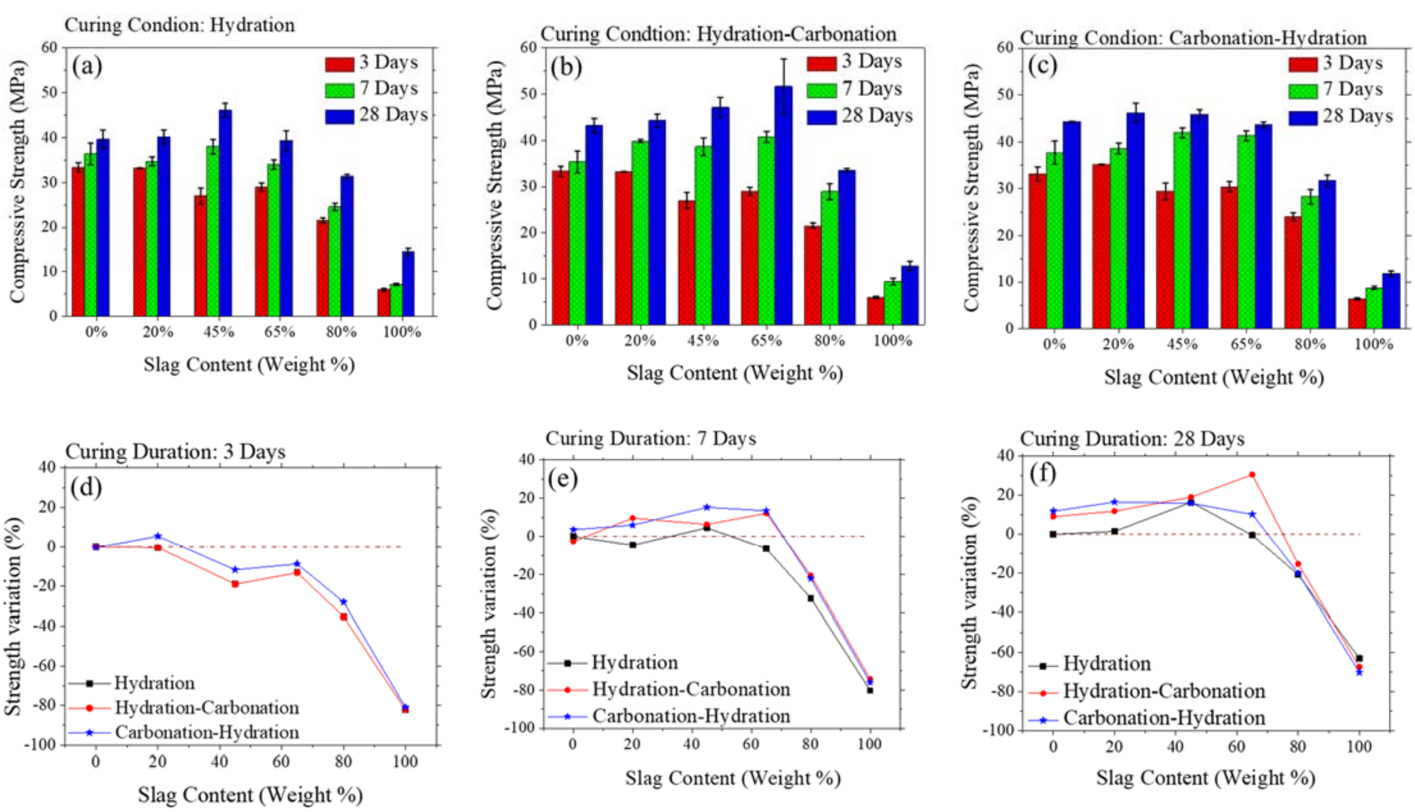

Figure 1: Cylinder Compressive strength (MPA) test result. (a) Hydration, (b) Carbonation followed by hydration, (c) Hydration followed by carbonation, Strength variation with hydrated batch (d) 3 days, (e) 7 days, (f) 28 days

Provide context as to how these activities are helping achieve the overarching goal of the project…

The overall goal of this project is to develop an alternative cementitious system which is more sustainable, and durable compared to the traditional Portland cement-based concrete. The high carbon footprint of traditional concrete is due to energy intensive manufacturing process of OPC. The results obtained from this project, to date, showed that up to 65% by weight of OPC can be replaced with GGBFS (an industrial by-product) when carbonation curing is incorporated. Such approach of reducing OPC usages provides a significant reduction of the overall carbon footprint of the concrete mixes. Furthermore, carbonation cured concrete batch with 65% GGBFS provided nearly 20 to 30% higher strength compared traditionally cured 100% OPC containing batch after 28days curing. Thus, these results demonstrated that it is possible to prepare sustainable concrete batches with lower carbon footprint and higher strength by combining the use of GGBFS and carbonation curing. The next stage of this research will investigate the durability performances of the concrete mixes formulated with GGBFS and carbonation curing.

Training

Graduate student got trained in different instruments and setup of carbonation chamber. Weekly research meeting helps in exchanging information, results and overcoming experimental difficulties.

Dissemination of research results

An abstract based on the findings of this project has been accepted in ACI Fall 2019 convention to be held in Cincinnati on October 2019.

Participants and Collaborators:

List all individuals who have worked on the project.

PI: *Warda Ashraf, Ph.D., University of Maine.*
Graduate Student: *Rakibul I. Khan, University of Maine.*

List all students who have participated in the project. (Include name, email address, class standing, major, and role in the research)

Student Name: Rakibul I Khan
E-mail: mohammad.r.khan@maine.edu
Major: Civil and Environmental Engineering
Role: Continuously doing literature reviews, conducting experiments and analysis based on project goal and literature with the help of PI.

What organizations have been involved as partners on this project? What was their role?
N/A
Have other collaborators or contacts been involved? If so, who and how?
N/A

Changes:

Discuss any actual or anticipated problems or delays and actions or plans to resolve them…
N/A

Planned Activities:

Next stage of this project will include the strength determination of paste samples containing GBBFS under carbonation curing. For understanding the reaction kinetics of slag batch thermogravimetric Analysis (TGA), and X-ray Diffraction (XRD) will be performed. To examine the rate of chloride penetration, RCPT will be performed.