Quarterly Progress Report:
Project Number and Title: 2.9: Carbonating Subgrade Materials for In-Situ Soil Stabilization
Research Area: New Materials for Longevity and constructability
PI: Aaron Gallant, Ph.D., P.E., University of Maine
Co-PI(s): Warda Ashraf, Ph.D., University of Texas at Arlington
Reporting Period: 01/01/2021-03/31/2021
Submission Date: 03/31/2021

Overview:

The effects of initial soil state parameters (i.e. initial water content and void ratio/density) on calcium carbonate binder formation in lime-mixed soil specimen and associated strength improvement were studied extensively studied for a wide range of soils. Previously we have reported the binder formations in coarse (i.e. sand) and fine (i.e. non-plastic silt) grained soils based on thermogravimetric analyses (TGA) carbonated between 3 and 24 hours and their unconfined compressive strengths (UCS). It was found that the soil specimens with 20% and 50% fine contents can achieve UCS of 3-3.5 MPa, similar to that of of lime-mixed sand or silt. These soil specimens were carbonated in the gaseous phase (i.e. diffusion-based carbonation). We have since investigated a new methodology to introduce CO_2 gas by delivering the gas is dissolved form, which refer to as "aqueous-phase" carbonation. The test setup is shown in Figure 1, where the carbon dioxide was dissolved in de-aired water under pressure and subsequently passed through the soil specimen under pressure. Preliminary results (Figure 2) demonstrate indicate that the chemical reaction is "instantaneous" and the CO_2 (dissolved in water) consumed was 90% of that introduced. However, the pore volumes of carbonated water required to generate the same degree of carbonation (calcium carbonate binder formation) will require a significant number of pore volumes of fluid to be introduced. Thus, the efficiency associated with this method of carbonation is governed by the concentration of CO_2 dissolved in water (function of pressure) and rate of seepage through the sediment.

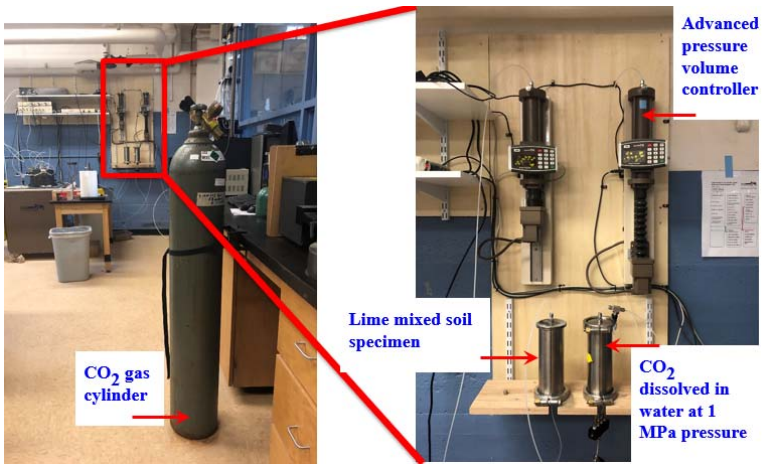

Figure 1. Laboratory test setup for aqueous based soil carbonation

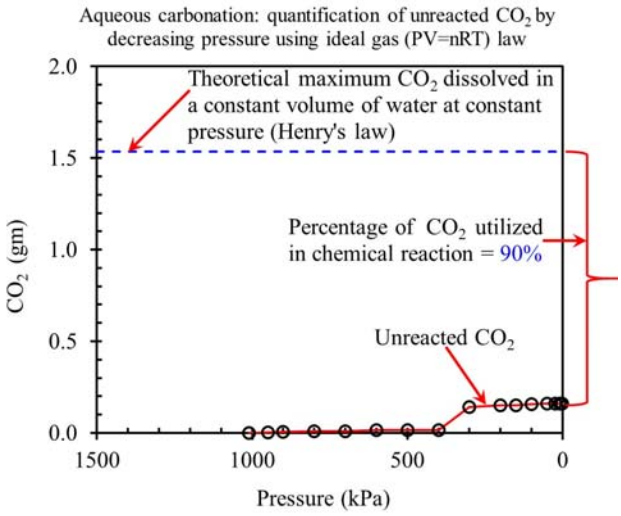

Figure 2. Carbon dioxide (CO_2) gas utilization when 100 cm^3 of carbonated water passed through the specimen under 1 MPa pressure

Elemental testing of Phase I of the project is being performed to characterize the factors contributing to soil carbonation and its application on different soil types for rapid improvement of the soil's mechanical properties (i.e. strength and stiffness). The elemental testing phase has provided a framework to consider the optimal conditions to stabilize soils via carbonation in shallow and deep deposits. This is now being carried over to execute bench- and "field-scale" trials.

One peer-reviewed conference paper has been published in Geo-Congress 2020: Foundations, Soil Improvement, and Erosion under Geotechnical Special Publication No. 315, Geo-Institute (G-I) of the American Society of Civil Engineers

(ASCE). Additionally, a total of three poster presentations have been made to date in various platforms including 2019 UMaine Student Symposium, Geo-Congress 2020 (held in Minneapolis, MN), and the 2020 TIDC Student Poster Competition (October 2020).

Table 1: Task Progress

Task Number	Start Date	End Date	% Complete
Task 1: Literature Review	September 2018	Ongoing	100% to date
Task 2: Elemental testing	December 2018	December 2020	100%
Task 3: Elemental trial of aqueous-phase carbonation.	February 2021	April 2021	75%
Task 3: Bench scale trial (gaseous carbonation at elevated pressure)	April 2021	May 2021	10%
Task 5: Pseudo Field-Scale Trial (Large scale soil box)	May 2021	August 2021	0
Overall Project:	September 2018	August 2021	65%

Table 2: Budget Progress

Project Budget	Spend – Project to Date	% Project to Date*

Table 3: Presentations at Conferences, Workshops, Seminars, and Other Events

Title	Event	Type	Location	Date(s)
Soil State Dependency of Carbonation for Rapid Strength Improvement	2020 TIDC Student Poster Contest	Student poster competition	Virtual	10/21/2020

Table 4: Publications and Submitted Papers and Reports

Type	Title	Citation	Date	Status
Peer-reviewed conference paper	Elemental testing of carbonated silty sand treated with lime	Hossen, S. B., Gallant, A. P., & Ashraf, W. (2020). Elemental Testing of Carbonated Silty Sand Treated with Lime. *Geo-Congress 2020*, ASCE GSP 315, Minneapolis MN, pp. 562-571.	February 21, 2020	Published
Peer-review Journal	Influence of initial soil state parameters on rapid strength gain of granular soils under low CO_2 pressure conditions	Hossen, S. B., Gallant, A. P., & Ashraf, W. (2021). Influence of initial soil state parameters on rapid strength gain of granular soils under low CO_2 pressure conditions. *J. Geotech. Geoenviron. Eng.*, ASCE (In preparation).	-	Under in-house review for final submission

Participants and Collaborators:

Table 5: Active Principal Investigators, faculty, administrators, and Management Team Members

Individual Name	Email Address	Department	Role in Research
Aaron Gallant, PhD, PE	aaron.gallant@maine.edu	Civil Engineering, University of Maine	PI
Warda Ashraf, PhD	warda.ashraf@uta.edu	Civil Engineering, UT Arlington	Co-PI

Table 6: Student Participants during the reporting period				
Student Name	**Email Address**	**Class**	**Major**	**Role in research**
SK Belal Hossen, EI		PhD	Civil and geotechnical engineering	Graduate Research Assistant

Use the table below to list any students who worked on this project and graduated during this reporting period. **N/A**

Table 7: Student Graduates			
Student Name	**Role in Research**	**Degree**	**Graduation Date**

Use the table below to list organizations have been involved as partners on this project and their contribution to the project. **N/A**

Table 8: Research Project Collaborators during the reporting period						
Organization	**Location**	**Contribution to the Project**				
		Financial Support	**In-Kind Support**	**Facilities**	**Collaborative Research**	**Personnel Exchanges**

List all other outputs, outcomes, and impacts here (i.e. patent applications, technologies, techniques, licenses issued, and/or website addresses used to disseminate research findings). Please be sure to provide detailed information about each item as with the tables above. **N/A**

Have other collaborators or contacts been involved? If so, who and how? (This would include collaborations with others within the lead or partner universities; especially interdepartmental or interdisciplinary collaborations.) **N/A**

Table 9: Other Collaborators			
Collaborator Name and Title	**Contact Information**	**Organization and Department**	**Contribution to Research**
			(i.e. Technical Champion)

Who is the Technical Champion for this project?
Name: Dale Peabody
Title: Director of Transportation Research
Organization: Maine DOT
Location (City & State): Augusta, ME
Email Address: dale.peabody@maine.gov

Changes:

We have investigated the possibility of aqueous based carbonation for field implementation. However, the challenges (as mentioned above) we have been facing encouraged us to carry out our large-scale soil box/field trial testing through diffusion-based carbonation that we had conducted in our elemental testing phase.

Planned Activities:

We plan to explore the potential use of industry by-product *Ground Granulated Blast Furnace Slag (GGBFS)* as an alternative alkaline source (apart from lime) to make soil carbonation a more sustainable and cost-effective ground

improvement method. As such, we will perform an exclusive test series based on our knowledge and understanding from the elemental testing results performed last year. We will perform diffusion-based carbonation at elevated pressure (e.g. 100-400 kPa) to reduce the carbonation time and the effects of pressure on soil carbonation at shallow stabilization. In parallel, we will review the literature to design the soil carbonation box and get involved with external experts to build it in our composite center on campus to demonstrate large-scale implementation of soil carbonation technology.