

3-2015

Proof of Concept: Biocement for Road Repair

Jian Chu

Iowa State University, jchu@iastate.edu

Zhiyou Wen

Iowa State University, wenz@iastate.edu

Follow this and additional works at: http://lib.dr.iastate.edu/intrans_reports



Part of the [Civil Engineering Commons](#)

Recommended Citation

Chu, Jian and Wen, Zhiyou, "Proof of Concept: Biocement for Road Repair" (2015). *InTrans Project Reports*. 129.
http://lib.dr.iastate.edu/intrans_reports/129

This Report is brought to you for free and open access by the Institute for Transportation at Iowa State University Digital Repository. It has been accepted for inclusion in InTrans Project Reports by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.

Proof of Concept: Biocement for Road Repair

Abstract

Road repair is an expensive operation every year. This cost can be greatly reduced if waste materials from the mining and biofuel industries can be used to substitute conventional materials for road repair or construction. The objective of this project is to develop methods to produce a new construction material, biocement, using waste products and apply the new material for road repair and construction. Two types of waste were used in this study. One is limestone fines produced from a limestone mine in Iowa. Another is organic acids, a byproduct produced from a pyrolysis-based biofuel manufacturing process. The limestone fines and organic acids can be used to produce biocement under ambient temperature in an inexpensive way. The cost-effective biocement can be used as a substitute for expensive cement for road repairs and construction. Biocement grout, or biogrout, can be injected directly into cavities or cracks in pavement for road repair. As the viscosity of biogrout is low, biogrout can penetrate better into the road pavement than cement grout. Biocement-mixed aggregate can be used for road base or subbase construction. Biocement solutions can also be applied directly on shoulders as a stabilizer or on unpaved roads as a dust control agent. The focus of this project is on the development of cost-effective biocement products and their effectiveness for road repair. Once the methods for biocement production and applications are established in laboratory scale, field experiments can be carried out as a follow-up study.

Keywords

Cost effectiveness, Cracking, Dust control, Limestone, Pavement maintenance, Paving, Stabilizers, Unpaved roads, Wastes, biocement utilization, biogrout, highway infrastructure, pavement, road construction, road repair, shoulder stabilization, compressive strength, waste material

Disciplines

Civil Engineering

Proof of Concept: Biocement for Road Repair

Final Report
March 2015

Sponsored by
Midwest Transportation Center
U.S. Department of Transportation
Office of the Assistant Secretary for
Research and Technology



About MTC

The Midwest Transportation Center (MTC) is a regional University Transportation Center (UTC) sponsored by the U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology (USDOT/OST-R). The mission of the UTC program is to advance U.S. technology and expertise in the many disciplines comprising transportation through the mechanisms of education, research, and technology transfer at university-based centers of excellence. Iowa State University, through its Institute for Transportation (InTrans), is the MTC lead institution.

About InTrans

The mission of the Institute for Transportation (InTrans) at Iowa State University is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, reliability, and sustainability while improving the learning environment of students, faculty, and staff in transportation-related fields.

ISU Non-Discrimination Statement

Iowa State University does not discriminate on the basis of race, color, age, ethnicity, religion, national origin, pregnancy, sexual orientation, gender identity, genetic information, sex, marital status, disability, or status as a U.S. veteran. Inquiries regarding non-discrimination policies may be directed to Office of Equal Opportunity, Title IX/ADA Coordinator, and Affirmative Action Officer, 3350 Beardshear Hall, Ames, Iowa 50011, 515-294-7612, email eooffice@iastate.edu.

Notice

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the sponsors.

This document is disseminated under the sponsorship of the U.S. DOT UTC program in the interest of information exchange. The U.S. Government assumes no liability for the use of the information contained in this document. This report does not constitute a standard, specification, or regulation.

The U.S. Government does not endorse products or manufacturers. If trademarks or manufacturers' names appear in this report, it is only because they are considered essential to the objective of the document.

Quality Assurance Statement

The Federal Highway Administration (FHWA) provides high-quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. The FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Proof of Concept: Biocement for Road Repair		5. Report Date March 2015	
		6. Performing Organization Code	
7. Author(s) Jian Chu and Zhiyou Wen		8. Performing Organization Report No.	
9. Performing Organization Name and Address Institute for Transportation Iowa State University 2711 South Loop Drive, Suite 4700 Ames, IA 50010-8664		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. DTRT13-G-UTC37	
12. Sponsoring Organization Name and Address Midwest Transportation Center 2711 S. Loop Drive, Suite 4700 Ames, IA 50010-8664		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes Visit www.intrans.iastate.edu for color pdfs of this and other research reports.			
16. Abstract <p>Road repair is an expensive operation every year. This cost can be greatly reduced if waste materials from the mining and biofuel industries can be used to substitute conventional materials for road repair or construction. The objective of this project is to develop methods to produce a new construction material, biocement, using waste products and apply the new material for road repair and construction.</p> <p>Two types of waste were used in this study. One is limestone fines produced from a limestone mine in Iowa. Another is organic acids, a byproduct produced from a pyrolysis-based biofuel manufacturing process. The limestone fines and organic acids can be used to produce biocement under ambient temperature in an inexpensive way. The cost-effective biocement can be used as a substitute for expensive cement for road repairs and construction. Biocement grout, or biogrout, can be injected directly into cavities or cracks in pavement for road repair. As the viscosity of biogrout is low, biogrout can penetrate better into the road pavement than cement grout. Biocement-mixed aggregate can be used for road base or subbase construction. Biocement solutions can also be applied directly on shoulders as a stabilizer or on unpaved roads as a dust control agent.</p> <p>The focus of this project is on the development of cost-effective biocement products and their effectiveness for road repair. Once the methods for biocement production and applications are established in laboratory scale, field experiments can be carried out as a follow-up study.</p>			
17. Key Words biocement utilization—biogrout—highway infrastructure—pavement—road construction—road repair—shoulder stabilization—unconfined compressive strength—waste material		18. Distribution Statement No restrictions.	
19. Security Classification (of this report) Unclassified.	20. Security Classification (of this page) Unclassified.	21. No. of Pages 15	22. Price NA

PROOF OF CONCEPT: BIOCEMENT FOR ROAD REPAIR

**Final Report
March 2015**

Principal Investigator

Jian Chu
Professor, Civil, Construction, and Environmental Engineering
Iowa State University

Co-Principal Investigator

Zhiyou Wen
Associate Professor, Food Science and Human Nutrition
Affiliate, BioCentury Research Farm (BCRF)
Iowa State University

Authors

Jian Chu and Zhiyou Wen

Sponsored by
Midwest Transportation Center and
U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology

A report from
Institute for Transportation
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
www.intrans.iastate.edu

TABLE OF CONTENTS

ACKNOWLEDGMENTS	vii
PRODUCTION OF BIOCEMENT USING MINING RESIDUES (LIMESTONE FINES) AND BYPRODUCT FROM BIOFUEL PRODUCTION (ORGANIC ACIDS).....	1
ASSESSMENT OF PROPERTIES OF BIOCEMENT-TREATED SOILS AND AGGREGATES	3
PROJECT ACCOMPLISHMENTS AND NEXT STEPS	7

LIST OF FIGURES

Figure 1. Use of limestone fines and corn cobs as raw materials to make soluble calcium	1
Figure 2. A bioreactor to produce soluble calcium solutions from limestone powder through an acidogenic fermentation process using corn cobs	1
Figure 3. Soluble calcium production from egg shells	2
Figure 4. Use of the soluble calcium grout to produce soil columns to assess the increase in shear strength	3
Figure 5. Use of column tests to assess the properties of sand treated by biocement	3
Figure 6(a). Unconfined compression test results on samples dried after biocementation treatment	4
Figure 6(b). Unconfined compression test results on samples wet after biocementation treatment	4
Figure 7. Summary of two series of tests to assess the unconfined compressive strength of biocement-treated sand samples both wet and dry	5

ACKNOWLEDGMENTS

The authors would like to thank the Midwest Transportation Center and the U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology for sponsoring this research.

PRODUCTION OF BIOCEMENT USING MINING RESIDUES (LIMESTONE FINES) AND BYPRODUCT FROM BIOFUEL PRODUCTION (ORGANIC ACIDS)

At the moment, the byproduct from biofuel production has limited availability. We therefore have been looking into a process to produce soluble calcium using organic acids and agricultural byproducts, corn cobs (Figure 1).



Figure 1. Use of limestone fines and corn cobs as raw materials to make soluble calcium

A reactor has been set up as shown in Figure 2 to carry out acidogenic fermentation to produce soluble calcium grout.

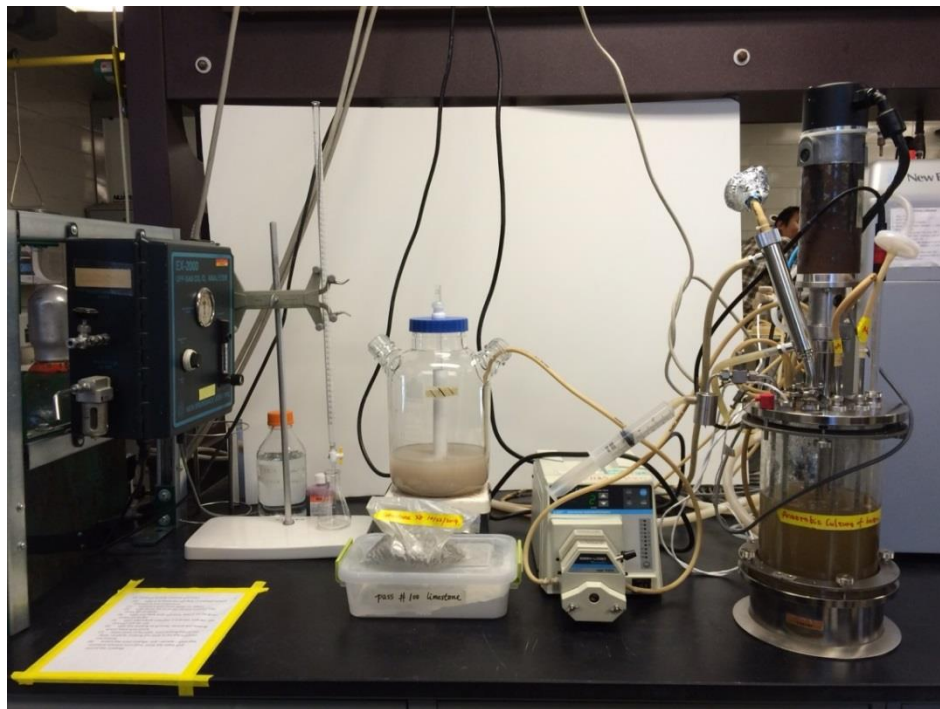
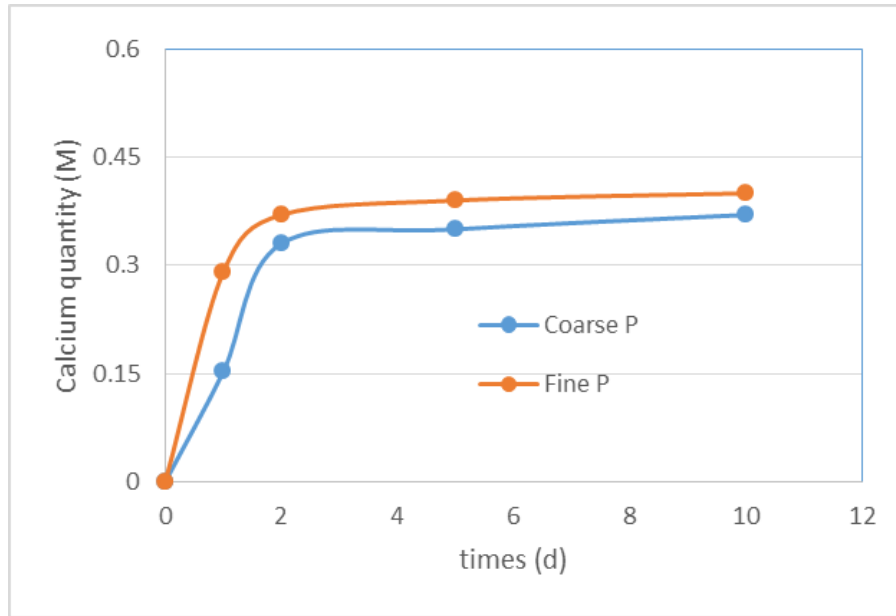


Figure 2. A bioreactor to produce soluble calcium solutions from limestone powder through an acidogenic fermentation process using corn cobs

We also investigated the possibility of using egg shells and organic acids to produce soluble calcium and have found this method feasible. Iowa is the top hen egg producer in the US. The 2014 production in Iowa was more than 58 million layers of the 303 million layers for the whole US. The egg shells are a good source of calcium. A study was carried out to use egg shells and organic acids to produce soluble calcium, which can be used to make biocement. The egg shells were crushed into powder to speed up the acceleration rate. Egg shells were crushed into two grain sizes: one coarse with particles less than 2 mm and the other fine with particles less than 0.25 mm. The results in Figure 3 indicate that the calcium product is not affected much by the grain size.



Coarse P: with eggs shell powder less than 2 mm
 Fine P: with egg shell powder less than 0.25 mm

Figure 3. Soluble calcium production from egg shells

Therefore, the production of soluble calcium using egg shells can be made simple. The egg shells only need to be crushed and then dissolve in organic acid, which is produced separately using agricultural waste and a setup as shown in Figure 2.

The second part of this research is to identify high-calcium-salt-tolerant strains to perform acidogenic fermentation to improve the efficiency of biocement production. We have obtained some soil samples from salt lakes around the US through Texas A&M University. By trial and error, we have selected some bacteria from the soil sample that can still have activities at a calcium-salt content exceeding 2.0M. These new bacteria species have improved the efficiency of the biocement treatment and helped to reduce the number of treatments required.

ASSESSMENT OF PROPERTIES OF BIOCEMENT-TREATED SOILS AND AGGREGATES

The soluble calcium grout produced using these processes has been used to treat sand or sand limestone mixture in the form of a soil column, as shown in Figures 4 and 5, to assess the amount of increase in shear strength of the soil as a result of biocementation between sand grains.

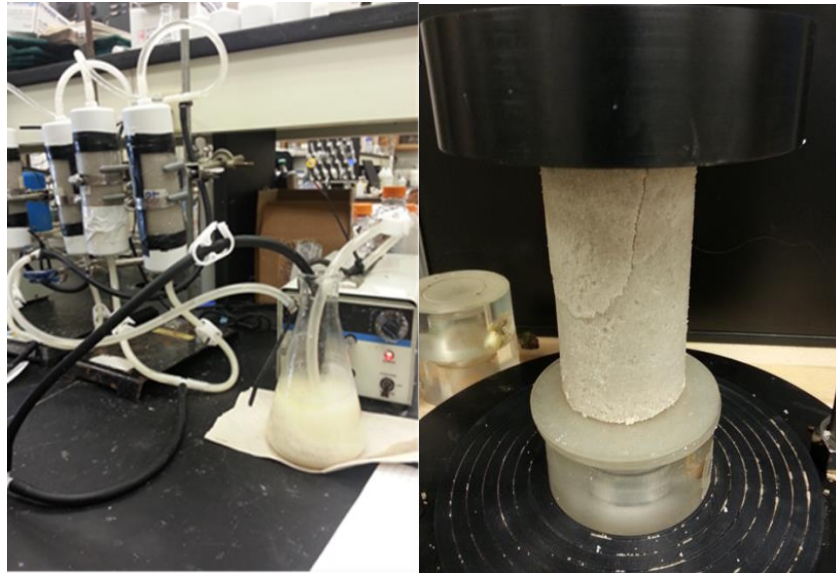


Figure 4. Use of the soluble calcium grout to produce soil columns to assess the increase in shear strength



Figure 5. Use of column tests to assess the properties of sand treated by biocement

Results are shown in Figure 6(a) for tests on dry samples and in Figure 6(b) for tests on wet samples.

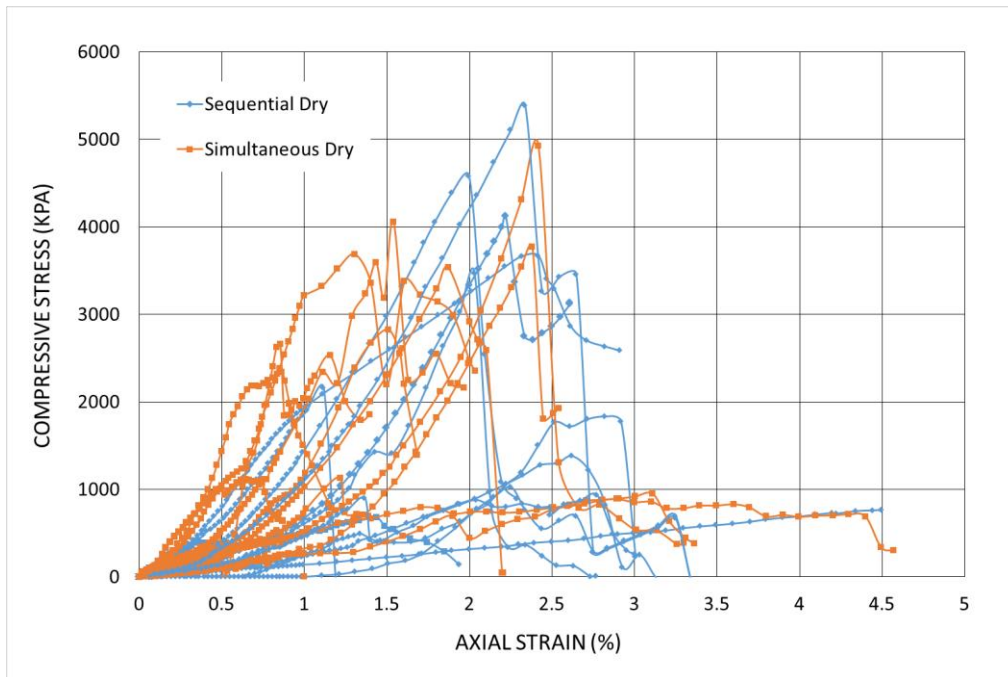


Figure 6(a). Unconfined compression test results on samples dried after biocementation treatment

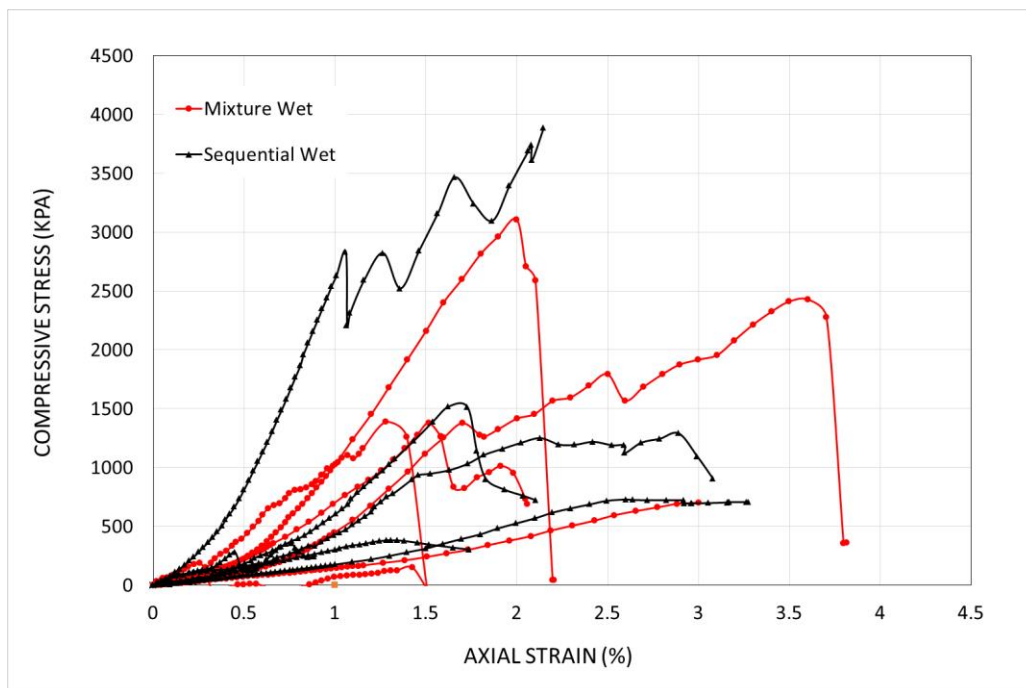


Figure 6(b). Unconfined compression test results on samples wet after biocementation treatment

The tests were carried out by putting sand samples in 50 mm in. diameter PVC cylinders and then percolating biocement solutions through the sand samples. Both sequential and simultaneous approaches were adopted. The sequential approach refers to a procedure of treating the samples with the urease-producing bacteria (UPB) suspension for one hour and then circulating the soluble calcium and urea mixture solution. The simultaneous method circulates the UPB, soluble calcium, and urea at the same time.

In theory, the bacteria cells should attach to the sand grains first before the microbial process takes place to generate calcium carbonate (CaCO_3). However, this will slow the construction process when the method is used for real-world applications. Therefore, the simultaneous method was tried. The samples after treatment were also tested at wet and dry (Figures 6a and 6b). In general, the dry samples show a greater strength due to the influence of unconsumed calcium salt.

The unconfined compressive strength (UCS) obtained from all of the tests are plotted against CaCO_3 content in Figure 7.

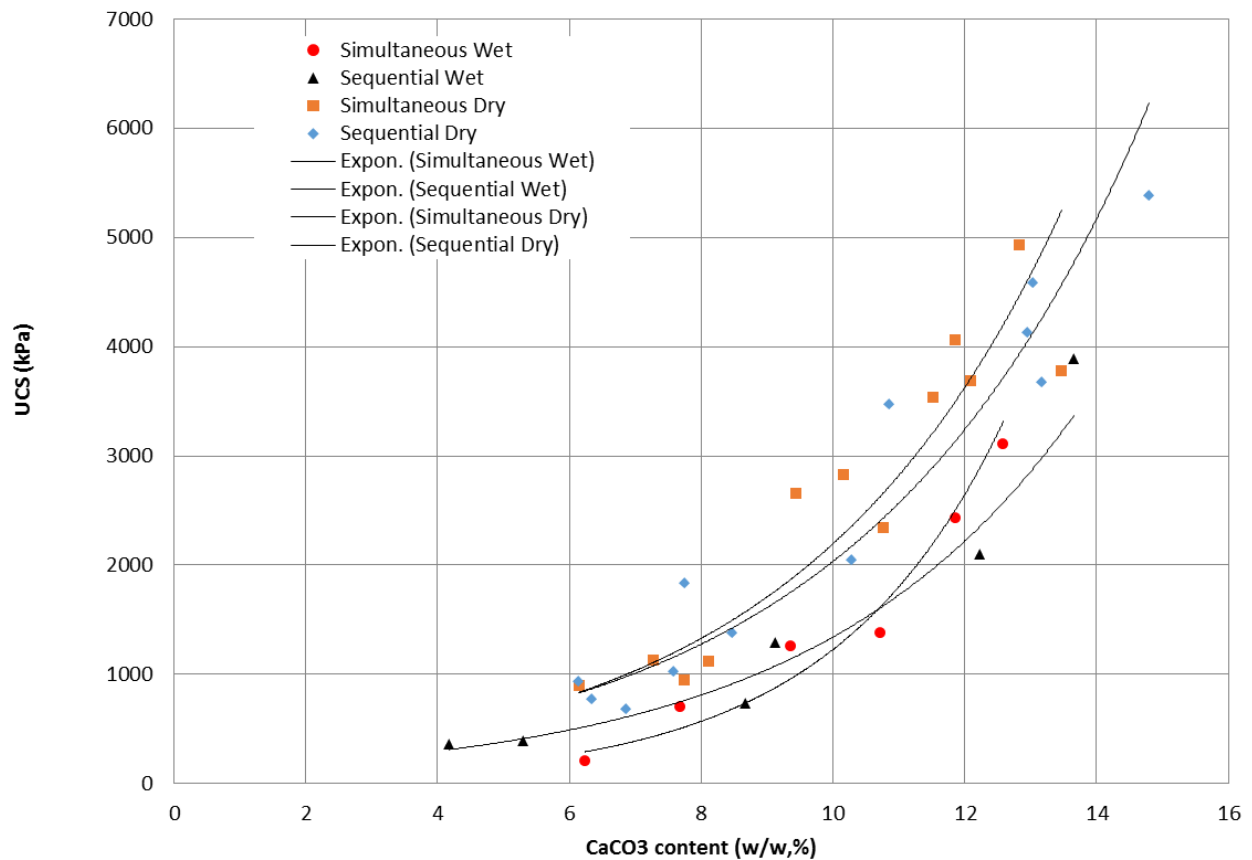


Figure 7. Summary of two series of tests to assess the unconfined compressive strength of biocement-treated sand samples both wet and dry

In general, the longer (or more number of times) the circulation, the more precipitation of CaCO_3 . The higher the CaCO_3 , the higher the UCS, as shown in Figure 7.

The comparison between results obtained from samples treated using the sequential and simultaneous treatment methods indicate that the results from the simultaneous method are comparable to the results from the sequential method, although the UCS produced by the simultaneous method is low in general. Thus, the simultaneous method can be adopted as an alternative to the common sequential method. However, the sequential method may still be more reliable when the best results are expected.

The UC strengths for dry samples are much higher than those for wet samples. This might be because of the additional cementation effect offered by the calcium salt. The additional strength due to calcium salt may not be stable after the samples become wet again. This is something that needs to be studied in the future study.

PROJECT ACCOMPLISHMENTS AND NEXT STEPS

The idea of turning waste into biogrout for road repair and construction has great potential to advance the current state-of-the-art in technology and make an economic impact. This proof-of-concept project accomplished the following:

- Produced bacteria strains for biocementation and soluble calcium for making biocement
- Established bioprocesses to produce soluble calcium grout using limestone fines combined with an agricultural byproduct or egg shells combined with an agricultural byproduct
- Established biogrouting processes to treat soil to achieve an unconfined compressive strength of up to 5.5 MPa (800 psi)
- Developed a new method to treat samples simultaneously (to inject the bacteria and reagent at the same time)

The major goal in the long-term is to use biogrout that is produced for road repair or construction. The next phase of the project is concentrating on increasing the calcium content of the soluble calcium grout and increasing the shear strength of the biotreated soil/gravel samples.