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Proof of Concept: Biocement for Road Repair

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16. 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.

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PROOF OF CONCEPT: BIOCEMENT FOR ROAD REPAIR

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TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGMENTS

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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.

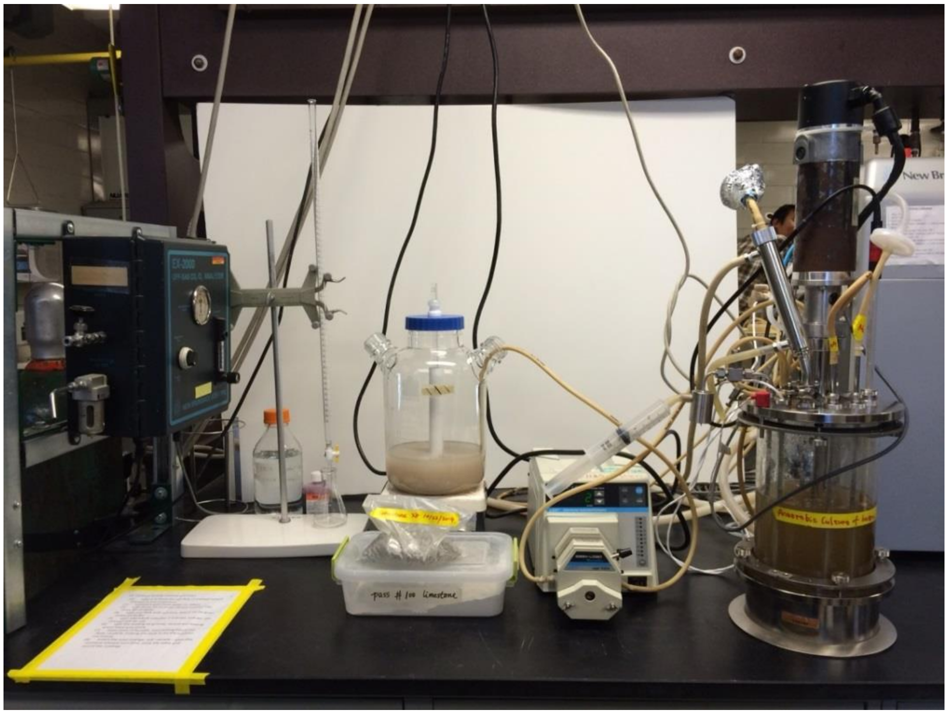
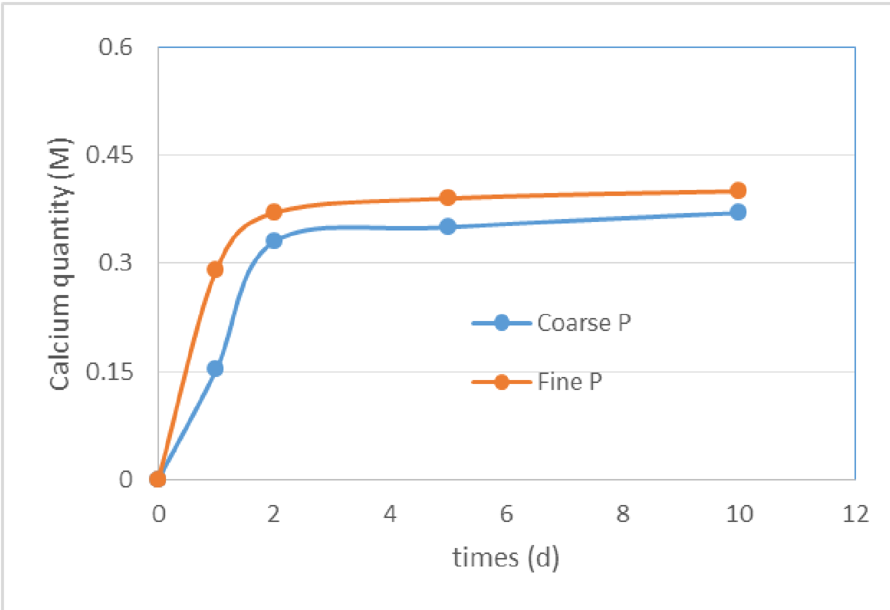


Figure 2. A bioreactor to produce soluble calcium solutions from limestone powder through an acidogenic fermentation process using corn cobs

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.

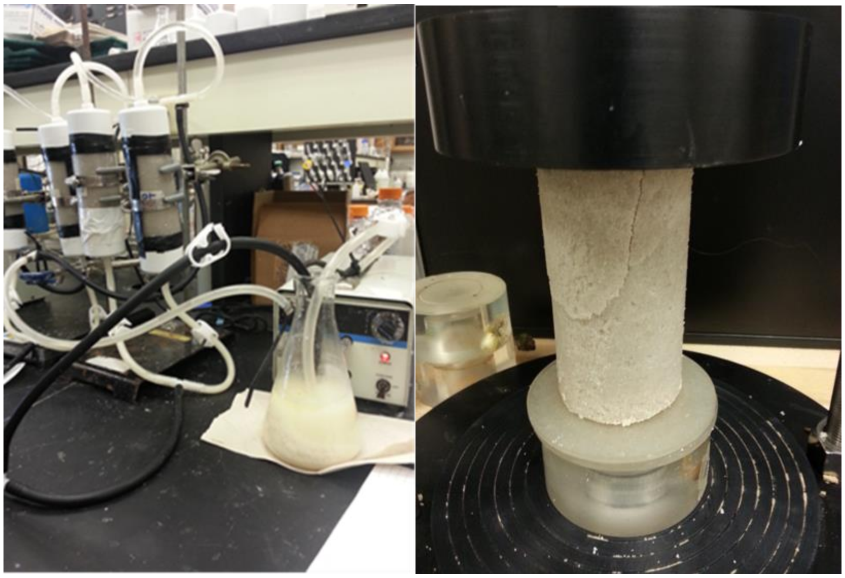


Figure 4. Use of the soluble calcium grout to produce soil columns to assess the increase in shear strength

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.

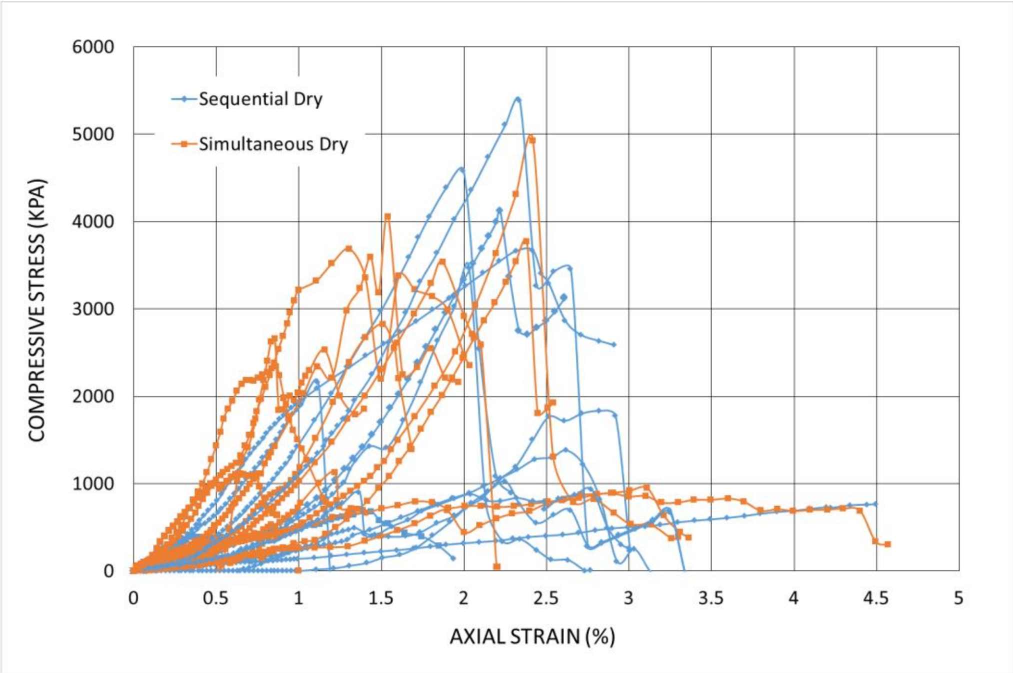


Figure 6(a). Unconfined compression test results on samples dried after biocementation treatment

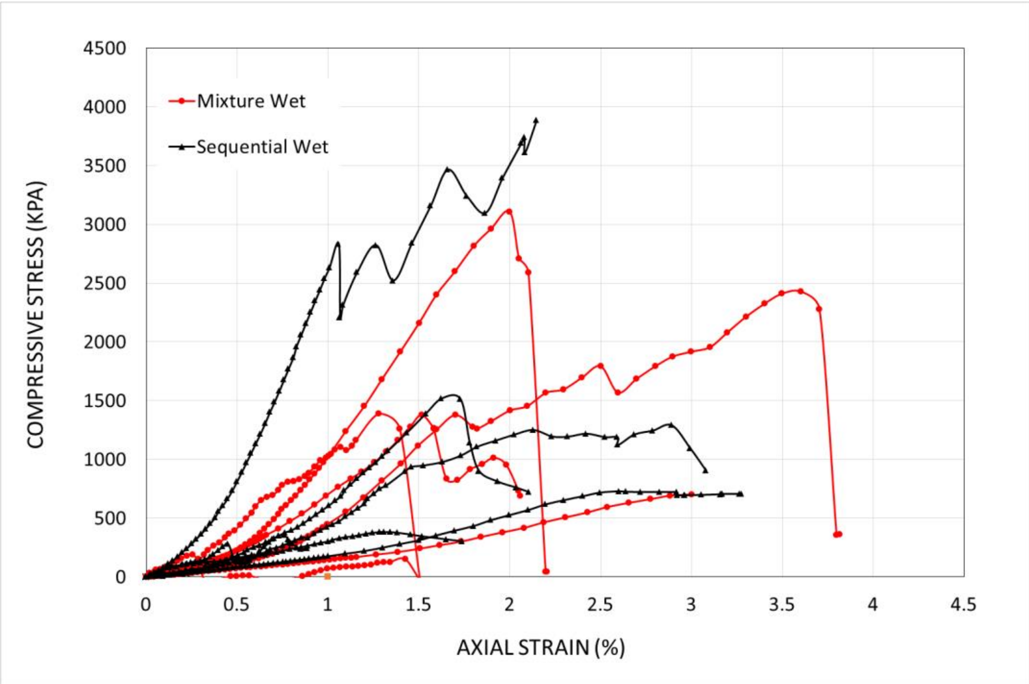


Figure 6(b). Unconfined compression test results on samples wet after biocementation treatment

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.

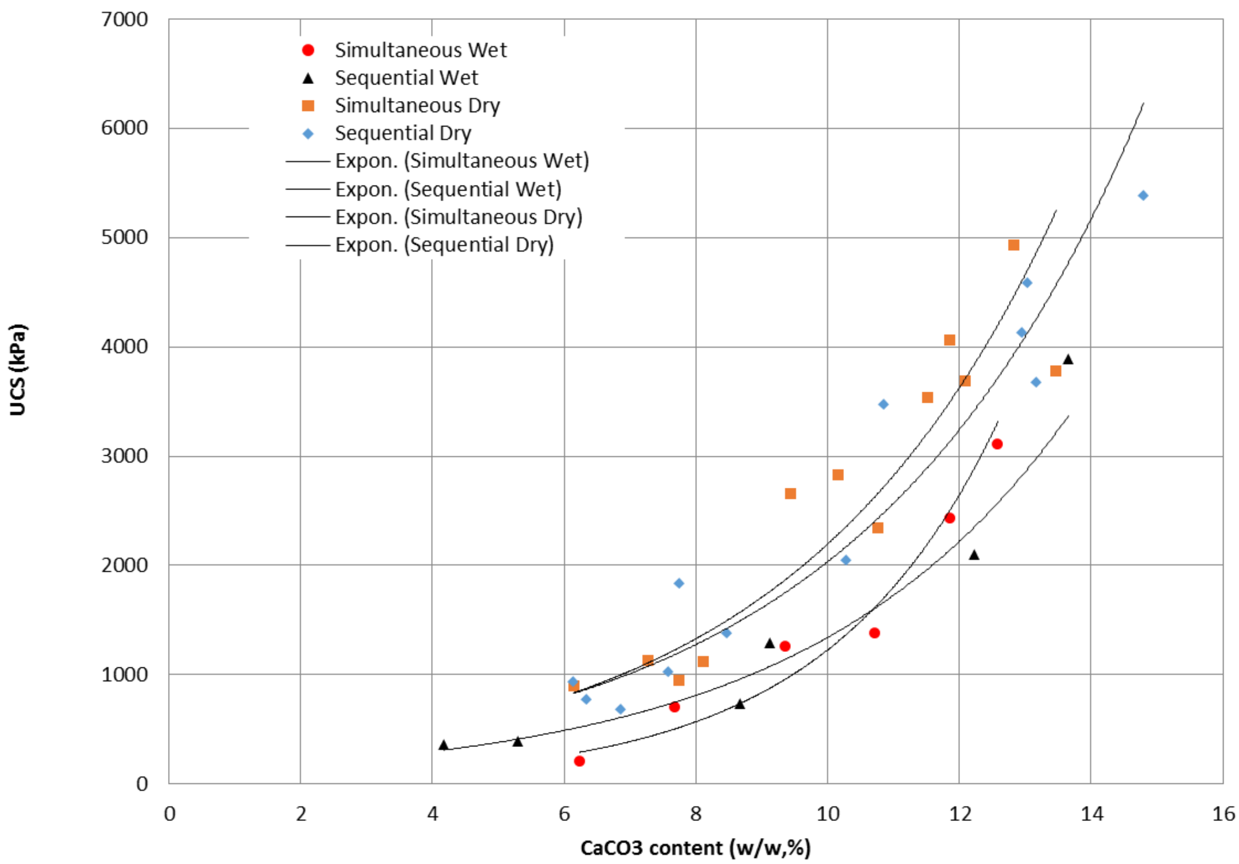


Figure 7. Summary of two series of tests to assess the unconfined compressive strength of biocement-treated sand samples both wet and dry

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 regent 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.