Development of Self-healing Biocement

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This project aims to enhance biocemented soil structures so that they may autonomously self-heal when damaged.

1. INTRODUCTION

Recent studies by Montoya and Dejong (2013), and Botusharova et al. (2017), demonstrated the ability of microbially induced calcium carbonate precipitation (MICP) treated soil structures to self-heal, in principle. Shear strength regain was achieved by injecting the nutrients and precursor chemicals required for MICP into a degraded biocement.

To enable a truly autonomous healing process, the nutrients and precursor chemicals (also referred to as the cementation medium), will need to be readily available within the soil matrix. This research explores the use of carrier materials to facilitate the storage and release of cementation medium from within the biocement.

2. MICROBIALLY INDUCED CALCIUM CARBONATE PRECIPITATION

The production of biocement for this work relies upon microbially induced calcium carbonate precipitation (MICP), via the ureolytic pathway:

1) Active ureolytic bacteria produce urease, which catalyses the hydrolysis of urea, resulting in the production of carbamate (NH_2COOH) and ammonia (NH_3).
2) Carbamate hydrolyses spontaneously to produce ammonia and carbonic acid (H_2CO_3).
3) Simultaneously, in the presence of water, the ammonia and carbonic acid equilibrate, to produce ammonium (NH_4^+) and hydroxide (OH^-) carbonate (CO_3^{2-}) ions.

The global reaction is as follows, (De Belie 2010):

$$CO(NH_2)_2 + 2H_2O \rightarrow 2NH_4^+ + CO_3^{2-} \qquad (1\text{-}3)$$

4) In the presence of calcium, calcium carbonate is precipitated.

$$CO_3^{2-} + Ca^{2+} \leftrightarrow CaCO_3 \qquad (4)$$

3. MATERIALS AND METHODOLOGY

Preliminary studies:

1) Culture of *Sporosarcina ureae,* and induction of sporulation.

3) Production of a concentrated cementation medium consisting of the nutrients and precursor chemicals (Oxoid CM001 nutrient broth, urea, ammonium chloride, sodium bicarbonate and calcium chloride dihydrate) required for MICP.

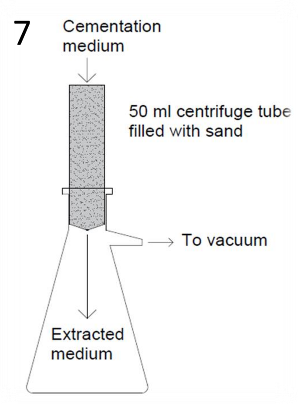
2) Immobilising the concentrated cementation medium within selected carriers including; diatomaceous earth (1), expanded perlite (2), and natural fibres such as coir (3) and jute (4), in addition to encapsulation within sodium alginate beads (5).

3) Quantifying and comparing the immobilisation capacity of the carrier materials through repeated soaking and drying cycles.

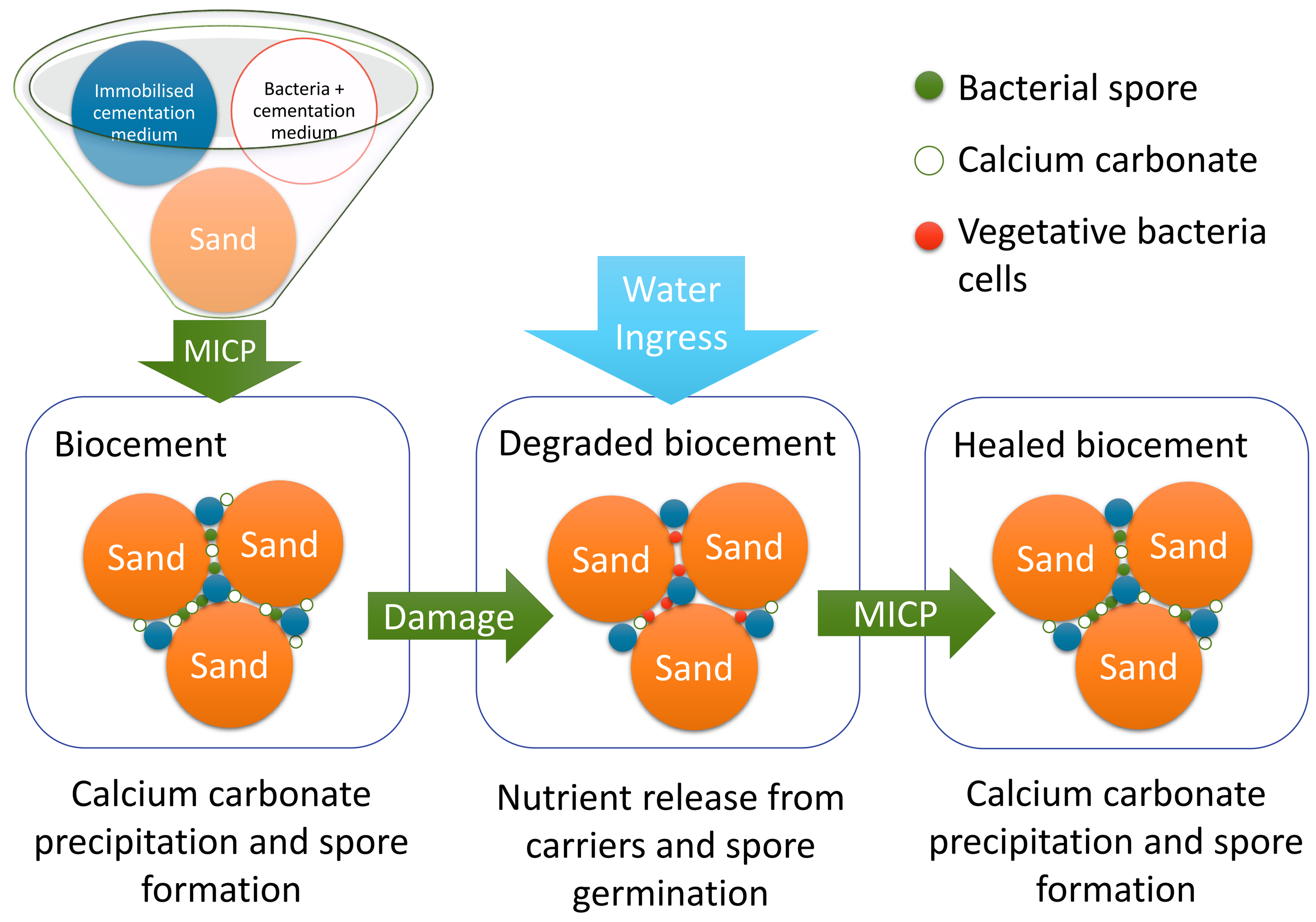
4) Quantifying and comparing cementation medium release from carriers, through immersion of loaded carriers in triplicate in deionised water for set periods, draining and drying.

5) Investigating effects of carriers on the MICP process, within aqueous solutions consisting of cementation medium obtained by soaking loaded carriers in deionised water, and inoculating this with *Sporosarcina ureae.* Use of ICP-OES to measure calcium concentration of samples.

6) Production of mini columns of biocement in triplicates (6), with and without a selected carrier material. Ten treatments of cementation medium over fourteen days via vacuum assisted surface percolation (7). Testing of effluent to monitor pH, dissolved oxygen and aqueous calcium.

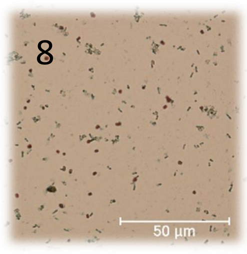


4. SELF-HEALING BIOCEMENT CONCEPT

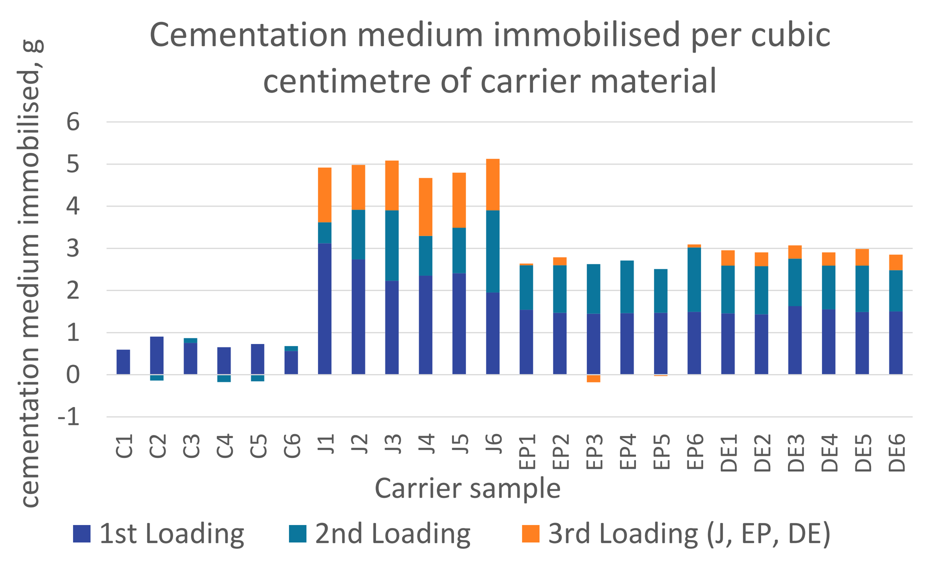


5. PRELIMINARY RESULTS

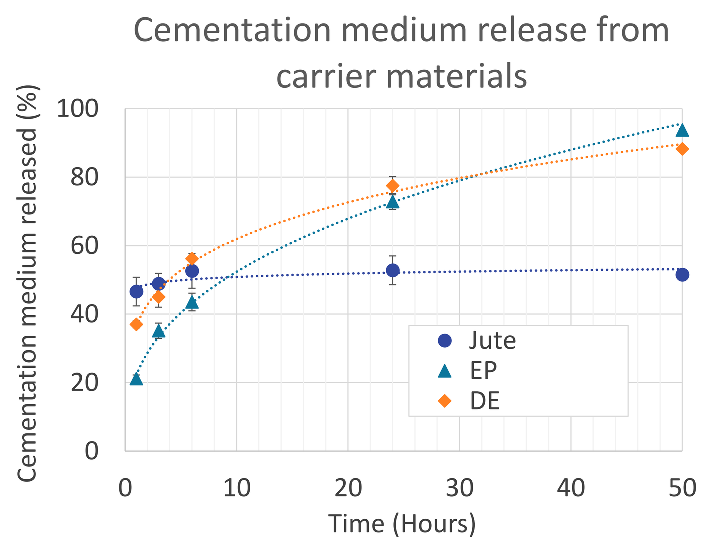
S. ureae (8) spores (stained using malachite green), as observed under an optical microscope, with vegetative cells stained red with safranin, 24 hours after immersion in sporulation medium.



Immobilisation and release of cementation medium

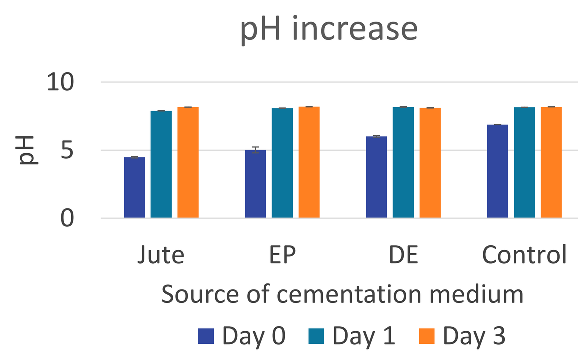


Cementation medium immobilised by coir (C) , Jute (J), Expanded Perlite (EP) and Diatomaceous Earth (DE), following repeated soaking of carriers in concentrated cementation medium for 24 hrs at 21°C.

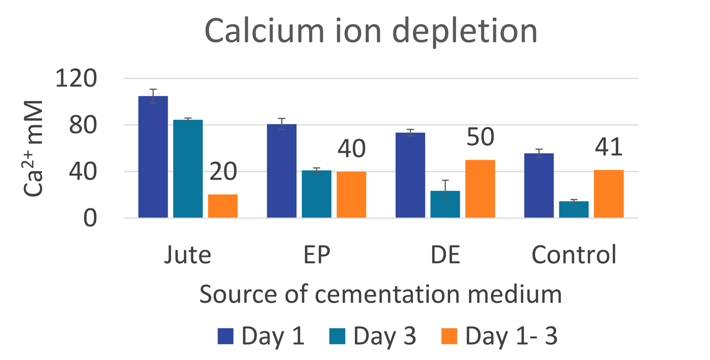


Cementation medium released into deionised water, as a percentage of medium immobilised, over 50 hrs, at 21°C.

Effect of carriers on MICP process

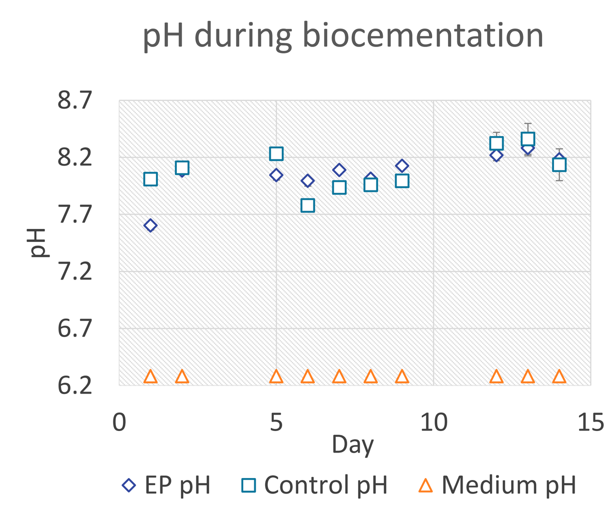


pH of solutions containing cementation medium of equal concentration released from carriers, compared to standard cementation medium (control), before inoculation with *S. ureae* and after inoculation and incubation at 30°C.

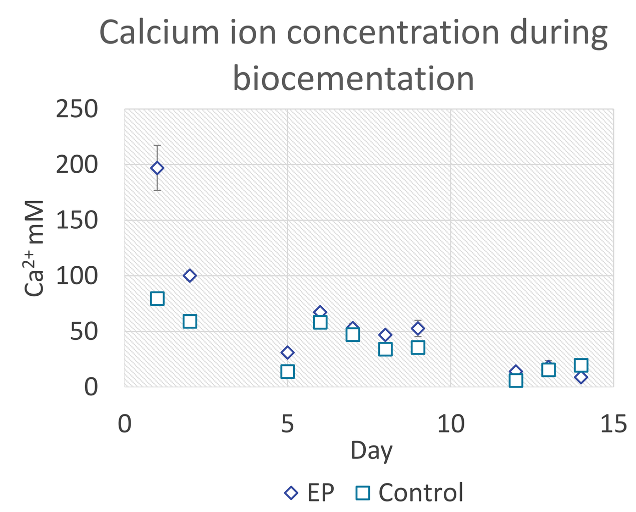


Calcium ion concentration in *S. ureae* inoculated solutions containing cementation medium released from carriers and standard medium as the control, following incubation.

Biocement incorporating expanded perlite preloaded with cementation medium



pH of effluent extracted during biocementation, compared to the cementation medium treatment (pH approx. 6.2).



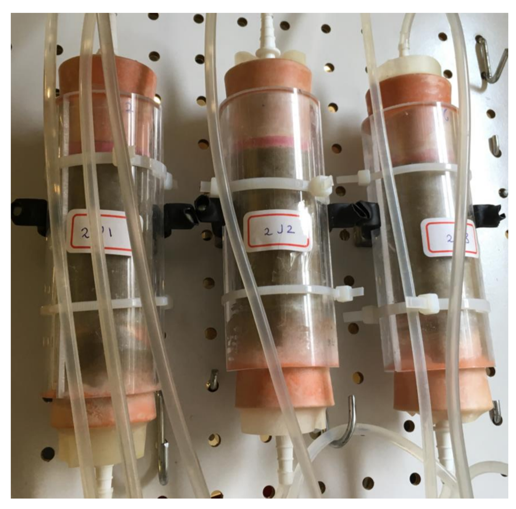
Calcium ion concentration of effluent extracted during biocementation.

Key findings and further work required:

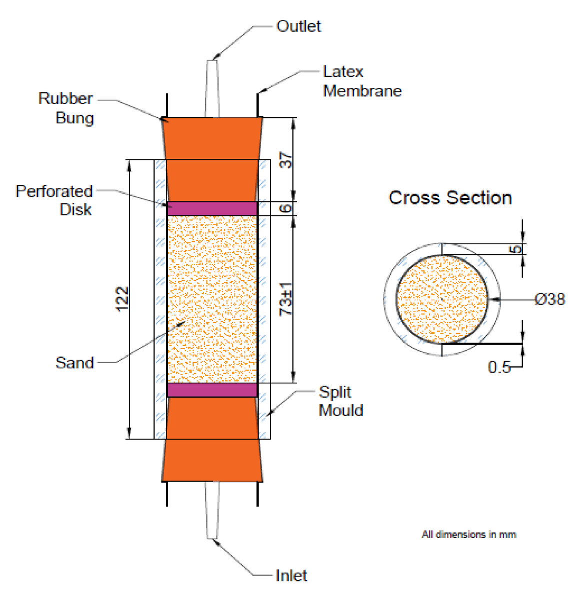
- Viability of carriers for cementation medium storage and release, with exception of Coir.
- Potential beneficial effect on MICP of use of diatomaceous earth.
- pH increase and calcium ion depletion indicating MICP.
- Loss of immobilised cementation medium during biocementation to be reduced.
- Further testing required with fibres.

6. CURRENT EXPERIMENTS: COLUMN STUDIES

- Expansion of studies with fibres to include use of hemp.
- Production of columns of biocement to facilitate injection of cementation medium and to test for self-healing following unconfined compression testing (physical damage).



Biocement columns produced by injecting cementation medium daily over 10 consecutive days.



7. POTENTIAL APPLICATION

Rail embankment stabilisation

- Current method of stabilisation via cementation – mixing soil with Portland cement and water
- Problems – expansion, not sustainable as subject to deterioration from vibrations and weathering
- Potential advantages of Self-healing MICP:
  - ✓ Sustainable eco-friendly approach
  - ✓ Improved mechanical properties of the soil structure - increased strength, stiffness and mitigation against dilation

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Montoya, B.M. and Dejong, J.T. 2013. Healing of biologically induced cemented sands. *Geotechnique Letters* 3, pp. 147–151

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Image 9: https://www.51m.co.uk/wp-content/uploads/2014/01/staffs-viaduct-250x180.jpg

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