

<https://doi.org/10.32762/eygec.2025.8>

INFLUENCE OF DEPTH AND LAND COVER ON THE BIOSTIMULATION PROCESS OF NATURALLY OCCURRING MICP COMMUNITIES

Anthony BRADSHAW¹

ABSTRACT

Microbially Induced Calcite Precipitation (MICP) is a developing area of ground improvement and soil reinforcement, it is an environmentally friendly, sustainable and energy saving method. MICP biocementation requires a series of biochemical reactions to allow microorganisms to form calcium carbonate crystals which in turn bind soil particles together. Much research has been performed on the positive effects MICP can have on sand reinforcement, strength improvement, erosion resistance and permeability of sand. However, it is a complex process largely affected by the microorganisms which are present, as well as several other factors. As research is still being performed on this method of soil improvement there are a lot of gaps in information which must be filled. This paper will discuss possible variables which change with depth and can affect calcium carbonate precipitation. A 21 day experiment was performed during the spring of 2024, which involved small samples of MICP treated soils being tested for their calcium carbonate content. Clay samples were tested down to a soil depth of 500mm, and the experiment revealed that to depths of 500mm that calcium carbonate content in MICP treated samples did not have a clear trend.

Keywords: MICP, bioweathering, biocementation.

INTRODUCTION

MICP is a developing area of soil improvement and carbon capture research. MICP is a type of bio-mediated cementation in which, due to a series of biogeochemical reactions, Carbonate is precipitated along the surface of soil particles and their particle contacts. This cementation works to bind the soil particles by using bacteria populations which are present in the soil, in turn increasing the peak strength, shear stiffness, erosion resistance and lowering the permeability of a material. There are also other benefits provided by MICP, such as dust suppression for construction sites, repairing cracks in cement-based materials and carbon capture. Carbon capture is possible in specific pathways due to the chemical reaction trapping more carbon dioxide (CO₂) in the ground than it produces.

The most common form of MICP soil improvement is ureolysis due to its easy reaction control and fast cementation rate. However, this pathway has inherent issues such as requiring specific strains of bacteria to produce the calcite precipitation, and producing ammonia, an unwanted byproduct, which can be extremely harmful to the environment.

This study used the pathway known as bioweathering by modified version of the medium known as B4 to treat soil samples. B4 is made up of yeast extract, glucose and calcium acetate. Natural weathering processes is an interesting

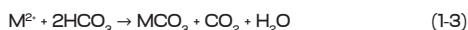
and newly developing approach for carbonate precipitation, due to their ability to capture atmospheric CO₂. This natural process starts with the dissolution of carbon dioxide in water, resulting in the formation of carbonic acid (H₂CO₃) (Equation 1-1) (Lopes et al. 2024). As carbonic acid is an unstable acid, it dissociates rapidly, resulting in the release of bicarbonate (HCO₃⁻) and hydrogen ions (H⁺) (Equation 1-2). Cation breakdown requires these released hydrogen ions, as the process depends on the availability of cation sources like calcium (Ca²⁺), magnesium (Mg²⁺) or iron (Fe³⁺). After they have been released and mobilised, the cations are able to react with the bicarbonate ions and form carbonates (Equation 1-3) (Lopes et al. 2024).



(1) - Formation of carbonic acid



(2) - Carbonic acid being converted into bicarbonate and hydrogen ions



(3) - Formation of carbonates with M representing cations

There is still much to learn about bacteria's function in the bio-weathering process, especially when relating to calcium carbonate formation in soil. CO₂

¹ Anthony Bradshaw MSc, Ryder Engineering, Newcastle, United Kingdom, Anthony.bradshaw@ryder.engineering

has an influencing role in natural soil carbonation as bacteria populations can result in the increase or decrease of the rate of soil carbonation.

The overall goal of the experiment was to understand how soil depth can affect Calcium Carbonate precipitation in undisturbed soil samples using the growing medium B4. These samples due to geographic and administrative constraints was locally sourced from the Northeast of the UK.

The following approach is a study into how soil depth can affect the rate of Carbonate precipitation. This research helps form the foundation to look at the feasibility of the Bioweathering pathway for soil improvement in the UK. How carbon and calcium reservoirs interact with MICP biocementation at depth and determine what areas of MICP require further research.

2 - METHODOLOGY

2.1 - MICP precipitation

Samples were extracted from Nafferton Farm, Northumberland at depths of 0mm and 500mm. Firstly, suitable spots for small hand-dug pits were chosen and then a surface sample was collected. Samples, were collected by inserting a 60ml plastic syringe with its bottom end sawn off into the ground and by using the cohesion of the soil was easily extracted in a single undisturbed section.

Secondly, the B4 solution had to be prepared, this was done using deionised water, yeast and glucose (Table 2-1). Calcium acetate was used as the main source of calcium required for the calcium carbonate reaction. Finally, a small amount of 0.5M sodium hydroxide was used to bring the solution's alkalinity between 8.2 and 8.5 pH as this is the most favourable environment for Calcium Carbonate precipitation.

Table 2-1 List of B4 components

Modified B4 bacterial solution
Per 1 litre of deionised water
4g of Yeast
5g Glucose
15g of Calcium Acetate
8.2-8.5 pH

The setup for the MICP treatment is shown in Figure 2-1 using the sawn-off syringes used for extraction, sealed with rubber stoppers and waterproof tape, zip-tied to a drilled wooden board. The chosen method of distribution was surface percolation, meaning the solution was allowed to sit on the top of the soil samples and slowly work its way down into the soil using gravity. Control samples were provided with 5ml of deionised water, and test samples were provided with 5ml of B4 solution as the samples had an extremely

low permeability which would raise the level of the solution 5 ml above the soil line. More solution was provided to the samples whenever the solution line would drop below 5ml above the soil line. Time is required for the cementation to take place, so the samples were given an incubation period of 21 days.

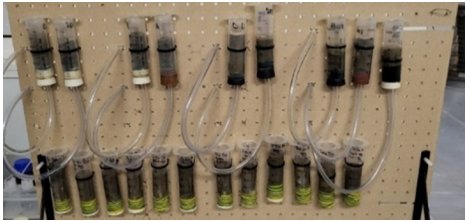


Figure 2-1 MICP sample board of tests on the 14 days after solution application.

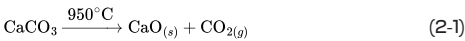


Figure 2-2 MICP treated samples after being removed from the tube, discolouration visible at the top showing a change in colour at the surface. Left B4 treated sample after 21 days. Right Deionised water treated sample after 21 days

2.2 - Loss of ignition (LOI)

Once 21 days had passed, loss of ignition tests were performed to analyse the heterogeneity and calcium carbonate production of the treated samples. The samples were extracted from the tubes and split into three equal sections, a top, middle and bottom section. These samples were then labelled and weighed, then heated at 105 °C for 24 hours to remove moisture.

Following this samples were ground into fine powder with a pestle and mortar starting with the top samples. To begin the loss of ignition tests between 6-8g was taken from the ground samples and placed into an oven at 550 °C for 5 hours to remove all possible organic matter. The samples were then allowed to cool down before being weighed and then placed back into the oven at 950 °C for 3 hours, this is the temperature at which CaCO_3 decomposes into calcium oxide (Equation 2-1).



(2-1) - Thermal decomposition of calcium carbonate

The weights of the samples were recorded after both heating cycles (M_{550} and M_{950}). The percentage

of loss on ignition at 950°C (LOI_{950}) was calculated following the research conducted by Dean (1974) and is represented by Equation 2-2, which shows the loss in mass of CO_2 due to the thermal reaction. The difference in mass was then divided by 0.44 which provides the fraction of CO_2 present in $CaCO_3$ (Equation 2-2) (Dean 1974).

$$LOI_{950} = \left(\frac{M_{550} - M_{950}}{0.44} \right) \times 100 \quad (2-2)$$

(2-2) - Calculation for calcium carbonate percentage. (Dean 1974)

2.3 - Total Organic Carbon (TOC) analysis

A small specimen of the top section of each sample was separated for a total organic carbon test with a total organic carbon analyser. Instead of being dried at 100 °C like the other samples they were dried at 40 °C, before being placed into smaller sample bags. These samples were crushed into a fine powder using mortar and pestle. Once this was complete smaller samples ranging between 0.150g and 0.158g were placed into crucibles before being put into the total organic carbon analyser which provided data for the organic and inorganic carbon contents.

3 - RESULTS

3.1 - Loss of ignition

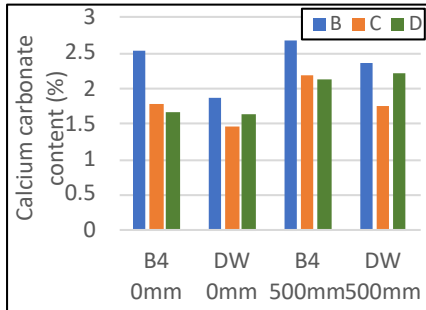


Figure 3-2 Average $CaCO_3$ percentage from top of samples from sample holes B, C and D at depths of 0mm and 500mm after 21 days of precipitation

Untreated soil samples showed an average calcium carbonate content of 1.82%. Samples treated with B4 and left to incubate for 21 days on average exceeded their untreated counterparts with an average calcium carbonate content of 1.99%.

Sample holes B, C and D were dug to a depth of 0.5m, and samples were gathered in Newcastle; the samples were primarily composed of Glacial till, and had an extremely high clay content. The samples showed a higher calcium carbonate content at 500mm compared to their 0mm counterparts. Sample hole B (Figure 3-2) showed both the highest calcium carbonate contents at 500mm and 0mm

being 2.69% and 2.57% respectively. Only the top sections of the MICP treated samples were used due to the extremely low permeability of the soil used resulted in the MICP reaction only taking place within the top of the samples. On average, the top sections of the B4 treated samples showed increases of 0.35% when compared to those treated with deionised water.

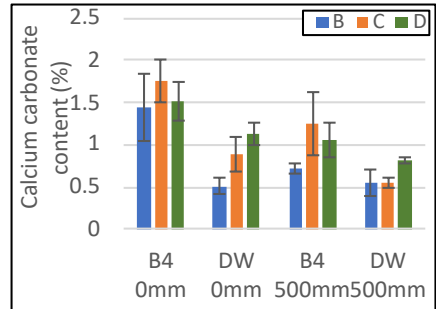


Figure 3-4 Average percentage of $CaCO_3$ in B4 and Deionised water treated samples provided by the total carbon analyser for Sample holes B, C and D at depths of 0mm and 500mm

3.2 - Total Organic Carbon (TOC) analysis

The results from the total organic carbon analysis show differing results from those of the loss of ignition.

Sample hole B (Figure 3-4) shows the B4 treated samples at 0mm depth producing much more $CaCO_3$ compared to those at 500mm, with a 0.94% difference between them. The sample at 500mm depth also produced less $CaCO_3$ than its deionised water equivalent which produced 0.05% more. This is highly irregular and is possible evidence of a failed reaction.

Sample holes C and D (Figure 3-4) follow the same trend as the samples from 0mm producing more than those at 500mm. The B4 treated sample at 0mm had the highest percentage of $CaCO_3$ at an average of 1.75%. Both B4 samples show considerably higher percentages compared to those treated with deionised water.

4 - CONCLUSION

Results from the LOI test and TOC analysis showed differing trends in data, with LOI showing B4 treated samples produced more $CaCO_3$ at a depth of 500mm than their surface-level counterparts. In these LOI tests, the samples treated with deionised water also had a higher calcium carbonate content with depth. TOC analysis revealed the opposite with surface-level samples of both B4 and deionised water-treated samples showing a higher percentage of $CaCO_3$. What both data sets did demonstrate, is a higher percentage of $CaCO_3$ in the samples treated with B4 when

compared to their deionised water counterparts, which is strong evidence that the B4 solution had a successful reaction causing more calcium carbonate to be precipitated.

Samples treated with B4 solution having a higher CaCO_3 content compared to their deionised water counterparts results in the shear strength of the soil increasing as well as lowering permeability. In practice this can be used for cheap, easy and environmentally friendly solutions e.g. strengthening of off road tracks in developing areas.

There are 5 key limiting factors which change with soil depth and affect the MICP reaction.

- pH. For the Calcium Carbonate precipitation to take place, the compound needs to be kept at a pH value between 8.2 and 8.5.
- Soil grain size, due to the heterogeneous nature of both MICP and soil's variations in grain size with depth can easily affect the amount of calcium carbonate precipitated. This is mainly because soils with a higher fine content have a lower level of permeability and a lower void ratio.
- Soil saturation can affect the flow of oxygen into soil masses, making pockets of anaerobia. Previous studies have shown that anaerobic bacteria are less suitable for MICP and yield worse results when compared to aerobic bacteria (Pakbaz et al. 2001).
- Calcium content. Calcium levels in soil can be affected by soil depth as a study by Jobbágy and Jackson (2004) has shown. Plant root systems' depth and intricacy have been shown to influence the distribution of cations in soils and depending on the environment.
- Carbon dioxide content is the second key reactant needed for the MICP reaction. CO_2 levels will be at their highest at the surface due to the largest exchange area between the soil and atmosphere being located there as well as soil organisms which deal with the breaking down of decaying organic matter being mainly located here too.

Possible reasons for seeing opposing trends between the two test sets are due to the scale of the reaction and the lack of varying depth data points. As the amount of CaCO_3 precipitated is in the range of <1% and the maximum depth reached was 500mm the difference in calcium carbonate content may not be enough to produce any accurate trends in the data.

Further works on this subject would require an area in which further depths could be reached, as only having data points at 0mm and 500mm is insufficient.

5 - ACKNOWLEDGEMENTS

This research was developed for the authors MSc Dissertation whilst studying at Newcastle University.

I would like to express my sincere gratitude to Dr Bruna de C.F.L. Lopes for their insightful guidance and continuous support during this research. I also wish to thank Isabelle César for their encouragement and assistance, which greatly contributed to the successful completion of this work.

REFERENCES

- Walter E. Dean, Jr. (1974) 'Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: Comparison with other methods', *SEPM Journal of Sedimentary Research*, SEPM, United States of America Vol. 44. doi:10.1306/74d729d2-2b21-11d7-8648000102c1865d.
- Heiri, O., Lotter, A.F. and Lemcke, G. (2001) 'Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results', *Journal of Paleolimnology*, Springer Netherlands, Netherlands, Volume 25, pp. 101-110. <https://doi.org/10.1023/A:1008119611481>
- Jobbágy, E.G. and Jackson, R.B. (2004) 'The uplift of soil nutrients by plants: Biogeochemical consequences across scales', *Ecology*, Wiley, United States of America, 85(9), pp. 2380-2389. doi:10.1890/03-0245.
- Lopes, B. de C.F.L. and Chrusciak, M.R. (2024) *Nature-based solutions applied to unpaved roads Engineering*, Coalition for Disaster Resilient Infrastructure, New Delhi, India.
- Pakbaz, M.S., Kolahi, A. and Ghezelbash, G.R. (2021) 'Assessment of microbial induced calcite precipitation (MICP) in fine sand using native microbes under both aerobic and anaerobic conditions', *KSCOE Journal of Civil Engineering*, Springer Nature, Berlin, Germany, 26(3), pp. 1051-1065. doi:10.1007/s12205-021-0300-x.