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Biocemented Sand as a Low-Carbon Alternative to Cement Grouting for Shallow Foundations

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Abstract

Loose sand beneath shallow foundations is commonly improved by injecting cement-based grout, and the manufacture of cement is a major industrial source of carbon dioxide. Microbially induced calcite precipitation, often called biocementation, binds sand grains with calcium carbonate formed in place through the bacterial hydrolysis of urea, at ambient temperature and with solutions of water-like viscosity. It is frequently described as a low-carbon substitute for cement grouting. This short communication considers how far that description is justified for shallow foundation work. It summarises the process and the engineering behaviour reported for treated sand, and then sets out what a fair carbon comparison would have to include: the energy-intensive manufacture of urea and calcium salts, the ammonium by-product and its treatment, and the quantity of reagent needed for a given strength. The note argues that biocementation has real technical attractions, notably low injection pressures and retention of permeability, but that its carbon advantage is a claim to be demonstrated case by case and not assumed. Uniformity of treatment, verification and by-product management are identified as the practical obstacles. No new experimental results are presented.

Keywords: *Biocementation, Microbially induced calcite precipitation, Ground improvement, Shallow foundations, Embodied carbon, Cement grouting*

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1. Introduction

Shallow foundations on loose or weakly cemented sand often need the ground beneath them stiffened or strengthened, and permeation or compaction grouting with Portland cement is the familiar means. Cement is effective and well understood, and it carries a heavy carbon burden: both the fuel burned in the kiln and the calcination of limestone release carbon dioxide, and cement production accounts for a significant share of global anthropogenic emissions ([Andrew, 2018](#)).

Among them, biocementation by microbially induced calcite precipitation has attracted the most research. The possibility of using biological processes in geotechnical engineering was set out by [Mitchell](#)

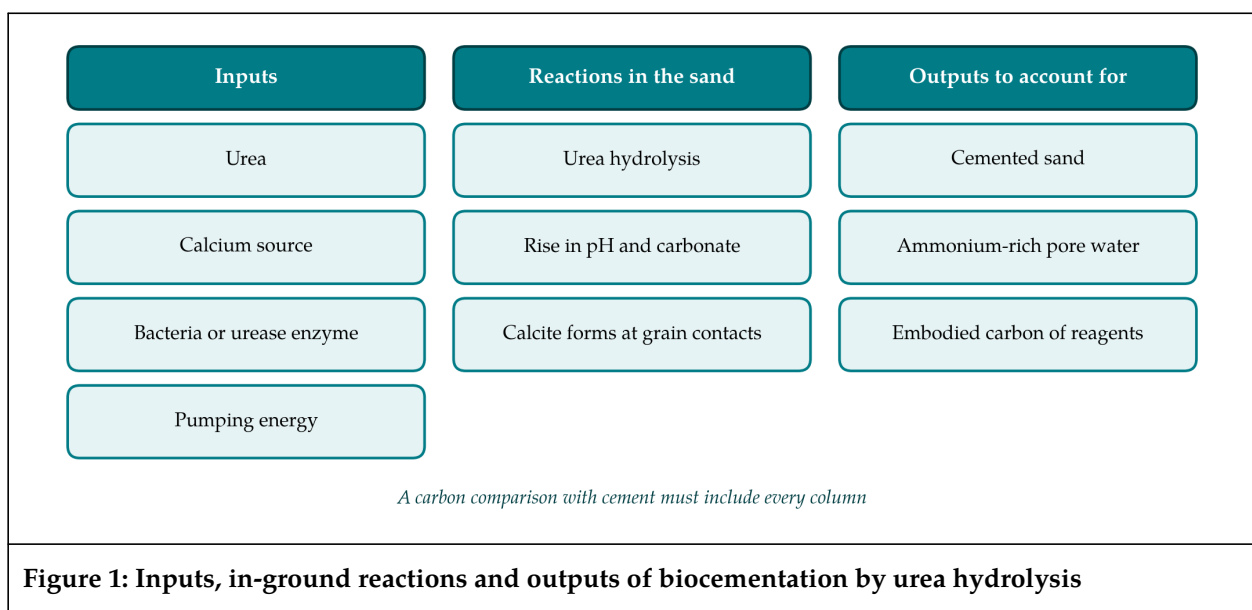
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and Santamarina (2005), and the first demonstrations that bacteria could cement sand to a useful degree followed soon after (DeJong et al., 2006; Whiffin et al., 2007). The technique is now routinely introduced as low-carbon or sustainable. This note asks what that label rests on when the application is the improvement of sand beneath shallow foundations.

2. How Biocementation Works

The usual route relies on the enzyme urease, supplied by the soil bacterium *Sporosarcina pasteurii*. Urease catalyses the hydrolysis of urea to ammonium and carbonate, which raises the pH of the pore fluid; in the presence of dissolved calcium, calcium carbonate then precipitates, preferentially at and near grain contacts (Stocks-Fischer et al., 1999). In overall terms, one mole of urea and one of calcium yield one mole of calcite and two of ammonium. Treatment consists of introducing the bacteria and then passing a solution of urea and a calcium salt, usually calcium chloride, through the sand in one or more cycles. Figure 1 sets out the inputs, reactions and outputs.



Because the fluids have a viscosity close to that of water, they can be injected at low pressure, and the precipitate occupies only part of the pore space, so the sand remains permeable after treatment. The method is suited to sands and coarse silts. In finer soils the pore throats are too small for bacteria to pass, a limit recognised from the outset (Mitchell and Santamarina, 2005). Applications and variants of the process are surveyed by Ivanov and Chu (2008) and DeJong et al. (2010).

3. What Treated Sand Offers a Shallow Foundation

Laboratory work has established the main features of the treated material. Cementation raises small-strain stiffness, which can be followed during treatment by shear wave velocity, and increases peak strength and dilatancy; with heavier cementation the response becomes stiffer and more brittle (DeJong et al., 2006; Montoya and DeJong, 2015). For a footing these are the properties that reduce settlement and raise bearing resistance. The treatment conditions matter: Al Qabany and Soga (2013) found that the concentration of the reagent solution affects the distribution of the precipitate and hence the strength obtained for a given calcite content.

Scale has been addressed in a small number of studies. van Paassen et al. (2010) treated a large body of sand in a container experiment and reported that cementation was achieved over metres but was unevenly distributed, with stiffness and strength varying along the flow paths. That finding goes to the heart of foundation use, where the weakest part of the treated zone governs. Table 1 compares the two techniques on the points that bear on a shallow foundation.

Table 1: Cement grouting and biocementation compared on points relevant to shallow foundations on sand

Aspect	Cement grouting	Biocementation
Injection	Particulate suspension; higher pressure	Water-like solutions; low pressure
Permeability after treatment	Greatly reduced	Largely retained
Main carbon sources	Kiln fuel and calcination	Manufacture of urea and calcium salt
By-products	Alkaline bleed water	Ammonium and chloride in pore water
Maturity	Standardised, long field record	Research stage, few field trials

4. The Carbon Question

The case for calling biocementation low-carbon rests on what it avoids: no kiln, no calcination, treatment at ground temperature. Those are genuine differences. They concern the process in the ground, however, and a comparison with cement has to begin further back. Urea is made from ammonia, and ammonia synthesis is among the more energy-intensive operations in the chemical industry. Calcium chloride also has to be manufactured or recovered and transported. The embodied carbon of the reagents therefore belongs in the account, as Figure 1 indicates.

The by-product belongs there too. Every mole of calcite precipitated leaves two moles of ammonium in the pore water. Left in place, ammonium is a contaminant of groundwater and can be converted by soil organisms to nitrate and to nitrous oxide, a potent greenhouse gas; flushed out, it has to be collected and treated, which costs energy. The need to manage ammonium is recognised in the literature on the technology as one of its principal challenges (DeJong *et al.*, 2010; Mujah *et al.*, 2017).

Finally, the comparison must be made for equal engineering performance and not per unit mass of binder. The quantity of calcite needed to give a footing the stiffness that a given cement grout would provide depends on the sand, the treatment recipe and the uniformity achieved, and inefficient conversion of reagents raises the true consumption. A carbon saving may well exist for some projects, particularly where waste-derived calcium or urea sources are available. The present state of knowledge does not allow it to be stated as a general property of the method.

5. Practical Obstacles

Three obstacles stand between the laboratory and routine foundation work. The first is uniformity: bacteria and reagents follow the more permeable paths, and precipitation near the injection point can starve the ground further away. The second is verification. Cement grouting is accepted on the basis of established tests and decades of case records, whereas for biocemented ground there is as yet no standard for proving that a specified improvement has been achieved, although in situ penetration testing has been used in field-scale trials (Gomez *et al.*, 2015). The third is durability under changing groundwater chemistry, since calcite dissolves in acidic water. Reviews of the field list these same matters among the outstanding problems (Mujah *et al.*, 2017).

6. Conclusion

Biocementation can stiffen and strengthen sand with low-pressure injection and without sealing the pores, which makes it a technically interesting option beneath existing and new shallow foundations. Its description as a low-carbon alternative to cement grouting is plausible and unproven. A fair assessment has to count the manufacture of the reagents, the fate of the ammonium and the quantity of treatment needed for equivalent performance. Until transparent life-cycle comparisons on that basis are available, the carbon benefit is a question to be answered for each scheme.

Conflict of interest

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