

Feasibility of peat soil stabilisation with solid waste material inclusions and biocementation treatments

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Abstract This paper studies the stabilisation of a peat railway embankment foundation soil from East Anglia, UK, using solid waste material inclusions and biocementation treatments. Peats are weak, high water content soils which lead to construction problems, due to the high water content and poor engineering properties. Chemical peat improvement to improve its engineering properties is commonly relying on Portland cement, which absorbs water while forming cementing gels. However, due to the negative environmental impact of Portland cement, the civil engineering industry is seeking innovative, more environmentally friendly alternatives. This study introduces soil biocementation based on biomimetic precipitation of natural minerals. Specifically, heterotrophic carbonic anhydrase producing bacteria that sequester CO₂ in the process are used. Solid waste/by-product materials such as wood saw ash, sawdust and ground granulated blast furnace slag filler/water absorbing materials are also used, as a means of contributing to solid waste management by waste recycling. The results indicate undrained shear strengths of 2-16 times higher than that of the untreated peat depending on treatment, although further study is needed to improve treatment homogeneity with possible modifications in the treatment protocol.

Keywords: peat stabilisation, solid waste inclusions, biocementation, carbonic anhydrase

1. Introduction

This paper addresses the biochemical stabilisation of peat soils using solid waste material inclusions. Peat is an unsuitable for construction soil, due to its very high water content and compressibility, including secondary compression (creep), as well as its generally low shear strength. It is thus typically excavated and landfilled and replaced by a more suitable soil for construction. However, current sustainability targets of the construction industry, and environmental concerns on the role of peatlands in the natural CO₂ cycle, render this practice increasingly unacceptable. Chemical peat improvement to improve its engineering properties is considered as a better alternative

towards sustainability. However, the most common agent used for chemical peat stabilisation is Portland cement, due to its ability to absorb water while forming cementing gels, and Portland cement comes with environmental impacts as well. Therefore, innovative, and more environmentally friendly cements are currently studied. This study assesses the use of bacteria for the biomimetic precipitation of natural minerals, acting as cementing agents (biocements), towards more eco-friendly peat stabilisation. In parallel, it proposes the use of solid waste/by-product materials to function as mineral additives, fillers, or water absorbing materials to address the high water content and large voids of the peat and the low mineral content. Such materials, including wood saw ash or saw dust were used by others (e.g., respectively, Anuar et al, 2024 or project CLARIFIER <https://project-geolab.eu/clarifier/>) but no biocementation of the modified peat was attempted, with the addition of these materials. In this paper, the hypothesis is that increasing the content of solids in the peat, would facilitate bacteria attachment onto solid surfaces, nucleation sites for calcite precipitation, building a mineral skeleton in the peat, potentially with calcite bridges forming between particles. Indeed, Gowthaman et al, (2021) using scallop shell powder for biocement-treated amorphous peat, found unconfined compressive strength improvement of >200% after 7 days of curing, while conventional biocementation led to little improvement.

2. Materials and methods

The peat soil used in this study came from trial pits in a location of East Anglia, from 4m depth. The peat soil of the bulk samples contained large pieces of wood and had a variable content of organic clay. The water content of the collected for testing samples ranged from 490% to 100%, the latter for samples predominantly of organic clay content; pH was 7.9-8.0 and carbonate content based on the acid washing technique was 2.47%. Organic matter content of the peat was 76%. X-Ray Diffraction (XRD) analysis of the peat showed that the mineral portion contained predominantly quartz, kaolinite and muscovite/illite. X-Ray Fluorescence (XRF) showed that the peat

consisted predominantly of Si (13.800 %), Fe (11.231%), Al (5.108 %) and S (5.104 %) but K and Ca were also detected at 2.938 % and 2.157 % respectively; Mg and Ti were detected at 0.652% and 0.56% respectively, whilst Cl, P and Na were 0.233%, 0.136% and 0.111% respectively (% based on sample weight). Low concentrations of other elements including heavy metals (i.e. Cr, As, Cu, Pb, Ni, Zn) were also detected. Based on von Post's classification the peat was H₄-H₃ (slight-very slight decomposition), B₂(500%-1000% water content)-B₃ (<500% water content); F₂ (moderate fine fibre content); C₂ (moderate coarse fibre content); W₂ (moderate wood content), N₃ (60-80% organic content), A₁ (slight smell); pH₀ (neutral pH). A considerable variability in the bulk sample was noted. Cylindrical specimens of 100mm height and 50mm diameter were premixed respectively with 20% by dry soil mass of number of solid waste/byproduct inclusions, namely ground granulated blastfurnace slag (GGBS), saw dust (SD) and saw dust ash (SDA); additional specimens of the same components with an added 10% of calcite seeds (to enhance nucleation) were prepared for the biocementation treatments. Control specimens of the same ingredients, where only water (of the same amount as in the chemical solutions) was supplied were also tested. Biocementation specimens were treated by percolation of biostimulation solutions for heterotrophic carbonic anhydrase (CA) producing bacteria in the soil, followed by biocementation solutions supplied separately (0.25M calcium acetate as calcium source, and 0.25M sodium bicarbonate, as CO₂ source). In a multi-step chemical reaction process, CA utilises gaseous CO₂ forming hydrated aqueous CO₂ (aq), which reacts with water to form H₂CO₃. These products ionise to form CO₃²⁻ and H₂O. To form a biocement via biomineral precipitates, the metal ion, here, Ca²⁺, reacts with CO₃²⁻, forming CaCO₃ where the CA enzyme serves as nucleation sites.

3. Results and discussion

Undrained shear strength (S_u) results were based on standard BS cone penetration using Hansbo's (1957) relationship cited in Leroueil and Le Bihan (1996); these were complemented by the respective pH, CaCO₃ and water content results, as a means of interpreting the findings on soil S_u . The main findings can be summarised as follows: (a) all specimens mixed with solid waste inclusions showed strength improvements compared to the S_u of the untreated peat (in compacted state: 17-24 kPa from vane shear measurements). Although not uniform throughout the sample due to uneven moisture distribution (e.g. water treated samples been often softer at the top due to ponding water and several biocemented samples forming a crust at the top), depending on treatment, S_u was

found to be between 2 (mixed GGBS with calcite without biocementation treatment) and 16 times higher than that of the untreated peat (mixed SDA with calcite with biocementation treatment). Some extreme values were discarded as unrepresentative/outliers. One reason for the increase in S_u in control specimens is the filler effect of the constituents. SDA composition depends on incineration conditions. In the literature some SDA were reported as self-cementing; we did not observe self-cementation of SDA when exposed to water. SDA is finer than SD, so it has a higher filler effect. Because of higher alkalinity SDA is more suitable than SD to be pursued for further study. GGBS, a well-known latent hydraulic binder can undergo mild alkaline activation in the presence of water and calcite; it is possible that in addition to biocementation by calcite precipitation some other cementing gels (e.g. calcium silicate hydrates) to form but this hypothesis needs to be verified by material analysis. In biocementation literature for peat soil, UCS of ~ 50kPa (i.e. S_u ~25kPa) are commonly reported. S_u = 43 kPa was achieved only by incorporating 50% of bamboo fibre, acting as water absorbing agent (Chen et al, 2021); (b) soil pH was mildly alkaline in most cases but in SD it was highly acidic (3.6-3.8); thus although 0.9% new CaCO₃ precipitation was achieved in the biotreated SD, SD would not create a suitable environment for calcite precipitation; its strengthening effect if mixed in peat would be physical (water control, possible matrix stiffening due to interlocking with peat fibres), rather than biochemical; (c) for samples without calcite seeds, 2.1-8% extra CaCO₃ compared to that of natural soil was measured. The highest increase of 8% was noted in parts of GGBS sample; (d) in all cases of biotreated samples and some control mixes with calcite seeds, less CaCO₃ than the original content was measured at the end of the tests; this could be due to some leaching of the added calcite but also, for biocemented treatments possibly due to CO₂ involved in the processes, which can acidify the pore water during the process; (d) In most cases but one, water contents of biotreated specimens were higher than the respective control, implying some increase in water retention.

4. Conclusion

The results show that improved strengths can be achieved upon premixing peat before biocementation treatment. SDA and GGBS merit further study as admixtures while SD appear to acidify soil which is unsuitable for calcite precipitation. Treatment uniformity needs to be addressed using a different implementation protocol.

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