

BIOFILMS IN GEOTECHNICAL AND GEO-ENVIRONMENTAL PROCESSES

Dadiri, M.B.¹ and Abubakar, H.F.²

¹Department of Civil Engineering Technology, School of Engineering Technology, Adamawa State Polytechnic, Yola

²Department of Agricultural and Bio-Environmental Engineering Technology, School of Engineering Technology, Adamawa State Polytechnic, Yola

Corresponding Email: hammanadamafarukabubakar@gmail.com

ABSTRACT

Regulatory bodies, in many countries, require part of the lining system, for such facilities, to comprise of a compacted clay layer with a hydraulic conductivity of 1×10^{-9} m/s or less. Suitable material can be expensive, or indeed impossible, to obtain in some areas. There are many examples of biofilms and biopolymers increasing the viscosity of fluids or causing reductions in the hydraulic conductivity of porous media. In many of these cases, the phenomenon is cited as detrimental to the operation of the system in which it occurred. "Biofouling" is often reported in heat exchangers, cooling towers, filtration media, pipes and ship hulls. In these cases, the biofilms may reduce conductivity, reduce flow or increase drag. There are also many widely used beneficial uses of biofilms and biopolymers. Biopolymers are used in the food and cosmetic industries as emulsifiers or thickening agents. Biopolymers have also been used in the oil well drilling industry to clog porous media to improve resource recovery. For many pathogenic bacteria, biofilm dispersal plays an important role in the transmission of bacteria from environmental reservoirs to human hosts, in horizontal and vertical cross-host transmission, and in the exacerbation and spread of infection within a host. Also, the bacterial cells form by biofilms effectively improved the geomechanical properties of sand. Continues growing bacteria cells improved the sand properties owing to microbially induced precipitation and related pore volume changes, whereas dead and resting cells generally caused smaller increases in friction angle and bearing strength. Consideration of soil as a living ecosystem offers the potential for innovative and sustainable solutions to geotechnical problems. Recent studies have sought to investigate the potential for biofilms and biopolymers to improve the hydraulic conductivity of material for use as liners in waste containment facilities. Geotechnical applications currently being explored include cementation of sands to enhance bearing capacity and liquefaction resistance, sequestration of carbon, soil erosion control, groundwater flow control, and remediation of soil and groundwater impacted by metals and radionuclides. It is proposed that by adding relatively small quantities of bio-substances to marginal material, a low permeability can be achieved. The researcher reviewed some of the published research to date. Other reported properties of biofilms and biopolymers indicate further promising potential. Some of the potential geotechnical and geo-environmental applications of these bio-substances are broached as well as some of the drawbacks to be overcome.

Keywords: biofilm, biopolymers, geotechnical, cementation and liners

1 INTRODUCTION

Biofilm is a thin layer but robust and mucilage adhering to a solid surface containing bacteria and other microorganisms. In recent years, land development and construction industries in Nigeria have seen intensive activities. Due to rapid development and as a result of the scarcity of good ground, marginal grounds have been earmarked for development. Engineers nowadays are faced with problems related to poor ground conditions [1]. Construction in these areas

needs proper ground improvement works to avoid problems such as sand liquefaction on large settlements during or after construction. Soil liquefaction happens when a saturated or partially saturated soil significantly loses strength and stiffness due to increasing or a sudden change of applied stress, causing it to behave like liquid [2]. Due to the relatively low shear strength of marginal ground, suitable ground improvement technology is seen as a viable option that can be used to treat these sites. Soil strength improvement technologies that are normally used are mostly via a chemical grouting process which involves injection or mixing soil with additives such as Portland cement, sodium silicate, lime, fly ash etc. [1]. As an example, the construction of the SMART Tunnel used several methods of grouting that included fissure grouting and cavity grouting in rock, and also jet grouting and compaction grouting in the soil layers [3]. The emergence of new ground improvement techniques has been a topic of interests among engineers. One that has been gaining popularity in the past decade particularly in the construction and engineering industry is known as construction biotechnology; with the major route under construction biotechnology being either the microbial production of construction materials or the applications of microorganisms in the process of constructions [4]. There is an increasing interest in engineering to mimic and maximize the benefits of natural processes. The aim is to achieve an engineering end that has minimal impact on the environment and that may also be less expensive to implement [6]. Whereas environmental engineers have been leaders among the civil engineering profession in this initiative, there are new possibilities being explored in geotechnical engineering. The growing pressures for development of less desirable engineering sites, especially as urban areas grow into densely developed megacities, have focused attention on new possibilities for technologies to achieve soil improvement and stabilization. Such new soil stabilization technique has other important applications outside of urbanized areas, such as ground stabilization against flood damage, and prevention of flood arising from natural causes, such as overflow of rivers [6]. These measures will be particularly attractive if they can be implemented over wide areas and at low cost. In situ production and accumulation of these metabolic products of soil-residing microbes clogs the pores in soil and reduces its permeability [5, 6]. Reduction in permeability has both advantages and disadvantages [5]. Bioclogging can reduce seepage in irrigation channel and reservoir, piping of earthen dam or dikes, increase oil recovery from reservoir and form a barrier to reduce the migration of heavy metals and organic pollutants [6,7,8]. However, reduced permeability due to microbial activities can also create significant geotechnical problems such as impaired sand filtration and difficulty in aquifer recharge [9, 10]. Therefore, it is necessary to analyze the changes in permeability of soil due to microbial activities, either to use as a bioengineering solution or in order to predict the problems which may arise in future. Efficacy of biofilm in reducing saturated permeability of sand and silt was investigated by several researchers and it was observed that permeability can be reduced up to 100% after only two to three weeks of treatment [11, 12, 13]. Along with biofilm, bio-mineral can also be used as bioclogging agent and capable of reducing permeability up to 65% [8, 14]. Reduction in permeability of a soil mass can be attributed to both biogenic deposits and biogas related unsaturation [15]. While previous studies have reported a decrease in the permeability of soil because of the biogenic precipitates, the effect of biologically induced unsaturation on the permeability of soil has not been studied so far. One of the biotechnology routes for a construction process is known as Microbially Induced Calcite Precipitation (MICP) or in short, known by most researchers as bio-cementation. It is relatively new to the field of geotechnical engineering and evolves from time to time, but its potential has been shown to be remarkable. It is a sustainable, environmentally friendly and a cost effective ground improvement technique. It is also known as bio-grouting when naturally harvested microbes are used to trigger precipitating calcite to bind the soil particles through the process of biocementation and bioclogging. This new technique incorporates a microbiological process to facilitate the improvement of soil properties without compromising the surrounding environment. Also, it can be realized through trans-disciplinary research combining the understanding of microbiology processes, geochemistry and also civil engineering [16]. Groundwater circulation is one of the factors often influence the generation of metabolic products. Several studies have attempted to investigate the effect of continuous supply of nutrients on metabolic product formation and/or permeability reduction by vertical flow of growth medium through a sand column [14, 17, 18]. But the hydraulic effect of the horizontally flowing growth medium, resembling groundwater in both mineral composition and velocity, has not been studied yet. The researcher intended to review the effect of horizontal flow of growth medium on

metabolic product formation by an aerobic microbial species *Lysinibacillus sp.* DRG3 through three different bioprocesses-non-calcifying, non-ureolytic calcifying and ureolytic calcifying and related changes in saturated and unsaturated permeability of sand. *In situ* soil improvement has the ability to alter the strength, hydraulic conductivity, and stiffness of soil. Since it can be designed to cause minimal disruption at the surface; the process is advantageous for use in urban areas or areas of difficult access. The ability to improve soil strength *in situ* has several important implications. For example, increasing the bearing capacity of soils can reduce settlement of structures such as in earthquakes, thus resulting in site improvement. Furthermore, construction on marginal soils such as loose sands, fills, mine spoils, collapsible soils, and expansive soils will be enabled due to strengthening of subsurface materials. Strengthening soils will also lead to increased load-carrying capability, which plays an essential role in slope stability. *In situ* soil improvement techniques can also be applied to controlling groundwater flow, e.g., via alteration of the hydraulic conductivity [19]. It may be desirable to increase permeability with soil improvement; however, it is more typical that a reduction in permeability is sought [19]. For example, reduction of permeability in a cut-off wall of soil surrounding an excavation, a tunnel, or the foundation of a structure, can be an effective way to control seepage and achieve a degree of waterproofing. It can also be used in design for containment of contaminated leachate, encapsulating hazardous waste, and initiating or enhancing *in situ* biodegradation of harmful substances [20, 21]. One of these natural processes is microbiological CaCO_3 precipitation. The bacteria-induced calcite precipitation process, especially using urea as a microbial substrate, has also been successfully implemented in the laboratory for improvement of permeable construction materials and plugging of fractured rocks [22, 23, 24, 25]. Despite the possibility of using microbial cementation of soils via CaCO_3 precipitation, the relationship between the bio-catalysis of urea and soil geo-mechanical properties is still not well-understood. There is a need to study the range of possible conditions necessary to recreate these natural processes *in situ*, and to evaluate the magnitude and the longevity of the effects on soil properties. The researcher review geotechnically beneficial effects, to assess the geomechanical and hydraulic benefits that is a product of these microbiological processes, and to evaluate abiotic factors on the geotechnical properties of soils. To accomplish these objectives, a series of laboratory tests were conducted to investigate the impact of factors such as relative concentrations of calcite-oxidizing bacteria on the entire process, the duration of each stage of the process, as well as the resulting improvement in soil strength, and possible changes in hydraulic conductivity.

2 MATERIALS AND METHODS

The reduction of hydraulic conductivity in silty sand with the addition of *Beijerinckiaindica*, which subsequently forms a biofilm. The samples were prepared by mixing the soil with a bacterial and nutrient solution and compacting at optimum moisture content. The samples were also, prepared for permeability testing by mixing 1% and 2% solutions of Xanthan Gum and 1% solution of sodium alginate with the soil to achieve 20% moisture content (wet of optimum). The present work investigated the reduction of hydraulic conductivity and the change in shear strength of clayey sand with the addition of commercially available biopolymers. The materials were prepared by mixing 0.5% and 1% solutions of Guar Gum, Sodium alginate, Xanthan Gum and IDPAC with the soil at a moisture content 2% wet of optimum.

2.1 Reduction in hydraulic conductivity

The reduction of hydraulic conductivity obtained by other researchers and the present investigation are shown in table 3.1 The results indicate a valuable reduction in hydraulic conductivity of the materials being tested. The results also indicate the relative effectiveness of the types of biopolymers used. In both studies Xanthan Gum was more effective than Sodium Alginate. The present investigation showed Guar Gum, to be the least efficient biopolymer trialed, with 2% being required to reach the target hydraulic conductivity of 10^{-9} rrüs.

2.3 Increase in material strength

Due to the viscosity of the biopolymer and biofilm and the adhesion to soil surfaces, it is reasonable to expect that there may be an increase in shear strength of soil due to the addition of biopolymers or biofilms. [25] conducted a series of undrained triaxial tests to assess the change in

material strength with the addition of biopolymers or the growth of biofilm. The results were reported as maximum deviatoric stress for a strain of 20%. If full saturation is assumed then the stress can be considered to be the cohesion of the sample.

3 RESULTS AND DISCUSSION

A summary of the results is presented in the Table 1. Chan also investigated the change in shear strength of clayey sand mixed with biopolymers. The results indicated a slight increase in cohesion with curing time. There was no apparent change in friction angle. Change in material strength [27].

Table 1. Change in Shear Strength of Clayey Sand Mixed with Biopolymers

Material	Deviatoric stress (kPa)
Untreated clayey silt	120
0.3% Xanthan Gum	160
0.5% Xanthan Gum I % Xanthan Gum	170
0.5% Sodium Alginate I % Sodium Alginate	180
	140

The body of research into the use of biofilms and biopolymer to modify soil properties, has demonstrated a significant decrease in hydraulic conductivity of porous materials is achievable. A reduction of at least two orders of magnitude has been reported by independent researchers using as little as 0.5% Xanthan Gum mixed with a fine grained soil matrix [25, 27]. Up to three orders of magnitude reduction in hydraulic conductivity has also been achieved by the addition of bacteria, and subsequent growth of biofilm, in silty sand [26]. The reduction of hydraulic conductivity has been shown to be dependent on the initial porosity of the material, the mechanism of clogging, the concentration and variety of bio-substance applied, the moisture content and the curing time [24]. Where the major mechanism of reduction is paniculate clogging of pores and biofilm production, a lower initial hydraulic conductivity resulted in a greater reduction. For both biofilm and biopolymer induced reductions, there appeared to be a minimum achievable hydraulic conductivity for similar conditions. This may be related to the bulk hydraulic conductivity of the polysaccharide suspension. Therefore, any further reduction of hydraulic conductivity may require the modification of the suspension properties or a reduction in the base material porosity. Where soils were mixed with a biopolymer solution and then compacted, the molded moisture content had an effect on the final hydraulic conductivity achieved [26]. The optimum moisture content for minimum hydraulic conductivity appears to be several percent wet of compaction optimum. The optimum moisture content for minimum hydraulic conductivity appears to be several percent wet of compaction optimum. This may be related to providing sufficient water to achieve a suspension of low enough viscosity to mix evenly through the sample and to fill an optimum void volume. The curing time also had an effect on the reduction of hydraulic conductivity [27].

5 CONCLUSIONS

Consideration of soil as a living ecosystem offers the potential for innovative and sustainable solutions to geotechnical problems. Recent studies have sought to investigate the potential for biofilms and biopolymers to improve the hydraulic conductivity of material for use as liners in waste containment facilities. Geotechnical applications currently being explored include cementation of sands to enhance bearing capacity and liquefaction resistance, sequestration of carbon, soil erosion control, groundwater flow control, and remediation of soil and groundwater impacted by metals and radionuclides. In addition to the in already achieved, there are other aspects of biofilms biopolymers, which their use attractive, or ties that are considered to be worthy of further investigation are

discussed below Gelatian deposits due to the functional groups polysaccharide which are the basis of some substitute exhibit ion exchange. This could be in heavy metals, Polysaccharides, such as sodium alginate set with divalent. This may be used to further reduce the bulk hydraulic conductivity of the biopolymers which may enhance of biopolymers on soil, biofilms produce mineral deposits. A period of time may increase the strength of the treated material by particles mineral deposits it may also decrease hydraulic conductivity by reducing the porosity of the over biopolymers as method of the soil properties.

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