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# EFFECT OF BIOGROUTING IN IMPROVING SOIL PROPERTIES-A REVIEW

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ABSTRACT

Soil stabilization implies modifying the properties of soil and making it into a strong and durable mass. Soil needs to be densified to improve its shear strength and bearing capacity. It can be achieved through various means like mechanical compaction, addition of chemicals or additives like lime, cement, bitumen and resin. Grouting technique incorporates injecting fluid or suspension called grout into the pores of soil. Chemical grouts and cement grouting are expensive and harmful ways which affect the ecosystem adversely. Hence alternative methods have to be proposed. Biogrouting is an emerging, environmental friendly and economical technique for stabilizing sandy soils where nontoxic micro-organisms are used as grouting material. Bio-chemical reaction happening due to the injected bacteria produces calcium carbonate precipitates. This technique which incorporates microbes for calcite precipitation is termed as Microbial Induced Calcite Precipitation (MICP). The precipitated calcium carbonate seals the cracks and voids within soil mass. Urea hydrolysis is the most preferred $CaCO_3$ precipitation method. It has highest rate of calcite precipitation and $CaCO_3$ yield than other existing methods. This paper presents a review on effect and feasibility of biogrouting for improving properties of soil using variety of bacterial concentration. The influence of MICP on the properties of soil such as shear strength, compressibility and permeability reported by researchers are evaluated.



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## INTRODUCTION

The soils having poor mechanical strength needs to be improved. Soil stabilization aims to improve the shear strength of soil thereby reducing the swelling/hydraulic conductivity and in overall increasing the bearing capacity of the soil. There are various techniques for soil improvement which includes the use of heavy machinery, chemical admixtures and grouting. Grouting is one among the common construction technique for geotechnical applications. Grouting techniques are done to increase strength and to reduce the permeability of soil. Traditionally chemical grouting or cement grouting are used widely in the construction industry. They are causing serious environmental hazards during their processing and implementation stages. These stabilization methods badly affect ground water flow and the release of carbon dioxide pollutes both air as well as water. The additives used in grouting such as lime, asphalt and resin changes the pH and may contaminate the soil. Thus there arises the need for a sustainable and eco friendly soil improvement method. Bio-geotechnical applications are gaining popularity nowadays. Recently bio grouting is used in various fields including improving the strength and durability of concrete, bricks, waste water treatment, soil improvement and mitigation of seismic liquefaction. Biogrout production depends upon the Microbial Induced Calcite Precipitation (MICP). MICP involves formation of calcium carbonate precipitation within the soil matrix, after injecting bacterial solution and cementation reagent (Urea and Calcium chloride dihydrate). MICP thus utilize urease producing microbes along with urea and dissolved calcium source. The calcite precipitation acts as binding agents to the sand particles and thus they behave as consolidated mass. MICP can be used for sand improvement to increase the shear strength and stiffness of soil matrix, while maintaining adequate permeability. Aerobic oxidation, nitrate

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reduction, urea hydrolysis and nitrate reduction are the other microbial processes that lead to the precipitation of calcium carbonate. Higher rate of $CaCO_3$ yield happens in urea hydrolysis. Urea hydrolysis is a chemical reaction in which urea reacts with water and produces an ionic product. This reaction is catalyzed by microbes supplied. When this reaction occurs in the presence of calcium ion ($Ca^{2+}$), calcium carbonate sediment is formed. Inside soil particles, after settling the produced sediment, a coating and bridge is formed sequentially around and between the particles and thereby increase the particles linkage. Hydrolyzing of urea in the absence of catalyzer is a slow and lengthy process. In the presence of urease, it is about $10^{14}$ times faster than the usual process. In this reaction, urease enzyme is discharged from a ureolytic bacterium, which acts as a catalyst for the reaction. Presence of non-ureolytic bacteria also accelerates MICP through addiction of nucleation sites regardless of chemical conditions. Various calcium carbonate producing bacterial strains are Bacillus subtilis, Sporosarcina pateurii, Bacillus sphaericus and Clostridium. MICP is attracting attention than chemical grouts because the microbial reaction in biogrout is expected to be slower than the chemical reaction in chemical grouts; a slower reaction would reduce the solidification speed, allowing the biogrout to spread through a greater volume of soil.

**Calcium carbonate precipitation by biogrouting**

Naturally cemented sand exists at earth's crust at particular portions depending upon the strata present. Cementation through $CaCO_3$ is achieved through biogrouting. The physical and mechanical properties of weak soil need to be improved. The effectiveness of MICP on loose and cohesion less soil was confirmed in previous studies by DeJong *et al.* (2006). Whiffin *et al.* (2007) reported that large scale soil improvement can be achieved through this technique. $CaCO_3$ precipitation has increased about 20% in organic soil through S. pasteurii bacterial action in studies done by Canakcia *et al.* (2015). Oliveira et. al (2016) reported that chance of $CaCO_3$ precipitation is greater in sandy and silty soils with strength gain from 40% to 106%. Carmona *et al.* (2016) shows that 95% precipitation ratio was induced during biocalcification for poorly graded sand treated with urease enzyme and 0.25 mol/L cementation reagent. The calcite precipitation was found to be reduced with increase in urea-$CaCl_2$ concentration. Out of various calcium chloride sources including calcium acetate and calcium nitrate, Enein *et al.* (2012) reported that calcium chloride produced the higher degree of crystallinity and greater amount of calcite precipitation. Gat *et al.* (2011) reveals that utilization of protein based growth medium and presence of Bacillus subtilis catalyzes MICP process by means of addition of nucleation sites in the form of bacterial cells.

**Effect of MICP on soil properties**

Several experiments revealed that MICP can reduce the hydraulic conductivity, water absorption and improve shear strength, compressibility.

**Shear strength**

Many studies have been conducted to evaluate the shear strength of soil treated with microbes. Soon *et al.* (2012) analysed that B. Megaterium concentration of $5x10^7$cfu/mL, 0.25M concentration of cementation reagent, $1.7x10^{-5}$ flow velocity and 48 h treatment duration exhibited significant increment ratios in shear strength from 1.41-2.64 for sandy silt and 1.14-1.25 for sand. Improvement in shear strength was analyzed due to higher calcite precipitation and more particle to particle contact in sandy silt. Biomass was found to be ineffective in improvement of shear strength of sandy silt. Rate of improvement in sandy soil has decreased and sandy silt has increased with increased soil density. Improvement ratios for 85%,90% and 95% soil densities were obtained as 1.25, 1.17 and 1.14 respectively for sand .Sharma and Ram krishnan (2016) conducted studies on the effect of MICP on the unconfined compressive strength of highly compressible clay (1.50-2.91) was slightly more when compared to that in intermediate compressible clay (1.45-2.26). For CI soil, S. pasteurii bacterial concentration of $1 \times 10^7$cfu/ml and 0.5M concentration of cementation reagent gave the highest increment, while for CH soil $1 \times 10^6$ cfu/ml and 0.5 M cementation reagent gave the best results. Shahraki *et al.* (2014) observed that for 1 x $10^8$ cells. $mL^{-1}$ concentration of S. pasteurii and higher cementation solution concentrations, strength and stiffness values of unconfined compression tests ranged from 50 to 240 kPa and from 6 to 56 MPa respectively. Greater improvements in stiffness and strength were achieved for lower bacterial cell and higher cementation solution concentrations, with a higher molarity of urea were proved to be effective.

The unconfined compression test results of enzymatic calcite precipitation conducted by Carmona *et al.* (2016) showed an improvement in value from 50 kPa to 140 kPa from variation of urea-$CaCl_2$ concentrations from 0.25 to 1.25 mol/L. Calcite minerals precipitated within the void spaces of soil particles increased the bond and thus improvement in soil shear strength. Dekuyer *et al.* (2012) reported that increase in shear strength is directly proportional to the increase in the produced calcite content. At the same calcite content, silica sand treated at lower degree of saturation exhibited higher values of undrained shear strength. Shear strength parameters increased due to the effective precipitation of calcite formation with decreasing degree of saturation. Obtained cohesion values of the untreated organic soil sample were 8.4 kPa & 5.8 kPa and internal friction angles are 30˚ and 43˚ at horizontal displacements of 2 mm and 6 mm, respectively. Similarly, cohesion values of treated sample with B. pasteurii, urea and $CaCl_2$ were 11 kPa and 2.7 kPa and internal friction angles are 38˚ and 50˚ at horizontal displacements of 2mm and 6mm, respectively was observed by Canakcia *et al.* (2015). The method increased the shear strength and reduced the compressibility of organic soil.

Chou *et al*. (2011) investigated that peak strength of direct shear and higher values of friction angles was observed under growing cell condition in loose silica sand with 99.7% quartz. Peak strength increased with normal stress. Peak strength was observed at normal stress of 21 kPa in loose sands. Improvement in shear strength was found to be due to the formation of calcite deposits through biocalcification in sand using microbe S. pasteurii that cement the loose soil. The dead cells were found to have no role in calcite formation. Shahaji *et al.* (2015) revealed that the coefficient of shear stress increased with normal stress and condition period for sand specimen. Indigenous bacteria such as Bacillus pasteurii could induce sufficient calcite precipitation to significantly modify engineering properties of sand compared to clay. Enein *et al.* (2012) shows that compressive strength of consolidated sand treated by calcium chloride was found greater than that treated with calcium acetate and calcium nitrate. More calcium carbonate was precipitated in case of calcium chloride. Difference in amount of calcite precipitation has contributed to greater compressive strength for calcium acetate than calcium nitrate.

This reduction is proved to be possible at a minimum calcite content of 1.0% (15 kg/m$^3$). Shahaji *et al.* (2015) proved that the coefficient of permeability decreased with increased concentration of bacterial solution and curing period. Filling of pores with calcite caused reduction in permeability for sand than clay. Investigations by Chou *et al.* (2011) shows that treatment with growing cells of S. pasteurii resulted in a decrease in hydraulic conductivity of loose and dense-silica

**Table 1. Comparison of shear strength properties**

| Author and year | Micro-organism | Soil | Microbial process | Properties | Result |
|---|---|---|---|---|---|
| Soon et.al (2012) | B. Megaterium | Sandy silt and sand | MICP | UCC | Shear strength of sandy silt is more |
| Sharma and Ramkrish-nan (2016) | S. pasteurii | CH and CL soil | MICP | UCC | Increased shear strength for CH than CI soil |
| Shahraki et.al (2014) | Sporosarcina pasteurii | Sand | MICP | UCC | Improvement in shear strength |
| Shahaji et. al (2015) | B. pasteurii | Black cotton soil, Red alluvial soil, murum and sand | MICP | Direct shear | Increased shear strength in sand |
| Canakci et. al (2015) | B. pasteurii | Organic soil | MICP | Direct shear | Improvement in shear strength |
| Chou et. al (2011) | S. pasteurii | Silica sand | Biocalcification | Direct shear | Improvement in shear strength |
| Carmona et al (2016) | | Sand | Biocalcification | UCC | Improvement in shear strength |
| Dekuyer et.al (2012) | | Silica sand | MICP | UCC | Improvement in shear parameters |

**Table 2. Comparison of hydraulic conductivity test results**

| Author and year | Micro-organism | Soil | Microbial process | Properties | Result |
|---|---|---|---|---|---|
| Soon et.al (2012) | B. Megateri-um | Sandy silt and sand | MICP | Permeability | More reduction for silty soil |
| Soon et.al (2014) | B. Megateri-um | Silty soil | MICP | Permeability | Reduced |
| Shahaji et.al (2015) | B. pasteurii | Black cotton soil, Red alluvial soil, murum and sand | MICP | Permeability | Reduced for sand |
| Chou et. al (2011) | S. pasteurii | Silica sand | Biocalcification | Permeability | Reduced |
| Dekuyer et.al (2012) | | Silica sand | MICP | Permeability | Reduced |
| Chu et. al (2012) | B. subtilis | Sand | MICP | Permeability | Reduced |
| Shahraki et.al (2013) | S. pasteurii | Sand | MICP | Permeability | Reduced |

**Table 3. Comparison of cbr values**

| Author and year | Micro-organism | Soil | Microbial process | Properties | Result |
|---|---|---|---|---|---|
| Chou et. al (2011) | S. pasteurii | Silica sand | Biocalcification | CBR | Increased CBR value |

## Permeability

Several authors have monitored reduction in hydraulic conductivity through laboratory investigations. Dekuyer *et al.* (2012) shows that permeability decreased with increase of produced calcite content ($CaCO_3$) irrespective of the degree of saturation at which the soil was treated for white silica sand. The results confirm the potential of MICP as a viable alternative technique that can be used successfully for soil improvement in many geotechnical engineering applications, including liquefaction of sand deposits, slope stability and subgrade improvement. Soon *et al.* (2012) conducted saturated hydraulic conductivity test of the MICP treated sandy silt with B. Megaterium concentration of 5 x 10$^7$ cfu/mL, 0.25M concentration of cementation reagent, 1.7x10$^{-5}$ flow velocity and 48 h treatment duration showed reduction ratios of 0.26-0.45 and 0.09-0.15 for sand specimen. The amounts of calcite precipitated in the treated sandy silt specimens ranged from 1.080% to 1.889% and 2.661% to 6.102% for sand specimen. Soon *et al.* (2014) observed that B. megaterium concentration of1 x 10$^8$ cfu/mL, 0.5M concentration of cementation reagent, 1.1 bar flow pressure and a treatment duration of 48 h showed 90% reduction in hydraulic conductivity for silty soil.

sand columns. Permeability has decreased from an initial value of 1 × 10$^4$ cm/s to about 2 × 10$^5$ cm/s. Clogging of pore space with calcium carbonate precipitates and biomass reduced the permeability of sample. Test results of Chu *et al.* (2012) reported that permeability has reduced to 1.6 × 10$^{-7}$ m/s (14 mm/d) after six treatments with B. subtilis and solutions of urea and calcium salt in surface or bulk of the sand. Shahraki *et al.* (2014) concluded that greater permeability coefficient reductions were achieved for S. pasteurii bacterial solution at6 × 10$^7$ cells/ml concentration 1.0M urea, 0.5M $CaCl_2$ cementation solution.

## CBR

DeJong *et al.* (2014) used S. pasteurii for urea hydrolysis under dead, resting and growing cell conditions. CBR value has increased when treated with growing cells in dense sand 99.7% quartz. Values obtained for dead, resting and growing cells are 39, 35 and 143 respectively for 10$^7$ cfu/mL. Higher relative density and increased number of contacts per particle within dense sand contributed to the higher CBR value.

**Conclusion**

In this paper a review on effect of biogrouting in soil properties is presented. From this detailed review it is revealed that

- Microbial induced calcite precipitation has proved to be a promising technique for soil stabilization especially for sands.
- MICP can be accelerated in presence of ureolytic and non-ureolytic bacteria. Protein based growth medium for microbes accelerates MICP.
- MICP was found to be efficiently improve the shear strength of sandy soil compared to clay due to the bridging of sand particles by calcite precipitation. Reduction in strength values were observed for higher concentration of cementation reagent.
- Hydraulic conductivity was reduced considerably in sand than clay during clogging of pores by calcite precipitation. Increasing concentration of bacterial solution and curing time contribute reduction in co-efficient of permeability values.
- CBR value was increased with increase in calcite precipitation which is catalyzed by growing cells.

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