Proceedings of the 20th International Conference on Soil Mechanics and Geotechnical Engineering– Rahman and Jaksa (Eds)
© 2022 Australian Geomechanics Society, Sydney, Australia, ISBN 978-0-9946261-4-1

Investigation of soil stabilization by cross-linking chitosan and sodium alginate biopolymers

Étude de la stabilisation des sols par réticulation de biopolymères de chitosane et d'alginate de sodium

Pooria Ghadir, Mohammad Reza Amiri Tasuji & Nader Shariatmadari
Department of Civil Engineering, Iran University of Science and Technology, Iran, pooria_ghadir@civileng.iust.ac.ir

Hadi Fatehi
School of Engineering and Built Environment, Griffith University, Australia

Khosro Shabani
Department of civil engineering, K. N. Toosi University of Technology, Iran

ABSTRACT**:** Biopolymers are environmentally friendly materials that are broadly used in various geoenvironmental applications such as removing heavy metals from contaminated soils, reducing erosion control, soil hydraulic conductivity and soil improvement. In this study, Chitosan-alginate films have been used through layer-by-layer assembly combined with crosslinking acid. Water susceptibility is a property of biopolymer treated soils which required more attention to be improved; thus, it has been tried to remedy this issue through biopolymer crosslinking approach. To this end, the effects of biopolymer content and biopolymer preparation method have been investigated. Unconfined compressive strength of the treated soil has been studied using unconfined compressive strength test. The results showed that cross-linking of biopolymers could enhance the mechanical strength compared to when they were used separately.

RÉSUMÉ: Les biopolymères sont des matériaux respectueux de l'environnement qui sont largement utilisés dans diverses applications géoenvironnementales telles que l'élimination des métaux lourds des sols contaminés, la réduction du contrôle de l'érosion, la conductivité hydraulique du sol et l'amélioration des sols. Dans cette étude, des films d'alginate de chitosane ont été utilisés à travers un assemblage couche par couche combiné avec un acide de réticulation. La sensibilité à l'eau est une propriété des sols traités aux biopolymères qui nécessitait plus d'attention pour être améliorée; ainsi, on a essayé de remédier à ce problème par une approche de réticulation biopolymère. À cette fin, les effets de la teneur en biopolymère et de la méthode de préparation du biopolymère ont été étudiés. La résistance à la compression non confinée du sol traité a été étudiée en utilisant un test de résistance à la compression non confiné. Les résultats ont montré que la réticulation des biopolymères pouvait améliorer la résistance mécanique par rapport à lorsqu'ils étaient utilisés séparément.

KEYWORDS: Chitosan; Sodium alginate; Cross-linking; Soil improvement.

1 INTRODUCTION

Ground improvement is the purposeful means of improving the geotechnical characteristics of marginal soils (Ghadir, Zamanian et al. 2021). Currently, various types of materials and methods are available for soil treatment purposes, and the most effective compounds are chosen according to their achievable results (Nicholson 2014). In general, ground improvement can be categorized to mechanical, physical, chemical, and biological approaches (Shariatmadari, Reza et al. 2020). Chemical modification is the oldest and most common method which is described as the addition of additives to soils for the purpose of changing the properties of soil to be acceptable according to design criteria (Ghadir and Ranjbar 2018, Shariatmadari, Hasanzadehshooiili et al. 2021). However, soil that is treated chemically is often prone to environmental problems making them less favourable (Fatehi, Abtahi et al. 2018, Hataf, Ghadir et al. 2018).

As an alternative, environmentally-friendly approaches implementing biological materials such as enzymes and microbes aim to enhance several aspects of marginal soil behaviors with a significantly smaller environmental impacts (Lear and Lewis 2012, Taha, Khan et al. 2013). Polysaccharides have been the major type of biopolymers investigated for ground improvement purposes; xanthan gum, gellan gum, lignin, agar gum, chitosan and sodium alginate are the examples of polysaccharide biopolymers. Most of biopolymers were utilized as water retention or adhesive agents (Chang, Im et al. 2015, Cai, Zhang et al. 2016, Chang, Im et al. 2016, Chang, Im et al. 2016, Chang, Im et al. 2017, Im, Tran et al. 2017).

Chitosan (CTS) is an animal based biopolymer with low cost, which is usually obtained from the hard outer skeleton of shellfish (Hataf, Ghadir et al. 2018). It is estimated that around 6 to 8 million tons of waste crab, lobster and shrimp shells is produced annually. In developing countries, these wastes usually end up in the sea or landfill, having a cost up to 150 US$ per ton in Australia (Yan and Chen 2015). Considering this great source, chitosan is able to provide geotechnical engineers with a low-cost biocompatible material (Hataf, Ghadir et al. 2018). Chitosan has been used in geotechnical and geoenvironmental contexts as an effective material to improve the behavior of soil. Studies have shown that chitosan-treated sand has functional implications in filters to remediate contaminated groundwater and is able to reduce the hydraulic conductivity of sandy soils which could create a suitable plugging effect (Khachatoorian, Petrisor et al. 2003, Wan, Petrisor et al. 2004). Furthermore, chitosan can bind metal ions and control the leachability (Kamari, Pulford et al. 2011). Chitosan is also able to make multiplexes with microorganisms due to its cationic property to improve water quality. Therefore, chitosan has a great potential for various geoenvironmental applications (Fang, Wenrong et al. 2004, Lertsutthiwong, Boonpuak et al. 2013).

Sodium alginate (SA) is a plant-based biopolymer, an anionic polysaccharide and a salt formed from alginic acid. It is a water soluble biopolymer which can link with water molecules and form a viscous gum. Sodium alginate is normally manufactured from the cell walls of marine brown algae (Ouwerx, Velings et al. 1998, Lee and Mooney 2012, Arab, Mousa et al. 2019, Fatehi, Bahmani et al. 2019). Moreover, the viscosity of alginate solution can be significantly affected by pH. Reduction in pH leads to a decrease in viscosity (Ouwerx, Velings et al. 1998). Also, hydrophobic and polar moieties, the side chain carboxylates, as well as highly charged molecules offers sodium alginate as a distinctive potential additive in soils (Fatehi, Bahmani et al. 2019).

The aim of this study is to evaluate the effect of using CTS and SA simultaneously to improve the behavior of sand. For this purpose, different samples with various amounts of additives were prepared and used to carry out unconfined compressive strength tests.

2 MATERIALS AND METHODS

2.1 *Soil*

In this study, the selected soil was the Firuzkuh sand (F161), a gap graded sand manufactured industrially in north-east of Tehran, Iran. The sieve analysis of the soil is presented in Figure 1.

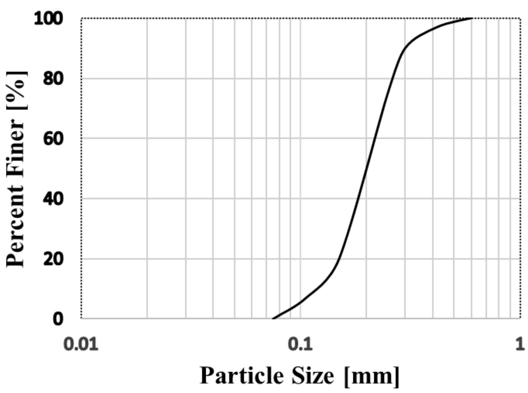

Figure 1. Particle size distribution curve of the soil used in the study.

2.2 *Film solutions*

In order to prepare the CTS solution, 1.1 g of CTS was dispersed in 62mL of acetic acid aqueous solution (2%, v/v). Also, for the purpose of enhancing flexibility and workability of the films, the Glycerol was added to the solution as a plasticizer (0.5%, v/v). As the addition of Ferulic Acid (FA) improves the mechanical properties of the films, the CTS solution was prepared with FA. For this end, 1.1 g of CTS was dissolved in 60 mL of acetic acid aqueous solution (2%, v/v). Then, 20 mg of FA was added to the solution after the CTS was completely dissolved. Moreover, glycerol (0.5%, v/v) was added when the solution was mixed uniformly.

By dissolving 1.1 g of SA in 100 mL of distilled water the SA solution was prepared. The mixture was left intact for a day until the SA was completely dissolved. Afterwards, the glycerol was added as a plasticizer (0.5%, v/v). Figure 2 demonstrates the .obtained solutions

2.3 *CTS-SA composite films*

The CTS solution was added dropwise to the SA solution slowly and uniformly with the volume ratio of 1:1, and then for 10 min it was centrifuged at 3000g (Figure 3). Next, the resulted mixture was cast onto a Plexiglas plate with the size of 30 cm × 20 cm and dried in an incubator for 24 h at 30 °C. When the films were completely dry, they were removed from the board (Figure 4).

2.4 *Experimental program*

Additives were added according to dried soil's weight. Considering the weight of the dried soil (132 gr), samples were prepared with the solution contents of 10% and 20%. In other words, 13.2 gr and 26.4 gr of biopolymer solutions were mixed with soil for 10% and 20% of biopolymer solution contents, respectively. For example, 0.145 gr of CTS biopolymer (0.11% according to dried soil weight) was used in 13.2 gr of CTS solution, and 0.725 gr of each biopolymer (1:1) was used in 13.2 gr of CTS-SA solution to mix with soil.

After preparing the samples, they were subjected to the Unconfined Compressive Strength (UCS) test. The molds were made of polypropylene and were 36 mm in diameter and 75 mm in height according to ASTM D2166 criteria. The soil was also compacted in the mold. For result accuracy, multiple tests were performed in a single test condition and samples were cured at the temperature of 60 °C.

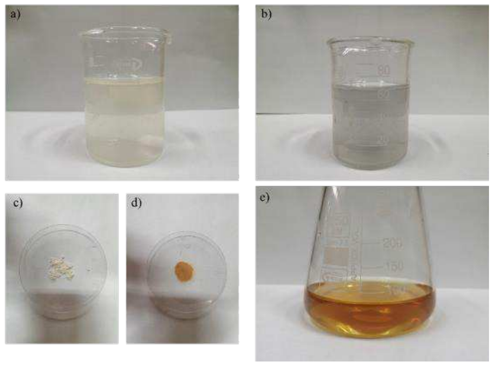

Figure 2. a) Chitosan solution, b) Chitosan solution with FA, c) FA, d) Sodium alginate, e) Sodium alginate solution.

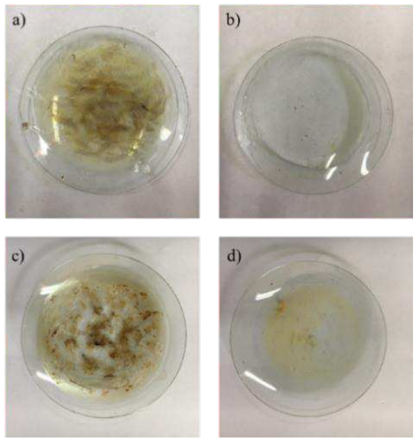

Figure 3. a) CTS-SA, b) Chitosan solution, c) Dry CTS-SA, d) Dry chitosan.

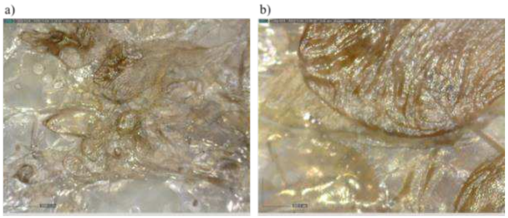

Figure 4. Optical images of CTS-SA.

3 RESULTS

Three types of samples were constructed, soil treated with SA, CTS, and CTS-SA biopolymers. The UCS test was carried out using standard UTM (Universal Testing Machine) device and in accordance with ASTM D2166. The loading process of the device was strain control with a displacement rate of 1 mm/min. The effects of additive amount on the treated soil samples was examined after 7 days of curing. 0.11% and 0.22% of biopolymers were added into the soil. Three samples were tested for each condition and the average was reported. As it can be seen in Figure 5. The natural sand and soil treated with 0.11% of SA biopolymer (10% of SA solution) showed no compressive strength. Also, Figure 6 shows the type of failure for treated samples.

As seen, compressive strength was significantly improved for the samples treated with additives. For samples with 0.11% of CTS and CTS-SA biopolymers, the UCS amount increased to 62 kPa and 36 kPa, after 7 days of curing, respectively. A tendency towards enhancement in the UCS values was maintained by increasing the additive amount to 0.22%. By adding 0.22% of CTS to the sand, strength of the soil increased by 271% (170kPa) compared to the sand treated with 0.11% of CTS. This increase for samples treated with 0.22% of SA and CTS-SA was 20 kPa and 105 kPa, respectively. While strength of the samples treated with 0.11% of SA and CTS biopolymers were 0 kPa and 62 kPa (62 kPa in total), respectively, the strength of the sample treated with the mixture of SA and CTS biopolymers (CTS-SA) with the volume ratio of 1:1 (0.11% of SA and 0.11% of CTS) was 141 kPa. In other words, the biopolymers yielded better results when they were used together.

As there is typically no charge on the sand particles surfaces, the compressive strength growth was mostly obtained from the binding properties of the biopolymer gel. The low compressive strength of the SA-treated sand is due to the poor distribution of the biopolymer solution throughout the sand sample and failure was happened in the area with the least amount of biopolymer. As a very low amount of chitosan gives a stiff gel, a higher strength was gained in comparison to SA. Applying SA and CTS together results in the direct interaction of cationic CTS with anionic SA which is expected to give a larger length of polymeric chains; this combination led to the obtainment of a relatively higher compressive strength.

4 CONCLUSIONS

Generally, the friction and cohesion are two main properties that the mechanical strength of a soil depends on. Load bearing mechanism is mainly based on a high frictional interaction forces between particles. Adhesion between particles can result in cohesion of soil composites which could excess the frictional bond.

The improvement of uniaxial strength can stem from the fact that biopolymers lie between the soil particles to bind them together, forming a bridge between the particles and increasing the frictional bond. This phenomenon can be the case for SA and CTS treated sand samples.

In samples that SA and CTS are used simultaneously, improvement in UCS could be related to increase in chains of the biopolymers that may be cross-linked to each other, or they may form a stronger bond between soil particles when they are in action together.

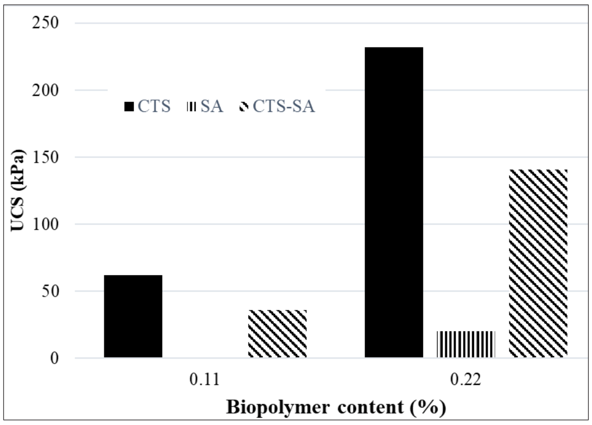

Figure 5. Results of unconfined strength test after 7 days.


Figure 6. Type of failure.

5 ACKNOWLEDGEMENTS

The project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 778120. Furthermore, this research was supported by Chem Concrete Pty Ltd and Gozar Accelerator.

6 REFERENCES

Arab, M. G., R. Mousa, A. Gabr, A. Azam, S. El-Badawy and A. Hassan (2019). "Resilient Behavior of Sodium Alginate–Treated Cohesive Soils for Pavement Applications." Journal of Materials in Civil Engineering **31**(1): 04018361.

Cai, G., T. Zhang, S. Liu, J. Li and D. Jie (2016). "Stabilization mechanism and effect evaluation of stabilized silt with lignin based on laboratory data." Marine Georesources & Geotechnology **34**(4): 331-340.

Chang, I., J. Im and G.-C. Cho (2016). "Geotechnical engineering behaviors of gellan gum biopolymer treated sand." Canadian Geotechnical Journal **53**(10): 1658-1670.

Chang, I., J. Im and G.-C. Cho (2016). "Introduction of microbial biopolymers in soil treatment for future environmentally-friendly and sustainable geotechnical engineering." Sustainability **8**(3): 251.

Chang, I., J. Im, S.-W. Lee and G.-C. Cho (2017). "Strength durability of gellan gum biopolymer-treated Korean sand with cyclic wetting and drying." Construction and Building Materials **143**: 210-221.

Chang, I., J. Im, A. K. Prasidhi and G.-C. Cho (2015). "Effects of Xanthan gum biopolymer on soil strengthening." Construction and Building Materials **74**: 65-72.

Fang, H., H. Wenrong and L. Yuezhong (2004). "Investigation of isolation and immobilization of a microbial consortium for decoloring of azo dye 4BS." Water research **38**(16): 3596-3604.

Fatehi, H., S. M. Abtahi, H. Hashemolhosseini and S. M. Hejazi (2018). "A novel study on using protein based biopolymers in soil strengthening." Construction and Building Materials **167**: 813-821.

Fatehi, H., M. Bahmani and A. Noorzad (2019). Strengthening of dune sand with sodium alginate biopolymer. Geo-Congress 2019: Soil Improvement, American Society of Civil Engineers Reston, VA.

Ghadir, P. and N. Ranjbar (2018). "Clayey soil stabilization using geopolymer and Portland cement." Construction and Building Materials **188**: 361-371.

Ghadir, P., M. Zamanian, N. Mahbubi-Motlagh, M. Saberian, J. Li and N. Ranjbar (2021). "Shear strength and life cycle assessment of volcanic ash-based geopolymer and cement stabilized soil: A comparative study." Transportation Geotechnics **31**: 100639.

Hataf, N., P. Ghadir and N. Ranjbar (2018). "Investigation of soil stabilization using chitosan biopolymer." Journal of Cleaner Production **170**: 1493-1500.

Im, J., A. T. Tran, I. Chang and G.-C. Cho (2017). "Dynamic properties of gel-type biopolymer-treated sands evaluated by Resonant Column (RC) tests." Geomechanics and Engineering **12**(5): 815-830.

Kamari, A., I. Pulford and J. Hargreaves (2011). "Chitosan as a potential amendment to remediate metal contaminated soil—A characterisation study." Colloids and Surfaces B: Biointerfaces **82**(1): 71-80.

Khachatoorian, R., I. G. Petrisor, C.-C. Kwan and T. F. Yen (2003). "Biopolymer plugging effect: laboratory-pressurized pumping flow studies." Journal of Petroleum Science and Engineering **38**(1-2): 13-21.

Lear, G. and G. D. Lewis (2012). "Microbial biofilms: current research and applications."

Lee, K. Y. and D. J. Mooney (2012). "Alginate: properties and biomedical applications." Progress in polymer science **37**(1): 106-126.

Lertsutthiwong, P., D. Boonpuak, W. Pungrasmi and S. Powtongsook (2013). "Immobilization of nitrite oxidizing bacteria using biopolymeric chitosan media." Journal of Environmental Sciences **25**(2): 262-267.

Nicholson, P. G. (2014). Soil improvement and ground modification methods, Butterworth-Heinemann.

Ouwerx, C., N. Velings, M. Mestdagh and M. A. Axelos (1998). "Physico-chemical properties and rheology of alginate gel beads formed with various divalent cations." Polymer Gels and Networks **6**(5): 393-408.

Shariatmadari, N., M. Reza, A. Tasuji, P. Ghadir and A. A. Javadi (2020). Experimental study on the effect of chitosan biopolymer on sandy soil stabilization. E3S Web of Conferences, EDP Sciences.

Shariatmadari, N., H. Hasanzadehshooiili, P. Ghadir, F. Saeidi and F. Moharami (2021). "Compressive Strength of Sandy Soils Stabilized with Alkali-Activated Volcanic Ash and Slag." Journal of Materials in Civil Engineering **33**(11): 04021295.

Taha, M. R., T. A. Khan, I. T. Jawad, A. A. Firoozi and A. A. Firoozi (2013). "Recent Experimental Studies in Soil Stabilization with Bio-Enzymes–A." Electron J Geotech Eng **18**: 3881-3894.

Wan, M.-W., I. G. Petrisor, H.-T. Lai, D. Kim and T. F. Yen (2004). "Copper adsorption through chitosan immobilized on sand to demonstrate the feasibility for in situ soil decontamination." Carbohydrate Polymers **55**(3): 249-254.

Yan, N. and X. Chen (2015). "Sustainability: Don't waste seafood waste." Nature News **524**(7564): 155.