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Geotechnical Characteristics of Bio-modified Sand: A Review

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Abstract—The usage of environmental friendly material for soil treatment and improvement are a key viewpoint for the sustainable development. Biopolymers are polymers produced by characteristic natural process and comprise of monomeric units that are accumulated into bigger arrangements and it is perceived as a choice to use instead of traditional chemicals due to their potential cost-effective, low environmental impacts, non- poisonous and non-secondary impact. Some geo-environmental and geotechnical application of biopolymers are now being explored includes binding the soil particles to improve strength, load carrying capacity, soil erosion resistance, liquefaction resistance, permeability coefficient, groundwater movement restriction. This paper presents the latest research works including laboratory experimental results and conclusion based on that. It was concluded for the review that biopolymers have great potential to enhance geotechnical engineering characteristics of soil at low concentration and can possibly substitute traditional binder in geotechnical engineering application as sustainable material for soil stabilization.

Keywords— Biopolymer, soil improvement, sustainability

I. INTRODUCTION

In geotechnical engineering particularly the soil treatment and use of soil (or earth) in development, is a long-standing specialized field, dating to the start of human civilization. In ancient Mesopotamia and Babylonia, mud was utilized as a typical construction material for different types of blocks (i.e., sun-dried and furnace terminated) to make the design of the city. Sumerians broadly utilized bitumen as a cementing to upgrade the strength and strength of Earth Wall (Potts 1997). In early Egypt, earth designing approaches were created to make embankment to control the yearly flooding of the Nile River. Architects in early China utilized a sticky rice mortar that contained amylopectin as a binder for construction of the Great Wall (Ham et al. 2016). As human development has proceeded, endurance and strength of construction materials have advanced as well. The invention of natural pozzolans material alike volcanic ash updated construction materials, including the famous concrete of old Rome.

The characteristic equation for Roman Concrete was a combination of volcanic dusts with a cementations material alike gypsum or lime, with blended aggregates, and it was utilized to achieve extremely strong constructions including arches and domes (Delatte 2001). Following industrial revolution, Portland Cement (Ordinary Cement) being to be the most popularly utilized building and construction material, for both architectural purposes and soil improvement and stabilization and strengthening purposes .

The principal goal of stabilization of soil and ground improvement activities is to alter the geotechnical characteristics of soil to enhance its design parameters, such as resistance of break under compression, load carrying capacity, permeability coefficient, stability, and erosion resistance(Chu et al. 2009).

In general two widely ground improvement and soil stabilization technique are used. The first is mechanical modification whereby the features of the soil are strengthened via physical methods, alike compactions, and removal of water, loading, and volume change. The second is stabilizing soil using chemical additives that connect the soil particles together with help of a chemical reaction, such as cement hydration or pozzolanic reactions. Traditional material commonly utilized for ground enhancements are cement, lime, fly ash; however, they have several environmentally unfriendly properties, which restrict their uses as a sustainable materials (Chang and Cho 2012; Worrell et al. 2001, Rehan and Nehdi 2005).

Portland cement is the most predominant common added substance which brings about treating the soil (Hojati and Radlińska 2017). Unluckily the utilization of extensive measures of cement in huge volume soil treatment project has a few disadvantages, especially regarding environment and sustainability perspective. In particular, huge measures of carbon dioxide (CO2) and nitrogen oxide (NOx) gases are radiated during the production of cement, with a certain level of air outflows as cement dust, which create another potential environmental problem((Chang et al. 2015), (Latifi et al. 2017). Carbon dioxide is the primary reason of environmental change, and cement is in responsible of 5–7% of the world's CO2 emanations and records for 12–15% of the total energy consumption in the (Gutiérrez et al. 2017).

As an option to conventional improvement of soil and treatment of soil methods, biological methodologies are presently being effectively examined in the field of geotechnical engineering, including microorganism infusion and result precipitation. Specifically, microbial produced biopolymers have been presented as a new binder, particularly for improvement of soil and treatment of soil.

Biopolymers are polymers produced by characteristic natural process and comprise of monomeric units that are accumulated into bigger arrangements and it is perceived as a sustainable material that can be used for soil improvement instead of traditional chemicals and material due to their potential cost-effective, low environmental impacts, non-poisonous and non-secondary impact.

Current investigations have declared a promising biopolymer impact on improving the strength and stability of soils (Chang et al. 2016, Orts et al. 2007). Microbial biopolymers show disintegration of soil decrease against surface water overflow in waterfronts (Ham et al. 2018) and Agricultural farmlands (Orts et al. 2000), while reinforcing and between molecule collaboration practices of the polysaccharide-type biopolymers, for example, dextran, beta glucan, Xanthan Gum, Guar Gum and gellan gum, with various types of soil have been examined by numerous scholars (Chang and Cho 2012, Chang et al. 2016, Chang et al. 2017, Chang et al. 2015c, Kwon and Ajo-Franklin 2013). This paper provides review of latest research works including experiment performed, results and with conclusion made.

II. Literature Review

A progressive approach has emerged over the last years to explore the possibility and effectiveness of using eco-friendly materials in industrial activities following significant concerns about the production of environmentally unfriendly materials and chemicals. Ground improvement techniques, as major activities in the construction sector, are no exception to this trend. A number of researchers have investigated the potential applications of biopolymers as non-hazardous materials for ground improvement. Some research accomplishments concerning the utilization of biopolymers as soil modifiers are written below.

2. 1. Effect of Biopolymer on Strength of Soil

Dehghan et al. (2018) conducted research on strengthing of soil by utilizing xanthan gum biopolymer. To evaluate the engineering feature of modified soil, Compaction, consolidation, permeability and triaxial test were conducted with different contents of biopolymer and curing times. The test result indicated that by adding a biopolymer, the maximum soil strength is improved from 228.7 kPa for natural soil to 550 kPa for soil stabilized with 2% xanthan gum after twenty eight days curing.It also noted that increasing of curing time leads to increase in compressive strength of soil.

Kullayappa and Suresh (2018) conducted Experimental Study by of expansive Soil Mixed with Guar Gum a Bio-Enzyme- (case study).Those tests are penetration resistance (CBR), Strength properties, Compaction properties, and SEM analysis.

The Author reported that maximum increase in CBR value of soil mixed with guar gum which occurs at 2.0 %.The un-soaked CBR value of soil with 0.5% to 2.0% of guar gum mixed with soil showed an increment of 46 to 217% whereas 2.5% of biopolymer admixed soil shows an increment of 143%. Soaked CBR values for soil with 0.5 to 2.0% of guar gum admixed soil indicates an increment of 40 to 165%. Beyond the 2.0%, guar gum percent the soaked CBR values reduced. The maximum un-soaked CBR value of 2.0% guar gum admixed soil is 3.2 times that of the untreated soil.

The UCS test showed that unconfined compressive strength of the admixed soil increases within biopolymer percentage and curing period. The UCS of natural soil is 1.02 kg/cm2 in all curing days and 3 days and 7days curing strengths of 2.0% biopolymer treated soil is 2.51 kg/cm2 and 2.72 kg/cm2 respectively. This indicates that UCT of admixed soil at 2.0% biopolymer for the sample tested with 7 days curing period is 2.6 times that untreated soil.

Wiszniewski et al. (2017) conducted a laboratory assessment of geomechanical properties of sandy soil improved by biopolymer using triaxial shear compression tests and unconfined compression tests at 0.0, 0.5 and 1.5% and 0.5, 1.0 and 1.5% of xanthan gum contents for triaxial and unconfined compression test respectively.

The Triaxial compression test result showed that soil treated with higher contents of Xanthan gum produced cohesion value. Internal friction angle value enhanced for 0.5% biopolymer content, but it decreases for 1.5%, while cohesion for that sample is almost 100 kPa. Based on the result; cohesion is most significant in strength improvement which was increased from 7.14 to 92.95kpa for cohesion less medium sand.

Unconfined compressive test (UCS) result containing respectively 0.5, 1.0 and 1.5% of biopolymers show that addition of biopolymer can remarkably improve the compressive strength of soil from 1.13MPa to 2.71 MPa. Samples were completely dry while testing; the water addition might cause some decomposition of the particles or more elastic behavior. Little effect of curing time observed on 0.5% sample. But Compressive strength decrease from 1.84 MPa to 1.13 MPa for 3 and 28 days curing time respectively.

Lee et al. (2017) Conducted direct shear test on biopolymer treated sand to know the effect of Xanthan Gum biopolymer on shear strength behavior of sand.

Pure (untreated) sand, xanthan gum-treated sand and gypsum-treated sand specimens were used for the experimental procedures in this study. Xanthan gum-treated sand specimens were prepared with 0.5%, 1.0%, and 2.0% xanthan gum contents to the mass of sand and 2.5%, 5.0%, and 10.0% xanthan gum solutions (xanthan gum content to the mass of water).

According to the shear test results, Xanthan gum content of 1.0% sufficiently improves the inter-particle cohesion of cohesion less sands 3.8 times and more (up to 14 times for dried state) than un stabilized sand, without consideration of the xanthan gum gel condition.

Chang et al. (2015) investigated the influence of Xanthan gum biopolymer on the strength of the soil. The authors performed an unconfined compression test with different soils and elastic modulus (secant modulus) were also determined during compression.

Xanthan gum treated soils showed significant increases in compressive strength and elastic modulus biopolymer enhances the inter-particle bonding of fine soil (i.e., clay), giving six-fold compressive strength improvement.

The authors reported that 1% Xanthan gum treatment results in much higher compressive strength than 10% cement treatment and generalized that Xanthan gum has strong potential for use related to environmentally-friendly purposes in place of conventional construction and building materials.

Long term durability assessment sand and clay soil is performed revealed that the compressive strength of both sand and clay slightly increased. The stiffness of Xanthan gum treated clay meanwhile remained nearly constant while that of sand showed a notable increase with time regardless of the Xanthan gum content.

Authors point out four factors that control strength of stabilized soil: (1) type of soil, (2) dehydration (e.g., moisture content), (3) Xanthan gum content, and (4) mixing method. And concluded that the strength increases with an increase in the Xanthan gum content to 1.5% and then decrease. As for the Fine soils have a better strengthening effect than coarse grained soils; however, the most effective soil type was a mixture of the two with a well- graded size distribution. Dry mixing method was shown to yield a more even distribution of Xanthan gum within the soil, thereby maximizing the strengthening effect on the soil.

Akbulut and Cabalar (2014) Conducted investigation geotechnical properties of biopolymer stabilized sand. California Bearing Ratio (CBR) and Unconfined Compression tests (UCS) were conducted to evaluate two major parameter of soils, viz; compressive strength, and bearing capacity.

According to the authors result, the addition of xanthan gum enhances the strength of unconfined compression between 0.11-0.36 MPa for 4 days cured samples, and 0.46-1.02 MPa for 32 days cured samples. It has been also observed that CBR values increase as the xanthan gum content and curing time increases.

Khatami and O'Kelly (2013) studied some mechanical properties of sand treated with agar and starch biopolymers over a range of concentrations (1–4 % agar and 0.5–1 % starch). Depending on the concentration biopolymer used the unconfined compressive strength of sand treated by biopolymers ranged from 158 to 487 kPa. Triaxial compression tests with various confining loads also showed that the biopolymers efficiently increased coherence and stiffness of the treated sand. The enhancement in properties of sand treated with agar and modified starch (biopolymers) has been found to be directly dependent on the amount of agar as the main element and starch as the additive.

Chen et al.(2013) conducted a study on utilizing guar and Xanthan gum, biopolymers that are produced by microorganism and cheap, to improve (MT) mine tailings. To determine undrained shear strength and liquid limit of air-dried MT mixed with a solution of biopolymers simple fall cone penetration technique was applied at various boipolymers contents. According to the authors report for given water content, the cone penetration decreases as the biopolymer concentration raises indicate that the addition of more biopolymer makes the mine tailing more stronger. For guar gum, the strength of mine tailing without water removal under shear. (Su) increases from 1.6 to 22.3 kPa when the content changes from 0% to 2%; for xanthan gum, the strength of mine tailing under shear without removing water (Su) increases from 1.6 to 5.0 kPa when the concentration changes from 0 to 3%. Guar gum was observed to be more successful incase of Xanthan gum(XG) in rising the undrained shear strength and liquid limit of the Mine Tailing, as the Guar gum (GG) solution was more viscous than the Xanthan gum(XG) solution at the corresponding Concentration.

Cabalar et al. (2011) performed a direct shear test to investigate the engineering characteristics of sand stabilized using Xanthan gum. The laboratory data revealed that the strength of sand under shear enhanced as Xanthan gum content increased beyond 1 %. Improvements in the highest shear force of nearly 14–166% achieved in a sample stabilized with 3% biopolymer (XG) contents, and about 93–288% achieved in a stabilized sample with 5% content. A reduction in the highest shear force of around 7–60% emerged in the sample stabilized with 1% biopolymer content.

It also revealed that that, xanthan gum biopolymer content is the main factor that affects engineering characteristics of sand; the effect of curing was not significant within the examined range of time.

2.2.Effect of Biopolymer on Hydraulic Conductivity of Soil

Dehghan et al. (2018) conducted laboratory test to investigate effect of biopolymer on permeability of soil expansive soil. The permeability coefficients for different values of xanthan gum and guar gum biopolymers for two different densities after 28 days of treatment show that significant reduction in permeability, depending on the biopolymer type. The permeability for soil without modification with rd = 14 kN/ m^3 was 4.9×10^{-6} m⁄s which was reduced by 18.6% of this initial amount by adding 0.5% xanthan gum. The permeability reduction was lower for guar gum, mounting to 88% of the initial amount for 0.5% guar gum. It was also observed that with an increase in density to 15 kN/ m^3 the permeability of untreated soil was reduced to 0.6×10^{-6} m⁄s.

Wiszniewski and Calabar (2015) conducted research on permeability of coarse and medium sand stabilized with biopolymer separately. To examine the impacts of bio-substance, at the concentration of 0.5 %, 1.0 %, and 1.5 %, by weight of dry were employed in a high transmitter of water sandy soil. The Authors reported that the ability of water to flow through soil remarkably diminishes with increasing biopolymers.

For coarse sand, an increase of 0.1% biopolymer to coarse sand diminishes hydraulic conductivity to 50% of the beginning value. Increase of 1% biopolymer decrease permeability from 7.16 *10-3 m/s to 5.75 * 10-5 m/s.
For medium sand, an increase of 0.5% to the medium diminishes permeability 10-3 % of the original value and for 1.5% diminish from 8.46*10-5 m/s to 2.84*10-11m/s, which is under one million times.
The scholars presumed that biopolymers (i.e., xanthan gum) can essentially reduce hydraulic conductivity (permeability) of coarse sand without producing environmental toxicity and biopolymer concentration was the main factor for advancement in the appearance of biopolymer stabilized sand.
Abouazza et al. (2009) conducted research on the pore plugging effect of biopolymers: Xanthan gum, sodium alginate and guar gum, and their effectiveness in decreasing the flowing ability of water through silty sand. Results indicate that the biopolymers cause a reduction of the initial permeability of the silty sand (1 * 10 -6 m/s) to three times and four times for 1% of sodium alginate and xanthan gum respectively. Moreover, a reduction of at least four orders of magnitude can be accomplished using even 0.5% xanthan gum, emphasizing its greater pore-plugging effect. The investigation indicated that guar gum to be the least efficient biopolymer, but it was still able to lesser the flowing ability of water through of the silty sand.
Khachatoorian et al. (2003) performed investigation on the plugging effect of biopolymers, namely xanthan, polyhydroxybutyrate (PHB), guar gum, polyglutamic acid (PGA) and chitosan in a laboratory-pressurized pumping flow system. Authors reported that all of the examined biopolymers have revealed mild to good plugging effects by decreasing the permeability ratio of sand over the 11-day experimental period.
Authors report that best plugging effect was achieved for PHB, with a permeability ratio reduction factor of 1014 over 11 days, followed by chitosan and PGA with a reduction factor of 107 over 11 days and only by a factor of 30 for guar gum and even a lower factor of 8 for xanthan.

2.3.Effect of Biopolymer on Compaction Characteristics of Soil

Dehghan et al., (2018) conducted an investigation on the strengthing of soil by utilizing guar guam and xanthan gum and performed compaction test with varies percent of the biopolymers to measure compaction properties of treated soil.
The result of compaction tests indicated that an increase in the amount of biopolymers leads to the decrease in the MDD (Maximum dry density) and the increase in the OMC (Optimum moisture content). For xanthan gum samples, with an increment of biopolymer from 0 to 2%, density is reduced from 18.83 to 17.55 kN/m3, and for guar gum samples, this value was decreased to 17.65 kN m3.
The OMC of the un stabilized soil was 13.2%. By increasing biopolymer amount with 2% xanthan gum and guar gum, the OMC was raised to 17.2% and 16.1%, respectively.
Kullayappa and Suresh P (2018) conducted Experimental Study by of expansive Soil Mixed with Guar Gum a Bio-Enzyme- (case study).Those tests are: Atterberg limits, Differential Free Swell Index (FSI), penetration resistance (CBR), Strength properties, Compaction properties, and SEM analysis.
From compaction result, the MDD of untreated soil to 2.0% of biopolymer treated soil is increased from 1.45 g/cc to 1.68 g/cc. The OMC for untreated soil is 23.67% and for 2.0% treated soil is 18.10%. The decrement decrease of moisture content until 2.0% concentration of Guar gum. Beyond the 2.0% guar gum of biopolymer the water contents may be increases.
Ayeldeen et al. (2017) investigated the possibility of using biopolymer to improve the mechanical behaviors of collapsible soil. Two types of biopolymers were (xanthan gum and guar gum) utilized and compaction tests were conducted to know compaction characterization of treated soil. Test results indicated that maximum dry unit weight decrease with increasing biopolymer concentration for both xanthan and guar gum, For xanthan gum specimens, the unit weight decrease from 19 kN/m3 to 17.2 kN/m^3 by increasing the concentration from zero to 2% while in the case of guar gum, the unit weight reached 16.7 kN/m^3 at a biopolymer concentration of 2%.
The optimum water content was found to increase with the increasing solution concentration. Meanwhile, the optimum water content (OMC) increased from 12.4% to 15.3% and 14.4% for zero concentration, to 2% for guar gum and xanthan gum, respectively, due to the increasing absorbed water used to dissolve the biopolymer by increasing the concentration.
Ayeldeen et al. (2016) studied the mixture of biopolymers and sandy soil physical characteristics. Performed laboratory compaction test to know compaction characterization of biopolymer treated soil. The maximum dry density was observed to increase with increasing gum concentrations for the three biopolymers however, the density decrease for higher contents of biopolymers. Density raised from 19.10kn/m3 to 20.14 kN/m^3 for both guar gum and modified starch at 1 % concentration before it began to reduce to about 20.08 kN/m3 at a concentration of 2 %.
The MDD (Maximum dry density) of sand-biopolymer mixture and Viscosity of biopolymer solution is strongly related. The mixture dry density initially increased with increasing solution viscosity for the three sand/biopolymer mixtures. The mixture dry density reached its peak point at a viscosity of approximately 40 to 50 mPa s depending on the biopolymer. After the peak density, the high-viscosity solutions shifted the soil particles away from each other, which reduced the soil density. For example, increasing viscosity of guar gum solution from 50 to 140 mPa s caused a reduction in density from 20.21 to 19.97 kN/m^3. It was noticed that Optimum moisture content increase with increasing biopolymer concentrations for all specimens. This is due to increasing amounts of water being absorbed through the biopolymer with increasing concentration.

III. CONCLUSIONS

Ground improvement technique has been seriously examined and created over hundreds of years. The utilization of Cement in geotechnical engineering could be viewed as birth of present-day ground improvement methodology, and various exploration has since been performed to improve feature of cement. But, in the late twentieth century, environmental concerns offered to ascend to rising interest for environment-friendly techniques. The growth of green binder and numerous potential cement replacements, including use of biopolymer directly in the soil layer, have been introduced. From review of investigations it can be concluded that:

Biopolymers can enhance strength of soils, increase erosion resistance, bearing capacity and decrease permeability, volume change and offer various benefits in such applications, including being environment-friendly and effective at low concentrations. Optimum concentration of biopolymer for improvement is in the range of 1-2%. In contradiction to cement, biopolymers have great potential to diminish CO2 emissions and energy consumption. Besides, it shows functionality to encourage plants germination and stabilization and vegetation growth which can be practiced as countermeasures for farm-land protection and anti-desertification and facing other problem to environmental preservation.

Even though some studies in recent years have investigated nontraditional stabilization, still there is no standards for laboratory test, field application, optimum concentrations of biopolymer and preparation methods, selecting the appropriate types, dosage and amounts of nontraditional stabilizers for various soil types and engineering applications.

There is also limited literature on durability, compaction characteristics on cohesion less soil and case studies of practical implementation for non-conventional ground improvement.

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