IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 17, Issue 4 Ser. I (Jul. – Aug. 2020), PP 01-16
www.iosrjournals.org

Investigating the Potential of Biopolymers in Strengthening Of Clayey Soil

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Abstract
Soil treatment is an essential concern for geotechnical engineers. The aim soil treatment is to improve the properties of problematic soil such as stability, strength and erosion resistance. Conventional soil treatment materials have several shortcomings, especially from environmental stand point. Therefore various biological approaches recently have been explored as environmental friendly alternatives in geotechnical engineering. This study investigate the potential of two biopolymers xanthan gum and chitosan(environmental friendly)in strengthening of clayey soil. Xanthan gum is a polysaccharide which is commonly used in food industry as an additive and chitosan which is synthesized from shrimp shell waste. These two biopolymers are added in the soil separately to evaluate its potential on mechanical properties of clay soil at different concentration, mixing conditions and curing periods. The effectiveness of the biopolymers was determined by conducting compaction test and unconfined compression test on treated soil specimen, also SEM analysis was performed to investigate the interaction of soil-biopolymer mixtures

Keywords: *Stabilization, Xanthan gum, Chitosan, SEM, UCS*

Date of Submission: 30-06-2020 Date of Acceptance: 16-07-2020

I. Introduction

Geotechnical engineering especially the treatment and usage of soil (or earth) in construction is a venerable technical field, dating to the beginning of human civilization. Soil stabilization improves the properties of soil such as volume stability, strength, compressibility, permeability, durability, dust control etc, which makes the soil suitable for use. Soil stabilization is required in many geotechnical applications, including road construction, slope stabilization, erosion control, foundation, embankment treatment and coast line improvement. Therefore soil stabilization and the process of improving its properties is fundamental.

There are different methods of stabilization, which include physical, mechanical, chemical and polymer method of stabilization. Physical method involves physical process to improve soil properties. This include compaction method and drainage. Compaction process lead to increase in water resistance capacity of soil. Drainage is less common due to generally poor connection between method effectiveness and cost. But, compaction is very common method. Although, it make soil more resistant to water, the resistance will be reducing over time. Chemical soil stabilization uses chemicals and emulsion as compaction aids, water repellents and binders. The most effective chemical soil stabilization is on which results in non-water-soluble and soil matrix. There are many additives are available, among them most widely used soil strengthening additives, such as cement, have negative impacts on the environment. The most critical of these problems are CO2 and NOX (nitrogen oxide) emissions and particulate air suspensions. As a result, a suitable eco-friendly replacement for conventional materials is required. The use of polymers of biological origin, or biopolymers, has been proposed as a more environmental friendly and sustainable alternative. Biopolymers are carbon neutral and renewable. Polymer method of stabilization have a number of significant advantages over physical and chemical methods.

This study evaluate the viability of two biopolymers- xanthan gum and chitosan.

These biopolymers are cheaper and drastically less dangerous for the environment as compared to many chemical solution. Dredged marine clay are considered for effectiveness of biopolymer stabilization. The developing works in coastal areas involve dredging works for construction of structures, such as ports, water ways, and breakwaters, land reclamation and widening section of river or sea to facilitate economic activities and to erect coastal protection system. The process dislodges sediments from the sea bed, termed as dredged marine soil, and are generally considered as geo waste for dumping. Dredged clay has been re-used as a construction material, back filling of quay walls, artificial barrier layers of waste disposal sites, submerged embankments with proper treatment. The purpose of this study is to verify the engineering performance and efficiency of biopolymers (xanthan gum and chitosan) treated soil. The initial properties of soil have to be evaluated. Experimental test were carried out to identify the strengthening effect of biopolymers treated soil. Compressive strength measurement and SEM analysis were performed to investigate the macro and micro-interactions of soil-biopolymer mixtures. Long term durability was evaluated to verify the usability and sustainability of biopolymer treated soil. Various effects such as mixing condition, biopolymer concentration were also evaluated. The xanthan gum biopolymer used with concentration of .5%, 1%, 1.5%, 2%, 2.5% and chitosan biopolymer used with concentration of .06%, .12%, .18%, .24%, .3%. Finally, the efficiency of these two biopolymers are compared with the untreated soil

II. Objectives

- To determine the geotechnical properties of dredged marine clay.
- To evaluate the change in strength characteristics of clayey soil treated with biopolymers(xanthan gum and chitosan)
- To study the various effects such as mixing condition, biopolymer concentration and curing periods
- To study the feasibility of biopolymers as soil stabilizer.

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III. Materials and Methods

3.1 Materials

3.1.1 Dredged Marine Soil

Marine clay is the type of soil abundantly found at coastal corridors, off shore areas and many other parts of earth. The process of dredging dislodges enormous amounts of dredged marine soil and are generally considered as a geo waste for dumping. In India, usually the marine clay deposited in navigation channels are removed for providing sufficient draft to ship. These clays are removed from the bed of channel using dredgers and are deposited back into the sea far away from the navigation channel. But this practice is uneconomical since it is unproductive and consumes valuable resources. The problem can be tackled by using dredged clay in construction activities such that it will have no baleful effect on environment. This can be achieved by stabilizing the dredged marine clay with suitable stabilizers.

In the present investigation the dredged marine soil was collected from a disposal land located at Vypin (BPCL) , Ernakulam. The soil was in wet form. The collected samples were air dried and pulverized. Test were done to investigate the geotechnical properties of dredged soil. The specific gravity of sample was found by pycnometer method and the value was found to be 2.6. Therefore the specific gravity is in the range of organic clay (2.58-2.65). Liquid limit was obtained using Casagrande's apparatus and the value was 58%. Using sedimentation analysis and sieve analysis the particle distribution curve of the sample was obtained. It was observed that more than 60% of particle were less than .002mm in size. Therefore by Indian standard method of classification of soil, the sample was classified as clay of high compressibility. From the standard proctor test, the optimum moisture content was found to be 15% and corresponding maximum dry density as1.6g/cc.

Figure 3.1 dredged marine soil

Table 3.1 properties of raw soil

Properties	Values
Specific gravity	2.6
Optimum moisture content (OMC)	14.5%
Maximum dry density (g/cc)	1.612g/ cc
Unconfined compression strength	33.3KN/

	m^2
Liquid limit	58%
Plastic limit	30.3%
Plasticity index	27.6%
Classification	CH

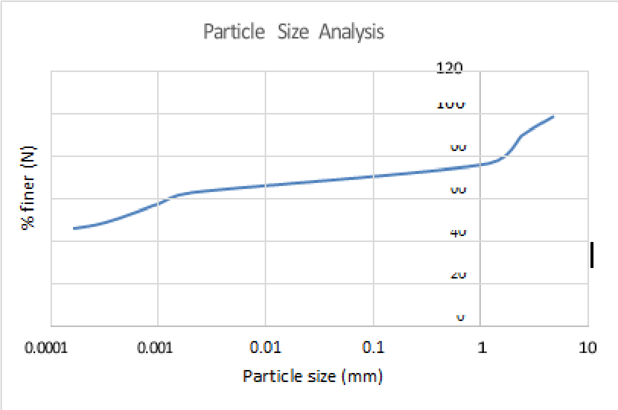

Figure 3.2 Particle size distribution curve

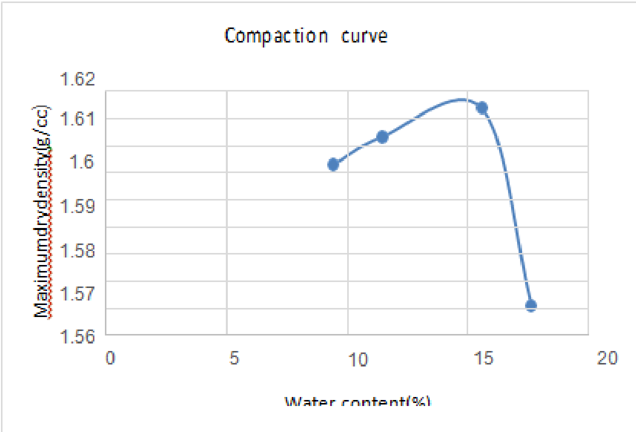

Figure 3.3 Standard proctor test for raw soil

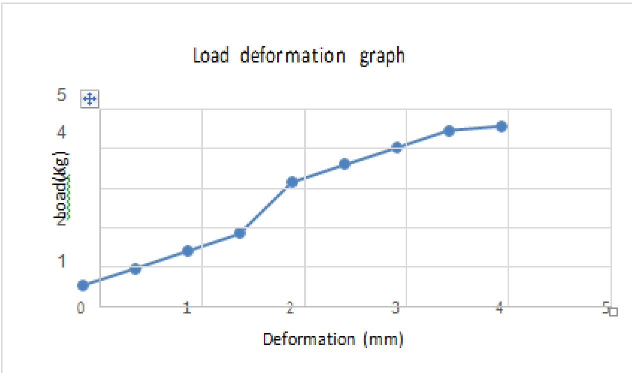

Figure 3.4 UCS for raw soil

Figure 3.5 failure characteristics of raw soil

3.1.2 Bioploymers

Biopolymers are polymers produced by living organisms; in other words, they are polymeric biomolecules. Biopolymers contain monomeric units that are covalently bonded to form larger structures. There are three main classes of biopolymers, classified according to the monomeric units used and the structure of biopolymer formed. They are polynucleotides, polypeptides, polysaccharides. Polynucleotides are long polymers composed of 13 or more nucleotide monomers. Polypeptides are short polymers of amino acid. Polysaccharides are linear bonded polymeric carbohydrate structures. Since biopolymers are synthesised as a result of biological processes and are often less harmful to the landscape and its biota, because of their natural origins of the three types if biopolymers. Polysaccharides have proven more useful soil binders than the polynucleotides and polypeptides. Biopolymers are more environmental friendly than many other chemical soil additives and can achieve the same amount of strengthening at much lower concentrations.

3.1.2.1 Xanthan Gum

Xanthan gum is anionic polysaccharide produced by the bacteria Xanthomonas campestris, which is commonly used as food additive and rheology modifier. The basic chemical structure of the xanthan gum (C35H49O29) is a linear linked β-D glucose backbone with a trisaccharide side chain on every other glucose. The trisaccharide side chain is aligned with the backbone, which produces stability and overall conformation through the use of hydrogen bonds. Xanthan gum's negative charge comes from its carboxylic acid (-COOH) groups, since hydrogen atoms easily dissociated from these carboxylic acid groups to form carboxylate (-COO) anions. Xanthan gum can also form hydrogen bonds with its numerous hydroxyl (-OH) groups. Small amount of xanthan gum significantly increase an aqueous system's viscosity, which makes it a commonly used commercial substance. However, since the xanthan gum solution is pseudoplastic, its viscosity decreases with an increased shear rate. Xanthan gum also forms a viscous hydrocolloid when mixed with water, so it can also considered dissolved in water.

Xanthan gum helps to create desired texture in many ice creams. Xanthan gum also help to suspend solid particles. In oil industries, xanthan gum is used in large quantities to thicken drilling mud. These fluids serve to carry the solids cut by the drilling and hit back the surface. The wide spread use of horizontal drilling and demand for good control of drilled solids has let to its expanded use.

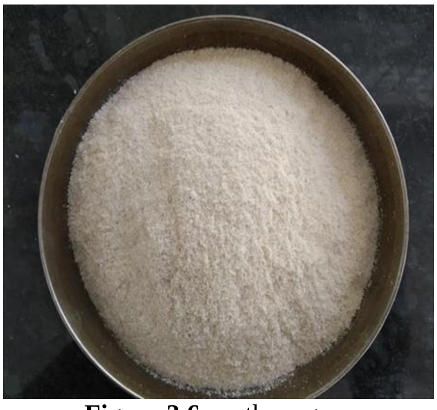

Figure 3.6 xantham gum

3.1.2.2 Chitosan

The other name of chitosan is chitin. Chitosan biopolymer can be produced from shell waste of sea food mostly from the shrimps and crabs or usually it is a little price biopolymer produced from the discarded crustacean shells of food industry. The production of shell waste from shrimps and crabs is evaluated to be 1.44 million tons. And also 40% of the waste is observed as solid waste which contains 25-30% of dry matters. As an alternative method of making environmental friendly and to reduce pollution geo environmental applications came into existence.

This chitosan biopolymer has been used in several fields like medicine, crop protection, cosmetics, biomaterial, food industry and material science, micro- biological. During irrigation chitosan is used as a constructive material to reduce soil erosion. Moreover chitosan is able to bind metal ions and limit leachability, even in the presence of K^+, Cl^- and $No3^-$ which are dominance in soil.as pollution increases with increase in population and even the waste is using in several fields, but there is no reduction in the pollution. So to researcher's point of view the shell waste obtained from sea food can be processed and utilized in our civil engineering applications like soil stabilization.

3.2 Specimen Preparation and Testing

The dredged marine soil used for this study was air dried and pulverized. The biopolymers (xanthan gum and chitosan) used in this study are in the form of fine powders. The effiency of two biopolymers are tested separately by conducting standard proctor test and unconfined compression test. Biopolymers are added directly into the soil (dry mix) and mixed until uniform mix was formed and then water is added to it. By conducting standard proctor test, maximum dry density and optimum moisture content are found. Test carried out on the basis of IS 2720 part 7.

Xanthan gum concentrations used in this study are 0.5%,1%, 1.5%, 2% and 2.5% and chitosan concentrations are 0.6%, 0.12%, 0.18%, 0.24% and 0.3%. using this optimum moisture content (OMC) unconfined compression strength of each specimen was carried according to IS 2720 part10 and found out the biopolymer (xanthan gum and chitosan) concentrations separately, which gives highest strength in UCS test. These two specimen concentrations (soil-xanthan gum treated and soil-chitosan treated) which gives highest strength in UCS undergoing SEM analysis to find the soil- biopolymer interactions.

With the concentrations of biopolymers (xanthan gum and chitosan), which gives highest strength in UCS test long term durability and different mixing (dry mixing and wet mixing) conditions are also tested. For each biopolymers (xanthan gum and chitosan) two types of samples are made to test unconfined compression strength at 0^{th}, 7^{th} day and 14^{th} day. The two types of samples are dry mix and wet mix. Dry mix means biopolymer powder are directly added to the soil, then water added to it and wet mix means biopolymers are initially diluted in the water, then added to the soil.

IV. Results and Analysis

4.1 Standard Proctortest

Standard proctor test was conducted separately on xanthan gum biopolymer treated soil and chitosan biopolymer treated soil to determine the optimum moisture content and maximum dry density in various concentrations. The test was conducted according to IS 2720 part 7. The mould was of 100 mm diameter, 127.3 mm height and 1000 ml capacity. The rammer weighs 2.6Kg with free drop of 301 mm. The soil was compacted in three layers and mould was fixed to a detachable plate.

4.1.1 Xanthan Gum Biopolymer Treated Soil

Standard proctor was initially conducted on xanthan gum biopolymer treated soil to determine the optimum moisture content and maximum dry density in different concentrations. The different concentrations used are 0.5%,1%, 1.5%, 2% and 2.5%.

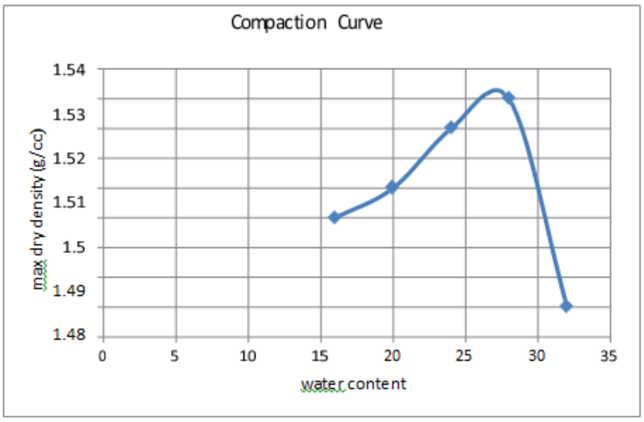

Figure 4.1 Standard proctor test for 0.5% xanthan gum treated soil

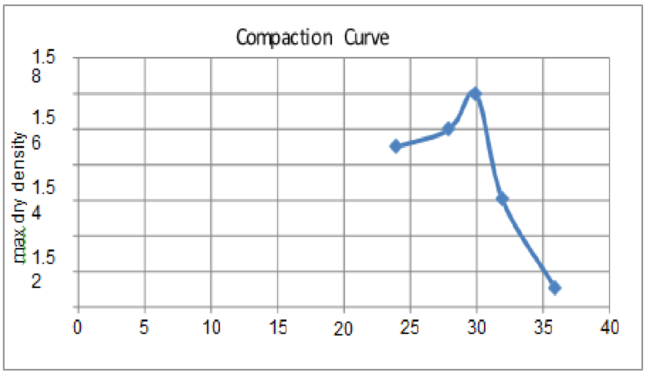

Figure 4.2 Standard proctor test for 1% xanthan gum treated soil

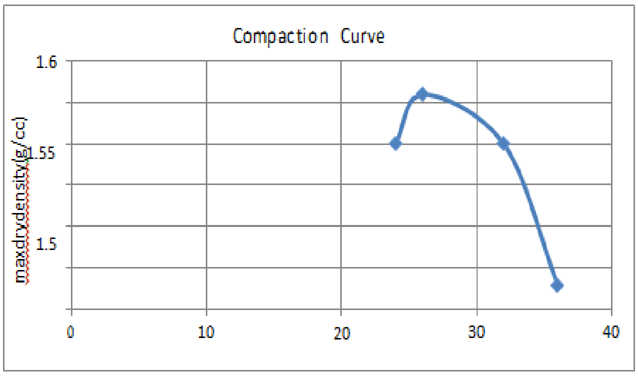

Figure 4.3 Standard proctor test for 1.5% xanthan gum treated soil

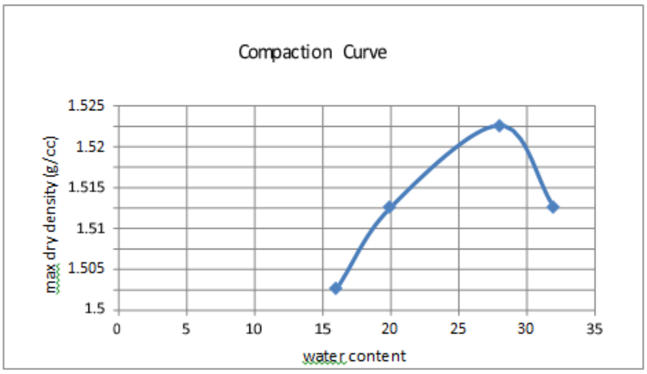

Figure 4.4 Standard proctor test for 2% xanthan gum treated soil

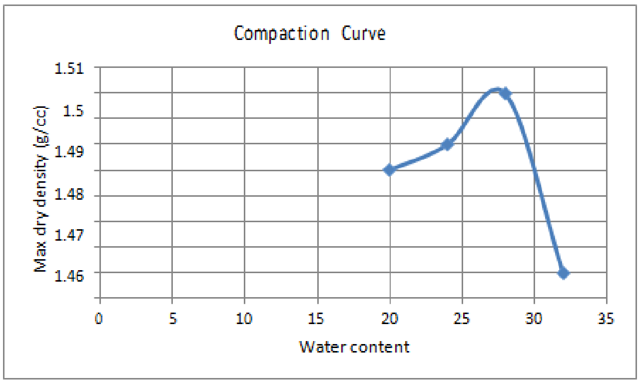

Figure 4.5 Standard proctor test for 2.5% xanthan gum treated soil

4.1.2 Chitosan Biopolymer Treated Soil

Standard proctor test was also conducted on chitosan biopolymer treated soil in various concentrations. The different concentrations used are 0.06%, 0.12%, 0.18%, 0.24% and 0.3%.

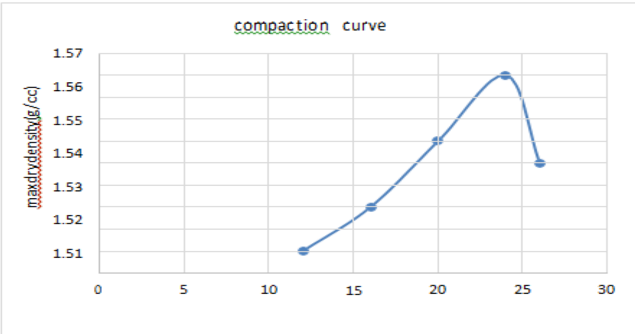

Figure 4.6 Standard proctor test for .06% chitosan treated soil

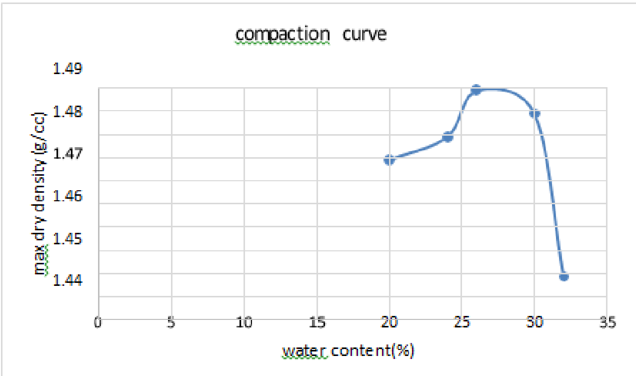

Figure 4.7 Standard proctor test for 0.12% chitosan treated soil

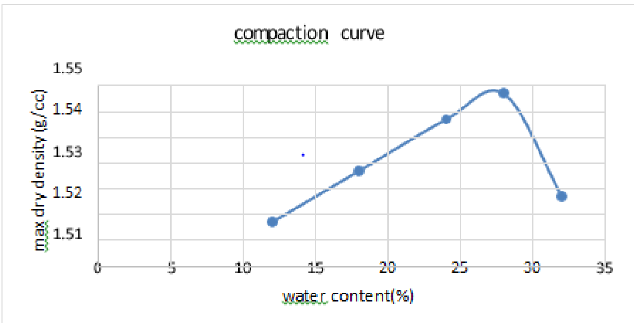

Figure 4.8 Standard proctor test for 0.18% chitosan treated soil

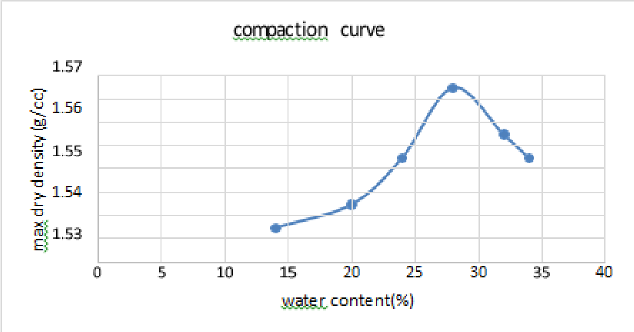

Figure 4.9 Standard proctor test for 0.24% chitosan treated soil

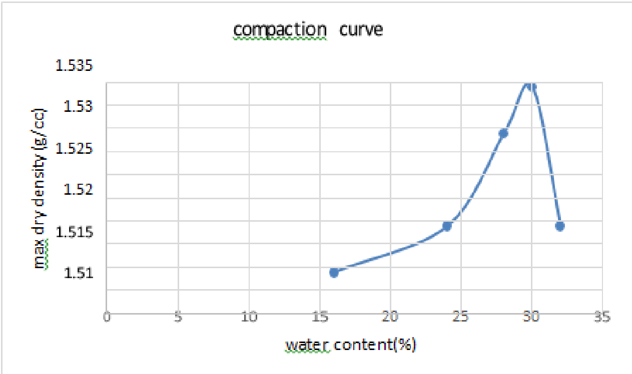

Figure 4.10 Standard proctor test for 0.3% chitosan treated soil

4.1.3 Variations in OMC and MDD for Biopolymers Treated Soil

The variation in OMC and MDD with the addition of xanthan gum treated soil and chitosan treated soil was observed. In xanthan gum treated soil variation in OMC was given in figure 4.12. Minimum OMC was observed as 26% when xanthan gum is at 1.5% and maximum OMC was observed as 29.8% when xanthan gum is at 1%. Variation in MDD for xanthan gum treated clay was observed as initially increases and then decreases. Maximum dry density observed when xanthan gum at 1.5% xanthan gum, which is 1.57g/cc.

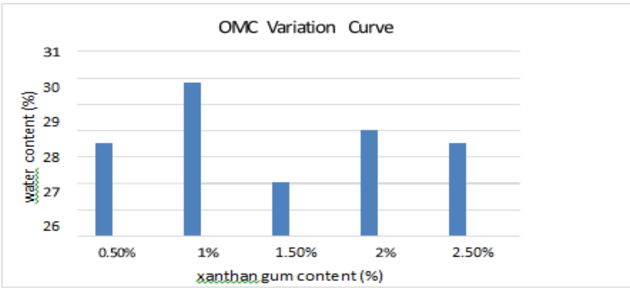

Figure 4.11 Variation in OMC for xanthan gum treated soil

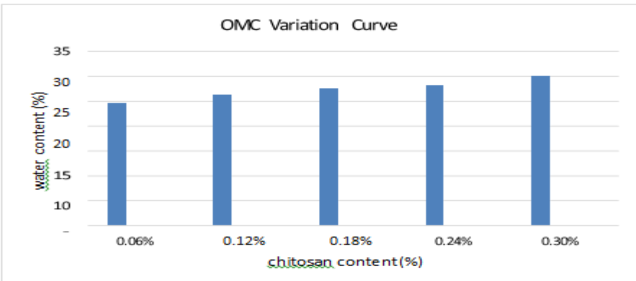

Figure 4.12 variation in OMC for chitosan treated soil

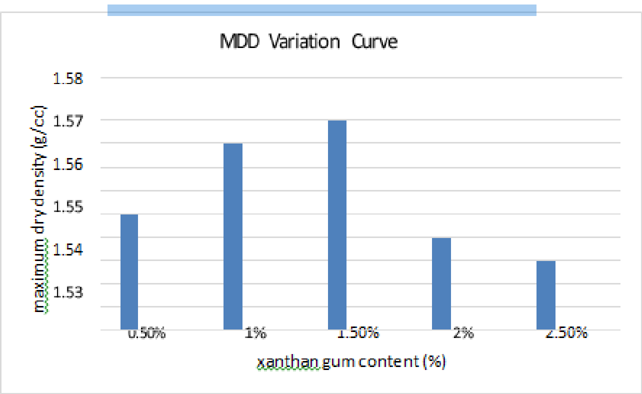

Figure 4.13 Variation in MDD for xanthan gum treated soil

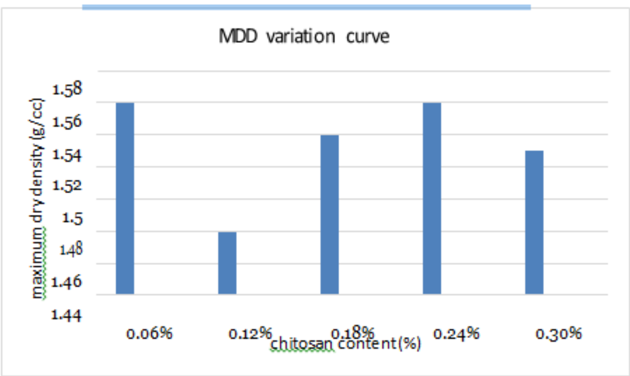

Fig 4.14 Variation in MDD for chitosan treated soil

4.2 Unconfined Compression Strength (UCS)

The unconfined compression test commonly used in civil engineering practice to obtain the compressive strength (UCS) of materials like soil and concrete. While loading the specimens under constant axial strain rate, the specimen should fail on their weakest plain after their compressive strength was reached. The unconfined compression test on biopolymers treated soil were conducted. The test was carried out on the basis of IS 2720 part 10. The specimen for UCS was prepared at their OMC. For the UCS test the soil specimen of 76 mm height and 38 mm diameter were casted using the split mould. The test equipment consist of a loading frame, with top plate attached to a load measuring device (proving ring) while the bottom plate is raised and lowered in the test. Vertical deformation of the specimen were measured with a dial gauge. The result were obtained by the graph plotted between deformation and load as shown in figure 4.17 and figure4.18.

Figure 4.15 unconfined compression tester

4.2.1 Xanthan Gum Biopolymer Treated Soil

The unconfined compression test of xanthan gum biopolymer treated soil was initially conducted in different concentrations. The various concentrations used are 0.5%,1%, 1.5%, 2% and 2.5%.

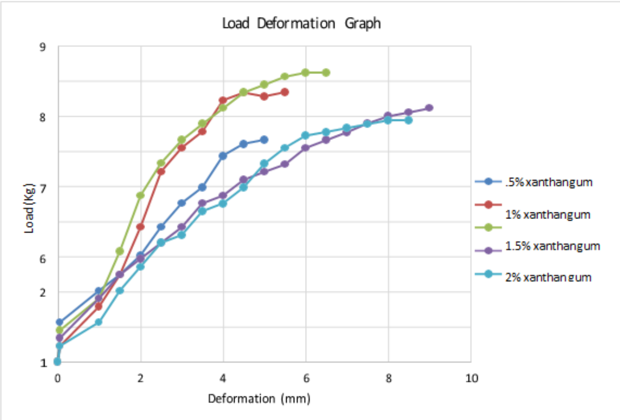

Figure 4.16 Load-deformation graph for xanthan gum treated soil

4.2.2 Chitosan Biopolymer Treated Soil

The unconfined compression test was also conducted on chitosan biopolymer treated soil in different concentrations and the various concentrations used are 0.06%, 0.12%, 0.18%, 0.24% and 0.3%

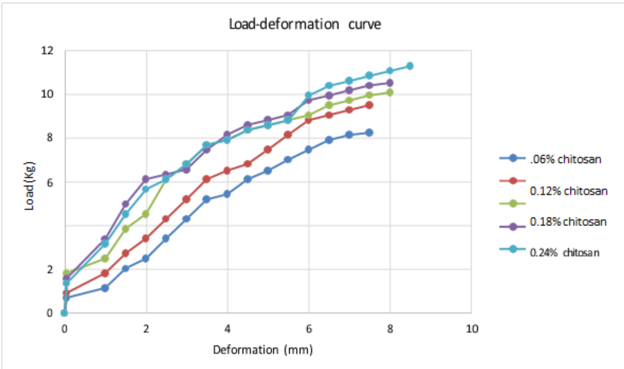

Figure 4.17 Load-deformation graph for chitosan treated soil

4.2.3 Variations In UCS Values of Biopolymers Treated Soil

In xanthan gum biopolymer treated soil the variation in UCS values was given in figure 4.20. The UCS values were initially increases and then decreases. Maximum UCS strength was observed when xanthan gum of 1.5% , which is 65.4 KN/m^2. High xanthan gum content should be avoided due to workability(high viscosity leading to poor mixing) problems.

Figure 4.18 Failure characteristic of 1.5% xanthan gum treated soil

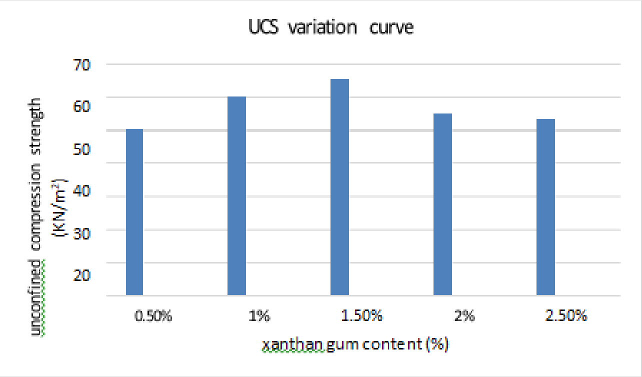

Figure 4.19 Variation in UCS values of xanthan gum treated soil

In chitosan biopolymer treated soil, an increment in chitosan concentrations leads to increase the UCS values. The maximum UCS value was observed as 104.8KN/m^2 when chitosan content of .3%. Even in smaller concentrations such as .3% of chitosan the strength is higher than the xanthan gum treated soil which was observed the maximum value as 65.4KN/m^2 at 1.5%.

Figure 4.20 Failure characteristic of 0.3% chitosan treated soil

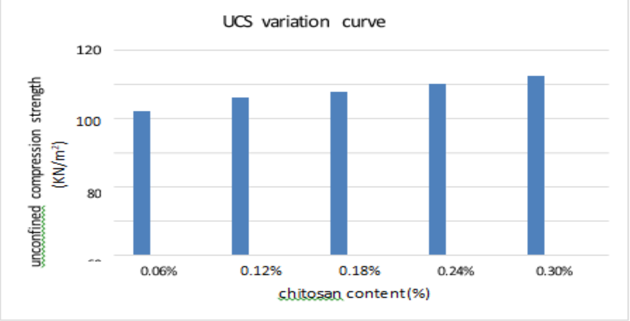

Figure 4.21 Variation in UCS values of chitosan treated soil

4.3 Scanned Electron Microscopy (SEM) Analysis

SEM images are used to determine the microstructural properties of soil fabric because it provide information on size, shape and study of orientation and aggregation of soil particle. SEM is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. Electron interact with atoms on the sample and produce various signals. It contain information about surface topography and composition of the sample. The electron beam is scanned in a raster scan pattern. In SEM mode, secondary electrons emitted by atoms exited by electron beams. They are detected by using Everhart-Thorney detector. Number of secondary electrons can be detected. SEM can achieve resolution better than one nanometre.

In this current study SEM images of raw soil, xanthan gum biopolymer treated soil (specimen that fail in UCS test-1.5% xanthan gum treated soil, which gives highest strength in UCS test was used), chitosan biopolymer treated soil (specimen that fail in UCS test-0.3% chitosan treated soil, which gives highest strength in UCS test) was observed.

The SEM images of samples at concentrations of 1.5% xanthan gum and 0.3% of chitosan shows the accumulation of biopolymers between the spaces of particles.

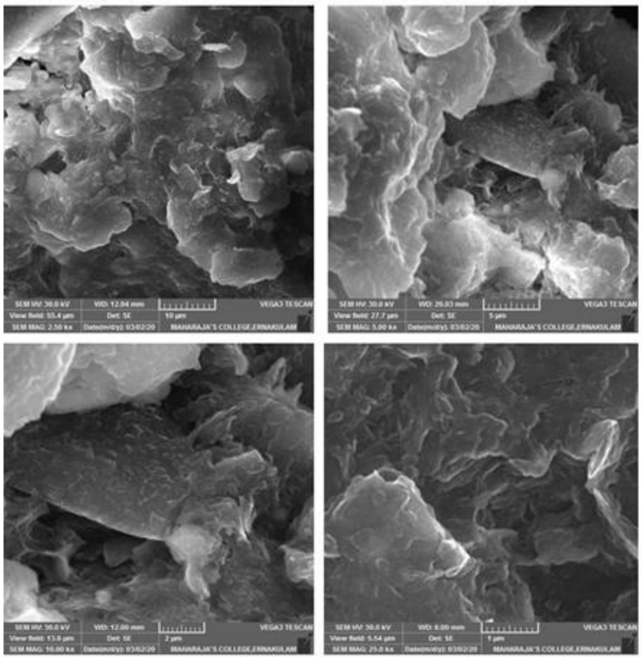

Figure 4.22 SEM images of raw soil

Figure 4.24 depicts the SEM images of the XG- biopolymer treated soil. This shows that the strength values of Xanthan treated soils greatly depend on the strength of the xanthan gum matrices existing in the pore spaces. Due to electrically charged clay particles xanthan gum created an interaction between the particles. Creating a stronger bond between the particles, XG increased cohesion and stiffness of soil particles. Therefore strengthening mechanism of xanthan gum treated fine soil can be explained as a combination of xanthan gum matrix strength and hydrogen or electrostatic bonding characteristic between xanthan gum and fine soil matrices.

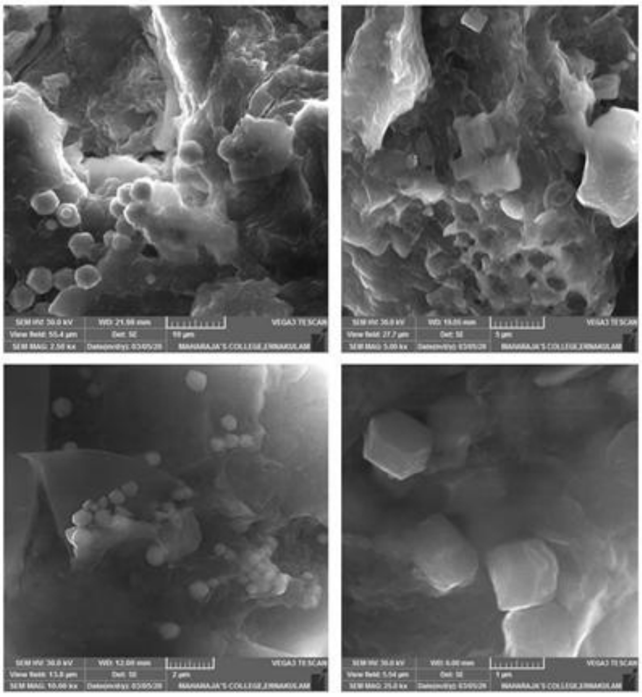

Figure 4.23 SEM images of xanthan gum biopolymer treated soil

Figure 4.25 depicts the SEM images of chitosan biopolymer treated soil. Also like XG chitosan increase the interaction between fine particles. The hypothesis of chitosan-soil micro behaviour is associated to cationic characteristics of chitosan which provide an electrical interaction between the biopolymer that governs the interparticle behaviour of the treated clay. The clay particles with negatively charged surface minerals are attached to each other with positively charged chitosan. Thus chitosan treated soil also increases the cohesion and stiffness of the fine soil particles.

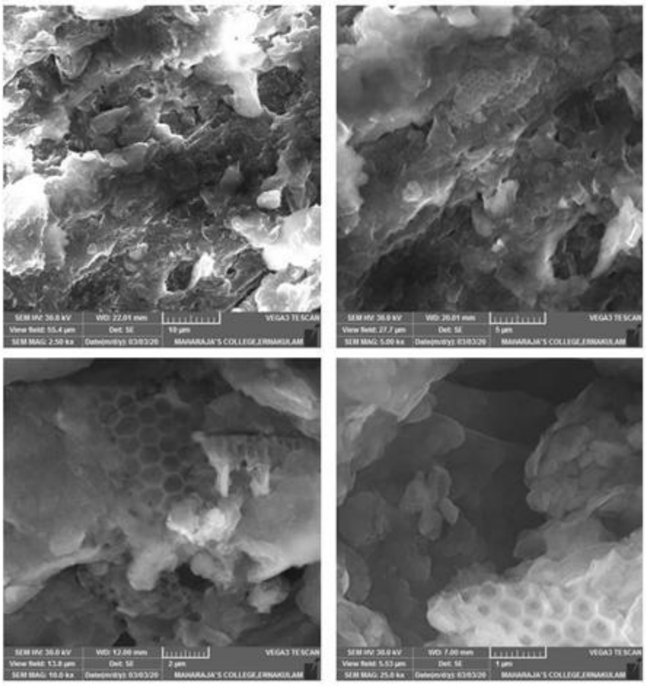

Figure 4.24 SEM images of chitosan biopolymer treated soil

4.4 Effect of Curing Periods

The decomposition problem is an important concern for polymers used in geotechnical engineering. Although xanthan gum is known as a thermostable biopolymer. In fact xanthan gum is a stable compound below 250^{0}C. it is also stable polysaccharide against oxidation, and is widely used as an anti-oxidation additive in oil and protein products. Moreover its stability in extreme conditions including acidic and alkaline environments and high salt concentrations provides high potential for use in various industrial purposes. However it sometimes shows decomposition by bacteria and aerobic organisms. Also Chitosan is made from shells of crabs and shrimps. Therefore the long term durability of xanthan gum biopolymer treated soil and chitosan biopolymer treated soil must be verified to allow recommendation of the usage of xanthan gum and chitosan in geotechnical engineering fields. Xanthan gum treated soil with 1.5% and chitosan treated soil of 0.3% are tested for long term durability made by dry mix. The strength of the sample was observed on 0^{th}, 7^{th}, and 14^{th} day.

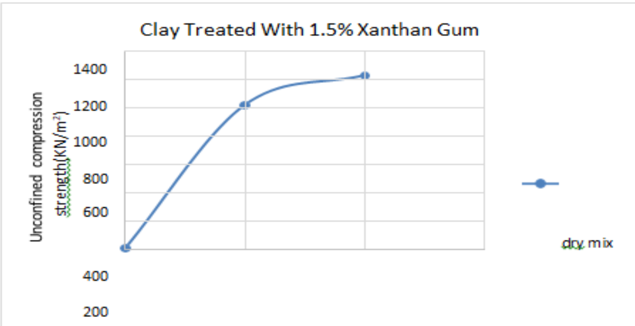

Figure 4.25 UCS strength of xanthan gum treated soil under curing periods

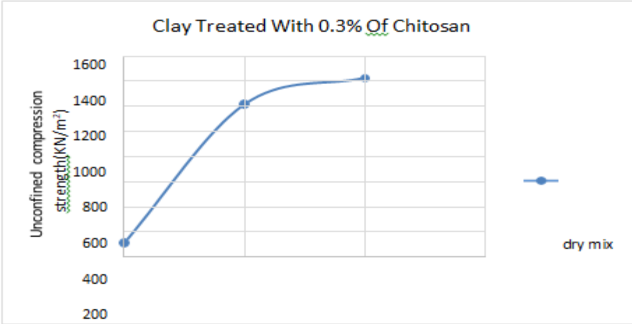

Figure 4.26 Long term durability of chitosan treated soil

From the figure 4.26 and figure 4.27 the compressive strength of xanthan gum treated soil and chitosan treated soil was increased up to 14 days. These durability assessment was carried out in without wetting and drying conditions.

4.5 Mixing Methods

For the sample preparation in curing test two different mixing methods were used. One is dry mixing in which the biopolymer powder was directly mixed with the soil before adding water and the other is wet mixing in which the biopolymer was first mixed with water to form hydro-solution before mixing in the soil. Both the mixing was carried out in room temperature.

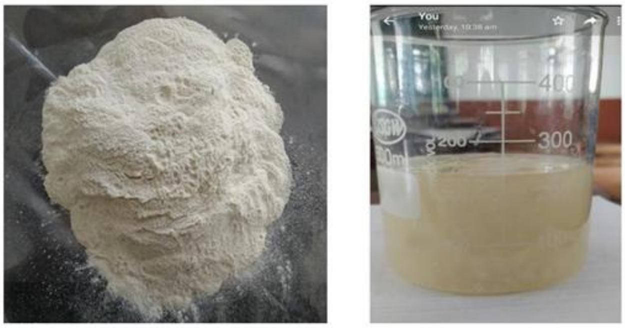

Figure 4.27 dry mix and wet mix

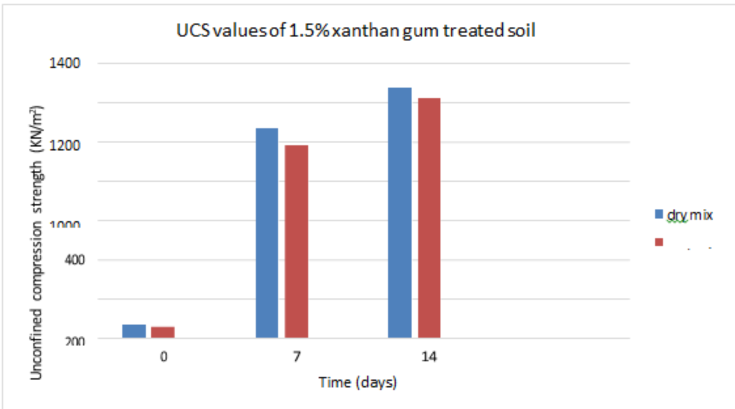

Figure 4.28 UCS strength of xanthan gum treated soil in dry and wet mix

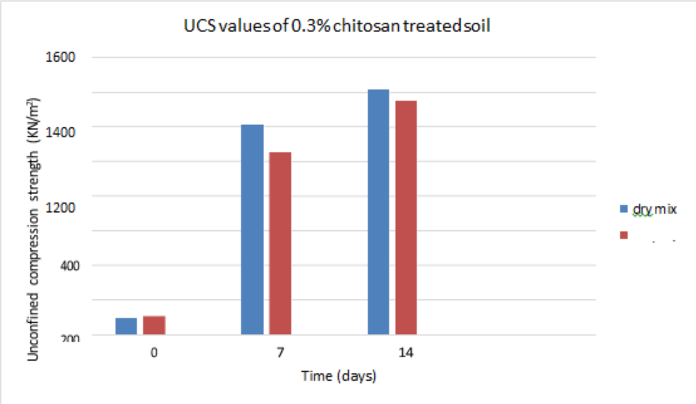

Figure 4.29 UCS strength of chitosan treated soil in dry and wet mix

Compressive strength results of both biopolymers treated soil shows that dry mixing is more effective than wet mixing. Because wet mixing is attributed to the solubility and viscosity of the biopolymers in water. Solubility increases with increase in temperature and also the viscosity increases. Also, high concentration of biopolymers further increases the viscosity. Therefore thorough mixing of biopolymers dissolved solution not have been possible in wet mixing. Meanwhile dry mixing provides a well distributed xanthan gum matrix in the soil. As a result compressive strength of the material prepared using wet mixing will not be same as that prepared by the dry mixing.

V. Conclusions

This study investigate the potential of biopolymers (xanthan gum and chitosan) utilization as an alternative to conventional materials. From the experimental investigation the following results were concluded:

The OMC, maximum dry density and UCS values of raw soil are 14.5%, 1.612g/cc and 33.3KN/m^2 respectively.When the raw soil treated with the biopolymers (XG and chitosan) OMC and UCS values increases and maximum dry density decreases.The effect of soil strengthening with xanthan gum content shown to be increased and maximum UCS value shown as 65.4KN/m^2 when the xanthan gum content is at 1.5%, OMC and MDD at this percentage of XG was observed as 26% and 1.57g/cc. Also the strengthening of chitosan added soil shown to be increased and the maximum UCS value obtained as 104.8KN/m^2 when the chitosan content is at 0.3%, OMC and MDD at this percentage of chitosan was observed as 30% and 1.53g/cc.The SEM images shows that both the biopolymers are filled in the space between fine soil particles, which increases the cohesion. Therefore this strengthening was achieved by increasing the interparticular attraction between the fine soil particles.The durability test shows that the compressive strength of both biopolymers treated soil was increased up to the 14th day.Compressive e strength of both biopolymer treated soil was shown that dry mixing is more effective than the wet mixing, this is because dry mixing provides well distributed biopolymer matrix in soil.

The above analysis indicates that, both the biopolymers (XG and chitosan) improves the strength characteristics of soil. There are also some other factors which depends on the strengthening of the treated soil, which include curing period and mixing conditions. From the result obtained, the usage of both the biopolymers for soil treatment can be recommended especially under lower concentrations, higher concentrations not guarantee greater strength, reduce workability and increase material cost.

Scope for Future Study

This work evaluates the compressive strength up to 14 days, by obtaining compressive strength up to 3 months long term durability can be evaluated. Also the durability strength was observed without drying and wetting condition, the stability under cyclic wetting and drying should be verified in further studies.

Acknowledgements

At the very outset we would like to give the first honours to God, who gave the wisdom and knowledge to complete this work.

We wish to extend our sincere thanks to our Project Guide Ms. Seena Mani, Assistant Professor Department of Civil Engineering and all our Project coordinators Dr Manu S Nadesan and Mr Abin Joy Assistant Professors Department of Civil Engineering for their valuable guidance and support throughout the work.

We sincerely extend our thanks to Mr. Aneesh P. C., Project coordinator and HOD, Department of Civil Engineering, for all the help, motivation and guidance through the seminar.

Our extreme thanks to Dr V Suresh Kumar, Principal for providing the necessary facilities for the completion of this project in our college.

We wish to extend our sincere thanks to all Teaching and Non-Teaching faculty in the Department of Civil Engineering for their valuable guidance.

We also thank our Parents, Friends and all our well wishers who had supported directly and indirectly, during the course of the Project Work.

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