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Investigating the Physical and Mechanical Characteristics of Shanghai Clay Curried with Various Biopolymers: An Experimental Study

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Abstract
Biopolymers have attracted a lot of attention from sustainable geotechnical engineering experts as of late due to their ability to improve soil mechanical characteristics. But there is a lack of information on how different biopolymers perform in healed soils in terms of their physico-mechanical characteristics. That is why this article treats Shanghai clay with biopolymers made of xanthan gum, chitosan, and guar gum. Compaction, unconfined compressive strength, and liquid-plastic limit tests are used to determine the fundamental physical qualities and biopolymer content of cured soils. Then, it talks about how various kinds of biopolymers affect these parameters. The order of increasing liquid-plastic limit was as follows: guar gum-treated soils, xanthan gum-treated soils, chitosan-treated soils, and uncured soils. The results showed that the liquid-plastic limit of soils treated with biopolymers increased with increasing concentrations of biopolymers. Relative to uncured soil and guar gum-cured soil, different biopolymer-cured soils exhibited a decreasing maximum dry density and an increasing optimal moisture content with increasing biopolymer content and xanthan gum and chitosan content, respectively.surface filth. Soils treated with biopolymers exhibited significantly greater compressive strengths compared to those untreated; the most robust compressive strengths were seen in soils treated with xanthan gum, and the compressive strengths of soils cured with biopolymers increased as the concentrations of biopolymers went up.

Keywords: *Shanghai clay, biopolymer, liquid-plastic limit, compaction, unconfined compressive strength.*

I. INTRODUCTION

The food industry makes extensive use of biopolymers, which are natural polymers made by creatures like plants and animals in their native habitat. As an alternative to more conventional reinforcing materials like cement and lime, biopolymers have the advantages of being hydrophilic, sticky, and eco-friendly [1]. In comparison to more conventional soil consolidation materials like lime or cement, biopolymers not only effectively consolidate soil but also greatly decrease carbon emissions from the process of soil extraction and consolidation. It is estimated that cement production alone produces up to 2 billion tons of carbon dioxide per year [2]. Numerous experimental investigations on the mechanical characteristics of soils treated with biopolymers have been conducted in the last few years. In their study on the compaction characteristics of soils treated with xanthan gum, Sujatha et al. found that the soil's maximum dry density fell and its optimal water content rose as the dose of xanthan gum increased [3]. When Chang et al. tested how adding junction cold glue and agar glue to clay affected its mechanical strength, they found that the treated clay had a much higher compressive strength than the untreated clay [4]. In their study, Ni Jing et al. looked at how β-glucan affected soil shear strength. The findings revealed that β-glucan may

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increase soil shear strength, internal friction angle, and cohesiveness [5]. Furthermore, xanthan gum considerably improved the compressibility of soils treated with it, according to Chang et al. [6]. Biopolymers improve soil engineering properties by interacting physically and chemically with soil particles and pore fluids. These interactions include, but are not limited to, increasing the viscosity of the pore fluids, filling the spaces between particles, increasing the surface area of contact between particles, and hydrogen bonding and ionic bonding to induce flocculation or cohesion of clay particles, among others. on pages 7–13.

In conclusion, much of the existing research on biopolymer-cured soils, both in the US and abroad, has focused on studying the effects of a single biopolymer on soil parameters, rather than comparing the findings for several biopolymers. Chemical bonding allows the various functional groups carried by biopolymers to connect with clay particles at various places, altering the organization and microstructure of soil particles, which might lead to varying healing effects; nonetheless, there is a dearth of relevant research on the subject.

To study how different types of ionic biopolymers affected the basic physical properties and compressive strength of the cured soil, this paper treats Shanghai clay with xanthan gum, chitosan, and guar gum and then conducts tests on the soil's liquid-plastic limit, compaction, and compressive strength.

TEST MATERIALS AND TEST PROGRAM

2.1 Test Materials

The test soil was taken from a residential pit under construction in Jiangpu Community, Yangpu District, Shanghai, with a depth of 7.17-8.55 m. The soil layer at this depth belongs to the Holocene Q4 sedimentary layer, which is dominated by clayey soil, and the soil locally contains a small amount of organic matter, mica, and thin layers of silt, and its basic physical properties are shown in Table 1. According to the Standard for Engineering Classification of Soil (GB/T 50145-2007), it can be seen that the soil is a low liquid limit clay.

Xanthan gum used in this study was provided by Ordos Zhongxuan Biochemical Co. Ltd, which consists of D-glucose linked by β-1,4 glycosidic bond, and every two glucose contains a trisaccharide side chain (D-mannose-D-glucuronic acid-D-mannose), and the furthest mannose from the backbone contains pyruvic acid group[14] , which has an anionic nature. Chitosan used in this study was provided by Shandong Qingdao Honghai Biotechnology Co., Ltd, which consists of a binary linear polymer of 2-acetamido-2-deoxy-D-glucose and 2-amino-2-deoxy-D-glucose linked by β-1,4 glycosidic bonds[15] and has cationic properties. Guar gum used in this study was provided by Beijing Guar Run Technology Co. Ltd, which consists of D-mannosyl units linked by β-1,4 glycosidic bonds, and D-galactosyl residues linked by α-1,6 glycosidic bonds as side chains [16], and is a nonionic biopolymer.

Table 1:Basic physical and mechanical properties of Shanghai soft clay

Basic physical indexes Numerical	Values
Maximum dry density(g/cm^3)	1.64
Optimum water content (%)	19.73
Pore ratio	1.21
Specific gravity	2.72
Liquid limit (%)	32.8
Plastic limit (%)	20.8
Natural saturation(%)	96.0
Heaviness(kN/m^3)	17.56

2.2 Pilot program

Liquid-plastic limit test: After the soil was dried (drying temperature 105 ℃), crushed and sieved through 2 mm sieve, the soil was stirred with chitosan, xanthan gum and guar gum powder respectively, and each of them was added with water to form a homogeneous mixture with different water content of 3 portions, and then left to stand in a sealed humidified cylinder for 24 h. The cone depth of cone meter was measured by using the GYS-2 Digital Soil Liquid-Plastic Limit Combined Determination Instrument with different water content. The water content of the sample was taken as the horizontal coordinate, and the cone depth was taken as the vertical coordinate, 3 data points were marked in double logarithmic coordinates, and the relationship curve between the cone depth and the water content was plotted; the water content corresponding to the cone depth of 17 and 2 mm was determined as the liquid limit and the plastic limit, respectively.

Compaction test: According to the results of the plastic limit test, the optimum water content of different biopolymer cured soils can be roughly determined. A total of 5 different water contents were taken near the plastic limit with a gradient of 2% water content, and the mixtures were prepared according to the method in the liquid-plastic limit test. The mixtures were loaded into a compactor in 3 layers and each layer was compacted 25 times by the free fall of a hammer. After the completion of the determination of the moisture content and dry density of the compacted soil samples, the moisture content as the horizontal coordinates, dry density as the vertical coordinates, marking five data points and plotting the compaction curve, the peak point of the curve corresponding to the longitudinal coordinate for the maximum dry density, the corresponding horizontal coordinate for the optimal moisture content.

Compressive strength test: take the optimum moisture content, make samples according to the maximum dry density, repeat each test condition 3 times to make test pieces, and take the average value of strength as the representative value of strength. The average strength is taken as the representative value of strength. The compressive strength test is carried out after 14 days of maintenance at room temperature of 25 ℃ and relative humidity of 50%.

TEST RESULTS AND ANALYSIS

3.1 Liquid-plastic limit test

The liquid and plastic limits of uncured and biopolymer-cured soils are shown in Table 2. The results show that the liquid-plastic limits of the biopolymer-cured soils (except in some cases) increased with increasing biopolymer content, but the liquid limit increased more significantly. For example, the liquid limit of 0.5%, 1.0%, 1.5%, and 2.0% xanthan gum cured soil was 35.64%, 40.9%, 43.93%, and 49.42%, respectively, which increased by 8.67%, 24.70%, 33.93%, and 50.67%, respectively, compared with the uncured soil. Comparing the liquid limit of different biopolymer-cured and uncured soils, there was a significant difference in the change of liquid limit of Shanghai clay by different biopolymers. The anionic xanthan gum and nonionic guar gum had significant effects on increasing the liquid limit of the soil, for example, in the case of 2.0% biopolymer-cured soil, the liquid limit wL increased from 32.80% to 49.42% and 62.58%, which were 51% and 89% higher, respectively; in contrast, the cationic chitosan had little effect on the liquid limit of the soil, and when chitosan content was increased from 0 to 2.0%, the liquid limit increased from 32.8% to 32.87% only. When the chitosan content increased from 0 to 2.0%, the liquid limit increased from 32.8% to 32.87%. Analyzing the reasons, there may be the following points: (i) the surface and edges of the clay particles were negatively and positively charged, respectively, and the anionic xanthan gum attached to the edges of the clay particles through electrostatic attraction, inducing the formation of flocculation structure between the clay particles, resulting in a porous soil, which could adsorb more water; (ii) the cationic chitosan attached to the surface of the clay particles through electrostatic attraction, inducing the formation of cohesive structure between the clay particles, which resulted in fewer pore spaces in the soil for the adsorption and storage of water. In addition, cationic chitosan exchanges cations with ions in the diffusion layer of clay particles, which can lead to a thinning of the thickness of the diffusion layer [17,18]. Therefore, although chitosan also contains hydrophilic group hydroxyl group (-OH), the combination of the above three effects of chitosan has little effect on the soil liquid limit; (iii) nonionic guar gum can increase the soil liquid limit to a greater extent is due to its large number of hydroxyl groups (- OH),

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Vol-09 Issue-02 July 2024

through the formation of hydrogen bonds with water to adsorb more water [19]. In summary, the physical and chemical interactions that exist between the biopolymer-water-viscous particles, leading to changes in the arrangement of soil particles, pore space, hydrophilicity and thickness of the diffusion layer are the main reasons for the differences in the liquid-plastic limit of different ionic biopolymer-cured soils.

3.2 Friction testing

The optimum moisture content as well as the maximum dry density of the unconsolidated and biopolymer-consolidated soils are shown in Table 2. Overall, the addition of biopolymers resulted in an increase in the optimum moisture content and a decrease in the maximum dry density of the Shanghai clay. Comparing different biopolymers treated Shanghai clay, it can be found that the biopolymers increased the optimum water content of the soil to different degrees, which is closely related to the fact that polysaccharide biopolymers contain hydrophilic groups, for example, the optimum water content of 1.0% biopolymer-treated Shanghai clay was the highest for the guar gum-cured soil (21.46%), followed by xanthan gum-cured soil (21.03%), and the smallest for the chitosan-cured soil (20.36%). 20.36%). In addition, the optimum water content of biopolymer- cured soils increased with the increase of biopolymer content. The reason for the above phenomenon may be that different biopolymers have different viscosities, as the greater the pore fluid viscosity, the more the soil particles are hindered from moving, more water needs to be added in order to achieve the purpose of reducing the pore fluid viscosity, promoting the sliding of the particles, and discharging the inter-particle gases [20], it is known that the viscosity of guar gum (8,000 cP) > viscosity of xanthan gum (1,500 cP) > viscosity of chitosan (75 cP). Due to the addition of biopolymers to increase the percentage of water per unit volume, the maximum dry density of cured soils decreases compared to uncured soils [21], which is manifested by the fact that the higher the optimum moisture content, the lower the maximum dry density.

Table 2: Liquid plastic limit and compaction test results

Style	Liquid limit（%）	Plastic limit（%）	Optimum water content （%）	Maximum dry density(g/cm^3)
Uncured	32.80	20.80	19.73	1.64
0.5%Xanthan gum	35.64	19.7	20.58	1.62
0.5%Chitosan	30.76	18.6	19.56	1.65
0.5%Guar gum	45.62	21.4	21.05	1.58
1.0%Xanthan gum	40.90	20.1	21.03	1.60
1.0%Chitosan	31.70	20.4	20.36	1.63
1.0%Guar gum	58.10	23.4	21.46	1.57
1.5%Xanthan gum	43.93	21.1	21.42	1.55
1.5%Chitosan	32.85	20.8	20.89	1.61
1.5%Guar gum	60.08	23.7	22.46	1.53
2.0%Xanthan gum	49.42	22.0	21.58	1.53
2.0%Chitosan	32.87	21.5	21.26	1.58
2.0%Guar gum	62.58	23.9	23.75	1.52

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Vol-09 Issue-02 July 2024

3.3 Compressive strength test

The compressive strengths of uncured soil and biopolymer-cured soil with different contents are given in Figures 1 to 4, respectively. The study comparing Figures 1~4 shows that in general (except in some cases), the compressive strength of biopolymer cured soils is greater than that of uncured soils. Xanthan gum had the most significant effect on increasing the compressive strength of Shanghai clay. When the xanthan gum content was increased from 0 to 0.5%, 1.0%, 1.5%, and 2.0%, the compressive strength of the cured soil was 3.51 MPa, 4.79 MPa, 5.8 MPa, and 7.24 MPa, which were 72.9%, 135.9%, 185.7% and 256.6%. The low content (0.5%- 1.5%) of chitosan and guar gum was not ideal for increasing the compressive strength of Shanghai clay, when the content was increased to 2.0%, the strength of chitosan-cured and guar gum-cured soils were 3.76 and 2.71 MPa, respectively, which were increased by 85.2% and 33.5% compared with the uncured soils. The biopolymer can increase the compressive strength of the soil, which is due to the gel formed by the biopolymer can fill the pores in the soil structure, form a bridge between the coarse particles (such as sand and powder particles), and induce the cohesion and flocculation of clay particles and the formation of agglomerates; with the increase of the maintenance time, the gel hardens, so that the bond between the particles is further strengthened [22], and the strength of the cured soil is increased.

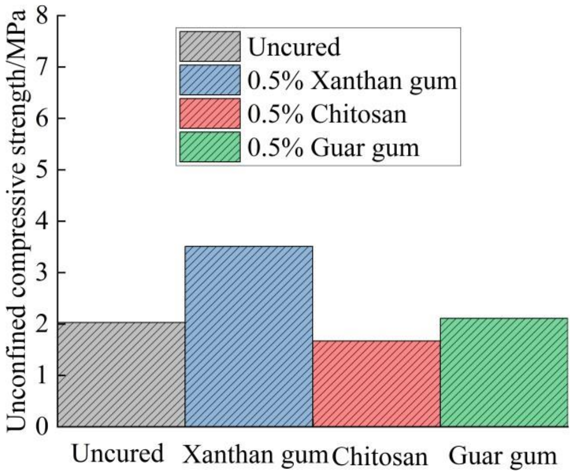

Fig.1: Compressive strength of biopolymer solidified soil with different 0.5% content

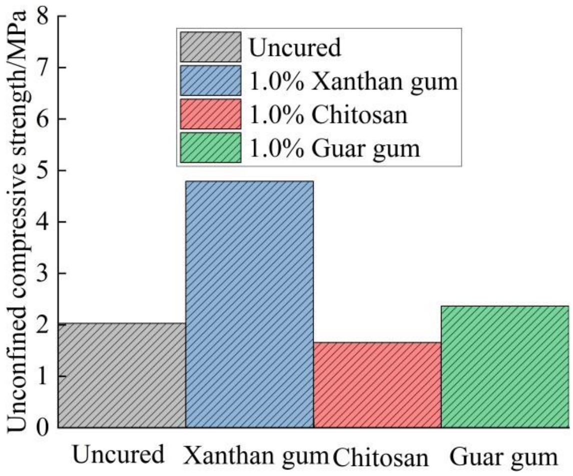

Fig.2: Compressive strength of biopolymer solidified soil with different 1.0% content

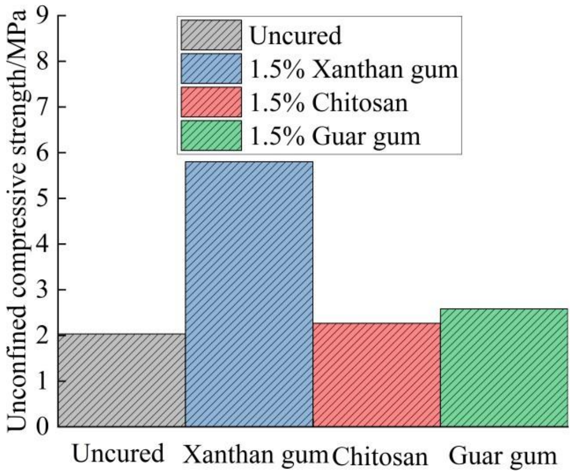

Fig.3: Compressive strength of biopolymer solidified soil with different 1.5% content

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Vol-09 Issue-02 July 2024

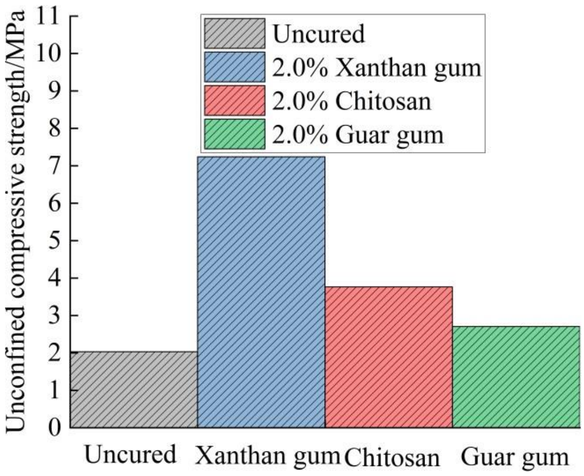

Fig.4: Compressive strength of biopolymer solidified soil with different 2.0% content

II. CONCLUSION

To investigate how the type and amount of biopolymer affected the fundamental physical characteristics and compressive strength of Shanghai clays, this study conducted tests on various biopolymer-treated Shanghai clays, including liquid-plastic limit (LPL), compaction, and unconfined compressive strength. The results showed that:

(1) As the biopolymer concentration in Shanghai clay grew, the liquid-plastic limit (LPL) of the clay also increased. Sorted by LPL, the following biopolymer-cured soils were tested: guar gum-cured, xanthan gum-cured, chitosan-cured, and uncured soil.

(2) Different biopolymer-cured soils had a decreasing order of maximum dry density, and as the biopolymer concentration grew, the ideal moisture content of the cured soil rose. The ideal moisture content was found to be as follows: guar gum-cured soil > xanthan gum-cured soil > chitosan-cured soil > uncured soil, in decreasing order.

Soil treated with xanthan had the greatest compressive strength when compared to uncured soil; soil treated with chitosan and guar gum had somewhat higher compressive strengths; and soil treated with biopolymer had a compressive strength that rose with increasing biopolymer concentration.

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