Improvement of engineering properties of soils by biopolymer additives

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ABSTRACT: Clayey soils can cause structural failures because of their excessive settlements, swelling-shrinkage behavior and low shear strength properties. For example, the natural soil mixtures in the landfill liner applications lose their function and performance and become permeable because of changes in site conditions. There are a lot of methods for the improvement of such soils; however some of them cannot effectively works for improvement and the others are too expensive for practical purposes. Application of biopolymers for soil improvement in geotechnical and geoenvironmental engineering is relatively new and there are limited studies on the effect of biopolymers on soil behavior. In this study, two types of biopolymers namely, xanthan gum and chitosan, with different proportions were used in compaction and hydraulic conductivity tests for investigation of the biopolymer effect on the engineering behavior of soils. The natural kaolin and bentonite samples were used as representative clayey soils. The results show that xanthan gum and chitosan biopolymers increased the maximum dry density of the bentonite-kaolin-sand mixtures. However, the effect is more significant in the presence of chitosan biopolymer. The chitosan and xanthan gum biopolymers decreased the hydraulic conductivity of the kaolin-sand mixtures. However, the effect of biopolymers on the permeability decreases in time because of the degradation effect.

1 INTRODUCTION

The improvement techniques for soil engineering properties are needed in geotechnical and geoenvironmental applications. For example, the natural soil mixtures (bentonite-sand and bentonite-zeolite) in the landfill liner applications lose their function and performance and become permeable because of changes in temperature, water level or ionic concentration. Hence subsurface layers contaminate and economical loss increases. There are a lot of methods for the improvement of soils; however some of them cannot effectively work for improvement and the others are too expensive for practical purposes. Moreover, the applications of biopolymers in geotechnical and geoenvironmental engineering are relatively unexplored, compared to other areas.

Biopolymers have a wide range of applications including oil exploration, textile, construction, cosmetics, pharmaceutics, and food processing industries make use of different types of biopolymers. Biopolymers are naturally occurring polymers derived from algae, fungus or bacteria sources. There are a variety of different types of biopolymers displaying different physical properties. Biopolymer powders are commercially available and when mixed with water functions as a colloid to thicken water based systems to produce gels, which can act as stabilizer and binders (Kamel, 2001). Polymers are hydrocarbon chains and they are classified as non-ionic, cationic, or anionic. All these biopolymers act in different ways in the soil-water systems. Non-ionic polymers bind to soil particles through hydrogen bonding. Polymers spread throughout the soil and replace adsorbed water molecules around the clays. For cationic polymers, negatively charged soil particles attract positively charged macromolecules and cause adsorption. For anionic polymers, cation bridges form between the polymer and anionic soil constituents (Seybold 1994).

In the literature, there are limited studies on the biopoylmer applications in geotechnical and geoenvironmental applications (Mitchell & Santamarina 2005). The applications of biopolymers in the geotechnical and geoenvironmental engineering were generally related with hydraulic conductivity and shear strength of the soils. Karimi (1998) studied on the geotechnical applications of biopolymer treated soils with an emphasis on silt to form impervious barriers. The results of the hydraulic conductivity tests indicated that the saturated hydraulic conductivity of Bonnie silt was reduced by two orders of magnitude when mixed with 0.3% xanthan gum by weight at water content greater than the optimum moisture content of the silt and that this effect lasted for at least six months (Martin et al. 1996). Karimi (1998) also performed consolidated-undrained (CU) triaxial tests on compacted samples of Bonnie silt mixed with xanthan gum solution and observed an increase in the shear strength of soil samples with age (i.e., with curing time) for the compacted samples. The maximum deviator stresses measured by Karimi (1998) during the CU triaxial tests indicate shear strength improvement of up to 30 percent within a week for specimens prepared with a “gum 1%” solution and in about 4 weeks using a “gum 3%” solution. Kavazanjian et al. (2009) investigated that surface application of a biopolymer emulsion can significantly increase the resistance of sandy and silty soils to wind-induced detachment.

In this study, two different types of biopolymers, xanthan gum and chitosan, with different proportions were used in the compaction and permeability tests for investigation of the biopolymer effect on the engineering behavior of clayey soils. In the experiments, the mixtures of kaolin, bentonite and sand were used with 0.25%, 0.5%, 0.75%, and 1% concentrations of xanthan gum and chitosan biopolymers.

2 MATERIALS and METHODS

The natural kaolin, bentonite and sand samples and their mixtures were used in this study. The sand sample was sieved through No. 30 sieve. The finer percentages from No. 40, No. 100 and No.200 sieves are 51.2%, 8%, and 1.4%, respectively. The clayey soil samples were oven-dried (80 °C-48 hours), crushed and sieved through No. 40 sieve (0.425 mm). The mineralogy of the kaolin and bentonite were determined by Shimadzu XRD-600 device. Grain size distribution and specific gravity of the samples were determined according to ASTM D-422-63 and ASTM D-854-92. Liquid and plastic limits were determined according to ASTM D-4318-98. The results of these tests are given in Table 1.

Table 1. Properties of soil samples used in this study

Property	Kaolin	Bentonite
Mineralogy	Kaolinite	Montmorillonite
	Kuvars	Quartz
	Alunite	Feldspat
Liquid limit	33.9%	421.4%
Plastic limit	27.3%	58.2%
Specific gravity	2.69	2.64
Clay fraction (<0.002 mm)	28%	98%

In this study, the different commercially available biopolymers, xanthan gum and chitosan, were employed in the compaction and permeability experiments. These biopolymers were chosen because they are widely used in industry applications. The xanthan gum and chitosan were supplied from Sigma Aldrich, USA and MP Biomedicals, France, respectively. The xanthan gum solutions were prepared with distilled water and mixed with magnetic stirrer at predetermined concentrations. The chitosan biopolymer solutions were prepared with diluted acetic acid solutions.

The compaction characteristics of the samples were determined according to the ASTM D698-07. The permeability characteristics of the soil samples were determined by rigid-wall permeameter according to ASTM D5856-95. The sample mixtures were compacted at their optimum water contents in compaction-mold permeameter for permeability tests under standard compaction effort. In the permeability tests, the specimens were allowed to saturate under the hydraulic head for at least one week. In order to maintain saturation, at least two pore volume of flow was allowed to pass through the sample.

3 RESULTS and DISCUSSIONS

3.1 Compaction Characteristics

The compaction characteristics of the kaolin-bentonite-sand mixtures were determined in the presence of different concentrations of the xanthan gum and chitosan biopolymers. The effect of the xanthan gum on the 20% bentonite-40% kaolin-40% sand mixture compaction behavior is shown in Figure 1. As xanthan gum concentration increases, the maximum dry density of the mixture increases. However, there is no significant change in the optimum water content.

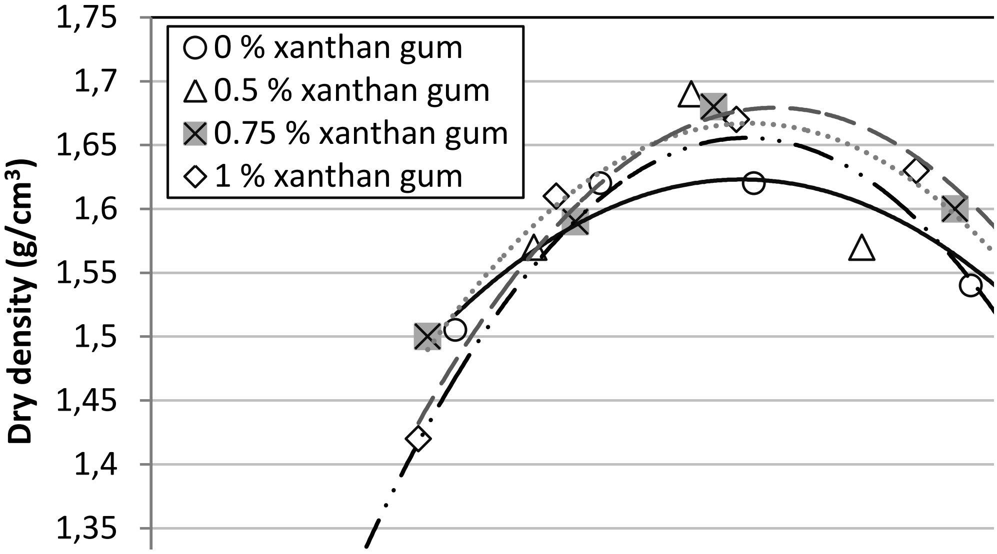

Figure 1. The xanthan gum effect on the compaction behavior of 20%bentonit-40% kaolin-40%sand mixture

The effect of chitosan biopolymer on the compaction characteristics of 20%bentonite-40% kaolin-40%sand is shown in the Figure 2. It clearly can be seen that as chitosan concentration increases the maximum dry density of the samples increases. The maximum dry density increased from 1.62 g/cm^3 to 1.71 g/cm^3 with addition of 1% chitosan biopolymer. However, there is no significant change in the optimum water content of the samples. The chitosan is a cationic biopolymer; it is adsorbed by the negatively charged clay particles. The chitosan decreased the diffuse double layer thickness around the kaolin and especially bentonite particles and increases the dry density of the mixture.

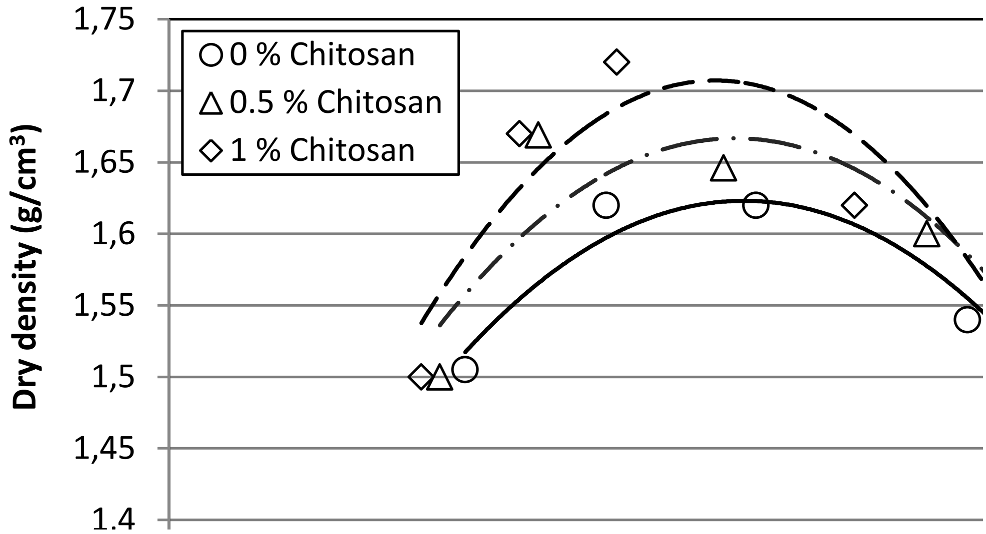

Figure 2. The chitosan effect on the compaction behavior of 20%bentonite-40% kaolin-40%sand mixture

The Figure 3 shows the bentonite content effect on the 20% bentonite-40% kaolin-40% sand and 30% bentonite-30% kaolin-40% sand mixtures in the presence of 0.5% of xanthan gum concentration. In the presence of 30% bentonite, there is a slight decrease in the maximum density of the mixture when compared with 20% bentonite mixture. The higher liquid limit of the bentonite (421%) causes reduction of the dry density of the samples.

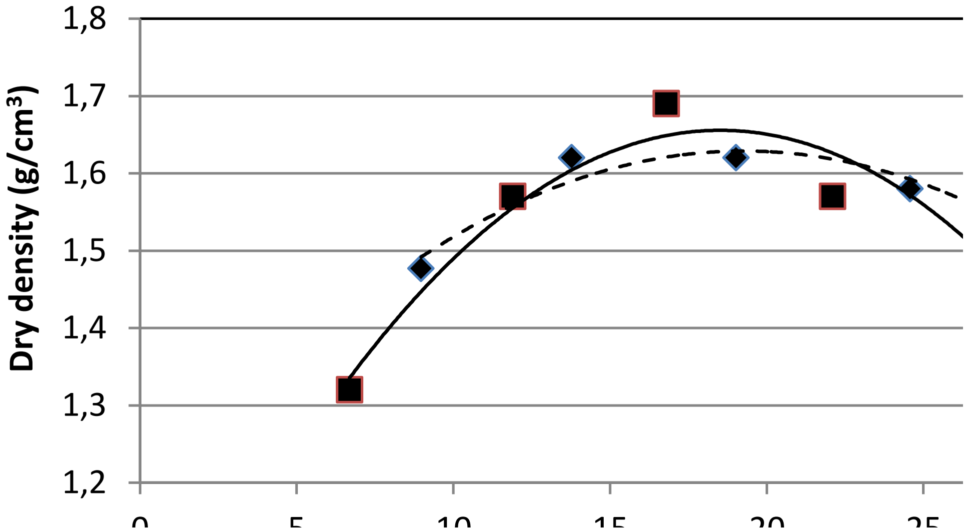

Figure 3. The effect of bentonite content on the compaction characteristics of bentonite-kaolin-sand mixtures in the presence of 0.5% xanthan gum

3.2 Permeability Characteristics

The permeability characteristics of the samples were investigated by rigid wall permeameter. In the permeability tests 30% kaolin-70% sand mixture was used. The mixtures were compacted at optimum water contents under standard compaction effort. The effect of xanthan gum biopolymer is shown in Table 2. As can be seen from the first week results xanthan gum concentration increase caused a decrement on the permeability values of the kaolin-sand mixture. The 1% concentration of xanthan gum decreased the permeability of the mixture almost 30 folds. The xanthan gum absorbs water; therefore, when an amended soil is wetted, the xanthan gum expands, forming a fibrous network (Czarnes et al. 2000) and fills the pores in the soil. Hence, xanthan gum concentration increase causes permeability decrease in the soils. The xanthan gum degradation effect was also observed by 2.nd and 3.rd weeks permeability tests results. These results have shown that xanthan gum degrades in the samples during in time. However, the results of the 3.rd weeks show that xanthan gum still have significant effect on the permeability characteristic of the mixture.

Table 2. The xanthan gum effect on the permeability characteristics of 30% kaolin-70% sand

Xanthan gum concentration	Permeability (1.st week) ($x10^{-5}$ cm/s)	Permeability (2.nd week) ($x10^{-5}$ cm/s)	Permeability (3.rd week) ($x10^{-5}$ cm/s)
0 %	4.13	4.13	4.13
0.25 %	1.87	2.12	2.38
0.5 %	1.30	1.55	-
0.75 %	0.63	0.93	-
1.0 %	0.15	0.23	0.28

The effect of the chitosan on the permeability of 30% kaolin-70% sand mixture is shown in Table 3. The general results show that as chitosan concentration increases permeability of the mixture decreases. The chitosan is a cationic biopolymer, negatively charged kaolin particles attract positively charged macromolecules and cause adsorption. By this adsorption, flocculated structure may occur in the sample. The 0.25% concentration of chitosan have more significant effect, it decreased the permeability more than xanthan gum. The degradation process is also effective on the chitosan. However, after 3 weeks chitosan has significant effect on the permeability behavior of the mixture. It should be noted that, 0.25% chitosan concentration can be selected as the optimum concentration for the applications. Increments after this concentration do not cause significant decrease in the permeability of the mixture.

Table 3. The chitosan effect on the permeability characteristics of %30 kaolin-70% sand

Chitosan concentration	Permeability (1.st week) ($x10^{-5}$ cm/s)	Permeability (2.nd week) ($x10^{-5}$ cm/s)	Permeability (3.rd week) ($x10^{-5}$ cm/s)
0 %	4.13	4.13	4.13
0.25 %	0.71	0.82	0.97
0.5 %	0.58	0.68	0.83
1.0 %	0.47	0.57	-

4 CONCLUSIONS

1. The xanthan gum and chitosan biopolymers increased the maximum dry density of the bentonite-kaolin-sand mixtures. The effect of chitosan is more significant than the xanthan gum.
2. There is no change in the optimum water contents in the presence of different concentrations of the used biopolymers.
3. The rigid wall permeameter test results show that both xanthan gum and chitosan decreased the permeability of the 30% kaolin-70% sand mixtures.
4. The 0.25% chitosan is found as the optimum biopolymer content for permeability applications.
5. The effect of both biopolymers decrease in time because of the degradation effect.
6. The degradation of the biopolymers should be investigated for long-term applications of the biopolymers.

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