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Stabilization of Low Plastic and High Plastic Clay Using Guar Gum Biopolymer

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ABSTRACT

In geotechnical engineering, soil stabilization provides practical and cost-effective solutions related to problematic soils. With the growing necessity for environmentally friendly and sustainable materials, researchers have been exploring alternative methods such as biological approaches for soil stabilization. Biopolymers are produced from living organisms and are considered to be environmentally friendly soil stabilizers. A detailed study on stabilization of soil using Guar gum biopolymer was carried out through intensive laboratory testing. For this purpose, low plastic (CL) and high plastic (CH) clays were treated with varying contents of Guar gum biopolymer (1%, 2%, 3% and 4%) by the weight of dry soil. The experimental program mainly focused on compaction characteristics, unconfined compressive strength, California Bearing Ratio (CBR) and swell potential tests. All the samples were prepared on dry mix basis. The UCS of cured and soaked samples was tested after 2, 7, 14, and 28 days of curing and soaking. Strengthening effect of Guar gum biopolymer was observed with the increasing biopolymer content and curing period. An increase of 182.64% and 243.30% was observed in the UCS of CL and CH respectively at the end of curing period using 2% biopolymer content. The results indicated a significant increase in the CBR of both CL and CH under soaked and unsoaked conditions. The incorporation of Guar gum biopolymer has shown significant improvement in geotechnical properties of low plastic and high plastic clays and can be adopted as a potentially sustainable soil stabilizer.

1. Introduction

Soil has a critical role in construction as it acts as ultimate load bearing material for structures such as buildings, roads, bridges etc. As a result of continuous construction and development works, the odds of availability of favorable soil at construction sites have decreased, which urges the engineers to utilize the land with unfavorable & problematic soil for the construction purposes. Clayey soils are expansive in nature as they tend to experience volumetric changes upon interaction with water. The swelling and shrinkage behavior of clayey soils instigates severe soil related problems. Improvement in soil

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properties has been an important consideration for engineers and researchers throughout the construction history. Soil stabilization is a process of modification of soil properties such as compaction, bearing capacity, strength, and swelling potential for improved engineering performance [1, 2]. Researchers have been examining a variety of soil stabilization practices such as compaction, drainage, pre-compression, consolidation, grouting, soil reinforcement, geotextiles, and chemical stabilizers [3]. The use of various soil stabilizers has been in practice such as cement, lime, gypsum, fly ash, rice husk ash, rubber wastes, bitumen, and slag [4]. Among these conventional additives, cement is one of the most abundantly used material for soil stabilization [5]. Cement has been identified as the leading source of carbon dioxide emission, causing approximately 5% of annual carbon dioxide production [6]. The excessive use of conventional soil stabilizers, such as cement, leads to serious environmental impacts. Keeping in view the environmental sustainability, researchers have been intensively studying alternative materials such as geosynthetics, geopolymers, biopolymers, synthetic polymers, bio-enzymes, and microbial injections to be used as stabilizers [7]. Biopolymers are produced by living organisms and are considered to be environmentally friendly and sustainable materials to be used as alternative soil stabilizers [8]. The use of biopolymers in not utterly new in the field of geotechnical engineering, as humans used various materials such as straw and sticky rice binders for soil improvement in the past [9]. Utilizing the biopolymers can help in improving the soil properties such as compressive strength, erosion control, reduction in permeability and vegetation suitability [10]. Biopolymers have shown the capability of being sustainable materials for the improvement of strength and stability of various soils and found to be advantageous over traditional stabilizers in terms of being environmentally friendly and effective at low concentrations [11]. Soils treated with biopolymers exhibit that small concentration of biopolymers mixed with soils result in higher compressive strength as compared to large amount of cement mixed with soil [9]. Biopolymers on interaction with fine soil particles form soil-biopolymer matrices having the strength mainly linked by hydrogen bonding, thus improving the overall compressive strength and resistance of soil [12]. Addition of biopolymers at low concentrations has been reported to improve compaction characteristics, compressive strength, CBR, swelling potential, permeability, collapsible potential, and shear parameters [13-16]. Due to the lack of biological approach for soil improvement in Pakistan, a biopolymer commonly known as Guar gum was selected as the soil stabilizing agent in this work. The addition of Guar gum to the soil has been reported to improve the compaction characteristics, compressive strength, CBR, resistance to wind erosion, dust resistance, water retention capacity, collapsible potential, surface strength and other mechanical properties of the soil [6, 13, 16, 17, 18]. In this study, the effects of Guar gum on low and high plastic clays has been investigated.

2. Materials

2.1. Soil

Two types of soils, low plastic and high plastic clay, have been used in this study to investigate the effect of biopolymer on selected soil properties. The low plastic soil exhibiting swelling behavior used in this study was collected from Ballewala, Pakistan. Various studies have been conducted to control swelling and improve geotechnical properties such as compaction, compressive strength and CBR of Ballewala clay [19-22]. High plastic clay was prepared in the laboratory by mixing 25% bentonite with low plastic clay. Trial tests were conducted for the selection of suitable percentage of bentonite in order to prepare high plastic clay in laboratory. CL soil was mixed with 10%, 15%, 20%, and 25% bentonite and Atterberg Limits tests were conducted for each replacement. A significant change in liquid limit of the soil was observed at 25% bentonite mix, thus it was selected as the suitable percentage for preparing

CH samples in the laboratory. The geotechnical properties of low plastic and high plastic clays obtained through laboratory testing are shown in *Table1*.

Table 1. *Properties of untreated CL and CH.*

Property	CL	CH
Passing Sieve # 200 (%)	*94.42*	*97.09*
Clay Fraction (%)	*19*	*26*
Liquid Limit, LL (%)	*48*	*59*
Plastic Limit, PL (%)	*21*	*28*
Plasticity Index, PI (%)	*27*	*31*
Specific Gravity (Gs)	*2.67*	*2.69*
AASHTO Classification	*A-7-6*	*A-7-6*
USCS Classification	*CL*	*CH*
MDD (kN/m^3)	*17.80*	*17.50*
OMC (%)	*12.00*	*12.34*
UCS (kPa)	*170.53*	*211.44*
Un-soaked CBR (%)	*3.69*	*2.61*
Soaked CBR (%)	*2.12*	*1.36*
Swell Potential (%)	*5.89*	*7.83*

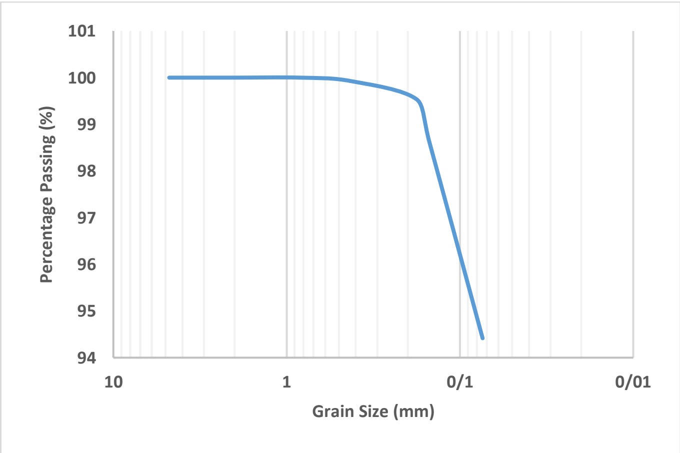


Fig. 1. *Grain size distribution of CL.*

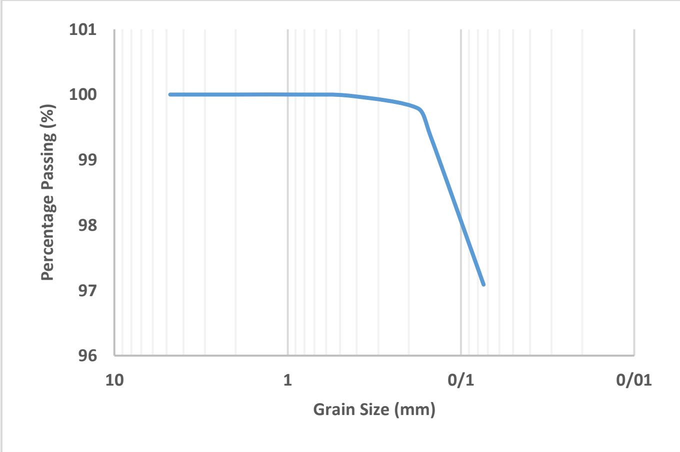


Fig. 2. *Grain size distribution of CH.*

The bentonite used in this research to prepare high plastic clay in laboratory was obtained from Lahore, Pakistan. The chemical composition of industrial bentonite clay, known as Sodium Bentonite, is shown in *Table 2*.

Table 2. *Chemical composition of bentonite clay.*

Name	Formula	Percentage
Silica	SiO_2	*50.0 to 65.0 %*
Alumina	Al_2O_3	*15.0 to 25.0 %*
Ferric Oxide	Fe_3O_3	*2.0 to 4.0 %*
Magnesium Oxide	MgO	*3.0 to 6.0 %*
Calcium Oxide	CaO	*0.50 to 2.0 %*
Sodium Oxide	Na_2O	*0.50 to 5.0 %*
Potassium Oxide	K_2O	*0.20 to 1.0 %*
Titanium Oxide	TiO_2	*0.20 to 0.50 %*

2.2. Biopolymer

Guar (botanically known as Cyamopsis Tetragonoloba) is grown in arid and semi-arid regions of Punjab and Sind provinces of Pakistan and its seeds are locally processed in industries to form Guar gum in powdered form, as shown in *Fig. 3*.

The industrially produced Guar gum used in this research was obtained from Karachi, Pakistan. Guar gum comes from polysaccharide family of biopolymers which is mainly composed of sugars galactose and mannose. The basic structure of Guar gum consists of a linear chain of *β-1*, 4-linked mannose with *α-1*, 6-linked galactose residues [23], shown in *Fig. 4*. The galactose residues are linked with every second mannose in the chain, thus establishing short side branches [16]. Guar gum biopolymer through its hydroxyl groups (-OH) can form frequent hydrogen bonds, which further adds up to the strength of soil-biopolymer matrices [24].

Fig. 3. *Guar gum powder.*

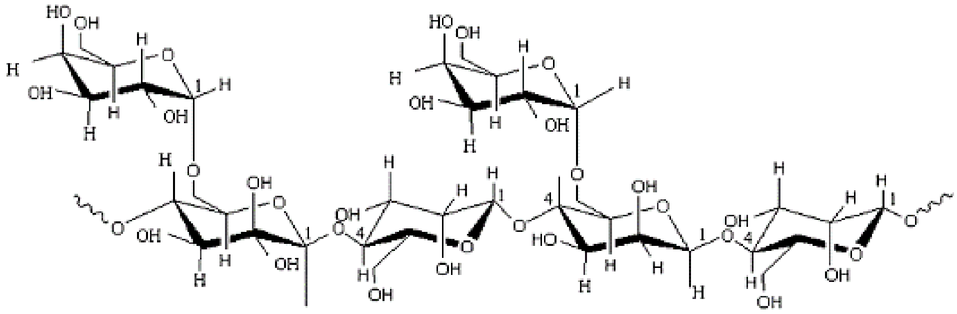


Fig. 4. *Structure of Guar gum biopolymer [23].*

3. Experimental Procedure

The experimental program mainly focused on the compaction characteristics, Unconfined Compressive Strength (UCS), CBR and swell potential of the soil. In order to evaluate the effectiveness of Guar gum biopolymer on these soil properties, a number of laboratory tests were conducted which include modified proctor test, unconfined compressive strength test and CBR test. In order to perform UCS and CBR tests, the samples were prepared at Optimum Moisture Content (OMC) obtained from modified proctor tests. UCS was performed in both curing and soaking conditions for evaluating the effect of curing period on the development of strength. CBR tests were also conducted under unsoaked and soaked conditions. Swell potential of the soil was determined from soaked CBR samples.

3.1. Sample Preparation

In light of the literature, dry mixing method was adopted for sample preparation [9, 13, 15, 17]. The Guar gum powder was thoroughly hand mixed with the soil and a predetermined amount of water was then added to the soil-biopolymer mixture to prepare the specimen for testing. In this study, different quantities of Guar gum biopolymer were used with the soil according to its percentage by weight of dry soil sample. The mixing percentages are denoted in this study as BP-1, BP-2, BP-3, and BP-4 for 1%, 2%, 3% and 4% biopolymer content, respectively.

4. Results and Discussions

The selected properties of soil were evaluated for assessing the effectiveness of Guar gum at four different percentages of biopolymer: 1%, 2%, 3%, and 4%, by weight of dry soil. The main results of this study are discussed below.

4.1. Compaction Characteristics

Compaction is a primary process in soil stabilization, in which a soil is compacted to a certain density after mixing the stabilizer. The attained density influences other soil properties such as bearing capacity, settlement, and shear strength. It is of prime importance to determine the compaction characteristics of soil mixed with varying percentages of biopolymer. The modified proctor test was performed using both low plastic and high plastic clays (CL and CH) mixed with each biopolymer percentage in order to determine the effect of Guar gum biopolymer on Maximum Dry Density (MDD) and OMC. The results for both the CL and CH soils are shown in *Fig. 5* and *Fig. 6*, respectively. The modified proctor test results for both CL and CH soils show an increasing trend in the MDD and corresponding OMC values for biopolymer content up to 2%. Guar gum biopolymer fills up the pore spaces in the soil and also bonds with the fine particles of clay, thus increasing the dry density of the soil. Upon further increase in biopolymer content, the MDD showed a decreasing trend but the corresponding OMC kept on increasing with the increase in biopolymer content. This can be attributed to highly viscous nature of Guar gum biopolymer, which changes the water absorption and specific gravity of the soil sample resulting in decrease in MDD at higher biopolymer content.

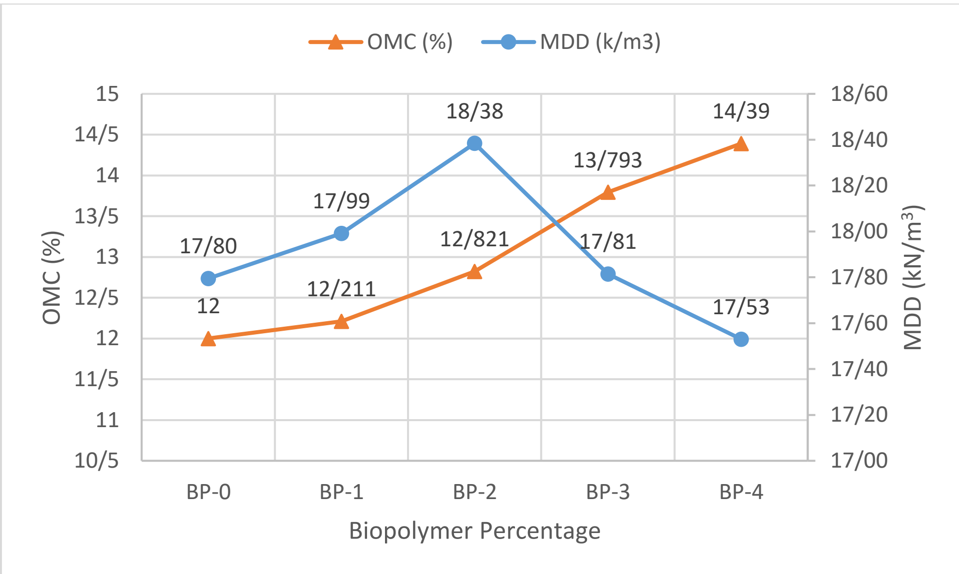


Fig. 5. *Trend of OMC and MDD at different biopolymer percentages for CL.*

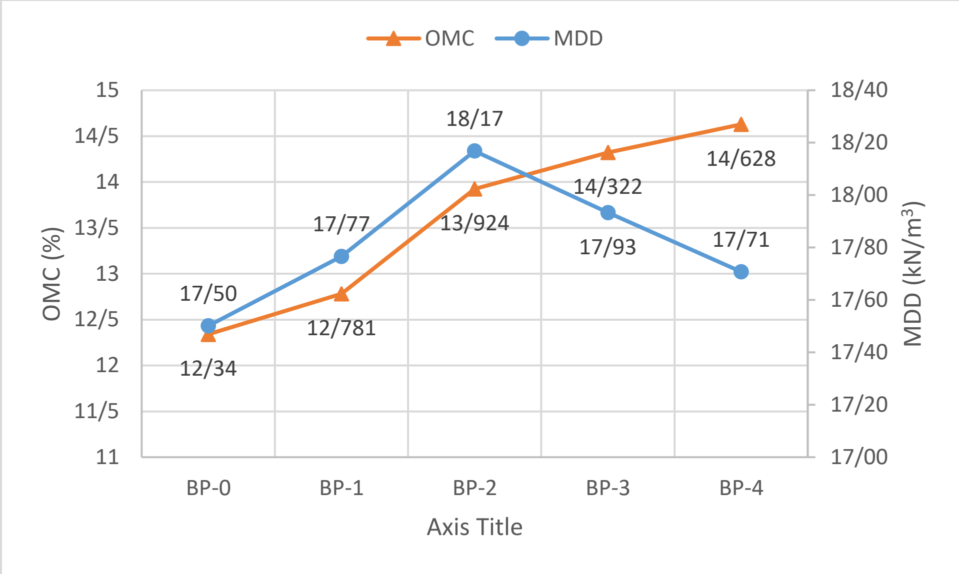


Fig. 6. *Trend of OMC and MDD at different biopolymer percentages for CH.*

4.2. Unconfined Compressive Strength

The unconfined compressive strength test was conducted using both CL and CH samples. The test specimens were prepared at MDD and OMC obtained from modified proctor test for different percentages of Guar gum biopolymer. The prepared specimens were wrapped in plastic sheet and left at room temperature for 24 hours before testing. *Fig. 7* shows the results of UCS tests for both the CL and CH soil specimens at different biopolymer percentages. For both soils, maximum values were observed at 2% biopolymer content. The effect of strength development with time was evaluated by curing the samples for 2, 7, 14, and 28 days in a thermostatically controlled oven. The prepared specimens were wrapped in plastic sheet and placed in oven at 40°C for desired curing period. The results of curing effect on strength of CL and CH soil samples are shown in *Fig. 8* and *Fig. 9*, respectively. For soaking test, the UCS cured samples were placed in desiccator for 48 hours. The soaking test signifies the strength of soil subjected to capillary rise of water. Biopolymers generally have high specific surfaces and upon interaction with fine particles of the soil, they form firm soil-biopolymer matrices.

Guar gum biopolymer have large hydroxyl groups which form a network of hydrogels between soil particles and free water linked by hydrogen bonds, thus contributing to the higher compressive strength of the soil [15, 25, 26]. The unconfined compressive strength of both CL and CH soil samples used in this study showed significant improvement according to both the curing period of soil-biopolymer mix and also the content of biopolymer. The maximum values were achieved at 2% biopolymer content. Upon further increase in Guar gum biopolymer content, a decrease in UCS values was observed for both CL and CH soils. It was also observed that the UCS of both soils attained maximum values after 28 days curing for all the biopolymer contents, among which the maximum value was obtained in BP-2 case. The UCS value of CL and CH soils increased from 170.53 kPa to 482 kPa and from 211.44 kPa to 725.88 kPa, respectively after 28 days of curing. It indicates an increase of 182.64% and 243.30% in unsoaked UCS of CL and CH, respectively.

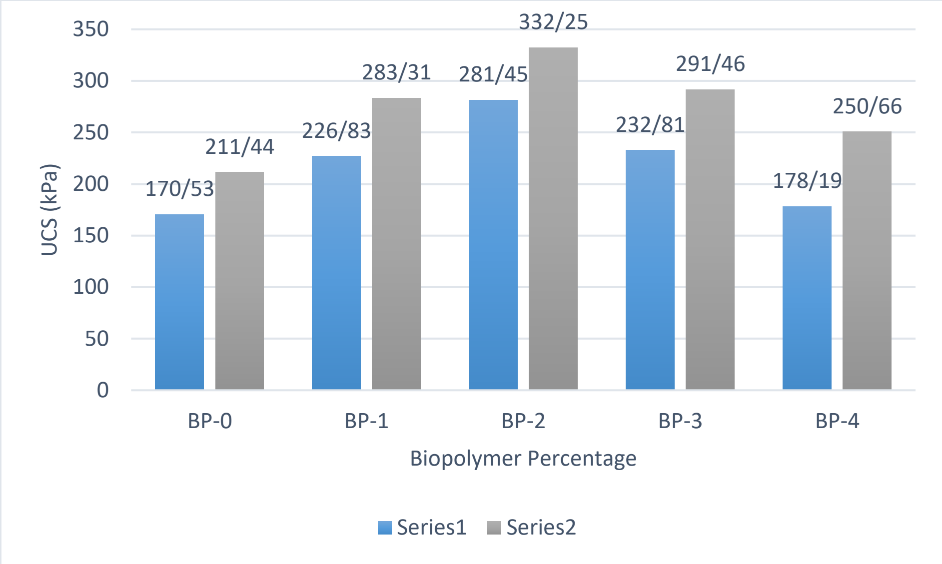


Fig. 7. *UCS of uncured CL and CH samples at different biopolymer percentages.*

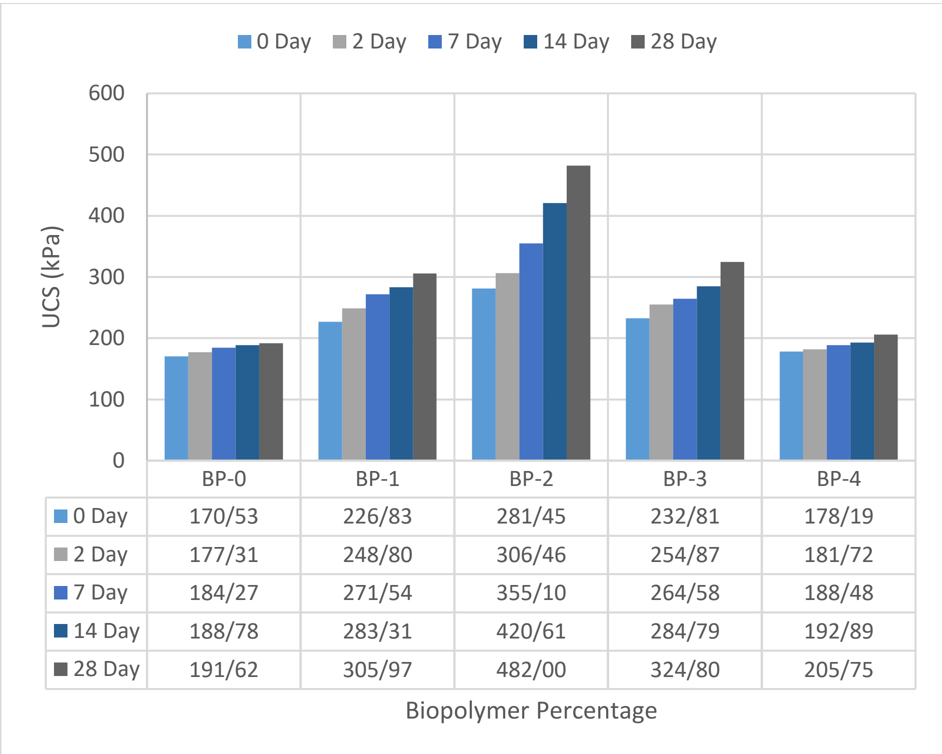
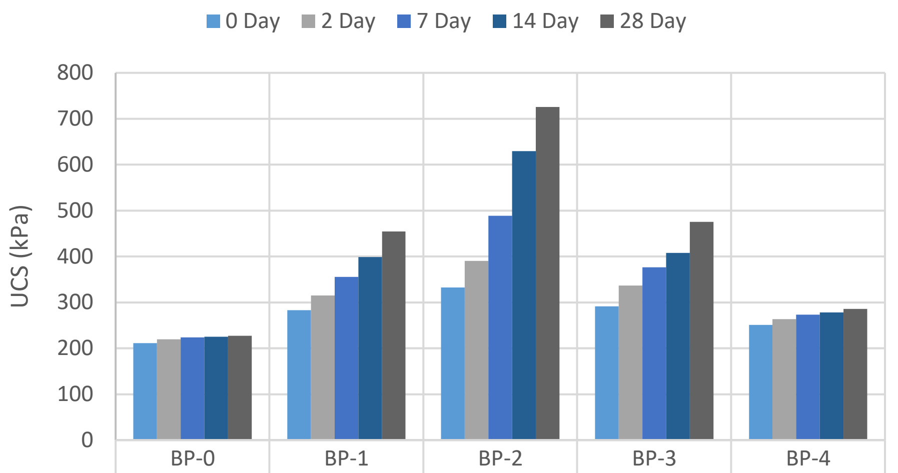


Fig. 8. *UCS of CL soil at different curing periods.*



	BP-0	BP-1	BP-2	BP-3	BP-4
0 Day	211/44	283/31	332/25	291/46	250/66
2 Day	219/87	314/89	390/11	336/57	263/21
7 Day	223/49	355/59	488/96	376/67	273/23
14 Day	225/07	398/83	629/10	408/05	278/22
28 Day	227/22	454/44	725/88	475/33	285/77

Fig. 9. *UCS of CH soil at different curing periods.*

In the presence of moisture, clays experience swelling and reduction in density, which results in the loss of strength. In order to replicate such conditions, soaking test on UCS samples was conducted. The results of soaked UCS samples at optimum biopolymer content for both CL and CH soils are shown in *Fig. 10* and *Fig. 11*, respectively. The results are shown for the optimum biopolymer content in the case of BP-2 since maximum strength was observed in this case, as shown in *Figs. 6 & 7*. The results indicate the loss of strength for both CL and CH samples due to soaking in all the cases of biopolymer content. In BP-2 case, the strength for CL sample dropped from 482 kPa to 385.64 kPa, while for CH sample the strength decreased from 725.88 kPa to 550.64 kPa. It indicates a decrease of 19.99% and 24.14% in soaked UCS of CL and CH, respectively.

Both CL and CH soils exhibited a loss in the strength due to the presence of moisture, although in comparison with the untreated soil samples, the biopolymer-soil mix has shown a significant strength under soaking conditions. At optimum biopolymer content, an improvement of 275.89% and 252.93% was observed in soaked UCS of CL and CH soils, respectively. The comparison of soaked UCS of untreated and treated soil samples is shown in *Fig. 12* and *Fig. 13*, respectively.

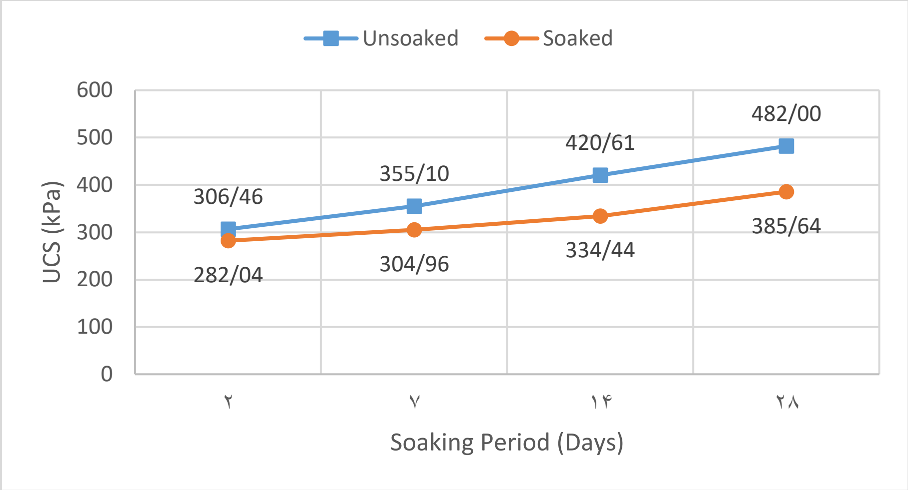


Fig. 10. *Difference in UCS of CL soil according to soaking conditions.*

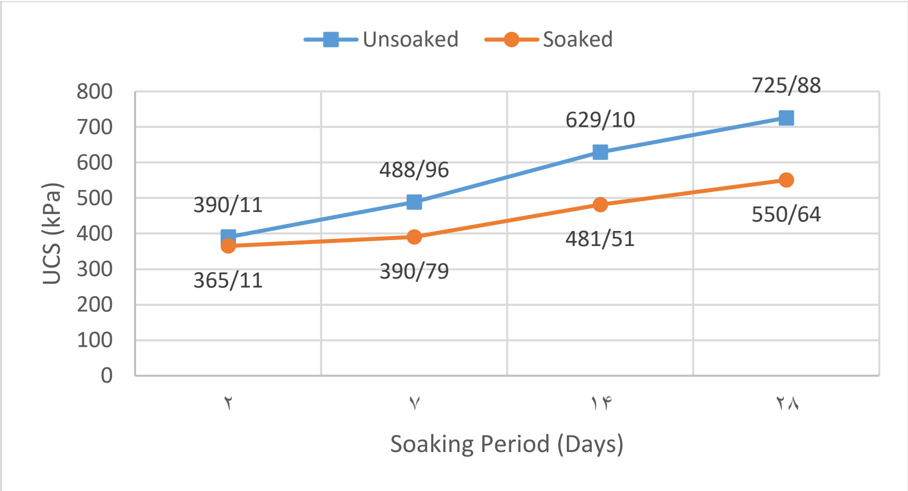


Fig. 11. *Difference in UCS of CH soil according to soaking conditions.*

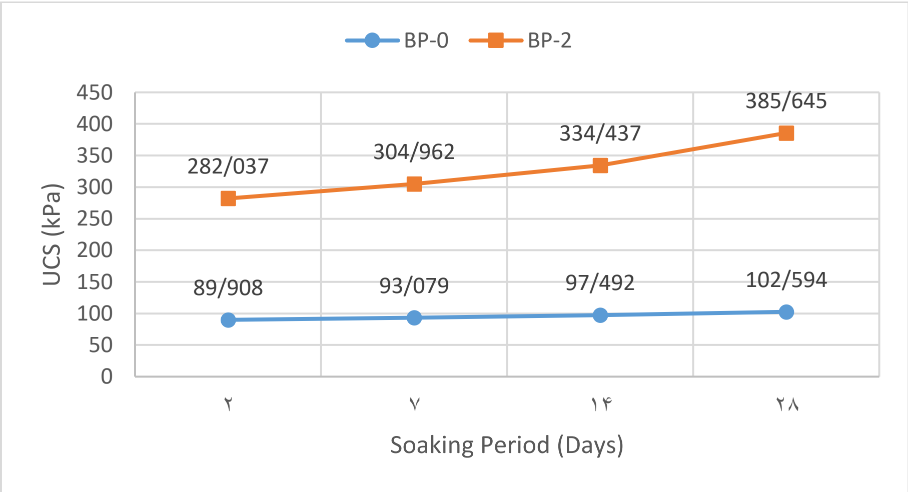


Fig. 12. *Comparison of untreated and treated UCS of CL according to soaking conditions.*

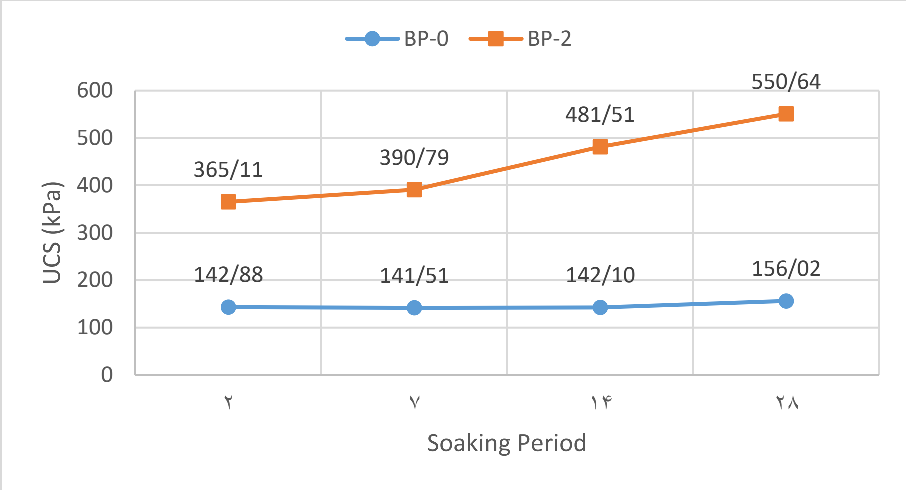


Fig. 13. *Comparison of untreated and treated UCS of CH according to soaking conditions.*

4.3. California Bearing Ratio

CBR value largely depends on the compaction characteristics of the soil. CBR samples were prepared at OMC obtained from modified proctor test for each biopolymer percentage. Both unsoaked and soaked CBR tests were carried out at all four percentages of biopolymer for both CL and CH soils. The results of CBR test for CL and CH soils are shown in *Fig. 14* and *Fig. 15*, respectively. It was observed from the results that the CBR value increased with increase in the biopolymer content up to 2%. Upon further increase in biopolymer content, a decrease in CBR of both CL and CH was observed under unsoaked and soaked conditions. The results indicate that the effect of Guar gum biopolymer was slightly more significant on the CBR value of CL soil as compared to that of CH soil since both the soaked and un-soaked CBR values in BP-2 case were slightly greater for CL soil.

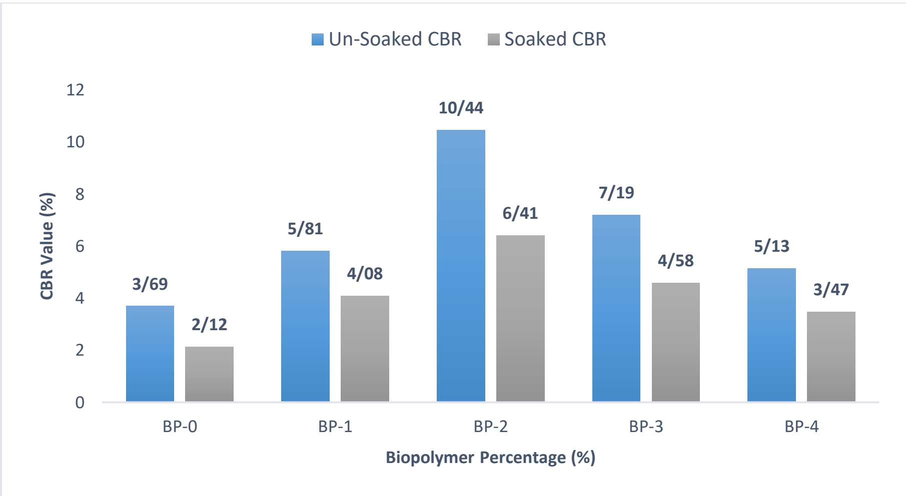


Fig. 14. *Soaked and unsoaked CBR of CL at different biopolymer percentages.*

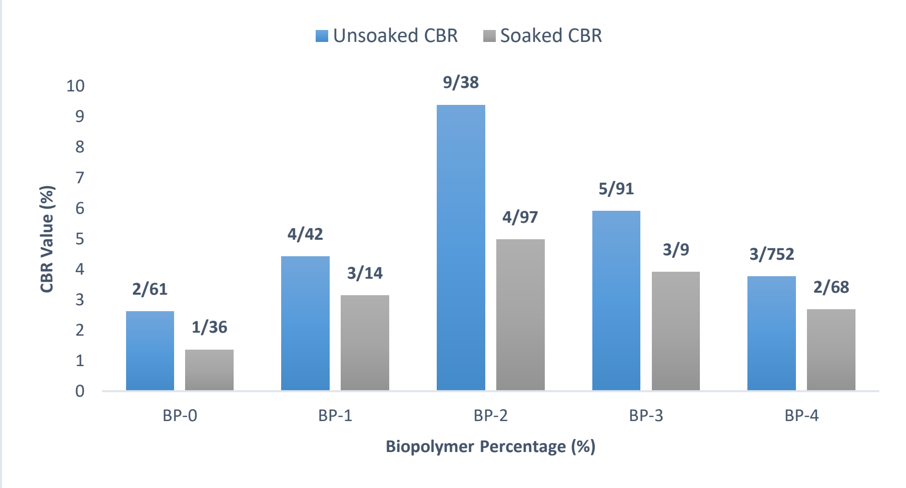


Fig. 15. *Soaked and unsoaked CBR of CH at different biopolymer percentages.*

The combined results of CBR for CL and CH under soaked and unsoaked conditions are presented in *Fig. 16* for comparison of the effectiveness of Guar gum biopolymer on subgrade soil strength.

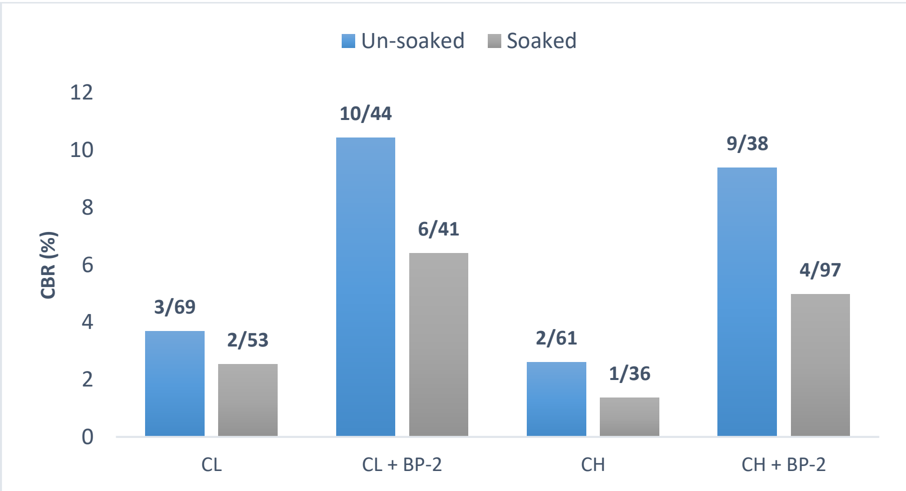


Fig. 16. *Comparison of soaked unsoaked CBR of CL and CH at optimum BP content.*

4.4. Swell Potential

Swell potential of both untreated and treated low plastic and high plastic soil samples was evaluated during the soaked CBR tests. The soaked CBR specimen was subjected to a 5 kg load and a dial gauge was attached to measure the change in the volume of soil specimen. The evaluation of treated soil specimen was carried out only at the optimum biopolymer content (BP-2 case) for both CL and CH. A significant reduction in the swelling potential of both CL and CH soils was observed according to the addition of optimum percentage of biopolymer. The results of swell potential for untreated and treated soil specimens are shown in *Fig. 17* for both CL and CH soils. As shown in *Figs. 16* & *17*, it was observed that CL soil exhibit better results after the addition of Gaur gum biopolymer.

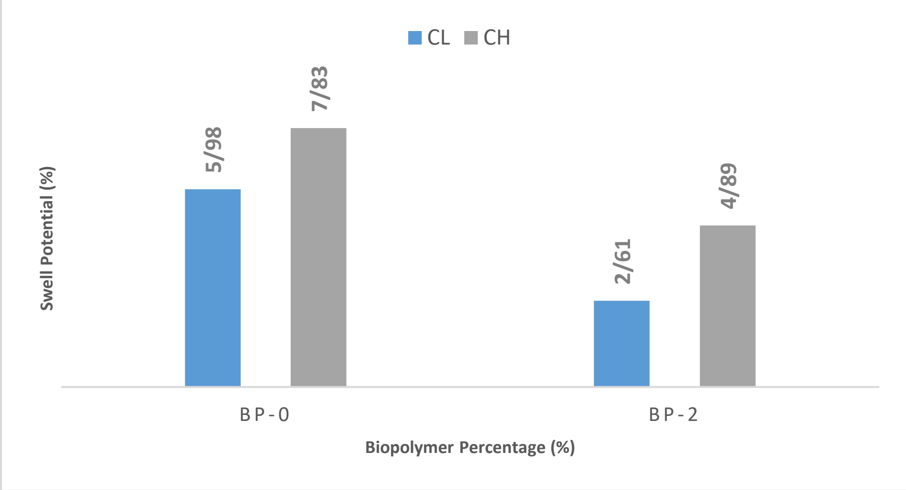


Fig. 17. *Swell potential of CL and CH soils at optimum BP percentage*.

5. Conclusions

With recent developments in construction industry, the most vital aspects involved in selection of the material to be used as soil stabilizer became the environment friendliness and sustainability. This work was focused on the use of Guar gum biopolymer as an environmentally friendly material to improve the geotechnical properties of low plastic and high plastic clays. An elaborate study was conducted to investigate the effectiveness of Guar gum biopolymer as potential substitute to conventional soil stabilizers. The chosen soil parameters to evaluate the feasibility of Guar gum biopolymer included the compaction characteristics, unconfined compressive strength, CBR, and one-dimensional swell potential. Based on the experiments conducted in laboratory on both the low plastic (CL) and high plastic (CH) clays, following conclusions were drawn:

- The optimum amount of Guar gum biopolymer to be used with CL and CH soils was observed to be 2%, making it the optimum biopolymer content in this study.
- The MDD of CL and Ch increased from 17.80 kN/m^3 to 18.83 kN/m^3 and from 17.50 kN/m^3 to 18.17 kN/m^3, respectively.
- For CL soil, the UCS value increased from 170.53 kPa to 281.45 kPa at optimum biopolymer content, which further increased to 482 kPa after 28 days of curing indicating an increase of 182.64%.
- For CH, the UCS value climbed from 211.44 kPa to 332.25 kPa at optimum biopolymer content, which further increased to 725.88 kPa after 28 days of curing indicating an increase of 243.30%.
- The strengthening effect of Guar gum biopolymer depends not only on the biopolymer content but also on the curing time.
- Both CL and CH soil samples showed a decrease in strength due to the presence of moisture under soaked conditions.
- After soaking, the UCS of CL samples treated with BP decreased from 482 kPa to 385.64 kPa indicating a decrease of 19.99%.
- Similarly, UCS of CH samples treated with BP decreased from 725.88 kPa to 550.64 kPa indicating a decrease of 24.14%.
- As compared to untreated samples, the soaked UCS of treated CL and CH samples was improved by 275.89% and 252.93%, respectively.
- At optimum biopolymer content, the unsoaked and soaked CBR values of CL soil increased up to 182.93% and 202.36%, respectively.

- Similarly, the unsoaked and soaked CBR values of CH soil increased up to 259.39% and 265.44%, respectively by using optimum biopolymer content.
- The resistance to swell potential of CL and CH soil specimens was improved by 56.35% and 33.74%, respectively.

The results presented in this study indicate that the addition of Guar gum biopolymer at low percentages (1-3% by soil-weight) can significantly improve the geotechnical properties of such soils. This study will help increasing the confidence in using Guar gum biopolymer so that it can be effectively adopted as a potential soil stabilizer. Biopolymers are considered to be renewable materials, therefore utilizing biopolymers in stabilization techniques and construction can help in developing sustainable industry.

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