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# Effects of Xanthan Gum and Lime on Physical Properties and Mechanical Behavior of Organic Soil

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*ABSTRACT*

A sample of organic soil collected from the Chaharmahal-Bakhtiari Province, Iran, was treated with 0.5, 1, 1.5, 2, 2.5, and 3% of xanthan gum and 1, 3, and 5% of lime. The untreated and the treated specimens were subjected to physical and mechanical tests, including soil classification, pH measurement, compaction test, unconfined compressive strength test, indirect tensile test, and direct shear test. An increase in lime by 3% led to the greatest increase in the compressive strength (5 and 6 times for the 7-day and 21-day samples, respectively) and the tensile strength (3.7 and 4.5 times for the 7-day and 21-day samples, respectively). Xanthan gum also improved the compressive strength (3 and 6 times for the 7-day and 21-day samples, respectively) and the tensile strength (5.9 and 7.5 times for the 7-day and 21-day samples, respectively). Increasing lime up to 3% enhanced the adhesion of the stabilized soil for 3.5 and 7.5 times that of the organic soil for 7 and 21 days of curing, respectively. Also, the friction angle increased by 40% and 68% times with the increase of lime up to 3% during 7 and 21 days of curing, respectively. Stabilization with xanthan gum led to 11.5 and 17.5 times increase adhesion for 7-day and 21-day samples, respectively. Moreover, xanthan gum increased the friction angle by 47% and 75% for 7-day and 21-day samples, respectively. The findings generally suggest that xanthan gum can be a good ecofriendly alternative to lime as a soil stabilizer.

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**NOMENCLATURE**

| | | | |
|---|---|---|---|
| A | Mass of the as-received test specimen (g) | T | Tensile strength (KN/m^2) |
| B | Mass of the oven-dried specimen | P | Maximum compressive force applied by the machine (kN) |
| C | Weight of ash | L | Length of the specimen (m). |
| D | Ash content | d | Diameter of the specimen (m). |

## 1. INTRODUCTION

As a substrate for all structures, soil has a special place in civil engineering. However, engineers increasingly face the challenges of construction on poor-quality and problematic soils due to rapid urbanization and the need for infrastructures [1]. Such soils have unfavorable geotechnical characteristics, including their significant settlement and low strength [2], which makes it necessary to stabilize them. Improvement of soil can change and enhance its properties, ultimately leading to the reduction of structure settlement, better soil shear strength, and higher bearing capacity [3,4]. Geotechnical engineering offers various methods to stabilize problematic soils, one of which is the use of additives [5, 6]. It should be noted that the type of additive and its composition as well as soil characteristics are the main parameters affecting the strength of stabilized soil [7].

Organic soil is a soft layer of soil with a high moisture content, high compressibility, low load-bearing capacity, low shear strength, and low density. It is composed of fine fractioned particles of organic matter and soft clay [8]. Since it is mainly formed as a result of the accumulation and decomposition of plants in wetlands or under water, it sometimes partly contains decayed plant matter. Due to its characteristics, organic soil tends to have very little load resistance even to small loads, and the roads, railways and other structures built on it are exposed to problems such

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as large and extensive cracking, even in the early stages of construction. From the geotechnical engineering perspective, this soil falls in the category of problematic soils [9,10]. Therefore, not only does this soil need treatment, but the treatment method is also an important issue. There are various techniques to improve the engineering properties of problematic soils, such as removing organic soil and replacing it with better alternatives, preloading, and using soil stabilization methods. If none of these are viable options, it might be better to relocate the project [11,12]. A common way of treating weak soils is to stabilize them. However, it may be difficult to choose a stabilization method in a systematic way. It is geotechnical engineers, indeed, that should determine a preferable method with regard to a wide range of technical and economic issues as well as the available labor and equipment based on personal experience and test results. Soil stabilization methods can be divided into physical-mechanical, chemical, and biological types [13,14]. Chemical stabilization has been widely done to improve the engineering properties of problematic soils. A review of the literature shows that organic soils, or the soils containing organic matter, can be successfully stabilized with traditional binders such as lime [15–17], cement [17-19] and fly ash [20, 21]. Meanwhile, for many years, researchers and engineers have used lime for stabilization as a popular soil improvement technique [2].

Although chemical stabilizers are effective, they cannot be considered eco-friendly because they can be toxic, alter soil pH, and contaminate groundwater. In addition, the processes through which these stabilizers are produced are usually large sources of greenhouse gas emissions [6]. In recent years, there has been considerable interest in using certain biopolymers, such as xanthan gum, instead of traditional chemical stabilizers with increasing public pressure to use eco-friendly and sustainable materials [22]. For instance, Chang et al. [23] sought to stabilize sand, clay, natural soil and red-yellow soil with the xanthan gum biopolymer. They achieved an improvement in the compressive strength and elastic modulus of those materials by adding increasing amounts of xanthan gum to them. As the Scanning Electron Microscope (SEM) images taken in this study showed, xanthan gum binds the sand particles that otherwise do not bond together, thereby improving the soil strength. This improvement depends on the strength of xanthan gum fibers. In clay, however, the improvement of strength occurs through the direct reaction of xanthan gum and charged soil particles (e.g., hydrogen bonding). As that study estimated, using 1 to 1.5% of xanthan gum as a stabilizer can be cost-effective. At the end, it was concluded that xanthan gum is a suitable material for soil stabilization as it does not decompose for a long time (750 days) and retains its compressive strength and elastic modulus. Latifi et al. [24] studied the use of xanthan gum biopolymer in the stabilization of peat soil and evaluated the effect of curing time (3, 7, 28 and 90 days). The optimal amount of xanthan gum to increase compressive and shear strengths was found to be 2%. While using more xanthan gum increases the compressive strength, it is not economical and causes excessive viscosity, which makes its use problematic. The results of study showed that prolonging the curing time improves the behavior of xanthan gum-peat soil mixtures. Ayeldeen et al. [25] used xanthan gum and guar gum to stabilize collapsible soils in dry and wet conditions. They reported that both biopolymers increase the cohesion, decrease the collapse potential, increase the optimum moisture content, and decrease the specific dry weight of the soil. In that study, the soil treated with guar gum showed 20% better results than the one improved with xanthan gum. In a study by Chang et al. [26] on the use of gellan gum biopolymer in sandy soil, it was found that the addition of this substance to the soil increases its unconfined compressive strength, cohesion, and internal friction angle. As also reported, gellan gum has a good reaction with soil and quickly decreases its permeability.

The uniaxial compression, direct shear, and consolidation tests conducted by Latifi et al. [27] on xanthan gum-treated kaolinite and bentonite clay soils showed that xanthan gum increased the hardness, shear strength, and compressive strength of these soils. These effects would be improved with longer curing. Smitha and Sachan [28] studied the behavior of a mixture of Sabarmati river sand (in India) with agar biopolymer by conducting a series of experiments. They showed that the agar biopolymer could increase the shear strength of the sandy soil by binding the sand particles together, covering the surface of the particles, and filling the void space among them. In an attempt, Muguda et al. [29] evaluated the effects of xanthan gum and guar gum biopolymers on the unconfined compressive strength and the tensile strength of a soil specimen containing kaolin, sand and gravel. As the results showed, both biopolymers successfully increased the compressive strength and the tensile strength of the soil specimen. In a study by Hataf et al. [30], chitosan biopolymer was investigated for its effects on the compressive strength and the shear strength of a low-plasticity clay specimen containing fine sand and gravel. The results showed that the biopolymer could improve the properties of the studied soil by increasing the interaction among its particles. As it was observed, in the specimens dried at room temperature (20°C), the biopolymer initiated cementation and crystallization on the external surface while the internal part was still moist. This caused poor crosslinking and, consequently, poor shear strength. Therefore, the best strengthening effect of the biopolymer would occur upon the complete evaporation of water. Chen et al. [31] investigated the effect of drying up on the shear strength of xanthan gum-treated sandy soil. In their study, the treated soil specimens that were dried in an oven at 40°C had higher shear strength than the untreated ones. However, there was no significant difference of shear strength between the xanthan gum-treated soil specimens dried at room temperature and those dried in the oven.

Dehghan et al. [32] investigated the effect of two biopolymers, xanthan gum and gaur gum, on the mechanical properties of collapsible soil. In order to evaluate the engineering characteristics, compaction, permeability, consolidation and unconsolidated-undrained triaxial tests were performed. The researchers reported that biopolymers reduced the maximum dry density and permeability and improved the mechanical properties of the collapsible soil. Singh and Das [33] found that xanthan gum decreases mass loss during repeated freeze–thaw cycles. As observed by Kwon et al. [34], the soil stabilized with xanthan gum polymer was more resistant to hydraulic erosion. According to Sujatha et al. [35], xanthan gum resulted in a link between its molecules and soil surface. This led to a decrease in soil permeability and a rise in the modified soil strength. As the results of this process, the new soil structure had lower maximum dry density and a higher optimal moisture content due to the resistance of the improved soil to compaction.

In addition, Hamza et al. [36] conducted a study to comprehensively examine the efficiency of biopolymer xanthan gum (XG), as a green building material, in stabilizing and improving the characteristics of the weak subsoil of structures. In this regard, a wide range of geotechnical properties was investigated, including compaction, unconfined compressive strength (UCS), elastic modulus (E50), energy absorption capacity (Ev), soaked and unsoaked California bearing ratio (CBR), swelling potential, and consolidation parameters for stabilized and unstabilized soils. The soil was stabilized with different percentages of XG (0, 0.5, 1.0, 1.5, 2.0, and 5.0%) within different curing periods (0, 4, 7, 14, 28, and 60 days). The results of the tests indicated a slight decrease in the maximum dry compaction of the stabilized soil and an increase in the optimum humidity. It was also shown that addition of xanthan gum biopolymer to soil could increase soil strength parameters (UCS, E50, Ev, and CBR). Besides, the compaction and the swelling of the stabilized samples decreased by 83% and 79%, respectively [36].

Bozyigit et al. [37] conducted research under the title of "Performance of eco-friendly polymers for soil stabilization and their resistance to freeze-thaw action". They used three types of polymers including xanthan gum, guar gum, and anionic polyacrylamide polymer to improve the strength properties of kaolin clay. The soil samples were stabilized with different percentages of the polymers and subjected to 5 and 10 freeze-thaw cycles after curing for 7, 14, and 28 days. Then, a uniaxial strength test was performed on the prepared samples. According to their results, the polymers increased the strength and resistance of the soil against the freeze-thaw cycles. This suggested the appropriacy of those eco-friendly polymers for areas that are subject to freeze and thaw conditions through seasons. It was also indicated that the curing period affects the strength of stabilized soil, although this effect is insignificant in samples containing anionic polyacrylamide [37].

As the literature suggests, many researchers have investigated the effects of xanthan gum, guar gum, modified starches, agar and glucan, and other such biopolymers on the properties and behavior of sand, silt, clay, and other typical soils [38,39]. Due to the acceptable test results and environmental considerations, biopolymers are considered as acceptable materials to clog pore spaces and increase the binding of soil particles [40-42].

The ability of a biopolymer to improve the properties and behavior of a soil depends on the type of the soil and its composition, the type and quality of the biopolymer, and the curing conditions [43]. The results of the literature review show the successful performance of xanthan gum biopolymer to stabilize clay and sand soil. This biopolymer has caused a significant increase in the strength parameters of the investigated soils. Some studies have used conventional materials, such as lime and cement, in addition to xanthan gum biopolymer in soil stabilization, comparing the results of stabilization with those of conventional materials and xanthan gum. The results obtained from all these studies show better the performance of xanthan gum than conventional materials in many instances. In addition to its successful performance in improving the mechanical behavior of soil compared to other stabilizing materials, xanthan gum can be a suitable alternative to traditional materials for soil stabilization due to its eco-friendly properties. The present research contributions are:

- Unlike previous studies which have examined the functions of the aforementioned biopolymers in clay and sandy soil, the present study deals with the effect of xanthan gum on the engineering performance of organic soil.
- Comparion has been made with organic soil treated by a tradintioanl method.
- Macro scale investigation on the effect of xanthan gum on soil was completed by direct shear, indirect tensile and compressive strength tests and additionally micro scale tests were carried out through Scanning Electron Microscopy (SEM).

## 2. MATERIALS AND METHODS

**2. 1. Organic Soil** The soil used in this study was taken from the Choghakhor region in Chaharmahal-Bakhtiari Province, Iran (Figure 1). The organic soil of this region lies at the depths of 0.5 to 4 meters. An image of this soil is presented in Figure 2(a).

**2. 2. Xanthan Gum Biopolymer** Xanthan gum is a mass-produced food additive typically used as a thickening agent. This substance is produced by *Xanthomonas campestris* in the process fermentation of glucose or sucrose. The biopolymer is an anionic polysaccharide composed of D-glucuronic acid, D mannose (a sugar obtained from the oxidation of mannitol), pyruvylated mannose, 6-O-acety l D-mannose, and 1,4-linked glucan, with the chemical structure ($C_{35}H_{49}O_{29}$) [23]. The gum is shown in Figure 2(b). The characteristics of lime used in this research are also provided in Table 1.

The most important application of xanthan gum is in the creation of artificial plasticity [44]. Under static conditions, adding a small amount of xanthan gum increases the viscosity of a liquid. This biopolymer also has interesting properties such as high resistance to temperature and pH changes, excellent solubility in cold water, ion salt compatibility, and retention capacity [45]. Furthermore, the anionic and hydrophilic surface characteristics of this substance facilitate reactions with cations [46,47]. Xanthan gum has a wide range of applications in various industries as a stabilizer, emulsifier, suspending agent, and thickener. For example, it is used as a thickening agent in the food industry, as drilling mud in the oil industry, and as a viscosity-modifying agent in concrete [23]. It can also serve as a stabilizer to ensure long-term durability and prevent the dispersion of particles. These features combined with wide availability make xanthan gum an interesting choice for soil stabilization. The xanthan gum used in this study was a whitish powder 92% of which could pass through sieve No. 200.

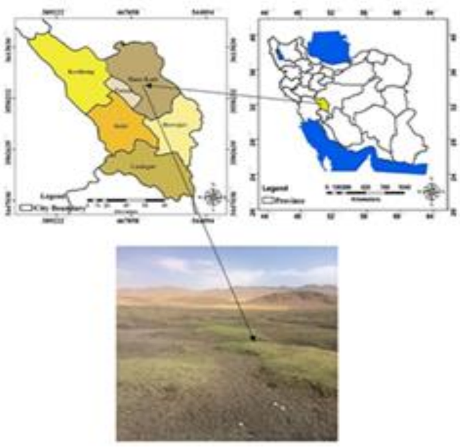


**Figure 1.** Study area

[2] Loss on Lgnition

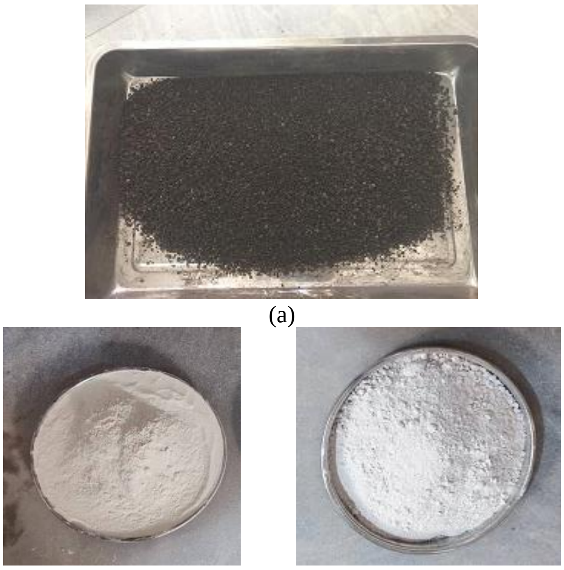
**TABLE 1.** The characteristics of the applied xanthan gum

| Parameters | Features | Results |
|---|---|---|
| Appearance | Whitish or light-yellow powder | Conform |
| Particle size (mesh) | 100% through 80 meshes, not less than 92% through 200 meshes | 200 |
| Viscosity (1% KCL, cps) | >1200 | 1566 |
| Shear ratio | ≥6.5 | 7.64 |
| V1/V2 | 1.02~1.45 | Conform |
| pH (1% solution) | 6.0-8.0 | 6.96 |
| Loss on Drying (%) | ≤15 | 6.65 |
| Ashes (%) | ≤16 | 10.3 |
| Pb (ppm) | ≤2 | Conform |
| Total Nitrogen (%) | ≤1.5 | Conform |
| Pyruvic Acid (%) | ≥1.5 | Conform |
| Total plate count (CFU/g) | ≤2000 | 300 |
| Moulds/Yeasts (CFU/g) | ≤100 | <100 |
| Coliform (MPN/g) | ≤0.3 | Conform |
| *Salmonella* | Absent | Conform |

**2. 3. Lime** Lime is one of the materials commonly used in soil stabilization. In this study, quick lime (Figure 2c) was used with the concentrations of 1, 3, and 5% by the weight of dry soil. The chemical characteristics of the lime used in this research are provided in Table 2.

**TABLE 2.** The characteristics of the lime used

| Chemical compounds | Amount (%) |
|---|---|
| CaO | 47.27 |
| $SiO_2$ | 8.71 |
| $Al_2O_3$ | 3.17 |
| $Fe_2O_3$ | 1.56 |
| $MgO$ | 0.987 |
| $K_2O$ | 0.79 |
| $SO_3$ | 0.678 |
| $TiO_2$ | 0.232 |
| $Na_2O$ | 0.082 |
| ZnO | 0.034 |
| SrO | 0.029 |
| MnO | 0.026 |
| CuO | 0.026 |
| PbO | 0.024 |
| Cl | 0.023 |
| LOI2 | 36.15 |



(a)

(b) (c)

**Figure 2.** Materials used in this research: a) soil, b) Xanthan gum, c) Lime

**2. 4. Classification of the Studied Soil** The studied soil was classified according to the widely used Von Post and ASTM organic soil classification systems [48, 49]. Von Post is the best-known system for the classification of organic soils. According to it, soils are of 10 classes of decomposition from H1 to H10 based on such factors as chemical properties, physical properties, rate of degradation, amount and type of plant matter in the soil, and genetic processes [50, 51]. H1 and H10 represent organic soils with the lowest and the highest decomposition rates, respectively. It should be noted that this classification system is qualitative and lacks quantitative boundaries for the exact differentiation of soil classes. In the ASTM system, however, organic soils are classified based on the amount of organic matter, the amount of minerals, and pH [44].

**2. 5. Chemical and Physical Properties of Organic Soils** Organic soils typically comprise large amounts of organic matter and water and smaller amounts of minerals and air. Given the variability of the ratio of these four components, it may be difficult to describe the physical characteristics of organic soils [50]. To determine the physical and chemical properties of the studied soil, a number of tests were conducted on its moisture content, organic matter content, ash content, pH, and specific gravity. The procedures of these tests are described in the following sections.

**2. 5. 1. Soil Moisture Measurement** Because of high precipitation and high groundwater level in the areas covered by organic soils as well as the water absorption property of the plant residues in these soils, they tend to have much higher natural moisture contents than fine-grained soils such as clay. In this study, soil moisture was measured according to ASTM D 2974-87 [52]. To this end, four 50 g specimens were placed as received in an oven for 24 hours. The moisture contents of the specimens were calculated using Equation (1), and then the four resulting values were averaged.

$$\text{Moisture content } \% = \frac{A-B}{B} \times 100 \tag{1}$$

In Equation (1), A is the mass of the as-received test specimen, and B is the mass of the oven-dried specimen both in grams.

**2. 5. 2. Measurement of Ash and Organic Matter Contents** The ash content and the organic matter content of the organic soil were determined according to ASTM D 2974-87 [52]. For this purpose, after the measurement of the moisture content, the specimens were placed in an oven, where the temperature was slowly increased to 440°C until there was no more change in the weight of the specimens. The weight of ash was measured by the subtraction of the weight of the oven-dried specimens from the weight of the moisture-containing specimens. Then, the ash content of the organic soil was measured by using the following equation:

$$D\% = \frac{C \times 100}{B} \tag{2}$$

where C is the weight of ash, B is the weight of the oven-dried test specimen, and D is the ash content.
The organic matter content was also measured by the subtraction of the ash content from 100 using the following equation**:**

$$\text{Origanic matter } \% = 100 - D \tag{3}$$

where D is the ash content.

**2. 5. 3. pH Measurement** Several pH tests were performed on the original organic soil specimens, the mixtures of organic soil with 0.5, 1, 1.5, 2, 2.5, and 3% of xanthan gum, and the mixtures of that soil with 1, 3, and 5% of lime after 21 days of curing. The testing was based on ASTM D2976 - 15 D [53].

**2. 5. 4. Specific Gravity Measurement** The specific gravity of the soil was measured according to ASTM D 854-14 [54]. This test was conducted on three samples taken from different sections of the soil, and the three measurements were averaged.

**2. 6. Proctor Compaction Test** The standard proctor compaction test was performed according to ASTM D-698 [55]. For this purpose, mixtures of organic soil with 0.5, 1, 1.5, 2, 2.5, and 3% of xanthan gum and with 1, 3, and 5% of lime were subjected to separate compaction tests.

To prepare the soil-xanthan gum mixtures, first, dry soil was mixed with the desired amount of xanthan gum in a mixer for a few minutes, and then mixing continued by hand with occasional spraying of water until the mixture became almost homogeneous. Next, the compaction tests were performed, and the optimum moisture content and the maximum dry unit weight were determined.

**2. 7. Unconfined Compressive Strength Test** Based on ASTM D2166 [56], some unconfined compressive strength tests were conducted on the organic soil, its mixtures with 0.5, 1, 1.5, 2, 2.5, and 3% of xanthan gum and its mixtures with 1, 3, and 5% of lime. All the test specimens were prepared with the optimum moisture contents and the maximum dry unit weights obtained from the compaction tests. Cylindrical test specimens were also created each with a height of 8 cm and a diameter of ۴ cm using a hydraulic jack (Figure 3). For better curing, the created specimens were placed in plastic bags tightly sealed after the removal of the trapped air, and then they were kept at room temperature. For each mix design (i.e., organic soil, organic soil + xanthan gum, organic soil + lime), two groups of specimens, one for 7 days of curing and the other for 21 days of curing, were prepared.

**2. 8. Indirect Tensile Strength Test** The indirect tensile test was performed according to ASTM C496 [57]. For this test, the specimens were created in the same number and with the same dimensions and curing times as in the unconfined compressive strength test. As instructed by ASTM C496 [57], which is related to the tensile strength of cylindrical specimens, each prepared specimen was inserted in the machine horizontally, with two metal plates placed at the top and bottom to ensure uniform linear load distribution (Figure 4). Thus, the centerline of the specimen was aligned with the symmetry line of the machine's loading plate. Then, the force was applied until the specimen cracked and fractured. The maximum compressive force applied to the specimen was inserted in Equation (4) to obtain its tensile strength.

$$T = \frac{2P}{\pi L d} \quad (4)$$

In the above equation, T is the tensile strength $(\frac{KN}{m^2})$, P is the maximum compressive force applied by the machine (kN), and L and d are the length and the diameter of the specimen (m).

**2. 9. Direct Shear Test** As instructed by ASTM D3080-04 [58], direct shear tests were conducted on the organic soil, its mixtures with 0.5, 1, 1.5, 2, 2.5, and 3% of xanthan gum and its mixtures with 1, 3, and 5% of lime after 7 and 21 days of curing. These specimens were also prepared with the optimum moisture contents and the maximum dry unit weights obtained from the compaction tests (Figure 5). They were kept at room temperature in sealed bags. For each mix design (i.e., organic soil, organic soil + xanthan gum, organic soil + lime), two groups of specimens, one for 7 days of curing and the other for 21 days of curing, were prepared.

## 3. RESULTS AND DISCUSSION

In the following, the results obtained in each part of the study are presented and discussed in separate sections.

**Figure 3.** Cylindrical specimen made of organic soil

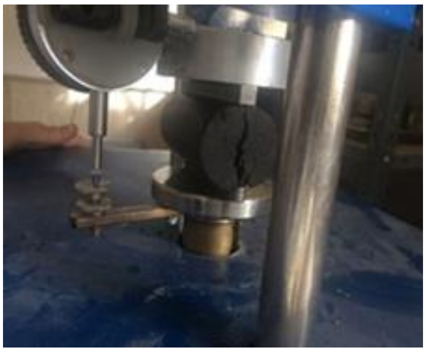


**Figure 4.** Preparation and loading of organic soil samples for indirect tensile testing

**Figure 5.** Preparation of a direct shear test specimen

**3. 1. Physical and Chemical Properties** The results of the measurements conducted to determine the moisture content, ash content, organic matter content, pH, and specific gravity of the studied soil are provided in Table 3.

**3. 2. Soil Classification** As the testing and examination of the studied soil showed, it can be classified from H3 to H6 on the von Post scale [51]. It also has an increasing rate of decomposition, and its color changes from brown to dark brown with depth.

According to the data provided in Table 3, the organic matter content of the soil ranges from 67% to 69.2%, its ash content is higher than 15%, and its pH is from 5.7 to 7. Thus, based on ASTM, this soil is classified as a regular type of organic soil with a high ash content and low acidity. Also, since it has a high amount of organic matter and plant residues, which burn when exposed to fire, its organic matter content was determined by the test proposed in ASTM D2974-87 [52]. As shown in Table 3, the soil contains a large amount of organic matter averaging around 68.1%.

**3. 3. Proctor Compaction Test** Based on the results of the proctor compaction test (Figure 6), the optimal moisture content of the organic soil was found to be 38.89%, and its maximum dry unit weight was 11.3 kN/m$^3$.

The results of the compaction test for the mixtures with different percentages of lime and xanthan gum are shown in Figures 6 and 7, respectively. As it can be seen, mixing the soil with lime and xanthan gum changed both the optimum moisture content and the maximum dry unit weight, increasing the former and decreasing the latter. Basically, adding lime to the soil results in an immediate cation exchange reaction, which causes the soil particles to clot together. This process leads to the appearance of more voids among the particles and, therefore, a more porous structure with a lower maximum dry unit weight. Since more water is needed to fill these voids, this process also increases the optimum moisture content of the soil. These effects for the lime-soil mixtures are illustrated in Figure 6.

**TABLE 3.** Physical and chemical properties of Choghakhor organic soil

| Property | Value | Standard |
|---|---|---|
| Natural moisture content (%) | 262-328 | ASTM D 2974-87 |
| Von Post class | H3-H6 | - |
| Specific gravity | 2.11 | ASTM D 854-14 |
| Organic matter content (%) | 67-69.2 | ASTM D 2974-87 |
| Ash content (%) | 33-30.8 | ASTM D 2974-87 |
| pH | 6.5 | ASTM D2976 - 15 |

Xanthan gum mixed with organic soil reacts directly with fine soil and water particles. As the amount of the gum increases in the mixture, the excess amount absorbs more water and makes the suspension more viscous, resulting in increased gaps among the particles and less desirable compaction (Figure 7). As other studies have also reported, an increase in the amount of xanthan gum increases the viscosity of the mixture and lowers its workability [23, 59], leading to the separation of the light soil particles and the reduction of the dry unit weight. Increasing the xanthan gum content of stabilized soils also increases their optimum moisture content. These results are consistent with the observations of Ayeldeen et al. [25].

**3. 4. Effects of Lime and Xanthan Gum on pH of Treated Soil Specimens** The pH measurements after 21 days of curing showed an increase in the pH value of the treated soil specimens. This increase was due to the alkaline conditions, which caused the hydration reaction to progress. In the lime-treated soil, this was due to the presence of ($OH^-$) and ($Ca^{+2}$) ions, which initiated a pozzolanic reaction. As for the xanthan gum-treated soil, the substance bound directly to the electric charges around fine-grained particles through the cationic and hydrogen bonds between carboxyl ($COOH^-$) and hydroxyl ($OH^-$) groups, causing the pH to rise [23]. The pH values of the treated organic soil specimens are given in Table 4.

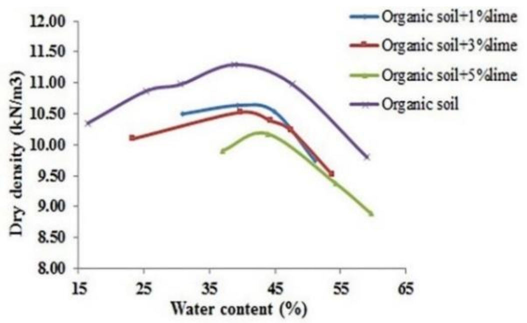



**Figure 6.** Proctor compaction curve of the lime-treated organic soil specimens

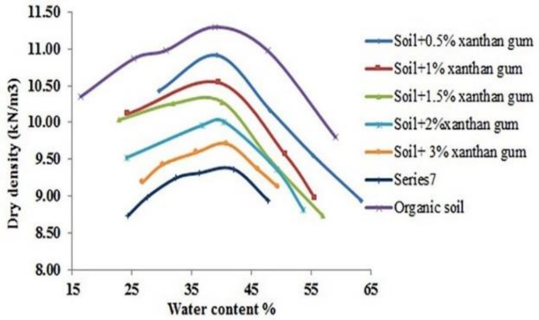



**Figure 7.** Proctor compaction diagram of the xanthan gum-treated organic soil specimens

**TABLE 4.** Effects of adding different amounts of stabilization materials on the pH of the organic soil

| Specimen | pH |
|---|---|
| Organic soil (untreated) | 6.5 |
| Organic soil + 1% lime | 8.19 |
| Organic soil + 3% lime | 8.25 |
| Organic soil + 5% lime | 8.38 |
| Organic soil + 0.5% xanthan gum | 7.04 |
| Organic soil + 1% xanthan gum | 7.06 |
| Organic soil + 1.5% xanthan gum | 7.15 |
| Organic soil + 2% xanthan gum | 7.22 |
| Organic soil + 2.5% xanthan gum | 7.29 |
| Organic soil + 3% xanthan gum | 7.36 |

**3. 5. Unconfined Compressive Strength** This section discusses the effects of lime and xanthan gum on the compressive strength of the studied organic soil.

**3. 5. 1. Effect of Lime on Unconfined Compressive Strength of Soil** After curing, the specimens made for unconfined compressive strength tests were subjected to compressive loading until fracture (Figure 8).

The unconfined compressive strength of the studied soil was measured on days 7 and 21 after the addition of different amounts of lime to it. The results are presented in Figures 9a and 9b. As it can be seen, adding lime to the soil increased its unconfined compressive strength. However, this effect peaked with 3% w/w of lime; the use of 5% lime, indeed, resulted in less unconfined compressive strength improvement. The 7-day unconfined compressive strength of the soil treated with 3% lime was 402 kPa, which was about five times that of the untreated soil (77.88 kPa). The unconfined compressive strength diagrams of the specimen cured for 21 days showed that prolonging the curing could greatly increase the compressive strength.

**Figure 8.** Plane failure of the specimens in the unconfined compression test

When lime is mixed with soil in the presence of water, the dissociation of CaO increases the concentration of calcium and hydroxide ions, which raises the pH of the environment. The high pH of the lime-treated soil increases the solubility and reactivity of the particles in the soil. The pozzolanic reactions taking place between the calcium ions and the dissolved silicates in soil result in stable elements such as calcium silicates and calcium aluminates. The resulting hydrate gels serve as natural binders, leading to higher strength and better cementation of the lime-treated soil. As these pozzolanic reactions progress, they slowly improve the strength of the lime-treated soil over a long period of time [15].

**3. 5. 2. Effect of Xanthan Gum on Unconfined Compressive Strength of Soil** The test results for the unconfined compressive strength of the organic soil treated with 0.5, 1, 1.5, 2, 2.5, and 3% xanthan gum after 7 and 21 days of curing are presented in Figures 10(a) and 10(b), respectively. As it can be seen in both diagrams, the compressive strength of the soil increased considerably with the addition of xanthan gum. The highest 7-day unconfined compressive strength belonged to the mixture with 3% xanthan gum, which was about three times as much as the unconfined compressive strength of the untreated specimen. After 21 days of curing, this ratio increased to 6. The results also show that adding xanthan gum to soil increases its ductility, which can be attributed

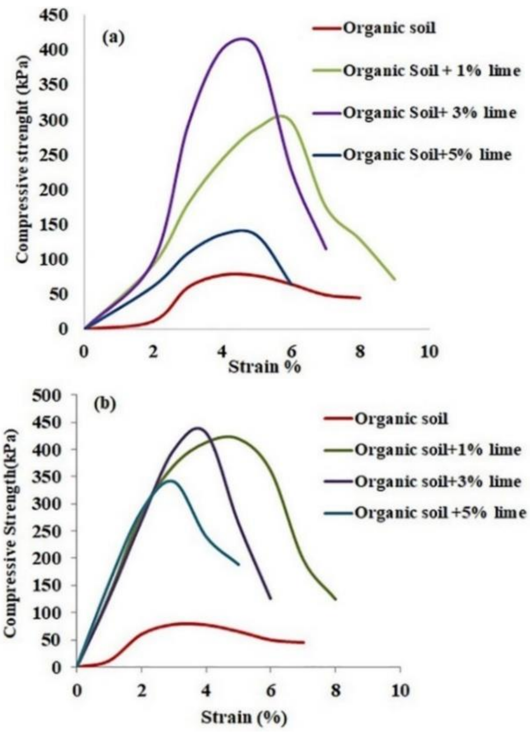



**Figure 9.** Unconfined compressive strength of the organic soil treated with different amounts of lime after a) 7 days of curing and b) 21 days of curing

to the binding property of this biopolymer. As shown in Figure 10, the specimens containing 1.5% to 3% xanthan gum had their maximum unconfined compressive strength at a 10% vertical strain, which suggests ductile behavior.

Besides, as the curing time increased, the greater reaction of xanthan gum with the soil particles resulted in a nonlinear increase in the compressive strength, but this increase slowed down as the amount of xanthan gum increased. This is because the growth of cementitious products over time causes soil particles to stick together and fill the pores in the xanthan gum-soil matrix [24]. The most effective range of xanthan gum content is from 1.5% to 2%; higher amounts of xanthan gum increase the viscosity of the mixture and decrease its workability. Other studies have also reported a similar pattern of compressive strength improvement in the treatment of other soils with xanthan gum [23, 24, 27].

These results are also consistent with the findings of a study by Arman and Munfakh [15] who explored the effect of xanthan gum on clayey soils. They reported that a higher compressive strength can be achieved with lower amounts of this biopolymer than with higher amounts of lime. The results of the study conducted by Latifi et al. [27] confirmed these findings.

**3. 5. 3. Comparison of Effects of Xanthan Gum and Lime on Unconfined Compressive Strength** The results of the unconfined compressive strength tests on the mixtures of the organic soil with lime and xanthan gum can be used to compare the effects of these two treatment agents. As shown in Figure 11, while both lime and xanthan gum improved the unconfined compressive strength of the organic soil, the latter was more effective in this respect.

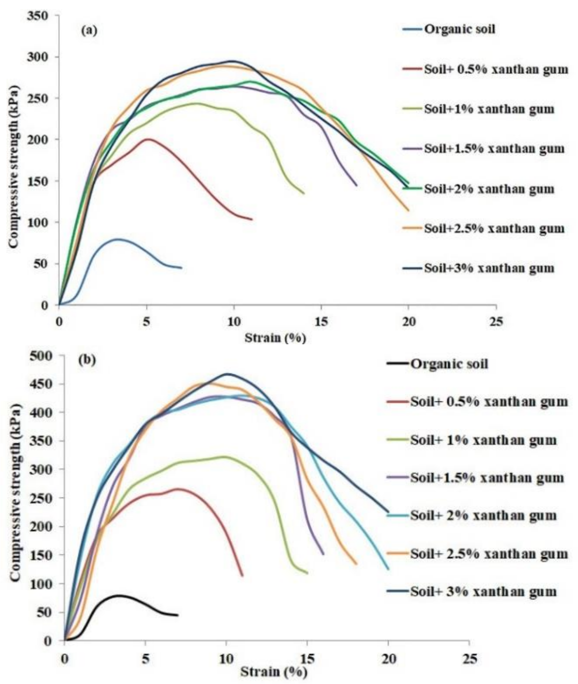



**Figure 10.** Unconfined compressive strength of the organic soil treated with different amounts of xanthan gum after a) 7 days of curing and b) 21 days of curing

These findings are interesting because, when it comes to stabilizing organic soils, the non-toxic, edible environment-friendly xanthan gum is a superior alternative to conventional lime treatment.

**3. 6. Comparison of Effects of Xanthan Gum and Lime on Tensile Strength** Figure 12 presents the results of the indirect tensile tests performed on the organic soil treated with different amounts of xanthan gum and lime after 7 and 21 days of curing. As the results suggest, xanthan gum significantly increased the tensile strength of the specimens. This is because, when combined with water and soil, xanthan gum increases the cohesion of the mixture, which results in increased tensile strength. Up to 3% of this biopolymer caused a significant improvement in the tensile strength, so much so that the 7-day tensile strength of the treated specimens (79 kPa) was 5.9 times higher than that of the untreated specimens (13.3 kPa). The curing time also had a positive effect on the tensile strength. As shown in Figure 12, the tensile strength of the specimens increased by about 24% when the curing time increased from 7 days to 21 days.

Treating the soil with lime also improved its tensile strength. For example, the tensile strength of the specimen treated with 3% lime was almost 3.7 times higher than that of the untreated specimen, as reported in Figure 12. This figure also compares the effects of lime and xanthan gum on the tensile strength of the organic soil. As it can be seen, in all the additive contents, xanthan gum provided a significantly better tensile strength than lime. For example, consider the 3% additive content. While the 7-day tensile strength of the specimen treated with 3% lime was 49 KPa, the 7-day tensile strength of the specimen

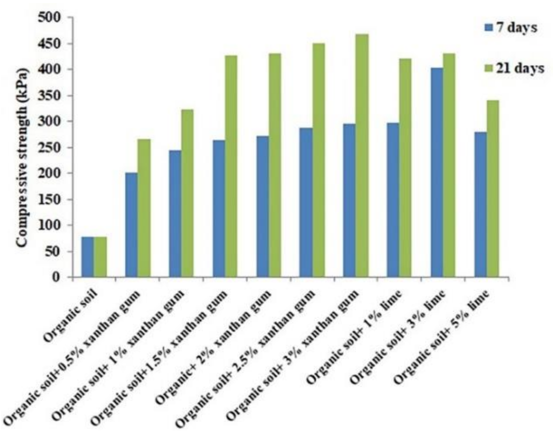



**Figure 11.** Comparison of the effects of xanthan gum and lime on unconfined compressive strength

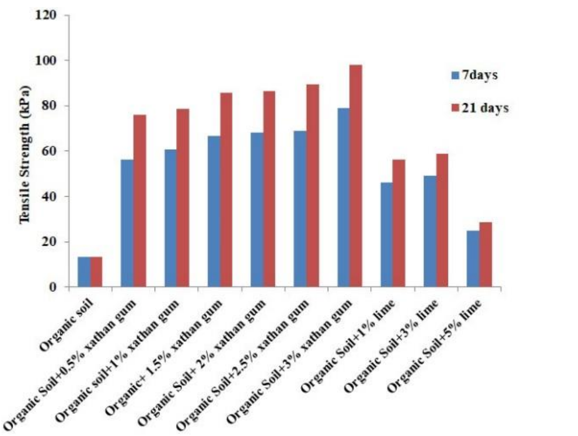



**Figure 12.** Comparison of the xanthan gum-treated and lime-treated organic soil specimens in terms of tensile strength after 7 and 21 days of curing

treated with 3% xanthan gum was 79 kPa. Thus, xanthan gum improves the tensile strength of soil better than lime, and the difference between the two increases over time. For example, after 21 days of curing, the tensile strength of the specimen treated with 3% lime reached 59 kPa, but that of the specimen treated with 3% xanthan gum went up as high as 98 kPa.

**3. 7. Shear Strength Parameters** The shear strength parameters of the soil including friction angle and cohesion were determined by plotting a failure envelope diagrams. The failure envelope of the specimens cured with xanthan gum for 7 and 21 days are also shown in Figures 13(a) and 13(b). As the results showed, adding different amounts of xanthan gum had a significant impact on the shear strength of the soil. When the concentration of xanthan gum was increased in the mixture, the cohesion and friction angle of the specimen were enhanced. It can be seen from Figure 14(a) that, for the specimen treated with 3% xanthan gum, the cohesion was 44.8 kPa after 7 days of curing, which was ten times higher than that of the untreated organic soil (4.3 kPa). Using Figure 14(a), it is possible to examine the effect of curing time on the cohesion. As it can be seen, an increase in the curing time to 21 days significantly increased the cohesion of the specimens. The cohesion of the specimen treated with 3% xanthan gum reached 69.4 kPa after 21days of curing. The treatment also increased the friction angle of the soil, for example, from 16.7 degrees in the untreated specimen to 25.1 degrees in the specimen treated with 3% xanthan gum and 7 days of curing. The results suggest that curing time has little effect on the friction angle of soil (Figure 14b).

The effect of xanthan gum on shear strength parameters is attributed to the long-chain functional groups like hydroxyl, ester, or amines in the structure of the gum. The characteristic reactions of these functional groups are facilitated with more reaction sites offered. Another factor that plays a role in this regard is the strength of the chemical bonds that bind the surfaces of soil particles and gel together [25, 38].

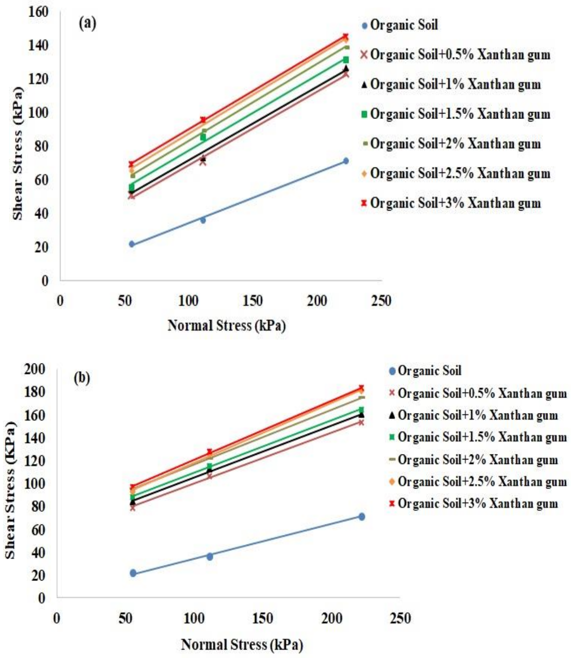



**Figure 13.** Shear failure envelope of the untreated organic soil and the organic soil treated with different amounts of xanthan gum after a) 7 days and b) 21 days of curing

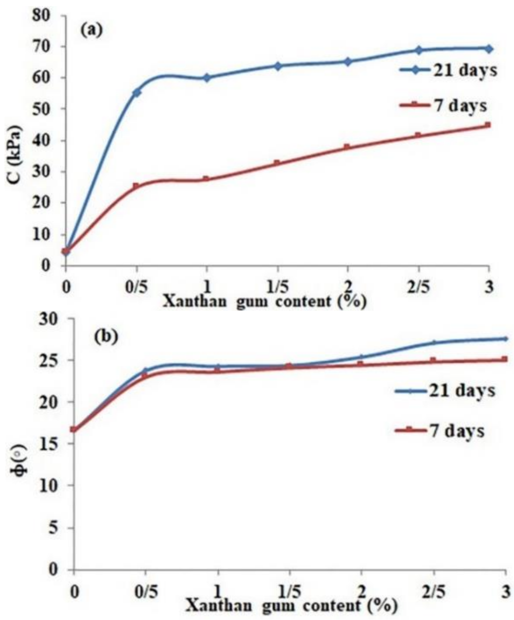



**Figure 14.** Cohesion and friction angle of the untreated organic soil and the organic soil treated with different amounts of xanthan gum after a) 7 days and b) 21 days of curing

The failure envelope of the specimens after 7 and 21 days of curing with lime are also shown in Figures 15(a) and 15(b). Lime could also improve the shear strength parameters. The effect of lime on the cohesion and friction angle of the organic soils are shown in Figures 16(a) and 16(b). From Figure 16(a), it is understood that, in 7 and 21 days of curing, the increase of lime up to 3% raised the cohesion of the stabilized and processed soil 3.5 and 5.7 times, respectively. The friction angel also increased due to the addition of lime. As lime was increased up to 3% during 7 and 21 days of curing, the friction angle grew 40% and 68%, respectively.

**3. 8. Effect of Time on Soil Stabilized with Xanthan Gum** Considering that stabilization with xanthan gum materials is more recent than lime, the long-term behavior of a stabilized sample was investigated. The review of the technical literature and the results of research on stabilization with lime show that pozzolanic reactions are completed and soil resistance increases in long periods, after which it no longer decreases. The present research mainly focused on the compressive and tensile strengths of the samples stabilized with xanthan gum, the results of which are presented below.

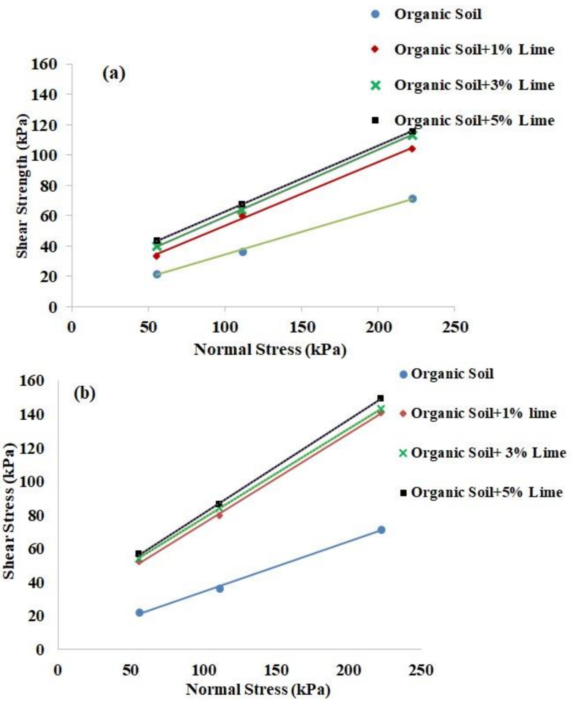
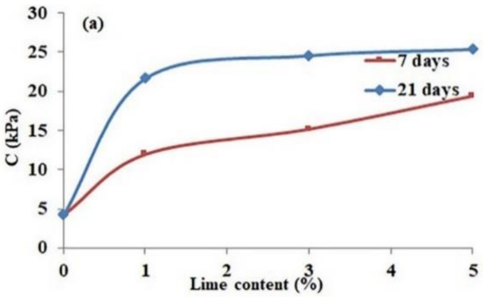



**Figure 15.** Shear failure envelope of the untreated organic soil and the organic soil treated with different amounts of lime after a) 7 days and b) 21 days of curing



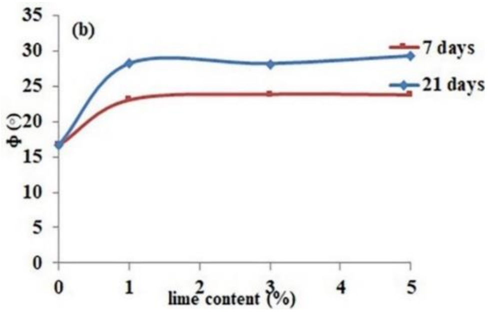




**Figure 16.** Cohesion and friction angle of the untreated organic soil and the organic soil treated with different amounts of lime after a) 7 days and b) 21 days of curing

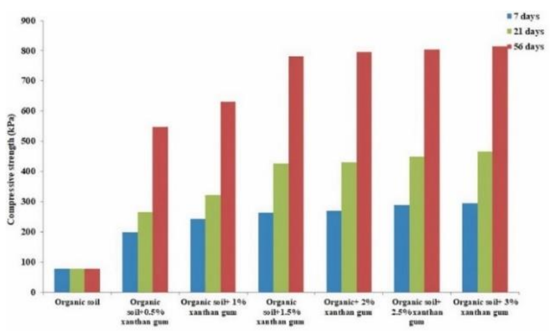
**3. 8. 1. Compressive Strength** As shown in Figure 17(a), the compressive strength of all the samples stabilized with xanthan gum and cured for 56 days were still on the rise. After this period, the compressive strength of the soil treated with 3% xanthan gum increased for about 10 times compared to the unstabilized soil. The results obtained in this research are consistent with those of the other studies investigating the effects of longer treatments with xanthan gum on soil stabilization. Chang et al. [23] investigated the strength of stabilized sand samples during 750 days of curing and showed no decomposition of xanthan gum or decrease in the strength. Latifi et al. [24] also showed that the strength of the samples stabilized with xanthan gum and cured for 90 days had an increasing trend.

**3. 8. 2. Tensile Strength** Figure 17(b) presents the tensile strength of the samples cured for 56 days compared to those cured for 7 and 21 days. As it can be seen, increasing the curing time up to 56 days enhanced the tensile strength, After this period, the tensile strength of the soil treated with 3% xanthan gum increased for about 9 times compared to the unstabilized soil.

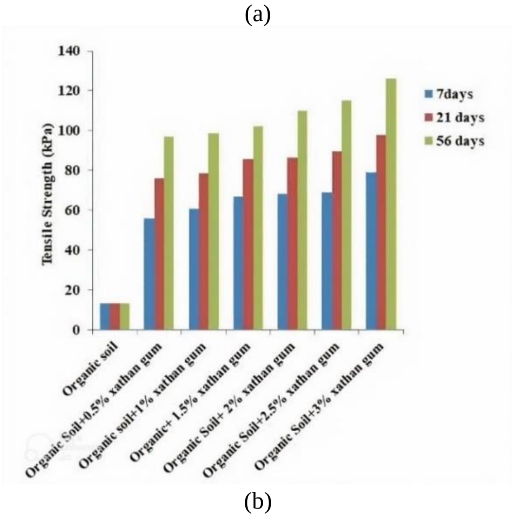
**3. 9. Microscopic Behavior** To further elucidate the effects of the treatments performed on the organic soil, the microstructure of the specimens was examined through scanning electron microscopy (SEM). Figure 18(a) presents the SEM image of the untreated organic soil as an example. As it can be seen, the constituting particles of the organic soil are spaced out, indicating high porosity. Each section of this organic soil has a series of internal pores inside its coarse-grained components and a series of external pores between the grains and the outer space. This explains the high water retention capacity of this soil, as water can easily fill the voids inside and among the soil particles [52].

As shown in Figure 18(b), the lime-treated organic soil, too, has much fewer cavities than the untreated soil, which can be attributed to the cementation process resulting from pozzolanic and hydration reactions. Furthermore, the bond formed between the products of the pozzolanic reactions and the soil constituents has increased the strength of the lime-treated organic soil.

As Figure 18(c) indicates, the xanthan gum in the treated soil covers the outer surface of the particles while filling the void space among them too. Due to the high cohesion of xanthan gum, some fibers are formed in the network of the constituting particles of the soil. The appearance of these fibers and the filling of the void space among the particles lead to reduced water retention capacity. The figures clearly show that the treated soil has a more compact and cohesive structure than the untreated soil. This explains the significantly improved strength parameters of the xanthan gum-treated organic soil compared to the untreated specimen. A similar process has been observed in the SEM examination of xanthan gum-treated clay [42].




(a)




(b)

**Figure 17.** The effect of time on the soil stabilized with xanthan gum: a) Compressive strength, b) Tensile strength

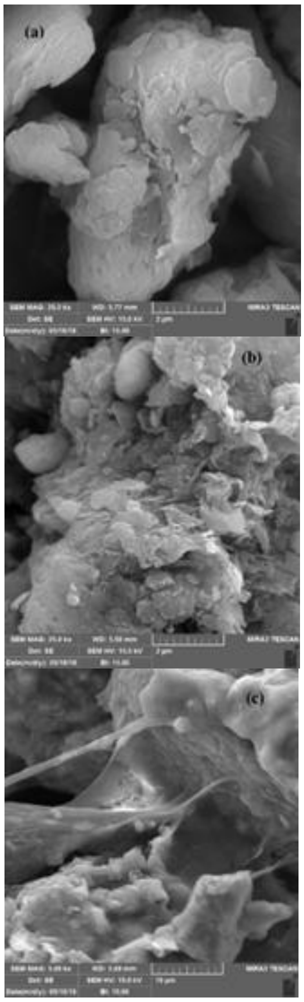


**Figure 18.** SEM image of the particles in the a) untreated organic soil, b) lime-treated organic soil, and c) xanthan gum-treated organic soil

## 4. CONCLUSION

Lime is a conventional soil stabilizer with significant positive effects on the mechanical properties of organic soils. However, it has major flaws in terms of environment-friendliness. The results of this study on the treatment of organic soil with xanthan gum as an environment-friendly stabilization agent indicated the ability of this gum to significantly improve the strength properties of the studied soil. The findings of the research are itemized as follows:

- Mixing the organic soil with lime or xanthan gum increased its optimum moisture content but decreased its maximum dry unit weight.
- The addition of lime and xanthan gum increased the pH of the treated organic soil to about 29% and 13%, respectively.
- The unconfined compressive strength of the organic soil treated with 1, 3 and 5% lime was measured

after 7 and 21 days of treatment. In general, the addition of lime increased the compressive strength of the soil; with 3% w/w of lime, the soil strength increased for about 5 times compared to the unstabilized soil, but it decreased with further addition of lime.

- The addition of xanthan gum to the organic soil improved its resistance. In this regard, the 7-day and 21-day compressive strengths of the samples were 3 and 4.7 times that of the unstabilized soil, respectively. Also, xanthan gum was significantly more effective than lime to improve this factor.
- The stress-strain curve of the unconfined compression test showed that the xanthan gum-treated organic soil specimens were more ductile than their lime-treated counterparts, bearing more strain at the same axial stress.
- The treatment of the organic soil with different amounts of lime and xanthan gum improved its tensile strength. In this respect, after 7 days, the tensile strength of the soil sample stabilized with 3% xanthan gum was about 9.5 times and the tensile strength of the soil sample stabilized with 3% lime was about 3.5 times that of the unstabilized soil.
- In the case of lime, the improvement in tensile strength reached its peak when the soil was treated with 3% lime, but it decreased with further increase in the lime content. However, in the case of xanthan gum, the improvement of the tensile strength continued for the entire range studied.
- Prolonging the curing process from 7 days to 21 days increased the tensile strength of all the specimens that were treated with lime or xanthan gum. However, this increase was higher in the xanthan gum-treated specimens than in their lime-treated counterparts.
- Comparing the lime-treated and xanthan gum-treated soil specimens in terms of shear strength parameters after different curing periods showed that xanthan gum is generally more effective in improving the shear strength of organic soil.

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Persian Abstract


**چکیده**

نمونه‌ای از خاک آلی جمع‌آوری‌شده از استان چهارمحال بختیاری با ۰.۵، ۱، ۱.۵، ۲، ۲.۵و ۳ درصد صمغ زانتان و ۱، ۳ و ۵ درصد آهک تثبیت شد. نمونه‌های تثبیت نشده و تثبیت‌شده تحت آزمایش‌های فیزیکی و مکانیکی ازجمله طبقه‌بندی خاک، اندازه‌گیریpH ، آزمایش تراکم، آزمایش مقاومت فشاری، آزمایش کشش غیرمستقیم و آزمایش برش مستقیم قرار گرفتند. افزایش ۳ درصدی آهک منجر به بیشترین افزایش مقاومت فشاری (به ترتیب ۵ و ٦ برابر برای نمونه‌های ۷ و ۲۱ روزه) و مقاومت کششی (به ترتیب ۳.۷ و ٤.۵ برابر برای نمونه‌های ۷ و ۲۱ روزه) شد. صمغ زانتان همچنین مقاومت فشاری (به ترتیب ۳ و ٦ بار برای نمونه‌های ۷ روزه و ۲۱ روزه) و استحکام کششی (به ترتیب ۵.۹ و ۷.۵ برابر برای نمونه‌های ۷ روزه و ۲۱ روزه) را بهبود بخشید. افزایش آهک تا ۳ درصد، چسبندگی خاک تثبیت‌شده را به ترتیب ۳.۵ و ۷.۵ برابر خاک آلی برای ۷ و ۲۱ روز عمل‌آوری افزایش داد. همچنین زاویه اصطکاک با افزایش آهک تا ۳ درصد طی ۷ و ۲۱ روز عمل‌آوری به ترتیب ٤۰ درصد و ٦۸ درصد افزایش یافت. تثبیت با صمغ زانتان منجر به افزایش چسبندگی به ترتیب ۱۱.۵ و ۱۷.۵ برابر برای نمونه‌های ۷ و ۲۱ روزه شد. علاوه بر این، صمغ زانتان زاویه اصطکاک را برای نمونه‌های ۷ روز و ۲۱ روزه به ترتیب ٤۷ و ۷۵ درصد افزایش داد. یافته‌ها به‌طورکلی نشان می‌دهد که صمغ زانتان می‌تواند جایگزین مناسبی برای آهک به‌عنوان تثبیت‌کننده خاک باشد.