Experimental Study on the Shear Strength of Silt Treated by Xanthan Gum during the Wetting Process

Junran Zhang *, Zhihao Meng, Tong Jiang, Shaokai Wang, Jindi Zhao and Xinxin Zhao

Henan Province Key Laboratory of Geomechanics and Structural Engineering, North China University of Water Resources and Electric Power, Zhengzhou 450045, China; z20201020288@stu.ncwu.edu.cn (Z.M.); jiangtong@ncwu.edu.cn (T.J.); wangshaokai@ncwu.edu.cn (S.W.); x201810207162@stu.ncwu.edu.cn (J.Z.); zhaoxinxinncwu@126.com (X.Z.)

* Correspondence: zhangjunran@ncwu.edu.cn; Tel.: +86-15890092736

Abstract: Traditional materials such as fly ash and lime are generally used to improve soils but can severely pollute the environment. Eco-friendly protocols, such as the application of xanthan gum, are therefore essential for soil treatment. In this study, a series of microscopic tests, water retention characteristics tests, and shear tests were carried out on silt, which are known to have poor engineering properties, to explore the effect and mechanism of xanthan gum treatment on the water retention and shear strength characteristics of silt during the wetting process. The results show that the water retention capacity of the treated silt increases with increasing xanthan gum content, and a hysteresis effect is clearly observed. The cohesion and internal friction angle of the silt strongly decrease with increasing water content, and the strength significantly weakens. However, the strength of the silt treated with xanthan gum is consistently higher than that of the untreated silt. The microscopic tests show that soil pores are gradually filled by xanthan gum with good water-retaining properties, thus significantly enhancing the water retention capacity. Furthermore, the hydrogel that cements the soil particles forms by the bonding effects between xanthan gum and soil particles, which greatly improves the silt strength.

Keywords: xanthan gum; silt; water retention capacity; strength; wetting process; microscopic tests

1. Introduction

Soil treatment measures (e.g., cement, lime, fly ash) are commonly used to improve the strength and water retention capacity of soils [1]. Traditional materials such as Portland cement have long been used in geotechnical engineering to treat soil, but a large amount of CO₂ is emitted during the production process of cement and lime [2]. One ton of Portland cement production has been shown to release approximately one ton of CO₂, and one ton of lime output releases approximately 0.86 tons of CO₂ [3]. Alternative materials, such as metakaolin and calcium hydroxide mixtures, alkaline aluminosilicate minerals, and fly ash–based inorganic polymer concrete, have therefore emerged to control and reduce carbon emissions [4–6]. Microbial soil treatment not only protects the ecological environment by controlling carbon emissions compared with traditional and inorganic methods but also significantly improves the strength and ductility of treated soils [7]. Microbial technology, namely biopolymers, has been applied to improve soil mass. For example, the unconfined compressive strength of 0.5% biopolymer was shown to be higher than that of 10% cement after treatment. The large-scale commercialization of biopolymers has good economic feasibility due to the high cost of cement in less-developed countries and can help improve the strength and durability of geotechnical engineering [8]. Driven by this huge catalytic potential and differing from traditional geotechnical engineering soil treatment technology, improved microbial soil treatment technology has been explored, including microbial and inanimate microbial improvement technology.
Since the onset of the 21st century, a series of studies have addressed different kinds of microbial technologies for soil treatment: synthetic hydrophilic polyacrylamide additives can improve the strength and stability of different soils [9]; casein and sodium caseinate biopolymers can improve the strength of sand [10]; the Panstrains of Enterobacteriaceae cultivated by cell-free fermentation liquid can stabilize soil [11]; and microbial-induced calcium precipitation technology (MICP) can strengthen and stabilize soil [12]. Recent studies showed that biopolymers could produce hydrogels and induce a pore-blocking effect, which can significantly reduce the permeability, whereas calcite precipitated by MICP does not have such a strong pore-blocking effect [13]. Inanimate microbial technology does not require a strict culture environment and offers greater advantages in enhancing the water stability of soil. Inanimate microbial technology can also produce hydrogel colloid and promote the transport of heavy metals in contaminated soil to improve the soil and protect the environment [14].

Numerous suitable biopolymers for soil improvement have emerged in recent years, and biopolymers have become popularized in engineering. For example, the commercial, large-scale production of composite fiber polymer has been applied [15], and the polymer lignin is widely used in manufacturing industries [16,17]. Polyacrylamide polymers have been widely used in the United States to irrigate land and control sand erosion and runoff protection, as well as to construct helicopter landing pads to reduce dust pollution [10]. Recent studies showed that gellan gum and agar gum could significantly improve soil durability [18], that xanthan gum can maintain water for vegetation growth in the soil to prevent desertification [19], and that both xanthan gum and gellan gum can improve the dynamic characteristics of sand [20]. Adding a small amount of biopolymer can greatly improve the soil strength, and guar gum is more advantageous for treating collapsible soil and clay using the wet mixing method, but xanthan gum is superior when treating silty fine-grained soil [21–23]. Xanthan gum can be used as a stabilizer for slope protection in geotechnical engineering. Xanthan gum also has a low application cost and very competitive price compared with other biopolymers [24].

In the late 20th century, Wallingford and Sanchez pointed out that xanthan gum is more capable of absorbing water than other polysaccharide polymers [25,26]. Xanthan gum can be used to effectively improve the water retention capacity of engineering soil, such as through hydraulic seepage barriers and underground pollution stabilization [14,24,27]. Zhou et al. [28] verified that xanthan gum significantly enhances the water retention of soil. Because xanthan gum can separate soil particles and fill soil pores, the pores of sand become larger [29], and its water retention performance is very strong [30], thus improving the water retention capacity of the soil.

Ayeldeen and Qureshi et al. [21,31] indicated that the addition of xanthan gum could improve the collapsibility resistance of collapsible soil, as well as the water disintegration resistance and strength of sandy soil. Cabalar et al. [32] showed that the compaction degree, viscosity, and strength of clays treated with xanthan gum were enhanced at low water content. Chang et al. [33] found that the unconfined compressive strength (UCS) of drying soil tended to stabilize upon increasing the xanthan gum content to a certain range. According to the UCS test results of Latifi [34], stability can be achieved by adding xanthan gum to bentonite and kaolinite at low water content. Soldo et al. [35] found that the strength of soil with 2% xanthan gum content is close to the maximum at low water content. Soldo and Sujatha et al. [36,37] indicated that water content is an important factor affecting soil strength and that the strength of silty sand and silt treated with xanthan gum is greatly improved at low water content. Engineering soil must usually be cured for a few days to reach a low water content state. Because the water content of engineering soil is low, the soil strength is generally high but easily affected by rainfall infiltration, which can reduce the soil strength and stability. Most soil treatment studies conducted strength tests in the range of high suction, but few tests have focused on soil strength over the entire range of water content of soil treated by xanthan gum. Recent studies showed a significant decrease in the wetting strength of sand after treatment with biopolymer
guar gum [38]. However, for sand treated with xanthan gum, the wetting strength was greater than the initial strength [39]. Based on the above research results, further in-depth tests were carried out to systematically study the influence of xanthan gum on the wetting strength characteristics of silt over the full range of water content.

The objective of this study was to investigate the effect and mechanism of the strength weakening characteristics of silt treated with xanthan gum (XG-silt) during the wetting process. A series of microscopic tests, water retention characteristics tests, and direct shear tests were carried out on XG-silt using scanning electron microscopy, mercury porosimeter, a WP4C dew point potential meter, and a Shear Trac-II test system. The experimental results qualitatively and quantitatively reveal the variation law and internal mechanism of the wetting strength characteristics of XG-silt, which provides a useful scientific basis for the design and construction of related geotechnical engineering projects.

2. Materials and Methods

2.1. Materials

Figure 1 shows that Henan Province is located in the North China Plain of the middle and lower reaches of the Yellow River, where silt is widely distributed. The silt sample location is at an engineering project in the Xingyang area, west of Zhengzhou city in northern Henan Province, which adjoins the south bank of the Yellow River. The experimental alluvial silt has poor early strength and water stability [40,41]. Xanthan gum is therefore used to strengthen the silt in the Yellow River flooding area due to the complex engineering properties of silt.

![Figure 1. Silt sample location.](image)

Xanthan gum is a high molecular anionic polysaccharide polymer produced by the aerobic fermentation of Xanthomonas and carbohydrates. It is carbon neutral, sustainable and reproducible, stable to acid, alkali, and heat, and has excellent compatibility with a variety of salts. It is made from non-food crops at a low cost and can be prepared in large quantities [26]. The xanthan gum used to treat the silt was purchased from Fu Feng Biotechnology Co., Ltd. in Inner Mongolia. The reagent was of food grade and analytical grade. The storage environment conditions were 25 °C and 35% relative humidity. Pictures of the dry silt and xanthan gum are shown in Figure 2.
The basic physical properties of natural silt are listed in Table 1. The grading curve determined by hydrometer analyses is shown in Figure 3. The gradation parameters of the soil sample are coefficient of curvature $C_c = 0.75$, nonuniform coefficient $C_u = 4.39$, and liquid limit $w_L = 21.4\%$, and the silt shows poor gradation with a low liquid limit.

Table 1. Basic physical properties of silt.

<table>
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<tr>
<th>Physical Parameters</th>
<th>Values</th>
</tr>
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</tr>
<tr>
<td>Liquid limit, $w_L$ (%)</td>
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<tr>
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<tr>
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</tr>
<tr>
<td>Maximum dry density, $\rho_{d\text{max}}$ (g/cm$^3$)</td>
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</table>

Figure 3. Grading curve of the silt.

The basic parameters of xanthan gum (XG) are shown in Table 2, and its molecular structure is shown in Figure 4.
Table 2. Basic physical properties of xanthan gum.

<table>
<thead>
<tr>
<th>Product</th>
<th>Grade</th>
<th>Viscosity/CP</th>
<th>Color</th>
<th>State</th>
<th>Shear Performance Value</th>
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<tbody>
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<td>food grade</td>
<td>1475</td>
<td>light beige</td>
<td>powder</td>
<td>7.7</td>
</tr>
</tbody>
</table>

Figure 4. Molecular structure of xanthan gum.

2.2. Methods

2.2.1. Sample Preparation

Soil samples were prepared following the dry method [42], which was commonly used in previous tests. The dried silt powder was fully mixed with dried xanthan gum. Water was then added, and the mixture was stirred evenly. Based on previous experimental studies, the optimal mass ratio \( m_{\text{silt}}/m_{\text{s}} \) of dried XG and dried silt in the water retention characteristics tests was set as 0.0%, 0.5%, 1.0%, 1.5%, and 2.0%, and the optimal mass ratio in the direct shear tests was set as 2.0% [21,33,34,43]. In order to ensure the uniformity of XG-silt, dry soil was stirred and mixed evenly with XG of the corresponding quality. Deionized water was added to form wet soil that avoids the influence of additional chemical components in the water. The soil was then sealed at a constant temperature for 24 h until the water was fully infiltrated. The initial water content of the specimen was 15%, and 92% of the maximum dry density, \( \rho_d = 1.63 \, \text{g/cm}^3 \), was selected as the initial dry density. After specimen preparation, a vacuum pump was used to vacuum and saturate the specimen for testing.

2.2.2. Scanning Electron Microscopy Tests

The specimen was rapidly frozen with liquid nitrogen (–190 °C) and vacuum-pumped for 24 h with a vacuum freeze-drying apparatus to ensure the specimen reached the dry state when the water of the specimen was completely sublimated. The dry specimens were then sliced into suitable sheet sizes, and scanning electron microscope (SEM) tests were performed at different magnifications \((\times 50, \times 100, \times 200, \times 500, \times 1000, \times 2000, \times 5000, \times 10,000)\) using a JBM-7500F field emission SEM (JEOL, Japan). Only four suitable magnification images \((\times 200, \times 2000, \times 5000, \text{and } \times 10,000)\) were selected to fully present the results.

2.2.3. Mercury Intrusion Tests

The pores of the soil sample are assumed to be cylindrical. Mercury is non-infiltrating and therefore does not flow into solid pores. Under low pressure, mercury first intrudes into the gaps and large pores, then gradually intrude into the micropores with increasing mercury pressure:
\[ P = -2\sigma \cos \theta / r \]  
(1)

where \( P \) is the mercury intrusion pressure [Pa], \( r \) is the pore radius [m], \( \sigma \) is the surface tension of the intrusion liquid, \( \sigma = 0.484 \text{ N/m} \), and \( \theta \) is the contact angle (130°).

2.2.4. Water Retention Characteristics Test

The saturated specimens were dried and wetted at constant humidity and temperature. The suction was intermittently measured using a WP4C dew point water potential meter (Figure 5). The test specimen’s initial size was \( d_0 = 33 \text{ mm} \) and \( h_0 = 7 \text{ mm} \).

![WP4C dewpoint potential meter](image1)

**Figure 5.** WP4C dewpoint potential meter.

2.2.5. Direct Shear Tests

The size of the test specimen was \( d_0 = 64 \text{ mm} \) and \( h_0 = 25 \text{ mm} \). Saturated specimens with 0.0% and 2.0% XG content were dried and wetted. The initial water content of the specimens was 22%. The drying and wetting paths of the specimens are shown in Figure 6. The specimens were uniformly dried to a state of 2% water content (drying path AB) and then wetted to a different water content (2%, 4%, 8%, 16%, or 22%). Fast shear tests were then carried out under vertical stresses of 50, 100, and 200 kPa. The automatic direct shear and residual shear test system is shown in Figure 7. The Shear Trac-II test system was operated by computer shear software and the control panel of the shear apparatus to receive immediate feedback on the loads and displacements monitored by the sensors.

![Drying and wetting paths](image2)

**Figure 6.** Drying and wetting paths.
3. Results and Discussion

3.1. SEM Images of Xanthan Gum-Treated Silt

Figures at four suitable magnifications (×200, ×2000, ×5000, and ×10,000) were present for microscopic analysis. At ×200 magnification, the macroscopic structure of soil particle distribution can be seen. At the magnification of ×2000, ×5000, and ×10,000, the internal microstructure of soil can be clearly observed. The following are the conclusions based on SEM pictures.

Figure 8a–c show the SEM test results of XG-silt at ×200 magnification. The mass cementation between the silt particles and XG becomes increasingly large with increasing XG content.

Figure 9a–c show the SEM images of XG-silt at ×2000 magnification. The pore diameter decreases with increasing XG content.

Figure 10a–c show the SEM images of XG-silt at ×5000 magnification. A comparison shows that more soil particles bonded together with increasing XG content, and the small particles became soil mass with cementation [44]. The gaps and pores of the samples were also gradually filled with XG with increasing XG content, showing observable cementation, and the samples became increasingly dense.
Figure 9. SEM pictures of XG-silt at ×2000 magnification: (a) $m_{bp}/m_s = 0\%$; (b) $m_{bp}/m_s = 1.0\%$; (c) $m_{bp}/m_s = 2.0\%$.

Figure 10. SEM pictures of XG-silt at ×5000 magnification: (a) $m_{bp}/m_s = 0\%$; (b) $m_{bp}/m_s = 1.0\%$; (c) $m_{bp}/m_s = 2.0\%$.

Figure 11a–c show the SEM images of XG-silt at ×10,000 magnification. Part of the XG formed a biofilm covering the surface of soil particles with increasing XG content, and the other part formed bridge connections (biological polymerization chains) between the aggregate gap [21,37,42]. Additionally, the small particle aggregates became larger with closer connections.
3.2. Mercury Intrusion Test

The pore size distribution of the treated specimens with different XG contents was investigated, which is helpful in analyzing the interaction between the silt and XG. Figure 12a,b show the cumulative pore size and differential pore size, respectively.

Figure 12. Mercury intrusion pore size distribution: (a) cumulative curves; (b) differential curves.

Kodikara et al. [45] found that there are aggregates in the soil, which leads to different pore sizes. The pore size distribution of soil is therefore generally bimodal and manifested as micropore and macropore peaks. Figure 12a shows that the cumulative pore intrusion of the mercury intrusion test specimens decreases from 0.1815 mL/g for XG-free silt to 0.1697 mL/g for silt with 2% XG, which implies that the pore size distribution decreases with increasing XG content. Figure 12b shows when 1% XG is added to pure silt, the large pores (10–80 µm) are gradually connected by XG hydrogels and reduced to medium pores (2–10 µm). Small pores (0.1–2 µm) in the silt are then filled with XG, and their number gradually decreases. The number of large and small pores in silt, therefore, strongly decreases, while the number of medium pores significantly increases. The pore size distribution of silt also turns into unimodal pore size distribution. Upon increasing the XG content from 1% to 2%, the medium pores in the silt are gradually connected by the filling of XG and hydrogels, resulting in a significant reduction in the number of medium pores and a large increase in the number of small pores.

3.3. Water Retention Characteristics Test

Figure 13 shows the water retention characteristic curve of the XG-silt specimens. Figure 13a,b show the drying and wetting curves, respectively, and Figure 14 shows the drying–wetting hysteresis curve. Figure 13a,b show that the drying curves all shift to the upper right with increasing XG content, which reflects an increase in the water retention capacity of the treated specimens. Especially in the range of low suction, the water retention capacity of the silt significantly increases with increasing XG content. Because XG carries carboxylic acid (–COOH) and hydroxyl (–OH) with a negative charge, it can interact with cations in the soil particles to generate a capillary force, thus absorbing and retaining more water [46].
3.3. Water Retention Characteristics Test

Figure 13 shows the water retention characteristic curve of the XG-silt specimens. The SEM and mercury intrusion test results show that more biofilms covered the surface of the soil particles with increasing XG content, and the bridging connections are found in the silt pores, which gradually filled with XG. The water retention capacity of the treated silt increased due to the strong water-retaining properties of XG [25,26,29,51], and the hysteretic circle area between the drying and wetting curves of the treated specimens also gradually increases with increasing XG content. The drying and wetting curves of specimens tend to be consistent in the high-suction range [50].

The SEM and mercury intrusion test results show that more biofilms covered the surface of the soil particles with increasing XG content, and the bridging connections are found in the silt pores, which gradually filled with XG. The water retention capacity of the treated silt increased due to the strong water-retaining properties of XG [25,26,29,51], and the hysteretic circle area between the drying and wetting curves of the treated specimens also gradually increases with increasing XG content. The drying and wetting curves of specimens tend to be consistent in the high-suction range [50].

Figure 14 shows that the water retention capacity of the treated specimens during the drying process is stronger than that during the wetting process, which is related to the water retention hysteretic effect of the soil during drying [47–49]. The hysteretic circle area between the drying and wetting curves of the treated specimens also gradually increases with increasing XG content. The drying and wetting curves of specimens tend to be consistent in the high-suction range [50].

The SEM and mercury intrusion test results show that more biofilms covered the surface of the soil particles with increasing XG content, and the bridging connections are found in the silt pores, which gradually filled with XG. The water retention capacity of the treated silt increased due to the strong water-retaining properties of XG [25,26,29,51], and the hysteretic circle area between the drying and wetting curves of the treated specimens also gradually increased. Previous experimental studies show that more water can be retained in soil pores after treatment with XG, which is consistent with the water retention characteristics test results of this study. Additionally, XG has a stronger water retention capacity than other polymers, which can improve the survival rate of vegetation in severely arid areas [19,52].
3.4. Direct Shear Test

3.4.1. Shear Strength Characteristics of Silt

Figure 15 shows the shear strength–displacement relation curves of pure silt with water contents of 2%, 4%, 8%, 16%, and 22%. The peak strength and residual strength of the silt specimens gradually increased with increasing vertical stress.

![Shear strength curves](image)

When the water content was 2% and 4%, the shear strength–displacement relation curves of pure silt showed a stress-softening phenomenon, and the peak strength was higher than the residual strength. When the water content was 16% and 22%, the shear strength–displacement relation curves of pure silt showed a stress-hardening phenomenon. When the vertical stress was 200 kPa, the shear strength–displacement relation curve displayed a stress-hardening phenomenon. The results show that with the increase in vertical pressure, the soil began to show a stress-hardening phenomenon [53,54].

Figure 15c,d show the stress softening into stress hardening of pure silt with water content increasing from 8% to 16%.

3.4.2. Strength Characteristics of Xanthan Gum-Treated Silt

Figure 16 shows the shear strength–displacement relation curves of the XG-silt samples with different water content. The peak strength and residual strength of the treated silt were found to gradually increase with the increase in vertical stress.
3.4.2. Strength Characteristics of Xanthan Gum-Treated Silt

Figure 16. Shear strength of xanthan gum-treated silt with different water contents ($m_{op}/m_s = 2\%$): (a) $w = 2\%$; (b) $w = 4\%$; (c) $w = 8\%$; (d) $w = 16\%$; (e) $w = 22\%$.

When the water content was 2%, 4%, and 8%, the shear strength–displacement relation curves of the treated silt showed the stress-softening phenomenon. When the water content was 22%, the shear strength–displacement relation curves of the treated silt showed a stress-hardening phenomenon. When the water content was 16%, and the vertical pressure was 50 kPa, the shear strength–displacement relation curve of pure silt showed a stress-softening phenomenon, and when the vertical stress was 100 kPa and 200 kPa, shear strength–displacement relation curves showed a stress-hardening phenomenon.

Figure 16c,d show the stress softening into stress hardening with water content increasing from 8% to 16% after the addition of XG.

3.4.3. Relationship between Strength and Water Content

Figure 17 shows the shear strength–displacement relation curves of the pure silt and XG-silt specimens with different water contents under vertical stress of 100 kPa. The strength of the silt specimens gradually increased with decreasing water content, as did the strength of the XG-silt specimens.

3.4.4. Variation Rules of Shear Strength Parameters

Figure 18 shows the relationship curves of water content, cohesion $c$, and internal friction angle $\phi$ of silt. Table 3 summarizes the parameters of the direct shear strength tests before and after silt treatment during the wetting process. Table 3 and Figure 18 show that at low water content (2–4%), the $c$ values of XG-silt increased by more than a factor of 2.3, and $\phi$ increased by more than a factor of 1.5. However, when the water content was lower than 8%, the sample strength was enhanced both before and after treatment, whereas $c$ and $\phi$ only slightly increased. At high water contents (16% and 22%), $c$ increased by factors of 1.4 and 1.8 times, respectively, and $\phi$ increased by factors of 1.4 and 1.9. The experimental results are consistent with those of Soldo et al. [35,36] and Chang et al. [55]. Additionally, the test results showed that the addition of XG can greatly improve the strength and stability of silt during the wetting process.
Figure 17. Wetting strength of the silt specimens with different water contents under a vertical stress of 100 kPa: (a) \(m_{mbp}/m_s = 0\%\); (b) \(m_{mbp}/m_s = 2\%\).

Figure 18. Comparison of shear strength parameters before and after treatment: (a) \(w\)-\(c\) relation curve; (b) \(w\)-\(\phi\) relation curve.

3.4.5. Discussion on Strength Mechanisms

According to the mercury intrusion test result, the pore size distribution of the silt specimen is bimodal. Therefore, in the shear process, the internal stress of the silt specimen is not uniform. By comparing Figures 15a and 16a, it is obvious that the pore structure in the silt greatly affects the shear stress of the soil and thus further affects the strength and stability of the soil in the range of low water content. According to SEM pictures and mercury intrusion test results, with the increase in XG content, the pores of silt are gradually filled with XG cement. Compared with Figures 15 and 16, it can be concluded that the stress-hardening phenomenon of the silt treated by XG is more obvious than silt when the water content is 2\%, 4\%, and 8\% because the pores of the silt treated by XG are supported by XG, which expands after absorbing moisture. Therefore, the water content of stress softening into stress hardening increased from 8\% to 16\%. The results indicate that XG can improve the strength and stability of soil after improving the micropore structure of the soil.
Table 3. Strength properties of the XG-silt specimens under different conditions (m_{bp}/m_{s}).

<table>
<thead>
<tr>
<th>w (%)</th>
<th>σ_v (kPa)</th>
<th>m_{bp}/m_{s} = 0%</th>
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<th>Increment of c</th>
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<tr>
<td></td>
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The mercury intrusion test results indicate that the pore size distribution of the silt specimen is bimodal. The dispersed pore distribution of the specimens results in an unstable structure. The silt specimen is easily disturbed by external loads; thus, the strength of the silt specimen is small. After adding XG, the silt pore size decreased, the pore size distribution changed into a unimodal pore size distribution, and the pore structure stability improved. The water retention capacity and shear strength of the silt, therefore, significantly increased. The SEM test results showed that the cohesion and internal friction angle of the silt specimens under different water content was significantly higher because XG blocks the pores of soil and produces a hydrogel that can bond silt particles together [39,55–57].

4. Conclusions

A series of microscopic tests, water retention tests, and shear tests were carried out to explore the effect and mechanism of the strength characteristics of silt treated with xanthan gum. The main conclusions are as follows.

The drying and wetting curves of the specimens all shifted to higher water retention capacity with increasing xanthan gum content, and the hysteretic circle area between the drying and wetting curves also gradually increased. Microscopic analysis showed that the pores of the specimens gradually filled with increasing xanthan gum content, and xanthan gum itself has strong water-retaining properties. The water retention capacity of the treated silt therefore increased.

The peak strength and residual strength of the specimens gradually increase with increasing vertical stress. The shear strength, cohesion, and internal friction angle of the pure and treated silt specimens significantly increased with decreasing water content. During the wetting process, the strength of the pure and treated silt specimens all significantly weakened with increasing water content, but the strength of the treated silt was notably higher than that without treatment. The microscopic analysis showed that xanthan gum fills the uneven pores in silt during the wetting process, which makes the pore distribution more uniform and the pore structure more stable. Xanthan gum forms hydrogel bonded with the silt particles, and the cementation between the soil particles was notable, thus significantly increasing the strength of the silt treated by xanthan gum.
As an eco-friendly and efficient material, xanthan gum can improve the strength and stability of silt after rainfall infiltration. Therefore, xanthan gum can be used to improve the engineering properties of soil during many projects, such as deep foundation treatment, slope treatment, highway subgrade treatment, etc. The shear strength prediction model based on experimental data needs to be further studied.

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