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Behavior of Gypseous Soil Treated by Arabic Gum Biopolymer Under Cycles of Wetting and Drying

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Keywords:

Biopolymers; Durability; Gypseous soil; Arabic Gum; Soil Improvement; Wetting and Drying.

Highlights:

- *Gypseous soil enhanced using biopolymer additives.*
- *Strength of soil was improved by Arabic gum biopolymer.*
- *Durability through wetting and drying cycles.*

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Abstract: Gypseous soil is classified as problematic soil since the main source that makes it problematic soil is the dissolving of gypsum in water. Treatment by biopolymers offers an environmentally friendly and sustainable way of soil enhancement that has recently been adopted by geotechnical engineers. However, it is vulnerable to periodical environmental impacts, particularly changes in moisture content. The main objective of this study is to find out the effect of wetting and drying cycles on the shear strength behavior of gypseous soil treated by Arabic gum biopolymer. Gypseous soil specimens of 40% gypsum content treated with 2% biopolymer Arabic gum were prepared for this investigation. The soil specimen was exposed to several cycles of wetting and drying (1, 5, 10, and 15 cycles). For each number of cycles, the shear strength parameters were evaluated for soil specimens. The results showed that the angle of internal friction (ϕ) increased until the fifth cycle, from 40° to 44°, and then approximately returned to its original value at 15 cycles. Similarly, cohesion increased by 67% at the 5th cycle and decreased to 58% at the 15th, respectively. Whereas the value of unconfined compressive strength (q_u) decreased with the cycles increasing, reaching 54% after the 5th cycle and 68% at cycle 15th. It can be concluded to some extent that Arabic gum reduces changes and deformations in treated soil samples for a limited number of wetting and drying cycles and preserves its shear strength.

سلوك التربة الجبسية المعالجة بالبوليمر الحيوي الصمغ العربي تحت دورات الترطيب والتجفيف

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الخلاصة

تصنف تربة الجبس على أنها تربة مشاكلية، حيث أن المصدر الرئيسي الذي يجعلها تربة مشاكلية هو ذوبان الجبس في الماء. توفر المعالجة بالبوليمرات الحيوية طريقة صديقة للبيئة ومستدامة في تحسين التربة والتي تبناها مؤخرًا المهندسين الجيوتقنين. ومع ذلك، فهي عرضة للتأثيرات البيئية الدورية، وخاصة التغيرات في محتوى الرطوبة. الهدف الرئيسي من هذه الدراسة هو معرفة تأثير دورات الترطيب والتجفيف على سلوك مقاومة القص للتربة الجبسية المعالجة بالبوليمر الحيوي الصمغ العربي. تم تحضير عينات تربة جبسية تحتوي على ٤٠٪ جبس ومعالجتها بالبوليمر الحيوي الصمغ العربي بنسبة ٢٪ لهذا البحث. عرضت عينة التربة لعدد دورات من الترطيب والتجفيف (١ و٥ و ١٠ و ١٥ دورة). لكل عدد من الدورات، تم تقييم متغيرات مقاومة القص لكل مجموعة من الدورات لعينات التربة. وقد أظهرت النتائج أن زاوية الاحتكاك الداخلي (ϕ) زادت حتى الدورة الخامسة من ٤٠° درجة إلى ٤٤° درجة ثم انخفضت حتى وصلت إلى ٣٩,٣٠ درجة عند ١٥ دورة، وبالمثل زاد التماسك بنسبة ٦٧٪ عند الدورة الخامسة وانخفض إلى ٥٨٪ عند الدورة الخامسة عشرة على التوالي، بينما انخفضت قيمة مقاومة الضغط غير المحصورة (q_uمع) زيادة الدورات لتصل إلى ٥٤٪ بعد الدورة الخامسة و٦٨٪ عند الدورة الخامسة عشرة. ويمكن الاستنتاج إلى حد ما أن الصمغ العربي يقلل من التغيرات والتشوهات في عينات التربة المعالجة لعدد محدود من دورات الترطيب والتجفيف ويحافظ على مقاومتها القصية.

الكلمات الدالة: البوليمرات الحيوية، المتانة، التربة الجبسية، الصمغ العربي، تحسين التربة، الترطيب والتجفيف.

1.INTRODUCTION

A number of attempts have recently been reported to reinforce soil utilizing the process of biological treatment or excretions (compounds that are generated biologically) for structures and geotechnical engineering purposes [1–3]. Microbes such as Sporosarcina pasteurii, for example, have been injected into sandy soils to precipitate calcite between soil particles, resulting in a cement-like effect with a minimal carbon impact [4–7]. Biologically generated biopolymers have been utilized directly as combining additives or binding agents for improving soil properties and strengthening and have demonstrated remarkable improvement of inter-particle interactions even at low amounts (e.g., a 1% or smaller proportion to the weight of soil has yielded UCS greater than 4 MPa) [8–11]. A prior investigation related to the use of xanthan gum biopolymer for strengthening of soil found that xanthan gum combined at 1.0% content with Korean residual soil raised compressive strength to up to (4.9 MPa) by nearly twice as much as 10% cement treatment on the same soil (2.6 MPa) [12]. The latest study identified thermo-gelation biopolymers like Gellan gum and agar gum as potential soil treatment binders for clayey and sandy soil types [9, 13]. When evaluating biopolymer-treated soils, soil type differences become important. Both Agar gum and Gellan gum displayed very considerable strengthening efficacy with clayey soils (reaching up to $13*10^3$ kPa for clayey soils) [9]. For pure sand, gel-type bio-polymer treatment increased interparticle cohesiveness on cohesionless soil, resulting in a considerable improvement in ground-bearing capacity [13]. Because of its improved geotechnical construction features, BPST may be used as an ecologically friendly ground-enhancing solution for preventing soil erosion/scouring and protecting slope surfaces [14, 15, 26]. However, climate-related weathering mechanisms such as cyclic soaking-drying and freezing-thawing are thought to weaken BPST-reinforced soils [16]. Further, these recurring weathering conditions can commonly hasten particle erosion and surface layer separation, resulting in an unsustainable vegetative ecology. To ensure the dependability of BPST field applications, the durability of BPST against changing atmospheric weathering conditions must be evaluated [17]. When the treated specimen was soaked in water, the unconfined compressive strength (UCS) of the 1.0% Gellan gum-treated sands abruptly decreased to one-tenth of the unconfined compressive strength of the dried condition. Furthermore, at the same Gellan gum concentration (1.0%) and water content (i.e., roughly 25.0%), the strength of Gellan gum-treated sand that was re-submerged (that is, soaked twice) was decreased to one-fifth of the strength of single submerged Gellan gum-treated sand (250.0 kPa) [9]. The compressive strength of Poorly Graded Sand Gellan gum was gradually reduced. After 10 wetting-drying cycles, the strength stayed high (i.e., greater than 70.0% of the original shear strength) [18]. The reduction in friction angle, cohesiveness, and peak shear stress in Well Graded Sand treated with Xanthan Gum was gradual [19]. Biopolymer improved the erosion strength of Acacia Gum Sodium Alginate-treated soil; however, wetting-drying enhanced mass loss for Poorly Graded Sand [20]. In order to evaluate the chitosan-treated sand silt, its strength varied after soaking-drying according to the type of soil, biopolymer type, and biopolymer concentration [21]. During wetting-drying cycles, several biopolymer-amended samples retained more than 70.0% of their initial mass. Some biopolymer-enhanced soil specimens retained up to 45% of their starting strength throughout seven wetting-drying cycles during the compressive strength testing [22]. Because of local biopolymer dilution due to water adsorption, cyclic Wet-Dry [25] and Freez-Thaw progressively eroded soil strength. The poorly graded sandy soil was extremely prone to these climatic effects. However, when the soil possessed fine concentrations of 15-25%, this issue was minimized [23]. Although some researchers have evaluated the durability of different types of soils treated with biopolymer by measuring qu after exposure to periodic soaking and drying conditions, previous studies are lacking to evaluate the durability of gypseous soils treated with Arabic gum through wet-dry cycles. Therefore, the main aim of this research is to investigate the durability of gypseous soil improved by 2% biopolymer Arabic gum on cyclic wetting and drying processes. Moreover, the normal and biopolymer-modified specimens were tested under soaking–drying conditions by direct shear and monitoring the mass stability of the treated samples. Given that Arabic gum is being studied as a biopolymer with significant promise for soil improvement, research into its durability will have an important effect on its application in geotechnical engineering practices.

2.MATERIALS AND METHODOLOGY

2.1.Gypseous Soil

Soil samples were collected at a one-meter depth from the ground surface located to the southwest of Al-Tharthar Lake. One naturally disturbed soil sample with 40% gypsum content was analyzed based on the gypsum content of the soil. Table 1 shows the physical and chemical properties of the soil. Figure 1 depicts the particle distribution curve of a soil sample. According to the Unified Soil Classification System (USCS), the soils are classified as poorly graded sand (SP).

Table 1 Physical and Chemical Characteristics for the Specimen of Soil.

Characteristics		Value	ASTM Standard
Unified Soil Classification system (USC's)		SP	ASTM D2487-17
Gravel fraction %		4.1	
Sand fraction %		92.6	
Fines fraction %		3.3	
Uniformity coefficient (Cu)		5.4	
Curvature coefficient of (Cc)		0.58	
Specific gravity (Gs)		2.44	ASTM D854
Atterberg's limits	(LL)%	24	ASTM D4318
	(PL)%	N.P	
Unit weight in field (γfield) kN/m³		12.9	ASTM D1556
Maximum dry unit weight (γdry) max) kN/m³		16.1	ASTM D1557
Minimum dry unit weight (γdry) min)kN/m3		10.30	ASTM D1557
Optimum moisture content (O.M.C)%		12	ASTM D1557
Gypsum content %		40	
Total soluble salts (T.S.S)%		47	
Organic Materials (O.M)%		0.26	
pH value		7.3	

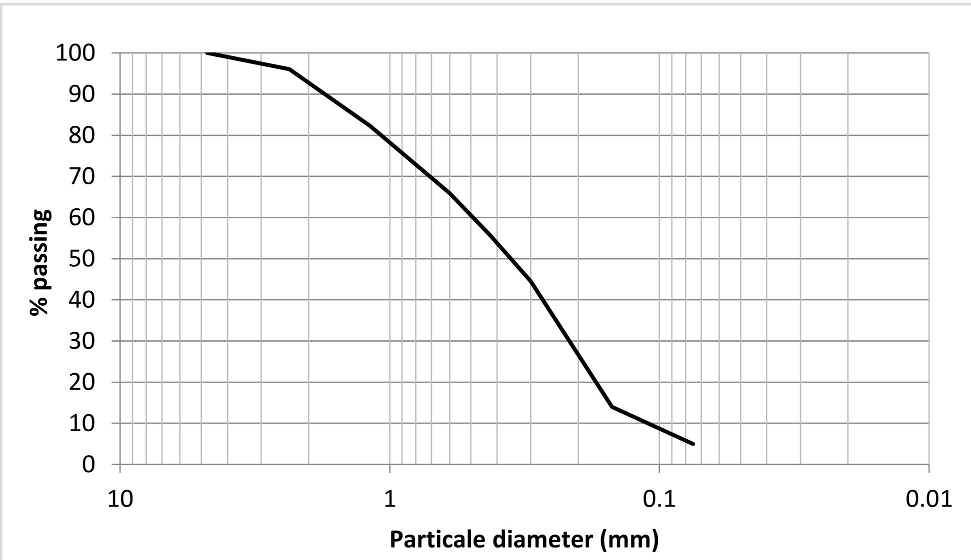

Fig. 1 Particle Size Distribution Curve for Soil Specimen.

2.2.Arabic Gum Biopolymer

Arabic gum is considered one of the natural materials obtained from the hardened sap of the Acacia (Sensu Lato) tree species, and it is known as Acacia Senegal. It is also known as Sudan gum, acacia gum, Senegal gum, Indian gum, and other names. Commercial sources of the gum include Sudan (80%), Senegal, and Somalia [24]. Table 2 displays typical Arabic gum qualities, while Fig. 2 depicts Arabic gum in powder and lump form.

Table 2 Characteristics of Arabic Gum (FAO, 1990).

Property	Range
Percent of moisture content	13.00% – 15.00%
Percent of Ash content	2.00% – 4.00%
Percent of Nitrogen content	0.26% – 0.39%

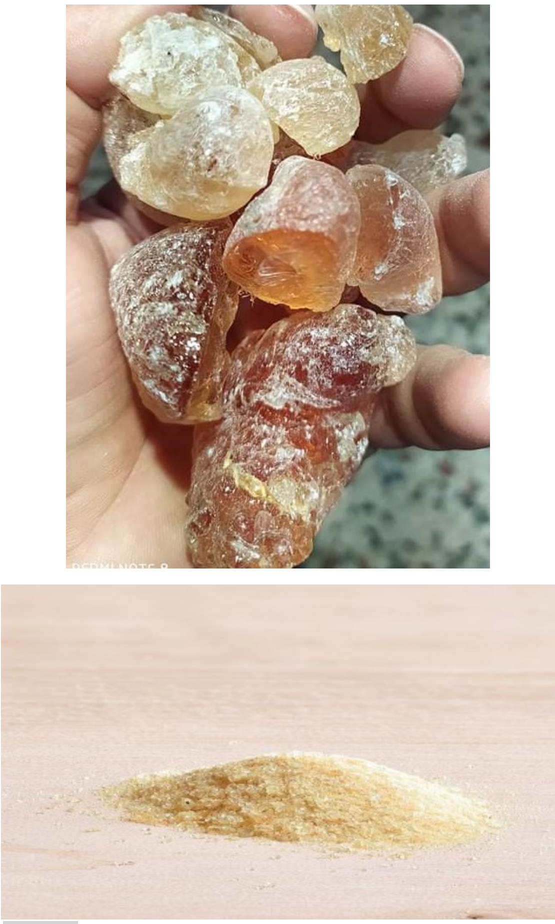

Fig. 2 Lump and Powder form for Arabic Gum Biopolymer.

2.3.Preparation of Soil-Treated Specimens

Prepare an Arabic gum solution with the appropriate moisture content by adding 2% (by weight) of the soil and mixing thoroughly in the magnetic device. To generate a soil-treated Arabic gum combination, combine it with soil. The addition of 2% of Arabic gum was adopted according to a previous studies conducted by Hussein [27] and Muhauwiss et. al. [28], which stated the typical value of Arabic gum additive to be 2% of the weight of soil specimen that has gypsum content of 40%. It transferred, and reformed the mixture into three layers in a mold of (50 mm * 50 mm * 20 mm) dimensions for the direct shear test conducted with a loading rate of 1.3 mm/min and five layers in a metal cylinder with a diameter of 43 mm and a height of 100 mm for the UCS (Unconfined Compression Strength test that performed by a loading rate of 0.8 mm/min) before curing it for fourteen days to undergo treatment. After that, the samples were removed and run through many wet and dry cycles before taking the targeted measurements. All samples were produced with the optimum moisture content and maximum dry density. It shaped the soil with a 40% gypsum mixture to make the biopolymer and soil mixture as strong as possible. Then, 2% of the soil's weight of Arabic gum was added to make an Arabic gum solution with the right amount of moisture (OMC). Figure 3 displays the remolded samples, the curing method, and the soaking case. Figures 4 and 5 depict the relationship between cohesiveness and internal friction angle during re-molding curing time. According to the results shown in Figures 3 and 4, the ideal treatment time is 14 days since there is little change in strength after this period.

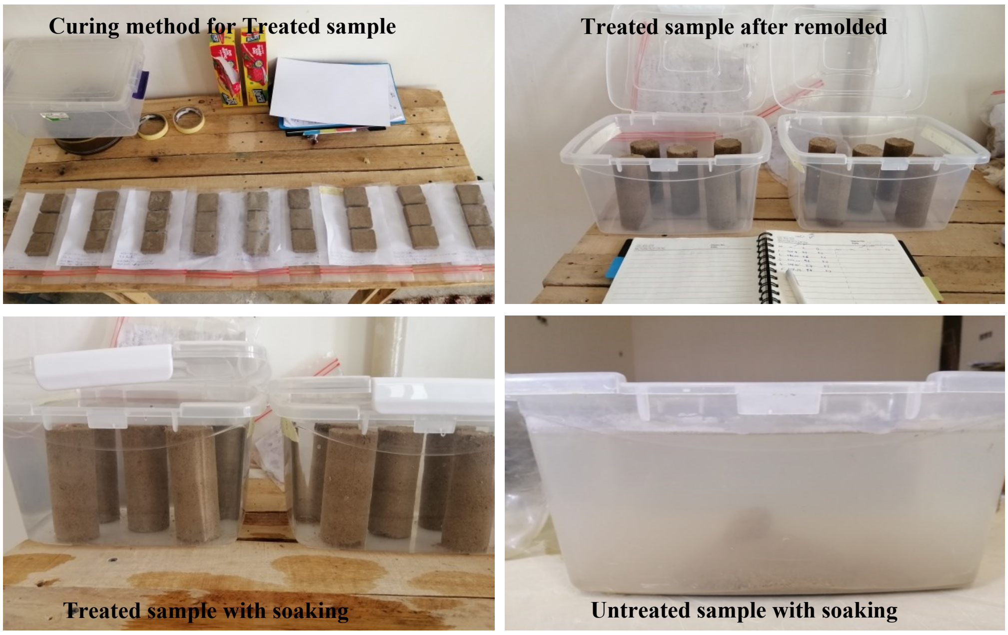

Fig. 3 The Remolded Samples, Curing Method, and Soaking Case.

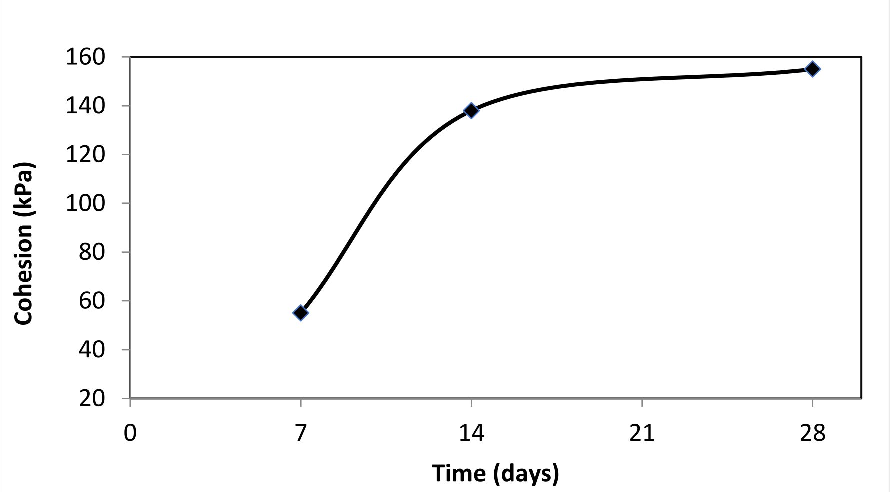

Fig. 4 The Relationship of Variation Cohesion with the Curing Time.

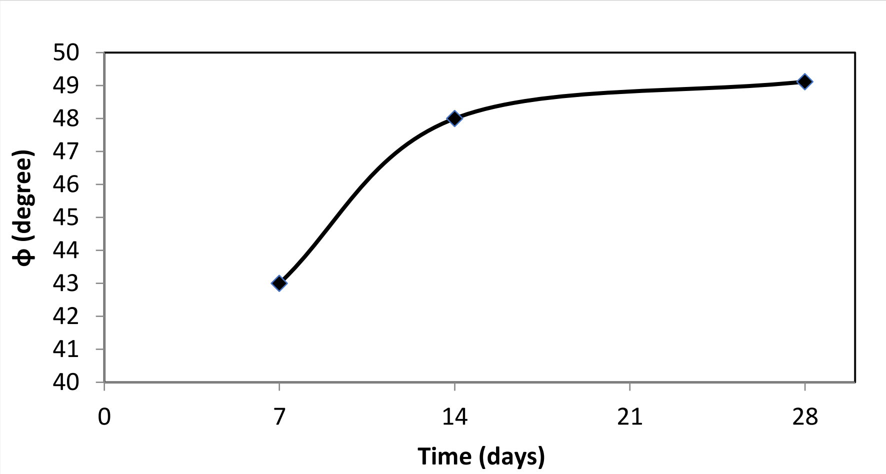

Fig. 5 Relationship of Variation of the Friction Angle with Curing Time.

3.RESULTS

3.1.Shear Strength Durability

The relationship between shear strength and the advance of soaking and drying cycles on the vertical pressure of 50.0 kPa is shown in Figure 6. A slight decrease in shear strength beyond the first cycle was noticed, and the increase persisted by a high percentage in the fifth cycle in comparison to shear strength at the zero cycle. Whereas the percentage of increase was 43% in the fifth cycle since the shear strength changed from 350 to 500 kPa. The significant increase may be caused by water uptake and the formation of hydrogels, leading to extra hydration of the hydrogel, condensation of Arabic gum biofilms after immersion and drying, and increasing pore filling. This allows increased overlap between treated soil particles and the formation of the sand and Arabic gum matrix in a single block, resulting in an increased number of cycles. Shear is required for contact fracture and overlap in the Arabic gum-sand matrix, thereby increasing shear strength. After the fifth cycle, the shear strength decreased and continued to decrease until the fifteenth cycle by 1.53%, whereas the strength in the fifteenth cycle was 198 kPa, while its value was 350 kPa for no cycles. The decrease may occur because the outer monomers of the gum biogel can absorb water molecules and separate after increasing the immersion cycles. That separate is from the main gel body, while the inner monomers retain their strength and structure to some extent. A large number of drying and immersion cycles leads to a larger amount of separation of monomers from the main gel body, followed by a continuous decrease in shear resistance [1, 8, 9]. The relationship of (c and ϕ) with wet-dry cycles for the soil specimen enhanced by 2% of Arabic gum is illustrated in Figures 7 and 8. The curves showed an increase in the (c and ϕ) values up to the 5^{th} cycle compared to the zero cycle. As can be noticed in Figure 9, which shows the relationship between the shear stress and H-displacement (Horizontal displacement), the rapid peak was at the 5^{th} cycle of 685 kPa with 3.2 mm horizontal distortion. After the 5^{th} cycle, the shear strength became 300 kPa in the 10^{th} cycle and declined to 200 kPa in the 15^{th} cycle with 3.5 mm horizontal distortion, respectively. After the 5^{th} cycle, the cohesion declined with a little increase in the angle of internal friction.

The values of (c and ϕ) with the progression of the soaking and drying cycles are shown in Table 3. The strength of the Arabic gum soil matrix was maintained until the 5th cycle and gave an increase in (c and ϕ) until the 5th cycle. The continuous increase until the fifth cycle may result from the wetting and drying, which strengthened the bond between the soil granules and the polymeric gels of Arabic gum. Repeating the soaking and drying cycles increased the enduringness of the polymeric gels. After that, the secession of the external monomers of the gum gel led to a decrease in the thickness of the gel, thus reducing the cohesion and the angle of internal friction with the continuation of the soaking and drying cycles and the thickness of the biogel.

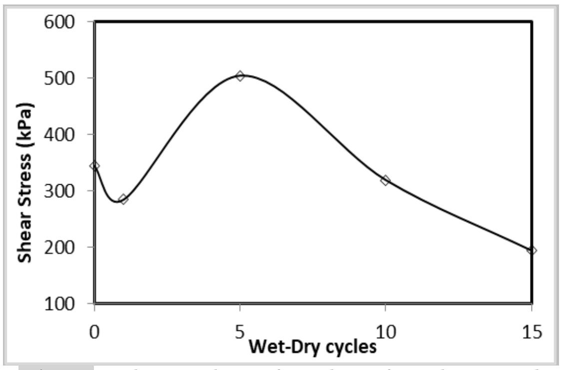

Fig. 6 Relationship of Cycles of Soaking and Drying with the Shear Strength at a Vertical Stress of 50 kPa for Treated Samples with 2% Arabic Gum.

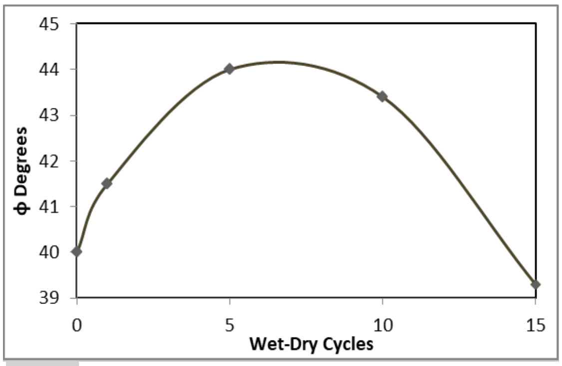

Fig. 7 Relationship of (ϕ) with Wet-Dry Cycles for the Soil Specimen Enhanced by 2% of Arabic Gum.

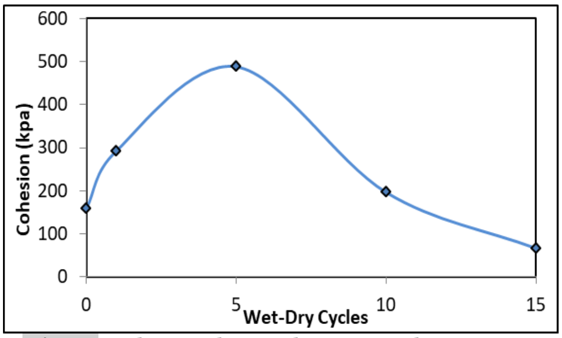

Fig. 8 Relationship Cohesion with Wet-Dry Cycles of the Soil Specimen Enhanced by 2% Arabic Gum.

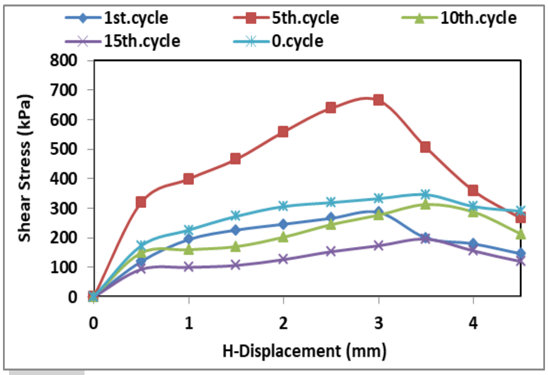

Fig. 9 Shear Stress with H-Displacement the Soaking and Drying Cycles of Samples Treated with 2% Arabic Gum.

Table 3 Shear Strength Parameters Values with No. of Cycles.

No. Cycle	Internal friction Φo	Cohesion (kPa)
0	40.0	158.35
1	41.5	292.33
5	44.0	488.00
10	43.4	196.33
15	39.3	66.33

3.2. Unconfined Compressive Strength Durability

The curve in Fig. 10 depicts the unconfined compressive stress of soil samples treated with Arabic gum after cycles of soaking and drying. The curve showed a decrease in UCS, and this decrease continued up to cycle 15, where the qu decreased from 1240 kPa in the 1st cycle to 582 kPa in the 5th cycle, compared to 1846 kPa before the soaking and drying cycles. Gum hydrogels adsorb water molecules, causing the outer shell monomers to separate from the main gel body at a faster pace, leading to a decrease in cohesion and a reduction in qu. The increase in soaking and drying cycles dramatically separated the biogel monomers from the gel body and significantly reduced the gel's thickness. This is what the curve shows until a large part of the submerged model collapses after the fifth cycle [8, 9]. Figure 11 displays the curve of the stress-strain relationship for UCS specimens enhanced by Arabic gum. The elastic modulus E50 decreased to 16.76 MPa at the 5th cycle after one cycle of soaking and drying, from 33.5 at 1st cycle to zero at 10th and 15th cycles. Continuing the soaking and drying cycles, the separation of part of the external gel monomers led to a decrease in the main gel's thickness with the soaking and drying cycles continuation. The biopolymer films shrank and became more brittle upon drying, which reduced their elastic stiffness.

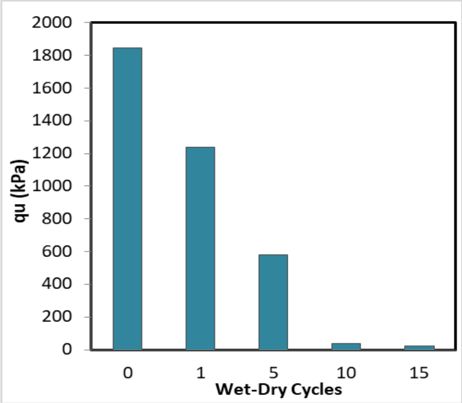

Fig. 10 Unconfined Compressive Pressure with the Soaking and Drying Cycles of Samples Treated with 2% Arabic Gum.

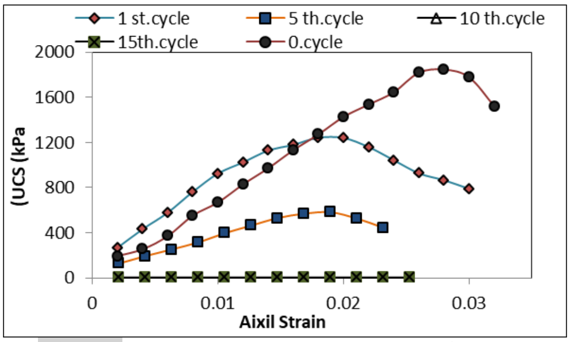

Fig. 11 Stress-Strain Relationship for the Soaking and Drying Cycles of Samples Treated with 2% Arabic Gum.

3.3.Cycles Effect on Untreated and Treated Soil with Arabic Gum Biopolymer

Figure 12 illustrates the stages of soaking, drying, and biopolymer treatment of untreated soil samples. Figure 12 illustrates how the biopolymers enhanced the durability of modular soil models. A complete breakdown of the untreated soil model 3, with the collapse occurring within 10 minutes of the start of the first immersion cycle, is clear, as shown in shapes A1 to C1 in Fig. 12. Submerging the specimens in water quickly caused a dissolving in the connections between the particles in the soil model, leading to its complete collapse. The samples treated with Arabic gum in pictures A3 to C3 show the soaking and drying cycles. In cycles 10 and 15, we can see that some of the samples changed in shape and collapsed. The collapsed ones took the form of stacked blocks compared to the failure form seen in the untreated samples. This mass breakdown was caused by the saturation of the Arabic gum hydrogels and the starting of separation from the main gel body. While collapsed samples were dependent on gel thickness, whereas areas with low gel thickness appeared to dissolve first, causing mass separation of the soil sample.

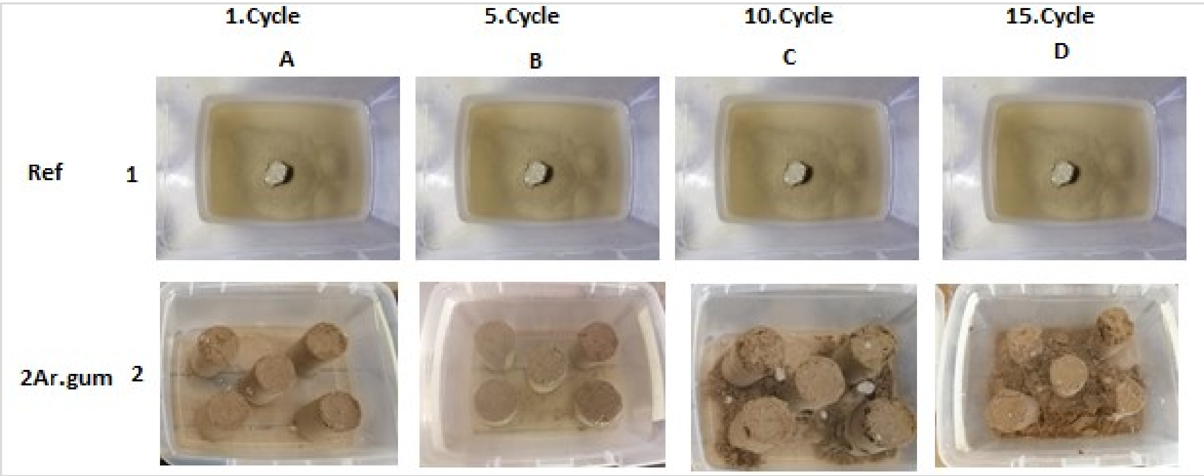

Fig. 12 Cycles of Soaking and Drying for Treated and Untreated Soil Specimens by Arabic Gum Biopolymer.

4.CONCLUSIONS

After several wet-dry cycles of soil samples treated with 2% Arabic gum and during many tests that were conducted, the following can be concluded:

- Arabic gum reduced changes and deformations in the treated soil models and maintained cohesion after cycles of repetition of wetting and drying, as demonstrated.
- Arabic gum-treated soil demonstrated resistance to shear strength loss through periodic wetting and drying.
- The biopolymer enhanced the shear strength through the increase in shear parameters (c, ϕ), and the decrease percentage was very slight by 1.75%.
- Rewetting and drying were demonstrated to restore part of the shear strength of the Arabic gum-enhanced soil specimen. The regeneration characteristic of Arabic gum caused the release of its structure in water

and reattached to surrounding soil particles. When the sample was dried, the repaired soil biopolymer bonded endurance and mended fissures in soil specimens.

- The value of q_u decreased by continuing the wetting and drying cycles, with a 54% decrease after the 5th cycle and a 68% decrease after the 15th cycle.
- The elastic modulus E50 decreased to 16.76 MPa at 5th cycle after one cycle of soaking and drying, from 33.5 MPa at 1st cycle to zero at 10th and 15th cycles.
- While biopolymers are vulnerable to water, some biopolymer types and amounts may significantly enhance soil's water resistance, according to this study. It also demonstrated that the water presence might cause an activation of the regeneration characteristics of Arabic gum, enhancing its capacity for soil stabilization and making it an excellent alternative for quick temporary construction but not for long-term building in regions with high water content change.
- It can be concluded to some extent that Arabic gum reduces changes and deformations in treated soil samples for a limited number of wetting and drying cycles and preserves its shear strength.

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NOMENCLATURE

C_u	Uniformity coefficient
C_c	Curvature Coefficient
G_s	Specific gravity
O.M.C	Optimum moisture content, %
O.M	Organic material, %
pH	Hydrogen number
P.L	Plastic limit, %
L.L	Liquid Limit, %
q_u	*UCS Unconfined compressive strength*
T.S.S	*Total soluble salts, %*
Greek symbols	
Φ	angle of internal friction, degrees
c	Soil cohesion, kPa
$\gamma_{dry)\,min}$	Minimum dry unit weight, kN/m3
$\gamma_{dry)\,max}$	Maximum dry unit weight, kN/m3
γ_{field}	Field dry unit weight kN/m3

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