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Effects of Xanthan Gum Biopolymers on Gypseous Soils Characteristics

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ABSTRACT

Gypseous soils are problematic soils that cause large deformations in the constructions that are built on it. Therefore, many binders have been used to reduce this impact. Traditional soil binders like lime or cement have environmental problems in terms of sustainability. Thus, sustainable substances have attracted appreciable interest in recently soil enhancement. Biomaterials are being developed to enhance geotechnical engineering properties like hydraulic conductivity, strength, and slope stability of varied soil types. This study aims at evaluating the engineering characteristics of gypseous soil treated with xanthan gum biopolymer. The tests performed on three types of gypseous soil with various gypsum contents and different properties. Gypseous soils were mixed with various contents of xanthan gum with a percentage of 2, 4, and 6. The compaction results indicated that xanthan gum decreases the maximum dry density and increases the optimum moisture content. The treated gypseous soils exhibited a low collapse potential by more than 30% - 45% with xanthan gum. The direct shear results of biopolymer treated soils showed significant shear strength gains. The results of the current study imply xanthan gum biopolymer improvement as an environmentally friendly method to improve the engineering properties of gypseous soil.

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تأثير البوليمرات الحيوية لصمغ الزنثان على خصائص الترب الجبسية

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الخلاصة

الترب الجبسية هي ترب انهيارية تسبب تشوهات كبيرة للأبنية المقامة عليها، ولأجل تقليل هذا التأثير استخدمت العديد من المضافات من ضمنها السمنت والجير، هذه المواد تواجه مشاكل من ناحية التنمية المستدامة. حديثا، حظيت المواد المستدامة باهتمام كبير في مجال تحسين التربة، حيث طورت المواد الحيوية لاستخدامها في تحسين الخصائص الهندسية للتربة مثل التوصيل الهيدروليكي والمقاومة وثباتية المنحدرات. هذه الدراسة تهدف لتقييم الخصائص الهندسية للترب الجبسية المعالجة باستخدام صمغ الزنثان (بوليمر حيوي)، حيث أجريت الفحوصات على ثلاث ترب جبسية مختلفة في الخصائص وفي نسبة الجبس واضيف لها صمغ الزنثان بنسبة 2% و4% و6%. تشير نتائج فحوصات الدمك الى ان صمغ الزنثان يقلل الكثافة القصوى الجافة ويزيد المحتوى الرطوبي الامثل بالإضافة الى ذلك تظهر الترب المعالجة احتمالية انهيار اقل بنسبة تتراوح بين (30%-45%). تظهر نتائج فحوصات القص زيادة ملحوظة في مقاومة القص وان مقاومة التربة المعالجة تقل بزيادة محتوى الجبس. تكشف نتائج هذه الدراسة ان البوليمرات الحيوية يمكن استخدامها في تحسين الترب الجبسية كمواد صديقة للبيئة.

الكلمات الدالة: البوليمرات الحيوية، الدمك، احتمالية الانهيار، التربة الجبسية، مقاومة القص، صمغ الزنثان.

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1. INTRODUCTION

Gypseous soil is a metastable soil, one of the spread problematic soils (i.e., unsuitable soils immediately used for construction or their behavior will exchange with the exchange in environmental conditions) everywhere the world in arid and semi-arid zones [1, 2, 3]. Gypseous soil is stable soil in its unsaturated case, but, underneath inundation states, the water breaks down the cementation action between the soil particles causing giant volumetric changes.

Several ways are obtainable within the literature to enhance gypseous soil behavior while selecting the suitable technique is more difficult with respect to various factors like; construction aspects , economic aspects, and collapsibility degree. Compaction may be effective to enhance the shallow layers of gypseous soil which might be appropriate for lightweight structures, whereas injection will effectively be used for the deep enhancement of significant or underground structures. Chemical additives is wide using to treat problematic soils by using many stabilizing materials such as; acrylate, cement, sodium silicate, and sulfur. Despite the good success of chemical materials in improving the behavior of problematic soils, it can't be as eco-friendly materials, because it may be toxic, contaminate groundwater, contaminate the soil, and modify the pH of soil [4, 5, and 6].

Recently, many attempts to treat problematic soil using biological approaches or secretion (e.g. biologically created materials) for geotechnical and construction engineering applications are stated. Biological techniques have eco-friendly benefits because of their low emissions and high capability to stop soil erosion, while cement, the most commonly used binding substance within the construction engineering is recognized to contribute severely to dioxide emissions (i.e., cement manufacturing accounts for about 7% of whole international emissions). Biologically made biopolymers are used directly as binders or mix additives for soil strengthening and improvement and have shown an excellent improvement of inter-particle interactions, even at low contents (e.g. a 1% or lower quantitative relation to the soil mass) [5,7].

"**Biopolymers** are organic polymers that are synthesized by biological organisms" [8]. Among biopolymers, xanthan gum has been actively investigated by many researchers to minimize the hydraulic conductivity of silty soil [9, 10] as well as to rise the shear strength of clayey soil by increasing the liquid limit [11]. A previous study focused on using xanthan gum as a soil strengthener and found that xanthan gum forms firm xanthan gum biofilms [12]. [13]Studied the effects of wetting and drying cycles on xanthan gum treated-sand and showed that the xanthan gum offered high durability against slaking. In addition, [14] conducted a review of the curing time of various biopolymers and the results showed that xanthan gum reaches 80% of its maximum compressive strength in a period of 14 days curing.

Though previous studies have presented that biopolymers are sustainable materials to improve geotechnical properties of various soils, the study of using biopolymers to treat the gypseous soil is almost nonexistent. Thus, this study aims at investigating the effects of xanthan gum biopolymer on the properties of gypseous soil, especially when exposed to water.

2. MATERIALS

1.2 Soil

The soil used in this study is disturbed natural gypseous soil; three completely different soil samples were chosen. The first one is taken from Tikrit city in Salah-Aldin Governorate with high gypsum content (55%) and designated as (soil1). The second is taken from Samarra city in Salah-Aldin Governorate with medium gypsum content (35%) and designated as (soil2). The third is taken from Tikrit city in Salah-Aldin Governorate too with low gypsum content (26%) and designated as (soil3). Fig. 1 shows the grain-size distribution curve of the soil samples. These soils are classified as poorly graded sand (SP) according to the Unified Soil Classification System (USCS). The physical and chemical properties of gypseous soils with the standards of tests are presented in Tables (1-3).

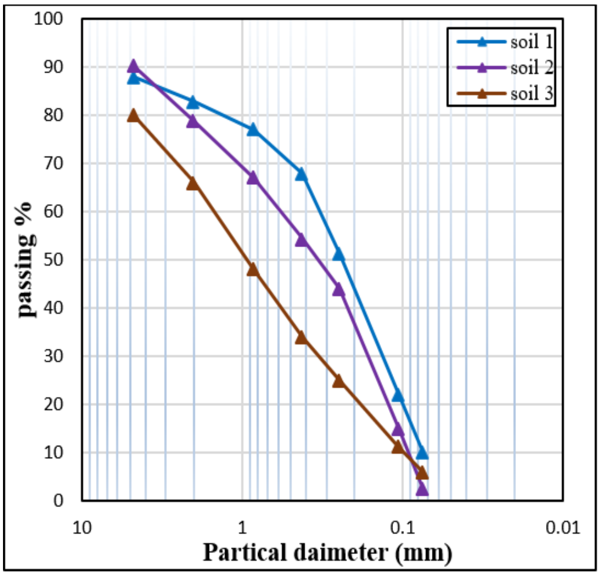

Fig. 1. The grain-size distribution curve

Table 1
Gypseous soils tests with their standards

Property	Standard
Grain size distribution	ASTM D422 [15]
Specific gravity	ASTM D854 [16]
Atterberg's limits (LL and PL)	BS 1377:2A [17] BS 1377:3 [18]
Compaction test	ASTM D1557 [19]
Field density	ASTM D1556 [20]
Chemical tests	BS 1377:3 [18]

2.2 Xanthan Gum

Xanthan gum ($C_{35}H_{49}O_{29}$) is a natural biopolymer formed by using aerobic fermentation of sugar by the "*Xanthomonas campestris*" microbes and composed of D-mannose, D-glucuronic acid, 6-O-acetyl D-mannose, pyruvylated mannose , and a 1,4-linked glucan. Xanthan gum is an anionic polysaccharide that simply adsorbs water molecules via hydrogen bonding, and that principally forms viscous hydrogels.

Thus, xanthan gum is usually used as fluid thickener within the food industry and as an stabilizer for drilling muds within the mining and petroleum industries because of its important viscosity increase in only a slight amount and availability with reasonable price [21, 22,23].

Xanthan gum produced by (Shandong Fufeng Fermentation Co., Ltd) was used in this study. Table 4 indicates the properties of Xanthan gum as reported by the manufacturer.

Table 2
Physical properties of gypseous soils

Soil symbol	Specific gravity (Gs)	Atterberg's limits		Grain size distribution		Compaction test		γ_f kN/m³
		LL%	PL%	C_u	C_c	$\gamma_{d\,max}$ kN/m³	O.M.C %	
Soil1	2.59	33	N.P	4	1.7	16.8	13	14.5
Soil2	2.62	32	N.P	5.3	1.4	18.2	10.2	15.2
Soil3	2.65	35	N.P	20	2.9	18.5	10.5	15.8

Table 3
Chemical properties of gypseous soils

Soil symbol	Total soluble salts (T.S.S)%	Organic matters (O.M)%	pH value	Gypsum content %
Soil1	62	0.12	8.01	55
Soil2	38	0.62	8.07	35
Soil3	31	0.51	8.12	26

Table 4
The properties of Xanthan gum (from Shandong Fufeng Fermentation Co., Ltd)

Biopolymer	pH	Viscosity (cps)	Ash content (%)	Color
Xanthan gum	6.0-8.0	≥1200	≤13	Cream-white

3. EXPERIMENTAL PROGRAM

3.1 Biopolymer- treated soil specimens

To prepare spoil samples for testing, the oven-dried soils first were passed through sieve 4.75mm to remove coarse particles. Xanthan gum-treated soil specimens were prepared with 2, 4, and 6% xanthan gum contents to the mass of soil. Xanthan gum were dissolved in distilled water (water content =10% to soil mass) to arrange xanthan gum hydrogel. A laboratory magnetic stirrer was used to offer uniform xanthan gum solution. Biopolymer solutions were totally mixed with dry soil. The biopolymer-soil mixture was poured and molded into fabricated metal molds to be appropriated for direct shear tests. specimens were extracted and dried at room temperature for 14 days to represent the (dry condition), whereas half of the dried specimens were soaked under distilled water at room temperature before applying direct shear tests to represent (soaked condition).

For collapsibility test, the biopolymer-soil mixture was poured and molded into metal molds to get curing time at room temperature. All specimens were prepared by field density for each soil.

3.2 Testing Program

3.2.1 Compaction test

A modified Proctor compaction test was applied according to ASTM D1557 [19]. The test was important for determining maximum dry density for every soil kind and optimum water content.

3.2.2 Direct Shear Tests

A series of direct shear tests were performed to determine the shear strength parameters of the soil samples. The tests were applied accordance with the procedure projected by ASTM D3080 [24] for samples in dry and soaked conditions. The specimen size was (60×60×20) mm.

3.2.3 Collapse tests

Collapse tests have been carried out by using the odometer device according to ASTM D5333 [25]. Double odometer test was carried out to determine the collapse potential (CP) of the soil. The severity in accordance the collapse potential is shown in Table 5.

Table 5
Collapse identification (from Jennings and Knight, [26])

Severity	No problem	Moderate	Trouble	Severe	Very severe
CP(%)	0-1	1-5	5-10	10-20	20 >

4. RESULTS AND DISCUSSION

4.1 Collapsibility of Xanthan Gum-Treated Soils

The collapse potential of gypseous soil is associated with the gypsum dissolution, the soil particles reorientation, and the breaking of the cementation between the soil particles [27]. The collapsible potentials are calculated at 200 kPa stress.
The highest value of collapsible potential for soil with high gypsum content (soil 1) was 6.6% which, according to Jennings and Knight [26], was recognized with a trouble degree of collapse. The collapse potential was 4.1% and 3.7% for soil 2 and soil 3 respectively, which

was recognized with a moderate trouble degree of collapse.

The collapse potential of xanthan gum-treated soils decreases with the xanthan gum content up to 4% and then increases, as the same trend of shear strength behavior.

The collapsible potential for soil 1 reduced to 3.1% with adding 2% xanthan gum concentration with efficiency percentage in decreasing the collapse potential of 45%, while the efficiency was about 53 % for 4% xanthan gum concentration and it was in the range of moderatee trouble degree of collapse.

While the collapse potential reduced to 2.6% and 2.1% for soil 2 and soil 3 respectively with adding 4% xanthan concentration and it was in the range of moderate trouble degree of collapse, Fig. 2. The soil with lowest gypsum content shows the maximum reduction in the collapse potential after treatment with 4% xanthan gum concentration.

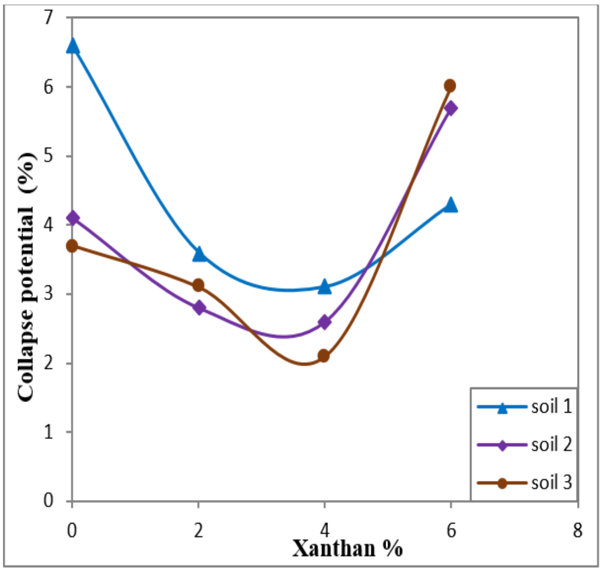

Fig. 2. Effect of xanthan concentration on collapse potential

4.2 Direct Shear of Xanthan Gum-Treated Soils

The dried state and soaked state show higher shear strength than the untreated state for three soils. The results show that the shear strength of the dry xanthan gum -treated soils is remarkably greater than that of the soaked xanthan gum -treated soils, whereas the soaked shear strength will become much less sensitive with xanthan gum content variation.

For dried state both the cohesion and angle of internal friction increase significantly due to the formation of firm xanthan gum biofilms. The cohesion of xanthan gum-treated soils also increases with xanthan gum content up to 4% and then decreases as found by [28], but remains higher than that of untreated soils, the higher content makes xanthan gum gels very thick, high viscosity, and poor mixing resulting in unverified results. A xanthan gum concentration of 2% was designated as the optimum concentration, as increase in xanthan gum concentration beyond this point exhibited less significant cohesion gains .The cohesion of 2% xanthan-treated soils increases up to 4 times, 6 times, and 13 times for soil1, soil2, and soil3 respectively than the untreated state, Figs. (3-5).

Meanwhile, for the soaked condition, the friction angle and cohesion values decrease but the cohesion remains higher than those of the untreated soils. When xanthan gum-treated soils soaked in water, the dried xanthan gum gels adsorb water due to hydrophilicity resulting in a reduction in viscosity (stiffness) of thick gels and inter-particle interaction. Water would decrease the cohesion of 2% xanthan-treated soil up to 67%, 92%, and 89% for soil 1, soil 2, and soil 3 respectively than the dried condition.

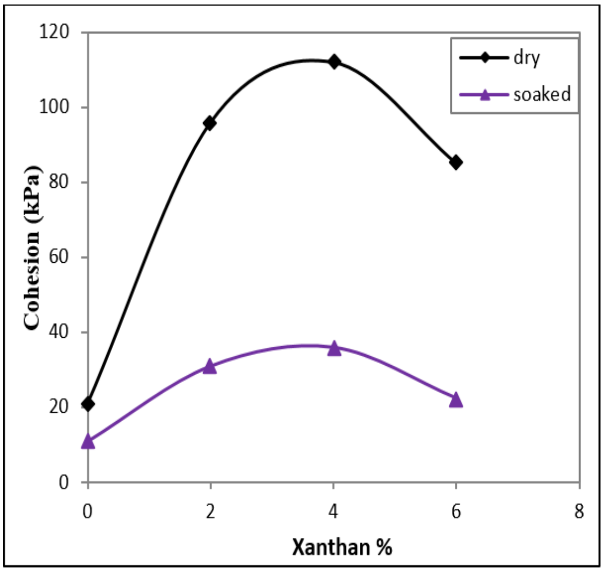

Fig. 3. Influence of xanthan concentration on cohesion of soil 1

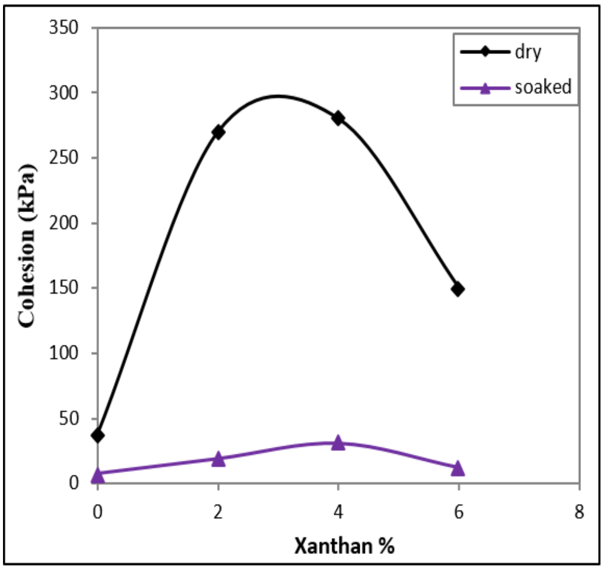

Fig. 4. Influence of xanthan concentration on cohesion of soil 2

The soil with medium gypsum content (soil 2) shows the maximum increases in the cohesion at dried condition. While for soaked condition, the soil with highest gyp*74sum content gives the maximum increases in the cohesion at both treated and untreated states. For dried state, the angle of internal friction of xanthan gum-treated soils increases with the xanthan gum content up to 2% as found by [23] and [28] and then decreases, but remains higher than that of untreated state, the higher xanthan gum content (i.e., thick xanthan gum gels) inside inter-granular pores render surface friction less roughness. The friction angle after soaking varied from 16.7° to 26.1° while it was between 39.5° and 48.5° before soaking, Figs. (6-8). the soil with lowest gypsum content (soil 3) shows the maximum increases in the friction angle at both dried and soaked conditions.

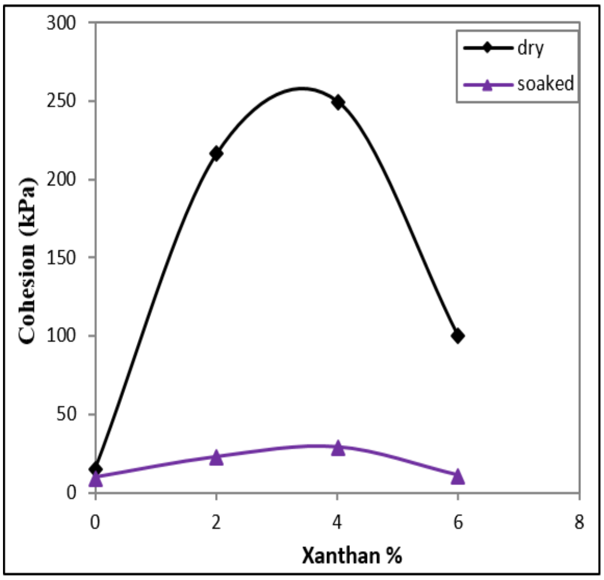

Fig. 5. Influence of xanthan concentration on cohesion of soil 3

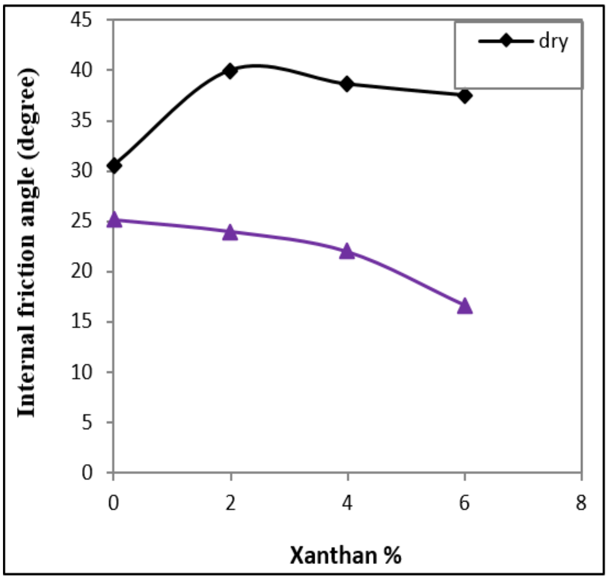

Fig. 6. Influence of xanthan concentration on friction angle of soil1

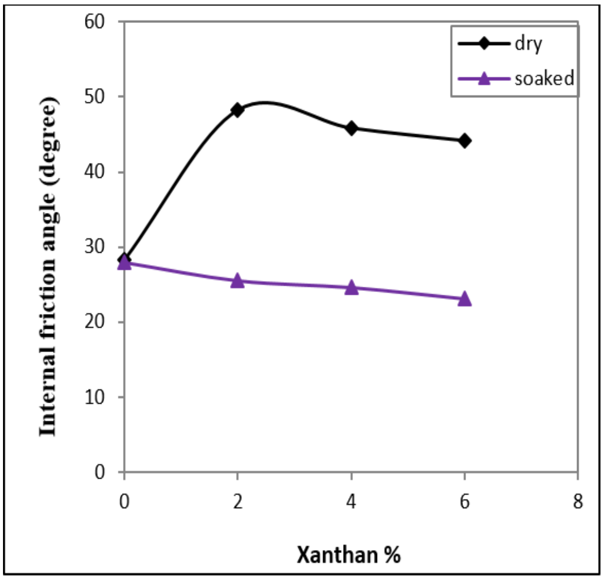

Fig. 7. Influence of xanthan concentration on friction angle of soil2

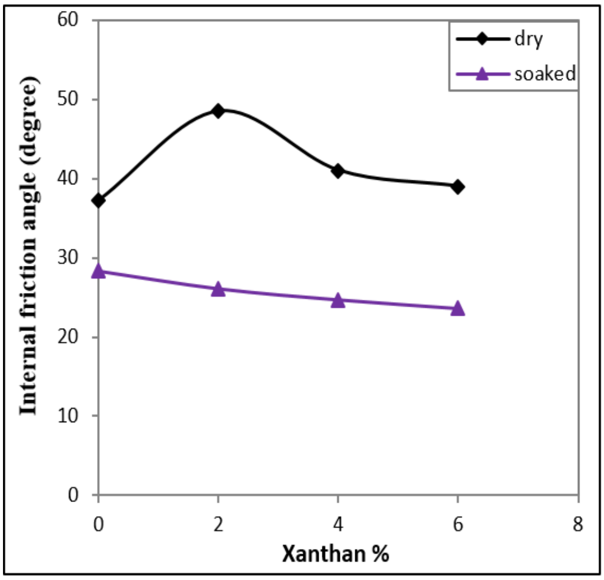

Fig. 8. Influence of xanthan concentration on friction angle of soil3

4.3 Compaction Characteristics of Xanthan Gum-Treated Soils

The results of maximum dry density (γd max) and the optimum moisture content (O.M.C) are presented in Fig. 9 and 10 Results show that an increase in the quantity of xanthan gum leads to a decrease in the maximum dry density and also a rise in the optimum water content as found by [5] and [28]. Meanwhile, the treated soil with the highest gypsum content (soil1) shows the maximum decrease in its maximum dry density. For xanthan treated soil1, with a rise of xanthan gum content from 0 to 6%, density is decreased from 16.8 to 14.2 kN/m³. While, xanthan treated soil2, the maximum dry density is decreased from 18.1 to 14.7 kN/m³ and for xanthan treated soil3, the maximum dry density is reduced from 18.5 to 15.8 kN/m³.

The optimum moisture content increased from 13.3% for untreated soil1, to 16% at a concentration of 6% for xanthan gum. While, it increased from 10% for untreated soil2, to 15% at a concentration of 6% for xanthan gum. In the case of soil3, it increased from 10.5% to 15% at the same concentration. The reduction maximum dry density decrease of treated soil can be attributed due to the characteristics of xanthan gum biopolymer solution --particularly the viscosity-- and also the weight of soil particles. The lightweight of the soil particles permits them to move away from one another because of the effect of the solution viscosity that causes a decrease within the density. In addition, the rising of solution concentration can raise viscosity, which can result in an additional reduction in soil density [4]. The reason for increasing the optimum water content is due to the rise of absorbed water consumed by the increased xanthan gum biopolymer.

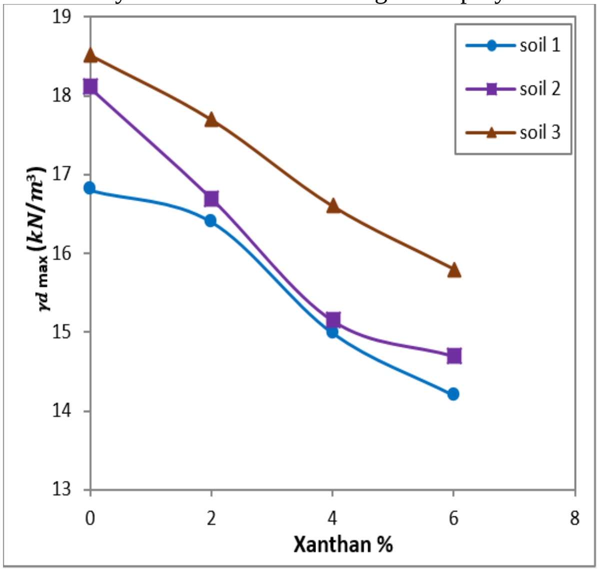

Fig. 9. Maximum dry density of xanthan gum-treated soils

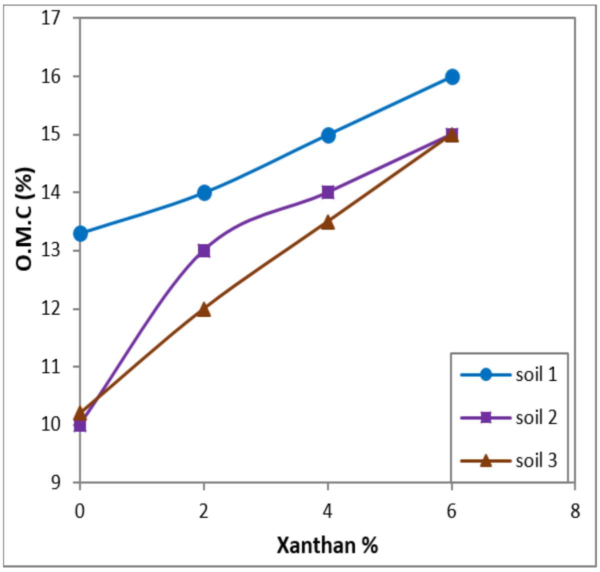

Fig. 10. Optimum moisture content of xanthan gum-treated soil

5. CONCLUSIONS

Based on the results presented in this study, the following conclusions were drawn:

1. The maximum dry density decreases with increasing the solution concentrations of xanthan gum from 18.5 to about 14.2 KN/m^3, whereas the optimum moisture content increased from 10.2% to around 16%. Moreover, the soil with the highest gypsum content shows the maximum reduction in its dry density.
2. The results of direct shear tests show enhanced shear parameters (internal friction angle and cohesion) of xanthan gum tread soils.
3. Mixing the gypseous soils with 2% xanthan gum concentration leads to a reducing in collapse potential by more than 30–45%.
4. The optimum xanthan gum concentration was found to be 2%, as increases in xanthan concentration beyond this content exhibited less significant shear strength increasing and collapsibility reducing.
5. Thus, based on above results, it can be concluded that biopolymer treatment shows promise as a tool to enhance gypseous soil behavior as a sustainable and eco-friendly materials.

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