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Improving The Engineering Properties of Gypseous Soils by Adding Polymers: A Review

Dunya Abdullah Khalaf[1*] ,Shaimaa Hasan Fadhil[2]

[1,2]Civil Engineering Department, Mustansiriyah University, Baghdad, Iraq.

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ABSTRACT

gypseous soils are distributed in many regions in the world. These soils have a considerable potential for collapse because of the presence of Gypsum, Gypseous soils was one of the most complicated salty soils that challenged the geotechnical engineers. Also, Buildings constructed on gypsum soil will experience unanticipated distortions that will eventually lead to disastrous of collapse. A number of stabilizers and methods have been used to stabilize the soil and render it to be more suitable for construction purposes. This paper gives an overview of some previous researches on the behavior of this soil when it stabilized with polymers. These studies reveal that treating the soils with polymers in liquid, powder or Fiber form improves the soil properties. These include a decrease in the collapse potential, an increase in durability, and improved permeability. Moreover, polymer stabilization is more economical and environmentally friendly than conventional techniques.

1.Introduction

Gypseous and gypsiferous soils (the two terms are used interchangeably, definitely are those soils that have. sufficient quantities of gypsum ($CaSO_4.2H_2O$) to change their engineering characteristics, The occurrence of gypsum in grains of soil. in dry weather is efficient to close the pore spaces between these grains, similar to the role of cement in concrete [1]. gypseous soils According to [2], gypseous soils occupy about 12.2 % of the territory of Iraq area.[3] provided a higher estimate, which indicates that about 50 % of the gypseous area is to be considered significant compared to other assessments. Conversely,[4] calculated that some 31.7 % of Iraqi land was covered is gypseous soil having gypsum varying from 10% to 70% This percentage poses a challenge on both agricultural and engineering applications, The first map that shows the occurrence of gypsum In 1960, [5] gave it as across Iraq (refer to Figure 1). In this map, five distinct Areas of gypsum are distinguished the first zone is identified by primary gypsum existing in the upper Jazirah region. The second zone is mixed with primary gypsum limestone, which is mostly found in the upper part of northern desert. The third zone a secondary gypsum which spans, defines it regions to the north and west of Baghdad The fourth zone is manifested by a pervasive one

Corresponding author E-mail address: dunyaabdullah@uomustansiriyah.edu.iq
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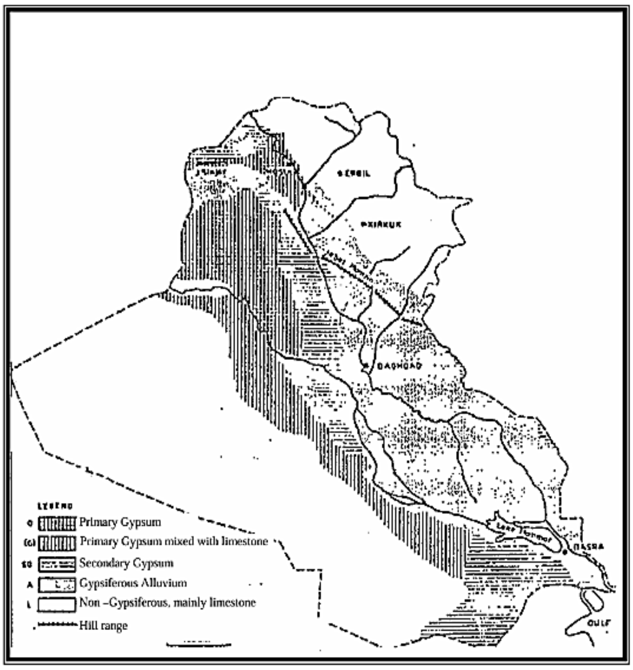


Figure 1: distribution of gypseous soils in Iraq [5].

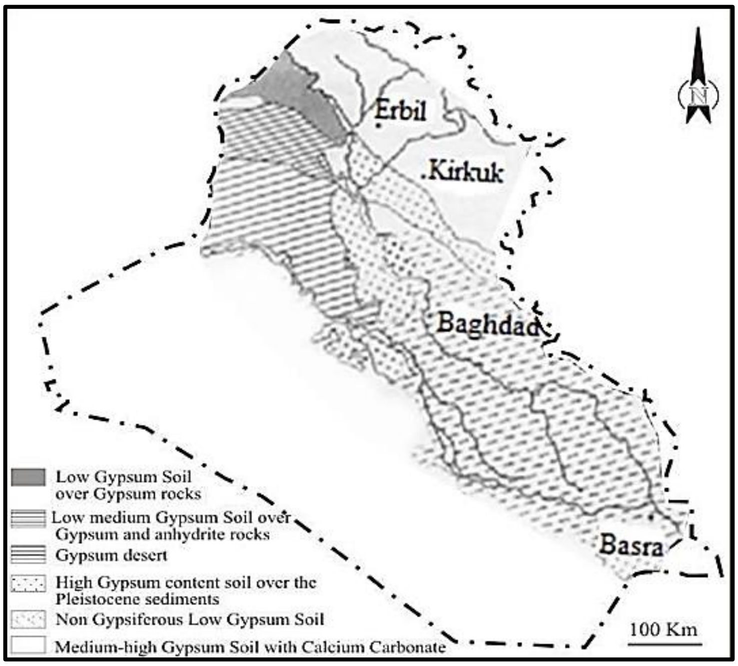


Figure 2: Regional distribution of gypseous soils in Iraq. [2]

gypsiferous alluvium is present that spans. the north south of the eastern side of Iraq the last zone is made up of non-gypsiferous soils are in the west of both the north-western regions and deserts to the south Barazanji (1973) present a more clear map showing the distribution Figure (2). of gypsum throughout Iraq, this map indicates that the northern section of the upper Jazirah features slightly gypsiferous soils situated above gypsum bedrock, followed by a gypsum desert associated with the lower Jazirah. In contrast, moderately to highly gypsiferous soils overlaying gypsum and hydrite rock are prevalent in the southern portion of the upper Jazirah. Furthermore, highly gypsiferous soils are concentrated within the upper and middle terraces of the Euphrates and Tigris rivers formed during the Pleistocene epoch. Moderately to highly gypsiferous soils that contain lime are located in the southwestern desert regions, while the eastern part of Iraq is primarily characterized by non-gypsiferous or slightly gypsiferous soils.[6]

2. Identification and Estimation of Collapsible soil

Current approaches for assessing collapsible soils generally adhere to several core principles:

1.Regional Methods: support the empirical ideas that enable. faster testing, including consistency limitations and physical indexes.

2. Laboratory Methods: This type. primarily is Oedometer tests performed. under wetting conditions.

3. Field Methods: These methods involve to plate load tests or cone penetration tests. measure behaviour of soils on-site.[7]

2.1 Regional methods:

This method is based because of the assumption that soil having sufficient space to store its liquid limit, moisture in a condition of saturation, is will collapse when it becomes wet. Various collapse criteria have been suggested in the literature, which consider factors such as dry density, Atterberg limits, moisture content, void ratio, clay content, and porosity. However, these criteria may often provide misleading assessments of collapse potential since they do not account Natural soil composition, including factors such as cementation and other characteristics that influence collapse behaviour, plays a critical role. As a result, these approaches can function as initial assessment tools to determine when it is essential to conduct direct laboratory tests for the characterization of site-specific behaviours.[8]

2.2 Laboratory methods: The only laboratory techniques available for estimating soil collapse are listed below.

A. Double Oedometer test: : The double oedometer test, first proposed by [9], involves preparing two identical soil samples that are subsequently tested separately using an oedometer apparatus. The first sample is evaluated in its natural condition. the second being subject to fully saturated testing. Both samples having had the same loading order, as depicted in Figure (3). The degree of collapse is quantified using a stress strain curve as the stress level is increased.

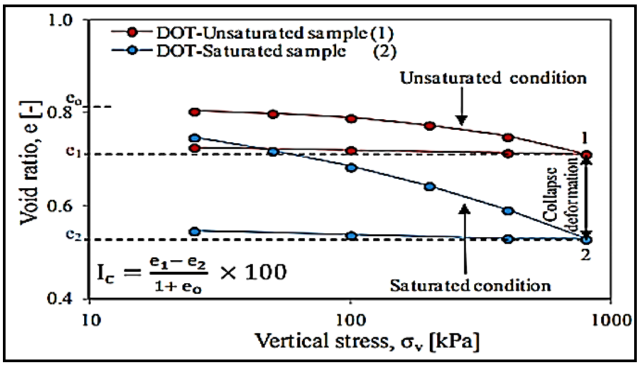


Figure 3. Results of the Oedometer (DOT) collapse test.

B. Single Oedometer Test: This method involves the insertion of a soil sample into the oedometer, increasing overburden stress is continued until the equilibrium of the strain. Afterwards, the sample is saturated with. distilled water with a pressure applied of 200 kPa is sustained. After such a loading stage is completed, the sample is kept under water 24 hours prior to maximum loading, this process is described in Figure (4), and its results. Collapse potential is ascertained. This method has been perfected by different researchers; for example,

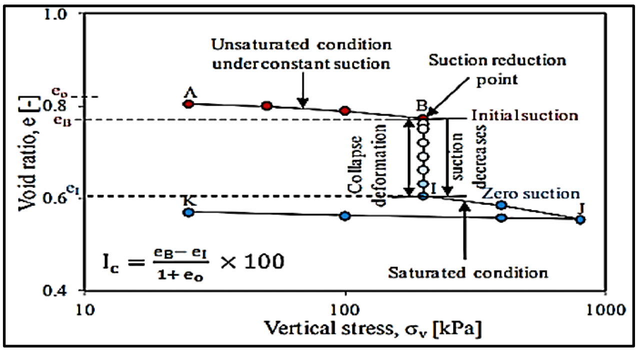


Figure 4. Results of the Oedometer collapse (SOT) test.

in 1948, [10] used a stress level 300 kPa to define collapse potential as:

$$cp = \frac{\Delta e}{1 + e1}$$

where:
Δe: change in void ratio due to saturation.
$e1$: void ratio just prior to saturation.

[11] suggested employing a stress level of 200 kPa to determine the potential for collapse, utilizing the following equation:

$$cp = \frac{\Delta e}{1 + e^{\circ}}$$

where:
Δe: change in void ratio due to saturation.
e°: natural void ratio

[2] suggested a classification system of gypseous soils on the basis of their gypsum content and the proposed sub-groups were Non-gypsiferous, Slightly, Moderately and Highly gypsiferous soils as displayed in Table (1).

Table (1): Classification of gypseous soils according to [2].

Gypsum content, %	Classification
0-0.3	Non- gypsiferous
0.3-3	Very- slightly gypsiferous
3-10	Slightly gypsiferous
10-25	Moderately gypsiferous
25-50	Highly gypsiferous
> 50	Gypsiferous soil to be described by the other fraction such as sandy gypsiferous soil

The most commonly used laboratory procedure in the evaluation of these soils is modified triaxial compression test which has been taken as a standard practice. That approach defined by

[12] and in combination with [13]was subsequently standardized by the American Society of Testing and Materials (ASTM) as designation D5333 in 1992. The Collapse Index is used to quantify the process of soil collapse that is caused by water infiltration. In particular, Collapse Index (Ie) is a one-dimensional strain which is produced during wetting when vertical stress is 200 kPa. In the year 2003, ASTM streamlined the Collapse Index classification system and established a qualitative framework of assessing the potential of collapse.

C. One-dimensional swell or collapse: More recently, in 2014, ASTM developed the standard D4546. (Standard Test Methods for One-Dimensional Swell or Settlement Potential of Cohesive Soils) aimed at evaluating the one-dimensional swelling and collapse characteristics of soils. These standard addresses both phenomena of swelling and collapsing. Behaviors induced by wetting across various stress levels pertinent to construction projects. The results from these tests, illustrated in Figure (5).

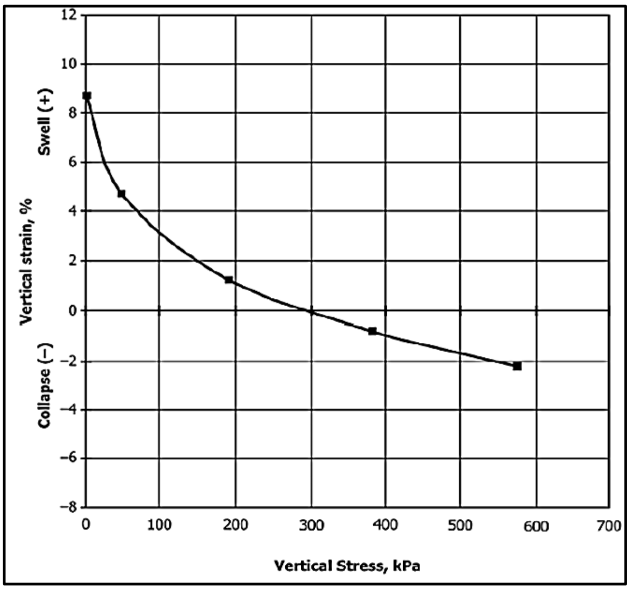


Figure (5) : Stress versus wetting-including swell / collapse strain. (ASTM D4546-21).

allow for the determination of swell and collapse ranges within a soil profile, enabling calculations of net ground surface heave or settlement. The D4546 outlines three methodologies:

1.Swelling or collapsing due to wetting in compacted fills.

2.Swelling or collapsing caused by wetting in natural soils.

3.Loading after wetting-induced settlement. swelling or collapse.

Now, the values of the result are fully. quantitative rather than qualitative, as defined in. the collapse potential classification provided in. the ASTM D5333 standard. The D4546 standard was published in 2021 with slight changes.. [11] established a framework for assessing the severity of collapse issues based on soil collapse potential, which is elaborated in Table (2).

Table (2): The severity of collapse potential [11].

Collapse potential, (CP) %	Severity of the problem
0-1	No problem
1-5	Moderately Trouble
5-10	Trouble
10-20	Severe Trouble
>20	Very Severe Trouble

2.3 Field methods: The difficulty with collapsible soils lies in the fact that they are not easily sampled due to their natural structural properties that hinder the collection of accurate data through laboratory analysis. As a result, many researchers have resorted to field testing methodologies ([14],2005). Field tests are commonly used to define and determine deposits of collapsible soil. However, conducting a comprehensive literature review shows that a few of the authors have come up with methods of measuring soil collapsibility. Most of these techniques are based on the techniques specified by ASTM standards, but their use is limited ([15]; [16]; [17]). Also, the standards that are already in place such as the British Standard, the Australian Code, and the Eurocode among others, have not thoroughly explored the complexities related to soil collapse.

3. Collapse Mechanisms:

The mechanisms of collapse have attracted a lot of scholarly interest (see references [18][9][19][20][21][22]). The phenomenon of collapse is mainly related to porous microstructure of soil As stated in [18],a fraction of fine-grained particles acts as a bonding agent to bigger grains, in which these contacts experience local compression in the infinitesimal intergranular voids thus contributing to strength (see Figure 6). In natural moisture circumstances, these soils show only slight compression that could be attributed to the high overburden pressures that are exerted by construction works; hence, their overall structural integrity is not largely compromised. However, at such a moisture content that a critical limit is reached, the fine silt or clay bridges that add to cementation start to decay, weaken, start to deteriorate, lose their firmness, or partially dissolve. Finally, these bonding agents cannot resist the forces of deformation, and structural collapse occurs, as Figure 6 shows, many researchers have studied the deformation of soil collapses using single and double oedometer tests such as [23], [24], [25], [26], [27], [28]. Based on their findings, the following conclusions were made:

1. As the initial dry density and water content rise, the potential of collapse diminishes linearly.

2. Conversely, an increase in applied pressure and a higher initial void ratio contribute to a greater risk of collapse.

3. In gypseous soils, the occurrence of collapse deformation is mostly associated with the breakdown of cementing connections between soil particles, which results from the dissolution of gypsum bonds. [29]

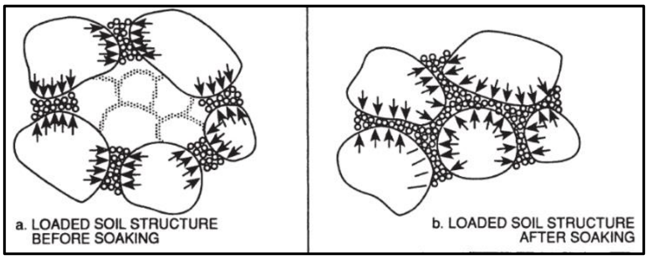


Figure (6): Collapsible soils depiction [9].

4. polymers: Polymers are essentially large molecules formed from repeated structures known as monomers. The process of polymerization leads to the creation of a polymer, which exhibits distinct physical and chemical characteristics that differ from those of the individual monomers. Both naturally occurring and synthetic polymers have been documented as effective agents for soil stabilization [30],[31]. Historically, the use of polymers for soil stabilization dates back to The World War II was the first-recorded application of a water-soluble polymer to increase the stability of soils used in constructing the military roads and runways [32]. However, the larger adoption of polymers in the engineering field has been hindered by the fact that they are expensive and practitioners have been preferring traditional stabilizers like Portland cement and lime Regardless of these economic limitations, polymers have been used successfully in various contexts, such as dust suppression in construction sites and in erosion control of winds in arid areas like the Middle East and slope stability reinforcement [33], [34], [35], [36]. In these uses, polymers have demonstrated a more desirable environmental performance as compared to cement and lime and especially in greenhouse-gas emissions and resource consumption. Polymers on the other hand require significantly less energy to make and produce significantly less greenhouse gasses[37].Some of these polymers are based on industrial by-products, which are inexpensive and considered waste products; lignin, a biopolymer that is collected as a by-product of the pulp and paper industry, and fly ash, a raw material of geopolymer that is a by-product of coal-powered power plants are notable examples [[38], [39].Biopolymers like polysaccharides that are found in nature are also extensively used in the food industry [40]. Over the last many decades, the synthetic polymers such as polyacrylamide have been utilized in the irrigation of agricultural soils due to their effectiveness in stabilizing soil aggregates, reducing soil erosion, increasing water infiltration and indirectly leading to better crop growth and yield [41].Such polymers have proven physical environmental benefits hence encouraging designers and contractors investigate their applications in soil stabilization further.[42]

4.1 Classification of Polymers:

Polymers can be classified through various methods, as illustrated in Figure 10, contingent on specific criteria [43]

A. Classification by Origin: This classification encompasses three subcategories[43].

1. Natural Polymers: These are polymers that occur in nature, including substances like cellulose, proteins, rubber, and resins.

2. Semi-Synthetic Polymers: This category comprises polymers formed by the chemical modification of naturally occurring ones to enhance their physical properties. An example of a semi-synthetic polymer is silicone.

3. Synthetic Polymers: These are laboratory-produced fibres synthesized through the polymerization of fundamental chemical components. Examples include polystyrene, polyethylene, synthetic nylon, and PVC.[44]

B. Classification by Structure: Polymers can also be categorized based on their structural characteristics into three types:

1- Linear Polymers: These consist of long, unbranched chains of repeating units where the monomers are tightly bonded with no side chains present. Notable examples include nylon, high-density polyethylene (HDPE), polyester, and polyvinyl chloride (PVC), as depicted in Figure (7).

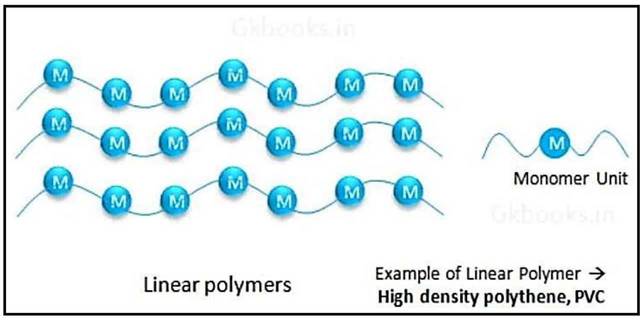


Figure (7) Structure of liner polymer [62].

2- Branched Chain Polymers: Branched chain polymers these polymers are made up of long, straight chains with side chains that connect to the main chains. Due to their irregular molecular packing, these polymers exhibit lower melting points, densities, and tensile strengths compared to their linear counterparts. Notable examples of branched chain polymers include glycogen, low-density polyethylene (LDPE), and polypropylene, as illustrated in Figure (8).

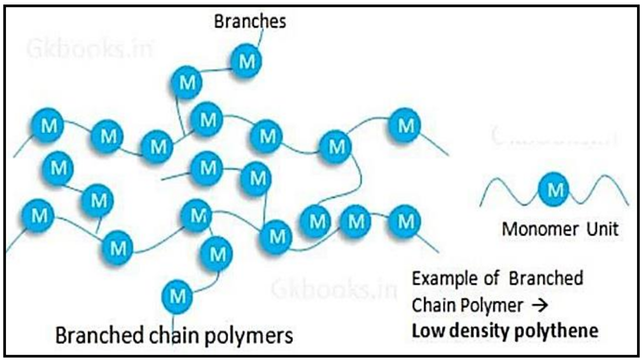


Figure (8) : Structure of branched chain polymer [62].

3- Cross-linked (Network Polymers): A network polymer is composed of two or more interlaced networks or chains that are intertwined but not chemically linked, as depicted in Figure 8. Such a complex structure enables network polymers to have distinct properties that render them stiff, hard, and brittle. Examples of network polymers include Bakelite and Melamine[45].

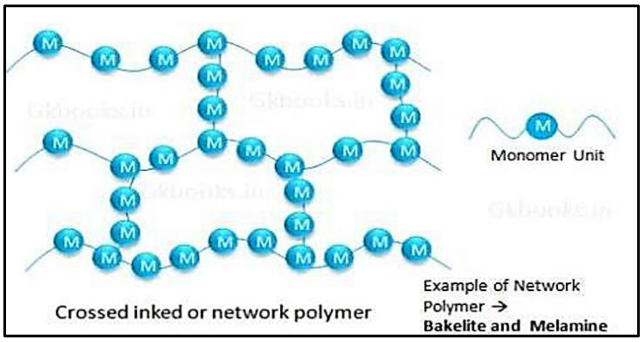


Figure (9) Structure of crossed-linked or network polymer [62].

C- Based on Molecular Forces: According to the forces at the molecular level, the mechanical properties of materials, including tensile strength, toughness, and elasticity, are determined by the intermolecular forces, which are the van der Waals forces and hydrogen bonding. [46], Based on the forces, the polymers can be classified as follows:

1-Elastomers: In elastomeric polymers, the chains are interconnected through weak intermolecular forces. These materials resemble rubber solids with elastic characteristics. The presence of weak interactions enables the polymer to stretch. A limited number of crosslinks are incorporated between the chains to facilitate the polymer's return to its original position after the force is released, as in rubber.

2- Fibers: The flexibility to form fibers and exhibit great tensile strength is one of the remarkable properties of many substances. This strength is largely due to strong intermolecular forces, such as hydrogen bonding included. The high concentrations of these strong forces also lead to the high concentration of chains, hence formation of a crystalline structure. examples are polyamides, polyesters, etc.

3- Thermoplastic polymers: are materials that can be melted and reformed on heating, then set to solidify when cooled. These polymers show intermolecular forces among their Fibers and elastomers. At the molecular level, temperature causes weakening of the secondary bonds, which allows easy translocation of adjacent chains under stress. Generally, thermoplastics have ductile and soft properties, and most linear polymers are classified as such. Examples include:

1- - Polymethyl methacrylate

2- - Polyvinyl Chloride (PVC)

3- - Polystyrene

4- - Polypropylene

4- Thermosetting polymers: are brtter at high temperatures. Being initially softened when heated, once cooled, they become solid, and fail to be reformed by heating any further; as a result, they are unable to be reshaped and are insoluble. Additionally thermosetting polymers are generally brittle and have higher hardness and strength than thermoplastic polymers [47].

D- Based on Polymerization Mode:

Polymers are also classified in two subgroups according to the polymerization mechanisms employed:

1- Addition polymers When monomers containing double or triple bonds are further aggregated to form larger molecules, the addition polymeric compound. Some of them include polypropene from propene and polythene from ethene.

2- Condensation polymers: These polymers are formed by combining two monomers and removing small molecules such as alcohol, NH3, and water.

E- Based On types of Monomers:

1- Homopolyme: In this type of polymer, there is only one type of repeating unit, e.g. polystyrene.

2- Hetropolymer (Copolymer):A polymer made of two different monomers is also called a copolymer; one such mixture is styrene rubber. [46]

5. Gypseous soil remedies

The soil present at a construction site is not always inherently adequate for supporting various structures, including buildings, bridges, highways, and dams (Das, 1984). Many soil types may be inadequate in their natural form; however, they can be modified through the incorporation of additives or by achieving optimal compaction. This process enhances their capacity to bear structural loads. Soil stabilization refers to the enhancement of soil characteristics through treatments aimed at diminishing its vulnerability to water effects. The following methods are available to improve the engineering properties of gypsum soils.[48]

Dhay Waddy Mohammed et al., 2019 In this investigation, poorly graded sandy soil with 36% gypsum was added with 3, 6, and 9 percent of Copolymer and Novolac polymer to improve the property of collapsibility, permeability, and compaction on the soil, the experimental results showed that there was a considerable improvement of collapsibility and permeability of the soil with polymer additives compared to that of the untreated In particular, the highest increase in the collapsibility was found when 3% polymer (both copolymer and Novolac) was used, with the subsequent rates of 44.5% and 46% during a three-hour period, respectively. In terms of permeability enhancement, results in Figure (10) showed increases of 98.6% for copolymer and 86.2% for Novolac polymer after one day. These findings are detailed in Table (3).[49]

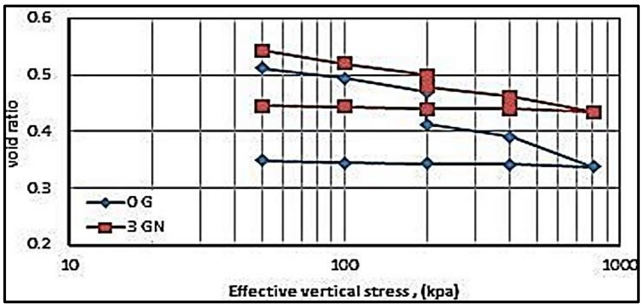


Figure (10) : Result of the SOT test for soil treated with 3% of Novolac polymer. [49]

Table 3 : result of permeability test before and after improvement. [49]

Materials (%)	Coefficient of permeability (cm/sec)
0G	1.7×10^{-3}
3GP	1.98×10^{-4}
6GP	2.3×10^{-5}
9GP	5.1×10^{-5}
3GN	5.31×10^{-4}
6GN	2.35×10^{-4}
9GN	3.69×10^{-4}

Maysam Th. Et al., (2020) In this research, the objective is to investigate the durability of gypseous soil when subjected to wetting and drying cycles following enhancement with polyurethane polymer, with a particular focus on how these cycles influence collapsibility the soil sample contained 65.5% gypsum, which was classified as (SP) the results reveal that the addition of different percentages of polyurethane polymer (PP) significantly enhanced the collapse potential (CP) and resistance to repeated wet and dry cycles for different curing times.Specifically, the reduction in CP for three concentrations of polyurethane polymer—3%, 6%, and 10%—was found to be 53%, 82%, and 93.2%, respectively, after the specimens underwent one cycle. After four cycles, the reductions for the same percentages were approximately 85%, 87%, and 94.6%. As illustrated in Figure (11), these results demonstrate that polyurethane can effectively serve as a chemical additive to improve the mechanical properties of gypseous soil with high gypsum content. [50]

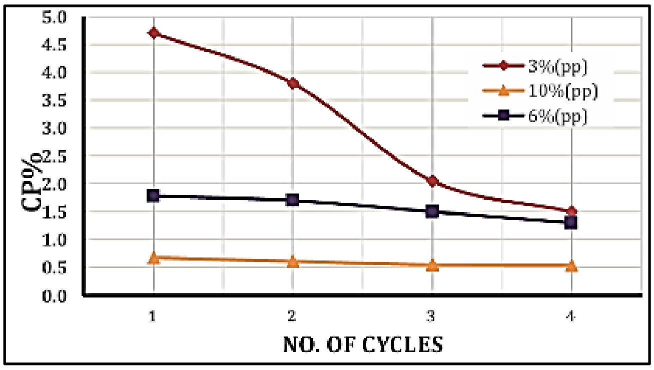


Figure (11) : variation of (cp)% with the number of wetting-drying cycles for gypseous soil treated by (pp). [57]

The study conducted by **Balqees A. Ahmed et al., (2020)** poorly graded sandy soil (SP) of 36% gypsum content tested improve the engineering properties by using Copolymer and Styrene-butadiene Rubber , result shows Increasing polymer content to 3% reduces collapse potential as shown in Table (4) , but higher percentages weaken cohesion and increase collapse risk. At 6%, Copolymer and Styrene-butadiene Rubber significantly lower permeability by forming waterproof bonds around soil particles. This same percentage also enhances bearing capacity due to improved cohesion as present in Table (5).[51]

Table 4 : the potential of the sample to collapse prior to and after the treatment by pectin during the leaching process.[56]

Percent added	0%	3%	6%	9%
Copolymer	9.47	3.47	5.74	6.21
Styrene-butadiene Rubber	9.47	3.05	3.68	4

Table 5: The result of direct shear of soil treated by copolymer and SBR (bearing capacity in kN/m2).

Materials	0%	3%	6%	9%
Copolymer	315.95	442.64	294.24	201.502
Styrene-butadiene Rubber	315.95	519.32	511.32	435.1

Dhay et al., 2020 A study was conducted to enhance the engineering characteristics of gypseous soil through the incorporation of Novolac polymer. The soil samples contained 36% gypsum. This investigation involved the addition of varying percentages of Novolac polymer (3%, 6%, and 9% w/w) and analyzed their effects in comparison to samples treated with cement at the same concentrations. The primary engineering properties assessed included permeability, shear strength, and collapsibility.

As illustrated in Figure (12), below, it was found that a 3% w/w addition of Novolac significantly improved collapsibility to a value of 57.8, while a concentration of 6% w/w notably enhanced both bearing capacity and permeability, achieving improvements of 25.2% and 86.2%, respectively.[52]

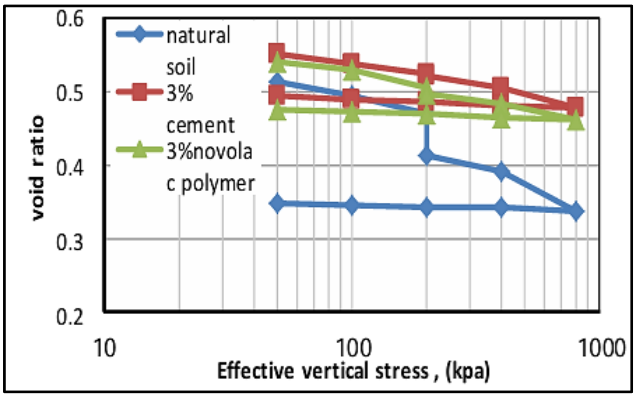


Figure (12): SOT of gypseous soil treated by cement and Novolac polymer.

Table 6 : The summery of result of changing the bearing capacity compare to natural soil under compaction.

Material	3 %	6%	9%
Cement	27.8	104	69.8
Novolac polymer	-1.7	25.2	11.66

Arwa F. Theyab et al., (2020): investigated three types of gypseous soil, with varying amounts of gypsum and inherent characteristics. Xanthan gum at concentrations of 2%, 4%, 6% was then applied to the soils. The findings from the compaction test results proved that the addition of xanthan gum resulted in the apparent reduction of the maximum dry density and at the same time raising of the optimum moisture content, Moreover, the gypseous soils that were treated had a significant reduction in the collapse potential, where they had a reduction between 30% to 45% as shown in Figure (13) ,The results obtained in the direct shear tests on the soils treated with the biopolymer showed that there were significant enhancements in shear strength as presented in Figure (13). Overall, with the results above, it is possible to conclude that the use of xanthan gum as a biopolymer is an effective and ecologically sustainable method of improving the engineering properties of gypseous soil [53].

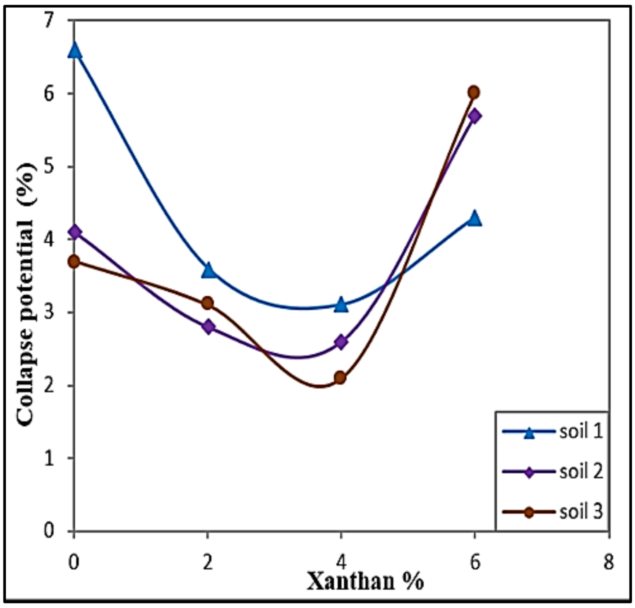


Figure (12): Effect of xanthan concentration on collapse potential.

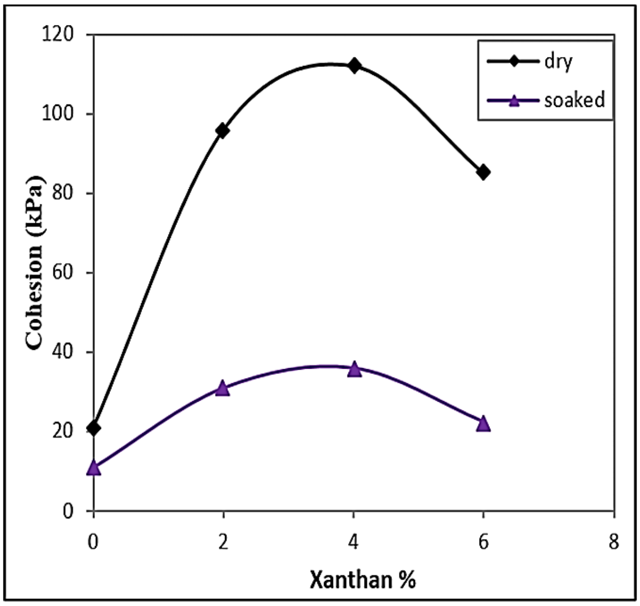


Figure (13): Influence of xanthan concentration on cohesion of soil 1.

F. A. Al-Wakel., 2021 demonstrated how polyurethane foam added to the properties of poor grade sandy soil containing 30 % gypsum, and rendered it capable of supporting shallow foundations. The aim of the experiment was to identify the effective region of treatment by physical models of footings that lie on the gypseous soil that was treated with polyurethane foam Results show that a 3% solution of polyurethane foam should be recommended to affect the behavior of gypseous soil mainly because it is effective in minimizing volumetric changes of strain and collapse potential as Figure (14). [54]

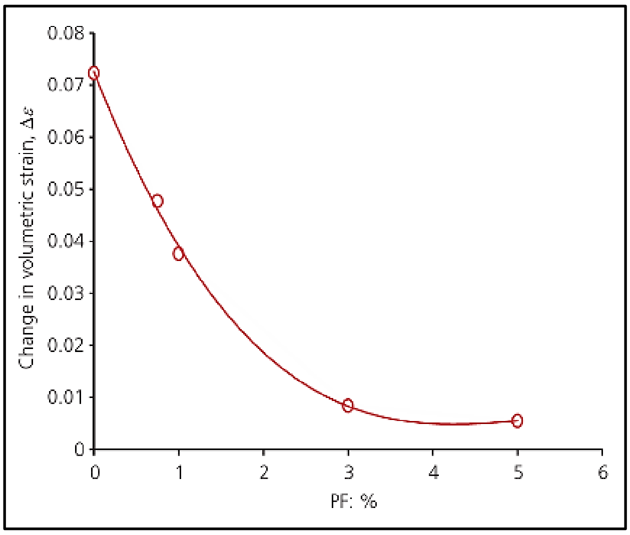


Figure (14) Plot of change in volumetric strain of gypseous soil versus PF content. [54]

shows the effect of the PF treatment on the volumetric strain change in the gypseous soil. The theoretical model developed in the current research employs a non-dimensional parameter in estimating final bearing capacity of a footing on the surface of treated gypseous soil using the available conventional theories.

Theyab et al., 2022 They demonstrate that recycling casein, an environmentally friendly material, can substantially enhance the properties of gypseous soil. By incorporating 2%, 4%, and 6% of the total soil mass into three samples classified as poorly graded sand (SP), they observed that the hydrophobicity of the casein binder helped to enhance the shear strength of the soil in saturated state, and therefore reduced the collapsibility of the gypseous soil. Even though maximum dry density decreased, cohesion of casein-treated soil increased up to fourteen times under soaked conditions with 6% of casein content relative to untreated soil. The risk of collapse of treated gypseous soils was reduced considerably, ranging from approximately 65% to 80%. It has been established that a casein percentage of 6% is optimal for achieving superior shear strength and reduced collapsibility. Furthermore, as the concentration of casein increases and gypsum content decreases, the potential for collapse diminishes. Notably, soils with lower gypsum content exhibit the most significant reduction in collapse potential when treated with a 6% casein solution. Figure (15), illustrates how varying concentrations of casein impact collapse potential.[55]

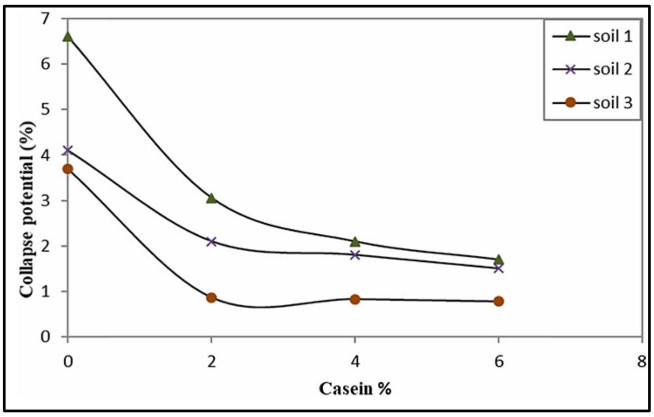


Figure (15) : Effect of casein concentration on collapse potential.

Ahmed H. Hussein et al., 2023 studied the effects of four different gypsum concentrations in soil—specifically 10%, 20%, 40%, and 62%—were examined. All soil samples were classified as (SP). The findings revealed that the incorporation of pectin, a biopolymer, of 0.5%, 1%, and 2% led to a reduction in total dissolved solids (TDS) as Figure (16) and collapse values, while also decreasing the time required to achieve steady state, independent of the gypsum concentration. The outcomes from the leaching process demonstrated a reduction in the collapse of treated soil samples as refer in Table (7). As the amount of pectin added increased, there was a corresponding decrease in the time taken to reach steady state, again regardless of gypsum content. Additionally, there was a notable decline in calcium hardness (CH) values attributed to the action of biopolymers which encapsulate soil particles and occupy pore spaces. Following an initial leaching phase, TDS values showed a slight uptick however, significant reductions in calcium levels were still evident due to particle encapsulation and pore occupation by the biopolymers.[56]

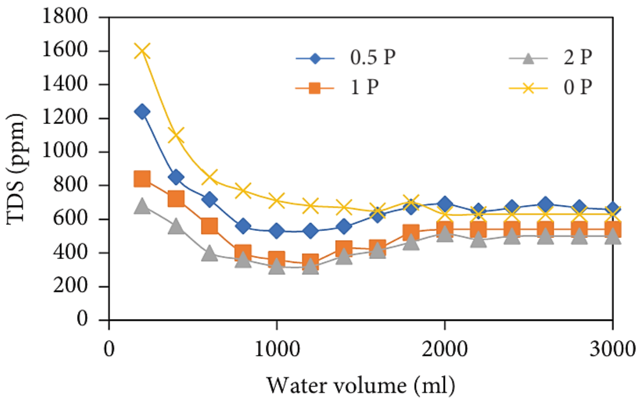
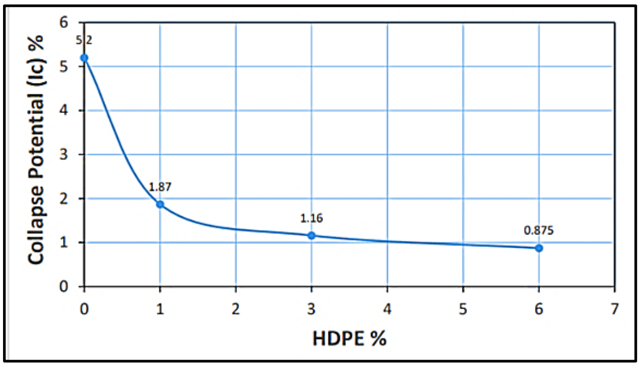


Figure (17): TDS-leachate water change of pectin treated soil 1 sample. [56]

Table (7) : the collapse potential of samples before and after pectin treatment during the leaching process [56]

Pectin (%)	Collapse potential (C_P %)							
	Soil 1		Soil 2		Soil 3		Soil 4	
	Min	Max	Min	Max	Min	Max	Min	Max
0	1.77	1.94	3.29	3.87	5.42	6.94	7.72	9.6
0.5	1.04	1.24	2.41	3.14	3.99	4.87	4.31	5.6
1	0.77	0.94	1.7	2.1	2.63	3.11	3.51	4.11
2	0.665	0.76	1.2	1.45	2.06	2.44	2.57	2.93

Maher M. Khazaal et al., 2024 conducted an experimental investigation to assess the impact of high-density polyethylene (HDPE) polymer on (SM) soil, which has a gypsum content of 38%. The results showed that addition of 1% HDPE increased the maximum dry density but the addition of 3 % and 6 % reduced this value, The double oedometer tests showed significant changes in potential collapse with reduction of 64%, 77.7%, and 83.2 % of potential collapse with the addition of 1%, 3%, and 6 % HDPE respectively as shown in Figure (18). also, the results of direct shear tests showed a complicated effect on cohesion, in dry conditions, cohesion increased at both 1% and 6% HDPE but decreased at the 3 %, whereas in the soaked condition, cohesion experienced a significant decline or disappeared altogether. Additionally, it was established that the internal friction angle (ϕ) improved with high concentrations of HDPE in dry and soaked condition as mentioned in Figure (15), the California Bearing Ratio (CBR) showed mixed behavior since it decreases in the dry state but increases as the proportion of HDPE in the mixture increases and gets saturated. In summary, this paper affirms that the introduction of HDPE polymer into gypseous soil modifies the engineering characteristics of these soils. Further investigations are recommended to be conducted to identify the ideal concentration of HDPE which can be used in ground improvement applications.[57]



Figure(14) Effect of HDPE polymer increasing on collapse potential. [57]

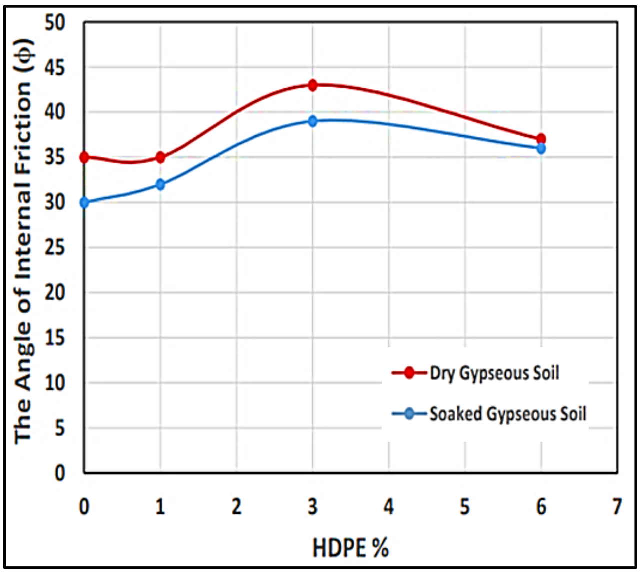


Figure 15. Effect of HDPE polymer increasing on the internal friction angle (ϕ) of gypseous soil. [57]

Farouk M. Muhauwiss et al., 2024 This research examines discuss the stability and strength of the pectin biopolymer-modified gypseous soil under wetting and drying cycles. A mixture of 40% gypsum and 2% pectin biopolymer was made and the specimens were subjected to repeated wetting and dry stages (1, 5, 10, and 15 cycles), The result shows that the shear strength of the pectin-amended gypseous soil improved significantly within the initial five cycles as shown in Figure (16) .that relates shear stress and horizontal displacement (H-Disp.).

Following this point, there was a gradual decline in strength up until cycle 15, attributed to the dissociation of pectin monomers when hydrated and their incomplete reformation during subsequent drying. This resulted in an approximate strength reduction of 22% after ten cycles. Notably, even after numerous cycles, some level of strength retention and restoration was still evident. Additionally, the volumetric stability of the enhanced samples remained consistent through to the final wetting and drying cycle.[58]

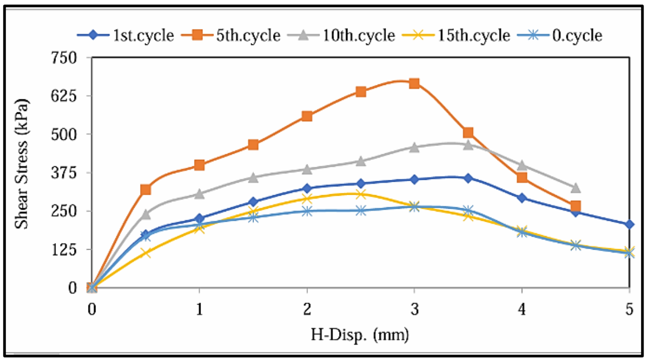


Figure (16): Horizontal – Displacement and shear stress relationship for wetting and drying cycle of pectin treated soil. [58]

Maher M. Khazaal et al .,2024 This paper examines the impacts of adding high-density polyethylene (HDPE) and Novolac polymers to gypseous soil in order to improve its geotechnical properties, Gypsum content of the soil was 38 percent and polymers were added in different concentrations (1%, 3%, and 6%.Both kind of polymers greatly increased the maximum dry density and optimum moisture content as well as reducing the collapse potential (Ic)Specifically, at HDPE contents of 1%, 3%, and 6%, collapse potential was diminished as shown in Figure (17), by 64%, 77.7%, and 83.2%, respectively. On the other hand the collapse potential decreases by 82.3%, 74.8% and 51.9% with the inclusion of Novolac polymer (as refer in Figure (18)), Under dry conditions HDPE content of 3 % and 6 % resulted in approximate increases in the internal friction angle of 22.9 %and 5.7 %, respectively.
Similarly, the inclusion of 3% Novolac polymer also resulted in a similar increase in the internal friction angle of about 5.7 %. In soaked conditions, Considerable increase in internal friction angle (ϕ) of up to 30 % was observed after addition of 3 % HDPE polymer, but only around 26.7 % increase was observed after the addition of 1 % or 3 % Novolac polymer. The findings indicate that HDPE and Novolac polymers can enhance geotechnical properties, however, their influence on California Bearing Ratio (CBR) is intricate and varies according to the percentage of polymer utilized as well as the moisture condition of the soil.[59]

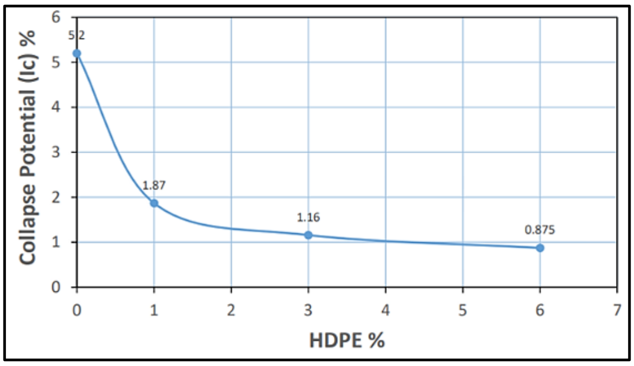


Figure (17): The relationship between increasing HDPE polymer content and collapse potential. collapse potential. [59]

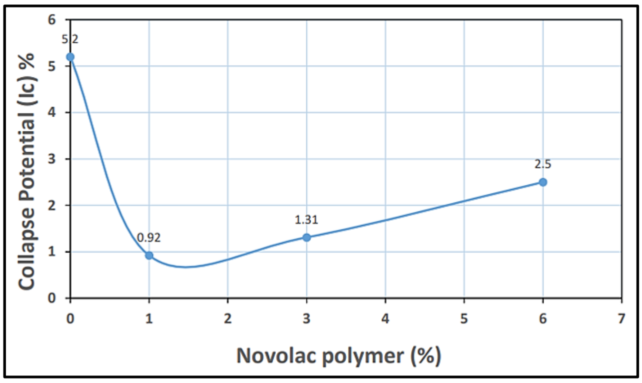


Figure (18) : The relationship between increasing Novolac polymer content and collapse potential. [59]

Hadidi 2024 This study aims at investigating the impact of addition of polyurethane on the structure of gypsum soil. This study builds on the previous study that defined the protocol to be used in the treatment of gypsum soils when exposed to aqueous flow within an experimental canal. In this study, the specimens used were collected in 2018 and have been stored at ambient temperature over the last four years. In the current research, a collection of analytical methods, namely X-ray Diffraction (XRD), X-ray Fluorescence (XRF), and Scanning Electron

Microscopy (SEM) were employed to assess the structural properties of the soil before and after treatment, Gypsum content analysis showed a percentage of 41. The X-ray diffraction analysis revealed that the effect of gypsum on the treated soil was negligible and the index of gypsum in the treated soil was low at a 2-theta value that may be explained by polyurethane incorporation. Besides, X- ray fluorescence (XRF) data indicated that the concentration of the constituent elements in the treated soil was higher than the untreated samples, and the reduction in Contents of Fe, Ca, K, S, and Zn was 83%, 32%, 54%, 85%, and 95%, respectively. Meanwhile, it was also found using scanning electron microscopy (SEM) that the cohesiveness of the gypsum-containing soil was enhanced upon the addition of polymeric material as shown in Figure (19), and this effect was particularly pronounced at magnifications of 1.00 Kx and 5.00 Kx.[60]

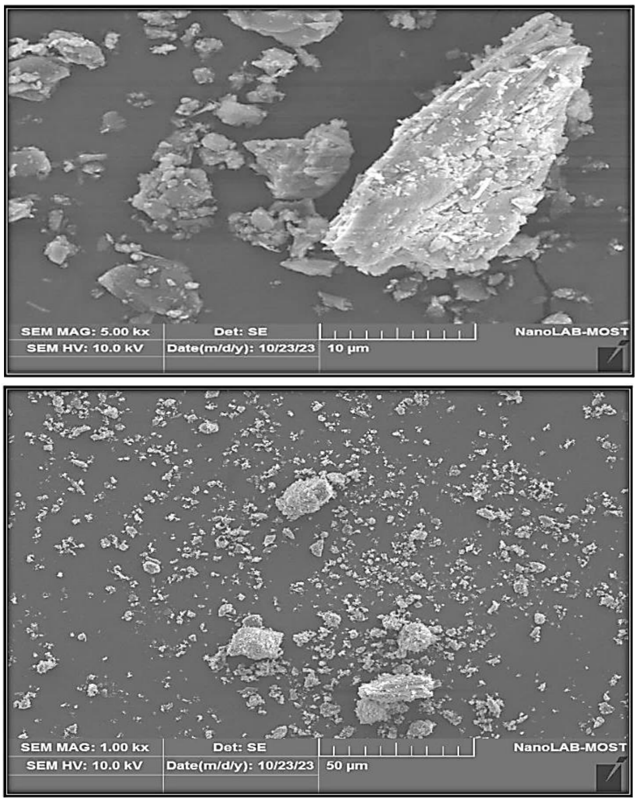


Figure (19): SEM test for (a) untreated (b) treated soil. [60]

Huda W. Abdulwadood 2025 aims to develope a practical and sustainable technique of soil stabilization that simulates natural decomposition of plastic waste in the subsoil. This was done by using polypropylene (PP) as a stabilizing agent in field experimentation, Sample gypseous soil, with 60 % of gypsum, was mixed with strips of discarded plastic bags in different levels of 0 %, 2 %, 4 % and 8 % of the dry weight of the samples, and the objectives of the study were to assess the effect of these additions on the strength properties and collapse potential as results are shown in Table (5), of gypseous soil. The findings revealed that plastic waste addition enhanced the geotechnical characteristics of gypseous soil, and the best results were recorded in the 2% and 4% additions, such levels performed better than the 8 % addition in direct shear experiments, which supports the claim made by Hamid (2017) that the PP content of samples should not be more than 5%, since such high concentrations can increase the sample collapsibility. Addition of plastic waste fibers which was in form of plastic bag waste fragments was particularly successful in decreasing the values of the collapsibility and considerably decreasing the collapse potential (CP).[61]

Table (5) : SOT result. [61]

SOT results	Natural sample	Reinforced soil sample		
		2%	4%	8%
Collapse Potential	8.85	0.07	0.68	0.52

6. Conclusion

stabilization the gypseous soils with polymer is an effective technique to mitigate their inherent geotechnical weaknesses, particularly collapse potential, permeability, and shear strength, polymers can effectively reduce collapse potential of gypseous soil and enhance it cohesion on the other hand some kind of polymers that use has it limitation so its necessary to know the limit and the right percentage to use also polymers can consider as sustainable and ecofriendly material to reinforce the gypseous soil .

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