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Stabilization of Expansive Soils Using Polypropylene Fiber

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Abstract

Current research main aim is to study the effect of adding polypropylene fiber (PPF) on the behavior of expansive soil to reduce the swelling as percentage (0.5, 1 and 2%) of the weight of dry soil. Expansive soil used in this research was prepared artificially by mixing Ca-based bentonite from geological survey and mining company with sandy soil brought from Karbala city as percentage 80% bentonite to 20% sand of dry weight. Multiple laboratory tests have been carried are (Unconfined Compression Test, One-Dimensional Consolidation Test, Swelling Test, Sieve Analysis and Cycle Swell Shrink Test). A conventional odometer cell was modified to allow the study of swell- shrink cycle test to be carried out under controlled temperatures and surcharge pressure. The results showed that the increase in percentage of (PPF) led to decrease the swelling and to increase the unconfined compression strength. The wetting and drying results of (PPF) showed that with continuous cycles the effect of (PPF) keeps on reducing the swelling and the 2% of (PPF) produces less ratio of swell - shrink, which has obtained higher than 57 % in the improvement factor of swell and shrink.

Keywords: Expansive Soils; Polypropylene Fiber; Wetting and Drying Cycles; Bentonite.

1. Introduction

Expansive soil usually refers to those clay minerals that have contradictory behavior (swell and shrink) due to changes in moisture content over time [1]. The montmorillonite clay mineral contributes mainly to this behavior. In Iraq and other countries the expansive soil contributes to many problems which observed on the structures that are established on the expansive soil. With increasing and decreasing of soil water content the soils will swell and shrink [2]. The environmental change around structures usually results in severe risk subsequent after they are built, the prediction of the heave of the light structure has likely received more attention than any other analyses associated with the expansive soil. So, it is important to study the properties of these soils and how to treat them to overcome these problems. The goal of most related work was to identify the swelling potential and swelling pressure that the soil may exhibit under an extreme condition of complete flooding. In the field the state of moisture change that may occur is cycles of wetting and drying which leads to cycles of swelling and shrinkage of the soil [3].

Residential buildings construction and other structures like highways, airports, bridges and seaports on expansive soil in high risk situation, as these soils are subjected to the cycle of drying and wetting resulting in shrinkage and swelling under structures foundation leading to crack into the structural. The damage average yearly cost to structures because of shrinkage and swelling estimated 400 £ million in the UK, 15 $ billion in the United States, and many billions dollars worldwide [4].

Therefore, the expansive soils require an amendment to meet the pre-design criteria of the application. Stabilization

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of soils can be done by two main ways, chemical and mechanical techniques. Chemical techniques mainly include the addition of chemicals such as (cement, lime and polymers) to the soil, thus altering the soil fabric into a coherent matrix of restricted swelling [5-8]. The mechanical approach uses soil compaction with the reinforcements support. Common reinforcements contain fibers of synthetic such as (polypropylene and nylon), natural such as (coir and palm) and other fiber such as (plastic waste strips and shredded tires). As the global community shifted towards a more sustainable mentality, alternative stabilization techniques that could replace or reduce the use of traditional cementitious agents were encouraged [9].

This research investigates the ease of using (PPF) in heavy expansive clay and the main advantage is the easily mixing of (PPF) with soil and low cost. One more advantage is that the (PPF) is a hydrophobic and chemically inert material that makes it does not absorb or react with soil moisture [10]. Two advantages of synthetic fibers over natural fibers can be given as follows: synthetic fibers can be produced according to required specifications. For example, geometry of fibers can be controlled, shape of fibers and surface conditions can be altered in order to improve friction properties of fibers. Most synthetic fibers don't biodegrade when subjected to changing environments of moisture, sunlight heat or cold [11, 12].

Soltani et al. (2018) showed the effect of two kinds of tape-shaped fibers, fiber-A width (2.5mm) and fiber-B width (7mm) were used as the reinforcements for the expansive soil. It was used three contents: (0.5, 1, and 1.5%) each fiber type have two lengths/aspect ratios (15/2.5 and 30/2.5) for fiber-A, and (15/7 and 30/7) for fiber-B. In case of constant width for a given fiber type it was noticed that the direct function of improvement of expansive soil is fiber content and length. The other case when increasing fiber width (decrease in aspect ratio) results in increase the total surface area of fibers and this will cause a larger contact area between fibers and soil particles, leading to give greater swelling resistance [9].

Priya et al. (2017) investigated that the optimum percentage of (PPF) is 1 % for stabilizing the soil, with 1% of fiber given the highest value from (UCS) and the free swell index value of the treated soil at the optimum percentage decreases to zero [13]. Deshpande and Puranik (2017) stated that the black cotton soil (expansive soil) blended with fly ash and (PPF) considered a good technique especially in ground improvement and engineering projects on expansive soils. The (UCS) increase with increasing (PPF) percentage. The optimum percentages of fly ash and (PPF) are 15 % and 1.5 % respectively for the (UCS). This work caters to society's challenges to reduce waste volumes and to produce useful materials from non-useful waste materials that lead to the establishment of a sustainable society [14].

Sravya and Suresh (2016) studied the effect of synthetic-fibers (polypropylene and polyester fibers) in the restricted swelling of expansive soils. One Dimensional swell-consolidation tests were utilized to determine the behavior changes in the soil samples. BEIt is noticed that with increasing of fibers content causes a decrease in swelling pressure and increasing the (UCS) and CBR [15]. Dang et al. (2016) investigated the effects of (bagasse fibers and hydrated lime) on the engineering Characteristics and behavior of expansive soils. The results of this work show that the bagasse fiber reinforcement which mixed with hydrate lime increased the compressive strength of expansive soil with increasing the additives percentages and curing time. Whereas the linear shrinkage of expansive soil decreased with increasing hydrated lime, bagasse fiber percentage and curing time [16].

Malekzadeh (2012) and Viswanadham et al. (2009 a) reported that (PPF) was effective in reducing the swell potential and swelling pressure of soils dramatically [17, 18]. Al-Akhras et al. (2008) studied the effect of two types of fibers (natural palmyra and synthetic nylon) on the swelling properties of three clay soils by using a one-dimensional odometer cell. The result of the test indicates that the fiber reduce swell potential and swelling pressure compared with same untreated soil [19]. Babu et al. (2008) investigated the effect of coir fiber reinforced black cotton soil and the results showed that the swelling decreases by approximately (40%) with increase fiber from 0.5 to 1.5% and the drop of compression index by about (35%) at fiber content (1.5%) [20]. It can dramatically reduce the excessive settlement of structures built above the soil. Actually, the scientific interest soil reinforcement by fiber started in the 1970s with a try to evaluate the effect of roots of the tree on the slopes stability [21]. Punthutaecha et al. (2006) studied the effectiveness of a collection of fly ash and polypropylene fibers in reducing swelling and shrinkage properties [22].

Note that fiber reinforcement is not only an alternative technology for improving but it can make many construction projects effective in cost and to environmentally friendly. We can get fibers from plastic materials and used tires so that their use will help to dispose the waste problem that occupies large amounts of landfills and otherwise these wastes can occupy large amounts of landfills. For this, the engineering of fiber-reinforced soil has become important in civil engineering and other related fields [23].

In this present research, an array of laboratory experiments were conducted including (Unconfined Compression Test, One-Dimensional Consolidation Test, Swelling Test and Cycle Swell Shrink Test, on untreated and treated expansive soil with different percentages of (PPF). The findings of this experimental investigation were analysed and discussed for better understanding the effect of reinforcement (PPF) on the behavior of expansive soil, effect of the wetting-drying cycle on treated and untreated soil.

2. Materials and Methods

2.1. Expansive Soil

Expansive soil used in this research was prepared artificially by mixing Ca-based bentonite from geological survey and mining company with sandy soil from Karbala city. Several trail mixes of bentonite and sand were done till getting 80% bentonite to 20% sand of dry weight considering the plasticity index. The physical properties of the soil used are illustrated in Table 1 and the grain size distribution of soil used show in Figure 1.

Table 1. Summary of physical properties of the soil used

Physical properties	Bentonite	Sand	Prepared soil	Specification
Specific gravity	2.80	2.68	2.77	ASTM D 854
Liquid limit (LL)	148.0	NP	99.0	ASTM D 4318
Plastic limit (PL)	45.0	NP	41.0	ASTM D 4318
Plastic index(PI)	103.0	NP	58.0	ASTM D 4318
%Clay	82	3.89	60	ASTM D 1140, D 422-63.
% Silt	18		22	
%Sand	0	96.11	18	
Maximum Dry density (gm/cm^3)	1.27	……	1.395	ASTM D 698-12
OMC%	35	……	27.5	
Soil Symbols according to USCS	CH	SP	CH	ASTM D 2487

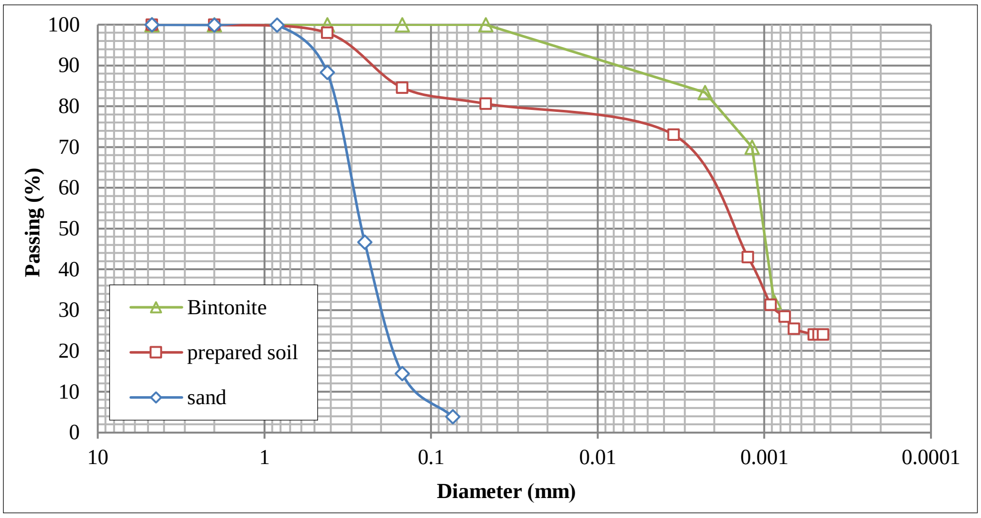

Figure 1. Grain size distribution of soils

2.2. Polypropylene Fiber

Figure 2 depicts the polypropylene fiber which is commonly used as a synthetic material because of its low cost, hydrophobic, and chemically inert nature. Polypropylene fiber doesn't allowed any reaction with soil moisture or leachate. The properties of (PPF) which brought from Sika Company are as illustrated in Table 2.

Table 2. Properties of polypropylene fiber

Property	Value
Colour	Transparent fibers
Density	0.91 gm / cm^3
Length	12 mm ±1
Dimeter	0.032 mm
Shape	Straight
Tensile strength	600 -700 Mpa
Elastic modulus	3.000 – 3.500 Mpa
Elongation	20-25 %
Chemical base	100% polypropylene fiber
Melt point	160 ° C
Ignition point	365 ° C

Figure 2. Polypropylene fiber (PPF) used inthe present research

2.3. Sample Preparation

In order to study the effect of (PPF) on the prepared soil, it is necessary to fix some parametric variables for soil condition such as dry density and moisture content of prepared soil for purpose of comparison. The prepared soil firstly passed from sieve No.4 then oven-dried with 105 ^{0}C. The dried soil mixed with the required distilled water by hand and stored for 24 hours to obtain soil with uniform moisture distribution. While the treated soil with (PPF) at first the prepared soil mixed with (PPF) well by hand to the degree of homogeneity. The required amount of water was added to the formed mixture. Finally, the mixture was sealed and cured for 24 hours.

The swelling and shear strength characteristics of the sample are determined. These characteristics determined to the sample were extruded by hydraulic jack from the mold using standard proctor compaction test, when the soil was compacted in the mould to dry density (1.395 gm/cm^3) and optimum moisture content (27.5%). The swelling characteristics studied on the specimens were obtained by inserting consolidation ring of 50mm diameter for the samples using compression machine. To ensure that the specimen is kept laterally confined during swelling, a disc of metal was used, its thickness is equal to the difference in height between the consolidation ring and specimen 4mm, and the diameter of the disc is 1mm less than the internal diameter of the ring is used [24]. The shear strength characteristics studied on the specimens were obtained by inserting tube of 38 mm diameter, cleaned and oiled it's walls for the samples using compression machine. The specimens were extruded from the tube by extruder and each specimen is cut to 76mm from its length.

2.4. Swelling Tests

2.4.1. Free Swell and Swelling Pressure

After preparing the test specimen as mentioned in section (2-3), the specimen and ring are installed into the odometer consolidation apparatus and the setting load was placed at the top of the weigh hanger to provide stress of 7 kPa on specimen and to allow the specimen to consolidate after 10 minutes, the first reading was recorded, then distilled water was added, final dial gage recording was taken after 24hours or until the rate of expansive becomes less than 0.005 mm/hr (ASTM D 4829-03). The height of the specimen was recorded by using a dial gage with sensitivity of 0.002 mm and percent of swelling is a function of the height specimen.

$$Swell\% = \frac{\Delta H}{H} \times 100 \tag{1}$$

Where: ΔH is the change in sample height, D2 -D1; D2: Final dial gage reading, D1: First dial gage reading, H: Height of the specimen.

The final swell which the specimen reaches before applying load is called swell percent, while the pressure required to bring the specimen into its original height is defined as swelling pressure.

2.4.2. Cyclic Swell Shrink Test

The modified odometer cell was adopted to study swell-shrink cycle test. This conventional cell was modified to allow conducting the test under controlled temperature and surcharge pressure, like the reported by [25, 26].

The device consists of conventional odometer cell which contains fixed ring with diameter 50mm and thickness 20mm between two porous stones, dial gauge with sensitivity of 0.002 mm, drainage valve and load 7Kpa placed over the cell. All the detail of odometer cell is shown in Figure 3. The odometer cell is surrounded by thermal source (Electrical Heater), the electrical heater comprises of coil between two flexible mica sheets with thickness of 0.6mm. The main features of this sheet are resistant to moisture, high electrical insulation and good thermal conductivity. The thickness of outer cover of the heater is 0.7 mm, it was coated with stainless steel layer, and the terminal of the coil was connected to the temperature control panel. The panel controls the temperature of the test constant at 45ºC by using stainless steel sensor which measures the temperature of the cell works with the temperature controller to stop the temperature on the required degree and prevent it from increasing. Finally, the odometer cell with the heater was placed in a container for more thermal protection as shown in Figure 4.

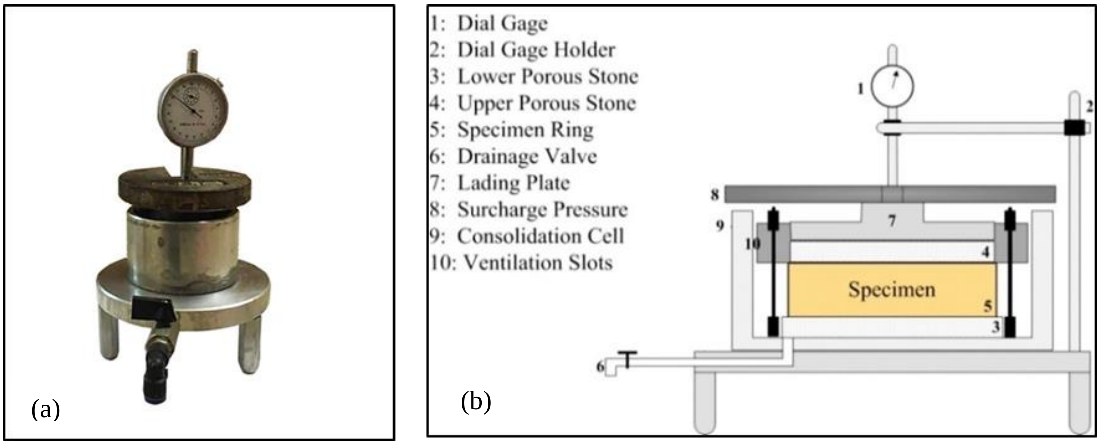

Figure 3. (a) Odometer Cell, (b) Layout of the Odometer Cell

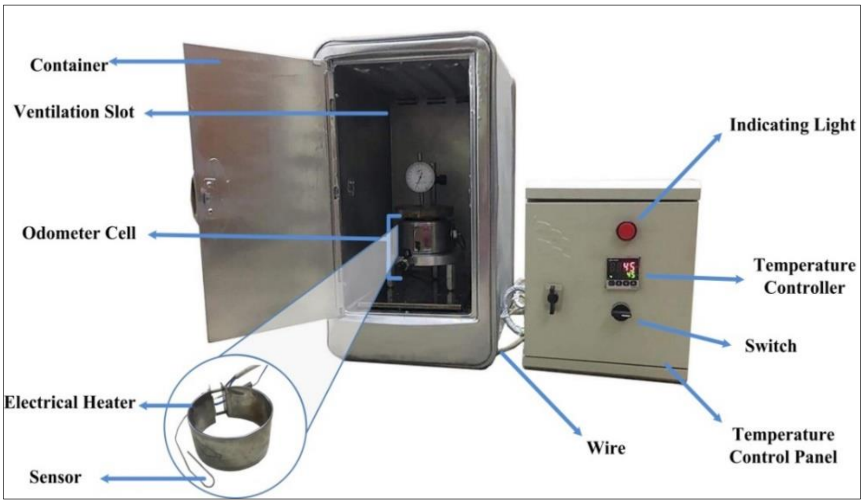

Figure 4. Modified Odometer Cell

After preparation the test specimen as stated in section (2-3) the specimen ring is installed on the odometer cell with applying surcharged pressure 7 kPa and allowing the specimen to be exposed to cycles of swelling and shrinkage. In the first stage, the specimen was submerged in distilled water and keep it for over three days for swelling process and this period decreases by increasing the percentage of additives. In the second stage, the water was removed from the cell by the drainage valve, the temperature controller was switched on 45 ºC to maintain constant temperature during drying process. The amount of shrinkage was recorded after the specimen reached the full shrinkage (No change in dial gage reading). The sample is left to cool to room temperature from 3 to 5 hours after shrinkage process. The sample was flooded with water for next cycle. The test procedure continues until the expected equilibrium condition is activated.

2.5. The One-Dimensional Consolidation and Unconfined Compression Test

After the end of the swelling pressure test Section (2-4-1), the consolidation test was conducted according to (ASTM-D 2435 – 96). The Unconfined Compression test was conducted according to (ASTM D-2166).

3. Results of Tests

3.1. Results of Unconfined Compression Test

In Figure 5 we can see that the adding (PPF) increases the unconfined compression strength (UCS) from (246.11 to 504.93) kPa and 2% (PPF) has given the higher (UCS) value. These values are shown in Figure 6 shows the test results which indicate that the (UCS) of the soil increases with an increase in (PPF) percentage, this behavior is related to the bridging effect of (PPF) that can effectively prevent the further development of failures and distortions of the soil. Another reason for increasing the (UCS), is the (PPF) percentage increases the soil particles that become closely linked, and because of the high connection between the soil particles the attraction between the particles increase. The shear failure occurred after a long time from the appearance of the crack. These results similar to the results obtained by the [15, 27, 28].

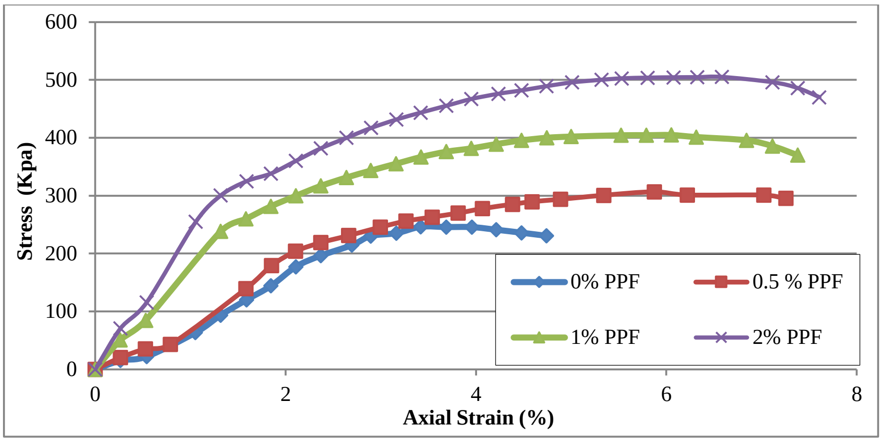

Figure 5. Stress-Strain relationship from the unconfined compression test for soils samples with different percentages of (PPF)

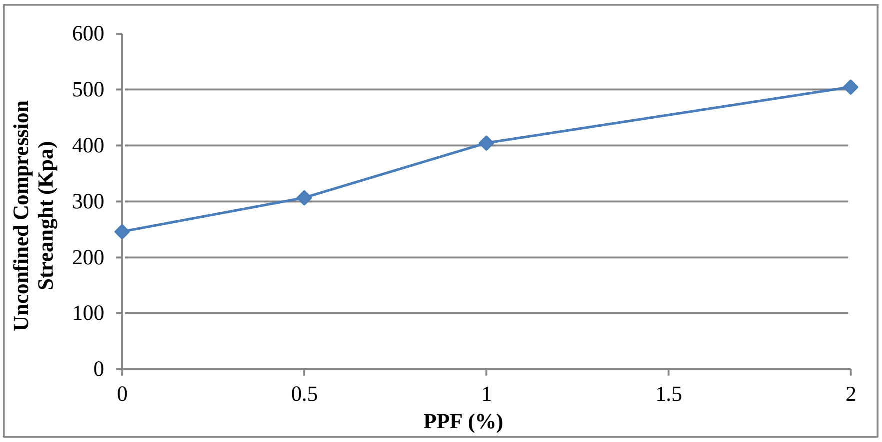

Figure 6. Effect of (PPF) content on unconfined compression strength

3.2. Results of Swelling and Swelling Pressure

In Figure 7, it is found that the free swell decreases from (13.47 % to 2.81%) and Figure 8 shows a decrease in swelling pressure from (245 to 75) kPa with adding (PPF). One of the reasons for this effect is that by adding fibers to a certain amount of soil, the non-swelling material (PPF) replaces some soil particles and thus, a decrease in soil swelling behavior is achieved. The other reason is that because of the contact between the (PPF) and the soil particles. During swelling the fibers are stretched and tension forces appear in the fibers that resist swelling and prevent further swelling. Also, when the fibers are added to the expansive soil the inbuilt capacity of fibers to bind soil particles together helps the expansive soil to reduce its swelling tendency and thereby swell pressure of the fiber reinforced soil. Similar results were obtained by the [15, 18, 29].

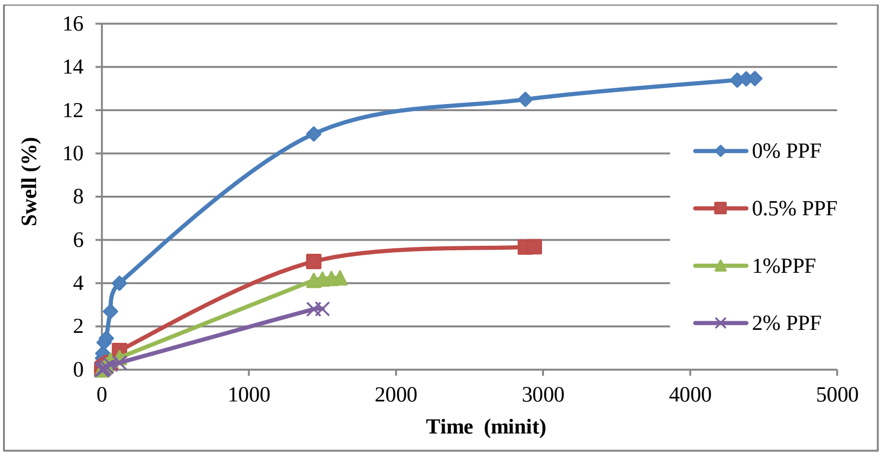

Figure 7. Time – Percent swell for the prepared soil and soil treated with (PPF)

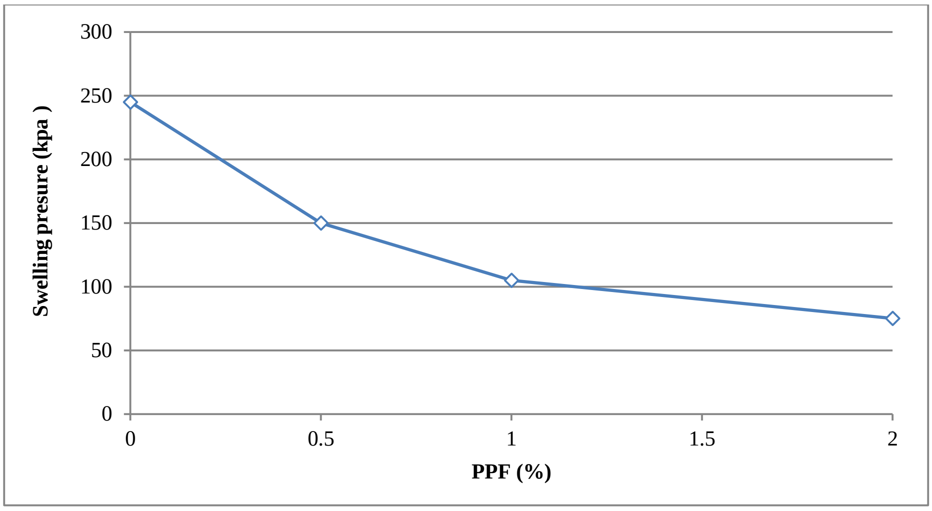

Figure 8. Effect of (PPF) content on swelling pressure

3.3. Cyclic Behavior

The effect of wetting-drying cycles on the swelling potential are determined by Cyclic Swell-Shrink Test. Figure 9 and Figure 10 show the results of the test for the prepared and treated soil. The highest values for wetting and drying cycles were achieved in the first cycle and then the swelling gradually decreased to a steady state value. Until this state, shrinking in any cycle is smaller than swelling in the same cycle. Sampling heights never return to their original levels, this behavior lies in the general cyclic behavior which reported by many authors [3, 30-35]. Also, the amount of swelling is also greatly reduced by the addition of the (PPF) which sets the cyclic curves below the untreated curve in a uniform manner.

Figure 9 shows that the number of cycles required to reach the steady state condition for the untreated soil and treated soil is found to be approximately 4 and 3, respectively. This means that the addition of the (PPF) will reduce the number of cycles to reach the state of stability and the cycles of wetting and drying did not alter the trend of the cyclic curves of the treated samples. This indicated that the (PPF) is remained effective to reduce the swelling and the shrinkage.

In Figure 10 it is noted that in the 5th cycle of the untreated soil the value of swelling is 1.398 % and be almost equal to the 2nd cycle when adding 1% and 2 % (PPF). This means that it can increase the number of cycles and obtain the value approximate to the additive values with low cost.

This method is easy to implement compared with other methods and does not involve high cost by flooding these soils with water periodically. Detailed laboratory tests should be conducted to identify appropriate duration of wetting and drying for different expansive soils, this is similar to [25].

The results can be explained in terms of fatigue phenomenon. The soil will reach the state of fatigue after several cycles of wetting and drying depending on the level of swell-shrink of the soil. Eventually, the soil reaches the minimum fixed ability to swell-shrink which is the steady state. The decrease in swelling is due to the progressive destruction of the clay structure matrix resulting from a periodic swelling. At the same time, periodic swelling leads to the reconstruction and rearrangement of the structure of large fine aggregates by changing structural elements. This phenomenon alters the behavior of expansive soil with increasing the number of cycles (swell- shrink), resulting from wetting-drying cycles [36].

Wetting and drying cycle make a change in the swell potential due to the break of the bonds between clay minerals and the amendments of the soil structure. The large inter pores reduce absorption rate of the sample along a range of wetting paths and this effect increase with the increasing of shrinkage and vertical pressure subjected to the soil. This can be assigned to the continuous rearrangement of soil particles during the cycles of drying and wetting that result in more destruction of the internal clay structure, reducing the specific surface and water content [37].

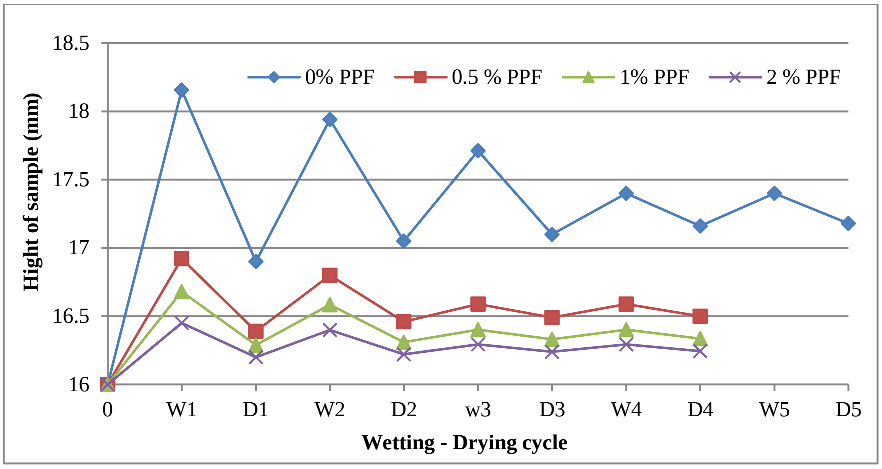

Figure 9. Wetting - Drying cycle for prepared and treated sample with (PPF)

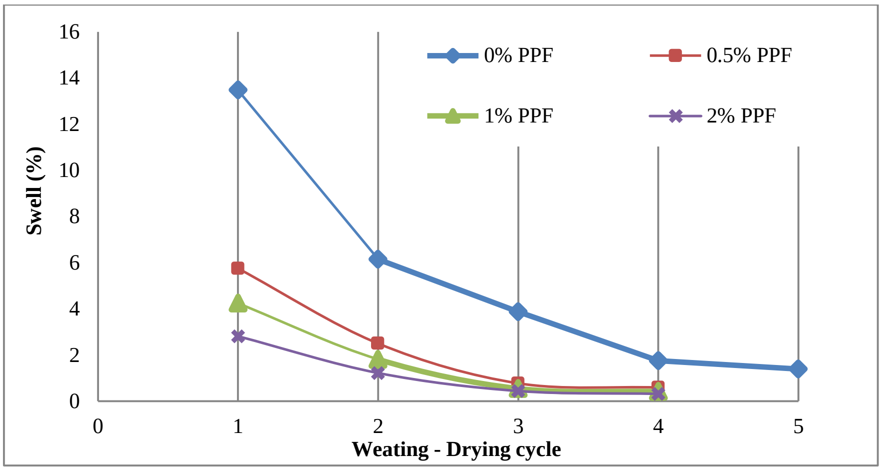

Figure 10. Swell % versus number of cycles for prepared and treated sample with (PPF)

3.4. Improvement Factors versus Number of Cycles

The improvement factor in any cycle $(I_w)_n$ represents the difference between the final swell of unreinforced samples W_u and the final swell of the reinforced samples (W_r) divided by the final unreinforced swell, [3].

$$(I_w)_n = \frac{(W_u)_n - (W_r)_n}{(W_u)_n} \tag{2}$$

Where; I_w: Swell improvement factor, W_u: Final swell of unreinforced sample, W_r: Final swell of reinforced sample, n: Number of cycles.

Similarly, the improvement factor for shrink is:

$$(I_H)_n = \frac{(H_u)_n - (H_r)_n}{(H_u)_n} \tag{3}$$

Where: I_H: Shrinkage improvement factor, H_u: Final shrink of the unreinforced sample, H_r: Final shrink of the reinforced sample, n: Number of cycles.

According to Figures 11 and 12, the relationship between the number of cycles and the improvement factors for swelling and shrinkage indicated that there are no specific trends affected by the improvement factors at the history of wetting and drying.

The increase in the improvement factor for swell and shrink depending on the amount of the additives and the number of cycles. By increasing the added material, the improvement factor increases and the percentage 2 % of (PPF) gives the highest percentage of improvement factor. Also, with the increased number of cycles increases the improvement factor and the 3rd cycle gives the highest values in the three different percentages. In general, for the first cycle, the improvement factor of swelling $(I_w)_1$ ranges between 57.3 and 79.1% based on added percentages. In steady state, the I_w ranges from 66.11 to 81.74 %. The improvement factor for shrinkage $(I_H)_1$ is 57.8 to 80.09% in the first cycle, and 62.91 to 81.25% is in the steady state. Thus, the advantage of using (PPF) remains active in swelling reduction during the periodic life of the expansive soil.

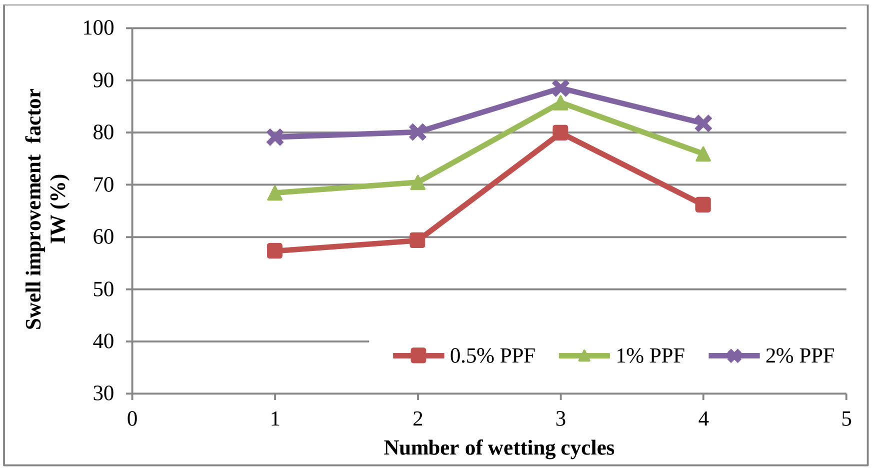

Figure 11. Relationship between the number of cycles and the improvement factors for swell

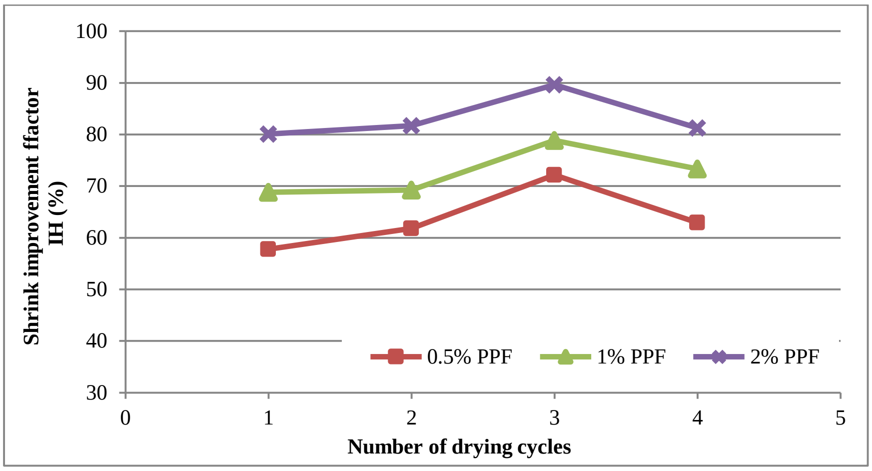

Figure 12. Relationship between the number of cycles and the improvement factors for shrink

3.5. Result of Consolidation Test

The result of consolidation tests of all samples with different percentages of (PPF) are shown in Figure 13, all results are drawn as the void ratio (e) versus the logarithm of effective stress (log σv).

Table 3 shows that the addition of (PPF) causes a reduction in Cc and Cs, this decrease is due to a decrease in the amount of clay replaced by fiber, another reason is because the nature of the fibers, as it is not only strong in the tensile strength, but also strong in compression strength, that's why compression index has decreased. The reduce of compression index by about 22% at percentage 2 % of (PPF). It can significantly reduce the excessive settlement of structures built above the soil. Similar results were obtained by [15].

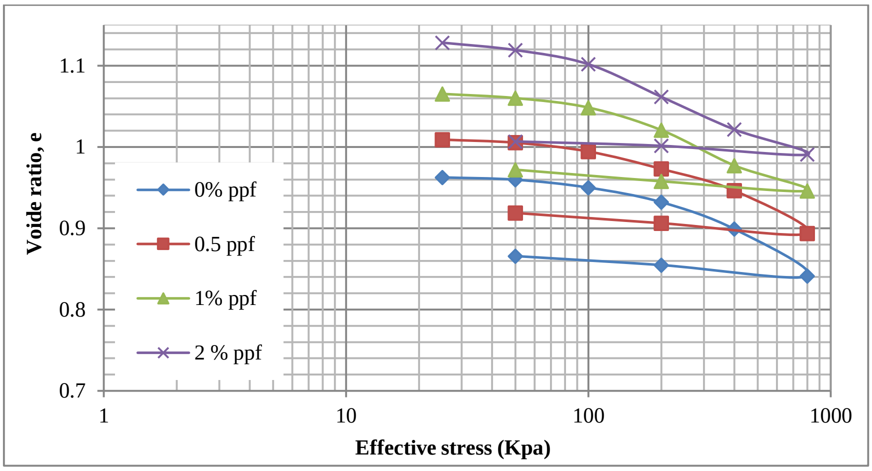

Figure 13. e-log σv for Soils treated with (PPF)

The permeability of the soil is calculated from the following equation:

$$K = Cv\, mv\, \gamma w \quad (4)$$

Where; Cv = Coefficient of consolidation, mv = Coefficient of volume change, γw = Unit weight of water.

As shown in the Table 3 it is observed that the values of coefficient of permeability and initial ratio (e_0) are increased not significantly with the increase of the concentration of (PPF).

Table 3. Result of consolidation test

Soil sample	0% PPF	0.5% PPF	1% PPF	2% PPF
Cc	0.150	0.129 void	0.124	0.117
Cr	0.022	0.020	0.019	0.017
Cv (m^2/sec)	3.45E-07	3.79E-07	3.86E-07	4.32E-07
k (m/sec)	2.9E-10	4.27E-10	5.21E-10	6E-10
e_0	0.964	1.014	1.075	1.140
mv(m^2/kN)	8.57E-05	0.000115	0.000137	0.000142

3.6. Micro Structural Studies

From Scanning Electron Microscopy (SEM), images for the prepared soil and treated soil are with 2% (PPF). Figure 14a is similar to structure with figure 14b, it can be noted that the voids are approximately equal, this means that the (PPF) did not alter the structure of the prepared soil. It can be seen that many clay minerals is attached to the surfaces of the fibers which make the contribution to bond strength and friction between the fiber and soil matrix as shown in Figure 14 (c). Figures 14 (d) and (E) show scratches and pits on the surface of (PPF) resulting from hard particles such as sand due to the exposure to loading or mixing that lead to form these, the formation of scratches and pits increase the bonding between the soil and (PPF), resulting in an increase in (UCS). It is found that (PPF) was not broken during the shear test but it is extended as shown in Figure 14f. This indicates that the (PPF) is not only strong in tensile strength but strong in compressive strength, for that reason it is shown that there is some increases in the (UCS) and decreases in the compression index with an increase in the (PPF) Percentage. Similar results are found by [27, 38].

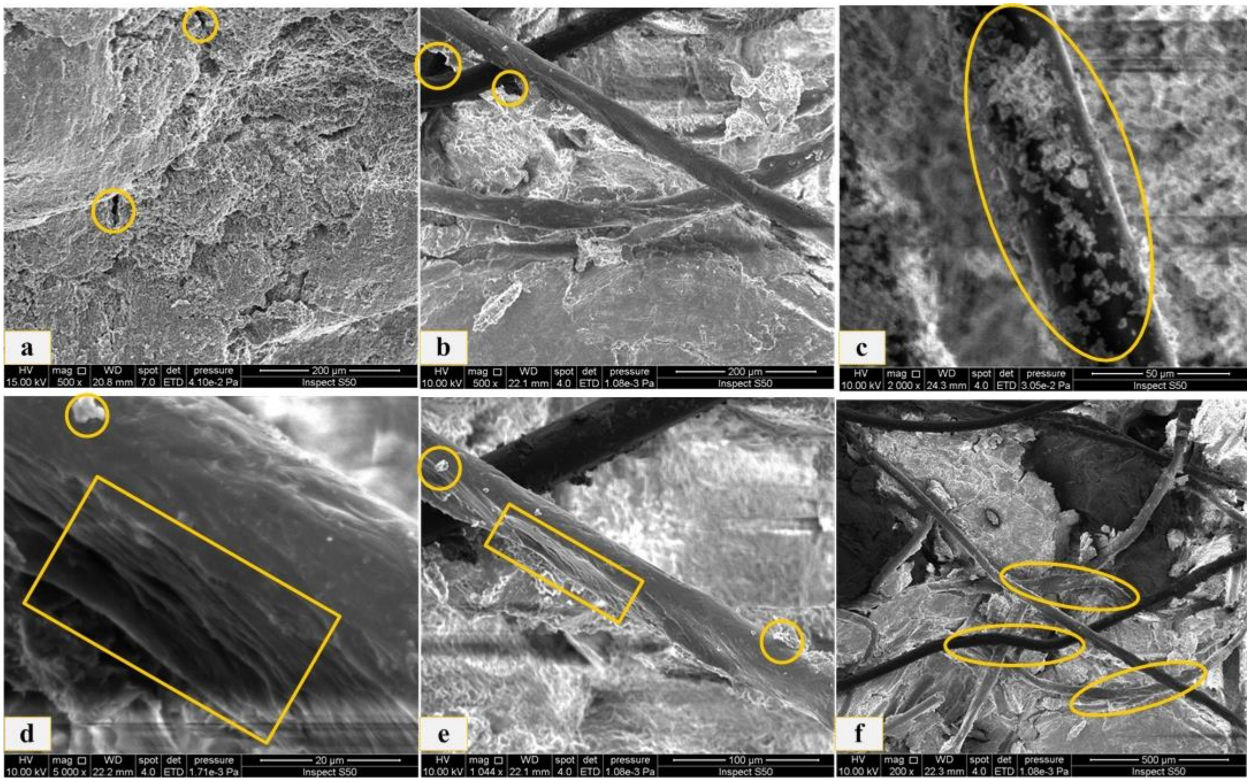

Figure 14. SEM images of prepared soil and treated soil with 2% (PPF): (a) prepared soil; (b) treated soil with 2%(PPF); (c) the clay mineral on the fiber surface; (d) & (e) the scratches and pits on the surface of (PPF); (f) the extension of (PPF) after the (UCS) test

4. Conclusions

This research has investigated the effect of (PPF) with percentage of (0.5, 1 and 2%) on the engineering properties, of expansive soil. It is found that the 2% of (PPF) is the best percentage which gives the highest value of the unconfined compression strength and lower value of swelling, the following conclusion can be drawn:

- With the increasing of the (PPF) percentage, the free swell and swelling pressure values decreased steadily, and the lowest values were finally obtained in stabilized samples with adding 2% of (PPF), the free swell and swelling pressure were reduced by about 79.1% and 69%, respectively.
- The addition of 2% (PPF) improved the unconfined compressive strength by approximately 51%.
- The addition of (PPF) decreased the compressibility.
- With the addition of (PPF), swell-shrink decreased with the increasing in the wetting-drying cycles. The first cycle gives the highest value of swell-shrink and swell remained higher than shrink at the same cycle.
- (PPF) is inexpensive, economical and so it can be used to improve large areas at a lower cost. On the other hand, it is environmental friendly as it can be used significantly to solve waste disposal problems.

5. Conflict of Interest

The authors declare no conflict of interest.

6. Funding

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7. References

[1] Al-Dahlaggi M H, "Effect of Calcium Chloride on Swelling Characteristics of Compacted Clays" M.Sc. Thesis, Civil Engineering Department, Al-Mustansiriyah University, Iraq (2001).

[2] Chen, F. H. "Foundations on Expansive Soils, Elsevier Scientific Publication Company." (1975).

[3] Orabi W K, "Cyclic behavior of reinforced expansive soils." M.Sc. Thesis, Civil Engineering department, Al-Nahrain University, Iraq (1996).

[4] Jones, Lee D., and Ian Jefferson. "Expansive soils." (2012): 413-441.

[5] Al-Rawas, Amer Ali, A.W. Hago, and Hilal Al-Sarmi. "Effect of Lime, Cement and Sarooj (artificial Pozzolan) on the Swelling Potential of an Expansive Soil from Oman." Building and Environment 40, no. 5 (May 2005): 681–687. doi:10.1016/j.buildenv.2004.08.028.

[6] Mirzababaei, Mehdi, S. Yasrobi, and A. Al-Rawas. "Effect of polymers on swelling potential of expansive soils. " Proceedings of the Institution of Civil Engineers-Ground Improvement 162.3 (August 2009): 111-119. doi:10.1680/grim.2009.162.3.111.

[7] Yazdandoust, Fateme, and S. Shahaboddin Yasrobi. "Effect of cyclic wetting and drying on swelling behavior of polymer-stabilized expansive clays." Applied Clay Science 50.4 (December 2010): 461-468 doi: 10.1016/j.clay.2010.09.006.

[8] Estabragh, A. R., H. Rafatjo, and A. A. Javadi. "Treatment of an expansive soil by mechanical and chemical techniques." Geosynthetics International 21.3 (June 2014): 233-243. doi:10.1680/gein.14.00011.

[9] Soltani, Amin, An Deng, and Abbas Taheri. "Swell–compression characteristics of a fiber–reinforced expansive soil." Geotextiles and Geomembranes 46.2 (2018): 183-189. doi:10.1016/j.geotexmem.2017.11.009.

[10] Miller, Carol J., and Sami Rifai. "Fiber reinforcement for waste containment soil liners. " Journal of Environmental Engineering 130.8 (August 2004): 891-895. doi: 10.1061/(ASCE)0733-9372(2004)130:8(891).

[11] Hoover, J. M., D. T. Moeller, J. M. Pitt, S. G. Smith, and N. W. Wainaina . "Performance of randomly oriented fiber reinforced roadway soils. " Lowa DOT Project-HR-211, Department of Transportation, Highway Division, Lowa State University (1982).

[12] Krenchel H, "Fiber reinforced brittle matrix materials." In: Proceedings of international symposium on fiber reinforced concrete, Ottawa (1973).

[13] Priya, CM Sathya, S. Archana, A. Bichu Albert, A. D. Deeraj. "Stabilization of clayey soil using polypropylene fiber." International Research Journal of Engineering and Technology (IRJET) 4.4 (2017): 1252-1255.

[14] Deshpande, Saurabh. Sanjay, and M.M Puranik. "Effect of Fly Ash and Polypropylene on the Engineering Properties of Black Cotton Soil." International Journal of Civil Engineering 4, no. 4 (April 25, 2017): 52–55. doi:10.14445/23488352/ijce-v4i4p111.

[15] Sai, Sravya, and Suresh Kommu. "Swell and Strength Characteristics of Expansive Soil Reinforced with Synthetic Fibers." i-Manager's Journal on Civil Engineering 6, no. 4 (2016): 21. doi:10.26634/jce.6.4.8236.

[16] Dang, Liet Chi, Behzad Fatahi, and Hadi Khabbaz. "Behaviour of Expansive Soils Stabilized with Hydrated Lime and Bagasse Fibres." Procedia Engineering 143 (2016): 658–665. doi:10.1016/j.proeng.2016.06.093.

[17] Malekzadeh M, "Effect of Polypropylene Fiber and Posidonia Oceanica Ash on the Behavior of Expansive Soil." Doctoral dissertation, Eastern Mediterranean University (EMU)-Doğu Akdeniz Üniversitesi (DAÜ) (2012).

[18] Viswanadham, B. V. S., B. R. Phanikumar, and R. V. Mukherjee. "Effect of polypropylene tape fiber reinforcement on swelling behavior of an expansive soil." Geosynthetics International 16.5 (October 2009 a): 393-401. doi: 10.1680/gein.2009.16.5.393.

[19] Al-Akhras, N. M., M. F. Attom,, K. M. Al-Akhras , and A. I. H. Malkawi. "Influence of fibers on swelling properties of clayey soil." Geosynthetics International 15.4 (2008): 304-309. doi: 10.1680/gein.2008.15.4.304.

[20] Sivakumar Babu, G. L., A. K. Vasudevan, and M. K. Sayida. "Use of Coir Fibers for Improving the Engineering Properties of Expansive Soils." Journal of Natural Fibers 5, no. 1 (April 18, 2008): 61–75. doi:10.1080/15440470801901522.

[21] Waldron, L. J. "The Shear Resistance of Root-Permeated Homogeneous and Stratified Soil 1." Soil Science Society of America Journal 41.5 (September 1977): 843-849. doi:10.2136/sssaj1977.03615995004100050005x.

[22] Punthutaecha, Koonnamas, Anand J. Puppala, Sai K Vanapalli and Hilary Inyang. "Volume change behaviors of expansive soils stabilized with recycled ashes and fibers." Journal of materials in Civil Engineering 18.2 (April 2006): 295-306. doi: 10.1061/(ASCE)0899-1561(2006)18:2(295).

[23] Shukla, Sanjay Kumar. "Fundamentals of fiber-reinforced soil engineering." Springer Singapore, (2017).

[24] Head, K. H. "Manual of Soil Laboratory Testing." Pentech Press, London, Vol. 2, (1994).

[25] Estabragh, A. R., B. Parsaei, and A. A. Javadi. "Laboratory investigation of the effect of cyclic wetting and drying on the behavior of an expansive soil." Soils and Foundations 55.2 (April 2015): 304-314. doi: 10.1016/j.sandf.2015.02.007.

[26] Tripathy, Snehasis, and Kanakapura S. Subba Rao. "Cyclic swell–shrink behavior of a compacted expansive soil." Geotechnical and Geological Engineering 27.1 (February 2009): 89-103. doi: 10.1007/s10706-008-9214-3.

[27] Tang, Chaosheng, Bin Shi, Wei Gao, Fengjun Chen and Yi Cai. "Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil." Geotextiles and Geomembranes 25.3 (June 2007): 194-202. doi: 10.1016/j.geotexmem.2006.11.002.

[28] Zaimoglu, A. Sahin, and Temel Yetimoglu"Strength behavior of fine grained soil reinforced with randomly distributed polypropylene fibers. " Geotechnical and Geological Engineering 30.1 (February 2012): 197-203. doi: 10.1007/s10706-011-9462-5.

[29] Viswanadham, B.V.S., B.R. Phanikumar, and Rahul V. Mukherjee. "Swelling Behaviour of a Geofiber-Reinforced Expansive Soil." Geotextiles and Geomembranes 27, no. 1 (February 2009): 73–76. doi:10.1016/j.geotexmem.2008.06.002.

[30] Al-Bayati I K, "Effect of Potassium Chloride on the Swelling Potential of Soils." M.Sc. Thesis, Civil Engineering Department, Al-Nahrain University, Iraq (2001).

[31] Al-Kubaisy B H, "Effect of Silica-Fume on the Strength and Swelling of Expansive Clays." M.Sc. Thesis, Civil Engineering Department, Al-Nahrain University, Iraq (2010).

[32] Al-Omari, Raid, Saad Ibrahim, and Ishraq Al-Bayati. "Effect of potassium chloride on cyclic behavior of expansive clays." International Journal of Geotechnical Engineering 4.2 (2010): 231-239. doi: org/10.3328/IJGE.2010.04.02.231-239.

[33] Al-Saudi N S, and O. S. Al-Rawi. "Effect of Seasonal Moisture Change on Swelling Behavior of Soil." Indian Geotechnical Journal 26.2 (1996):101-121.

[34] Ring III, George W. "Shrink-swell potential of soils." Highway Research Record 119 (1966).

[35] Subba Rao K S, "Swelling potential with cycles of swelling and shrinkage." In Proc. of the 6th Int. Conf. on Expansive Soils 1 (1987): 137-142.

[36] Kalkan, Ekrem. "Impact of wetting–drying cycles on swelling behavior of clayey soils modified by silica fume." Applied Clay Science 52.4 (June 2011): 345-352. doi: 10.1016/j.clay.2011.03.014.

[37] Sridharan, A., and Mehter Mohamed Allam. "Volume change behavior of desiccated soils." Journal of the Geotechnical Engineering Division 108.8 (1982): 1057-1071.

[38] Falorca, I. M. C. F. G., and M. I. M. Pinto. "Effect of short, randomly distributed polypropylene microfibers on shear strength behavior of soils." Geosynthetics International 18.1 (February 2011): 2-11. doi:10.1680/gein.2011.18.1.2.