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SHEAR STRENGTH CHARACTERISTICS OF PPF-TREATED GYPSUM SOIL PREPARED AT VARIOUS MAXIMUM DENSITIES

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Abstract

The problem with gypsum soils is that they have a high bearing capacity unless water reaches them. Nonetheless, it will create air spaces or cavities in these soils beneath the inundation states. It may collapse under the influence of the origin load and without additional external loads.

Several initiatives to address the soil problem have recently been documented using geofibers for soil stabilization and improvement. This has been very popular among practitioners over the past three decades due to the low cost and ease of deploying technology and the light weight of the additive (i.e. geofibres). In addition, they are sustainable and environmentally friendly materials.

This study aims to assess the engineering properties of gypseous soil treated with polypropylene fiber. The tests were carried out on three types of gypseous soil with varying gypsum content and properties. Then it was mixed with various proportions of ppf(0.25%, 0.5%, and 1%).The research focused on three primary soil characteristics: compaction, shear strength, and compressive strength. All three soil properties are critical in ground improvement techniques.

According to the compaction results, polypropylene fiber reduces the maximum dry density while increasing the optimum moisture. PPF-treated soils demonstrated significant shear strength gains in direct shear tests. Additionally, the unconfined compression strength is increased by more than 42.8-77. 3%. The current study's findings point to polypropylene fiber improvement as an environmentally friendly method for improving the engineering properties of gypseous soil.

Keywords: Gypseous soil _ Direct Shear Strength_ polypropylene fiber_ various densities.

1. INTRODUCTION

Gypseous soil has good engineering properties when dry, i.e., these soils have a high bearing capacity unless water reaches them and have low settlement and almost no creep. However, once wet, the structure becomes weak, and it begins to fall due to the rearrangement of soil particles, which may lead it to collapse under the influence of the original load and without any additional external loads [1]. Several constructions in Iraq have been found with different patterns of cracks and uneven deformations, caused mainly by exposure of the supporting gypsum soils to water [2].

Treating gypsum soils and reducing their impact on engineering structures has become an important issue facing engineers, especially in countries where gypsum soils are found. In the literature, there are several techniques to improve gypseous soil behavior, but choosing the right technique is more complex because of many considerations, such as construction aspects, economic aspects, and collapsibility degree. Compaction may be useful for improving the shallow layers of gypseous soil and acceptable for lightweight structures. In contrast, the injection will help to improve the deep layers of large or buried constructions. Deep foundations such as piles can be used by transmitting the structure's load to stable layers below the collapsible one; however, negative skin friction should be considered [3]. Furthermore, chemical stabilization has been widely used to treat collapsible soils using various stabilizing materials such as cement, sulfur, acrylate, and sodium silicate. Despite their success in improving the behavior of collapsible soils, chemical stabilizers cannot be considered environmentally friendly materials because they can be toxic, alter the soil's pH level, pollute groundwater, and pollute the soil [3][4].

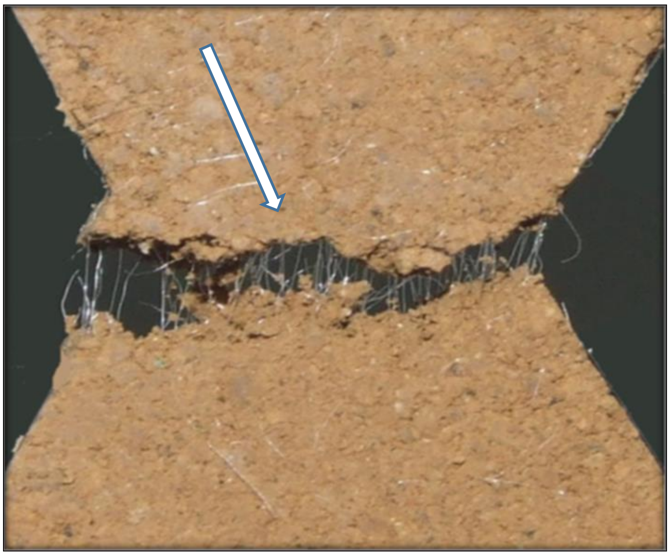
Several initiatives to address the soil problem have recently been documented using geofibers for soil stabilization and improvement very popular among practitioners over the past three decades due to the low cost and ease of deploying technology, light weight of the additive (i.e. geofibres), and history of successful cases. Adding geofibers to granular or non-cohesive soils improves the shear modulus, liquefaction resistance, and particle entanglement, as well as increases the load-bearing capacity [5].Various researchers have observed that adding geofibre to the soil as a reinforcing component increases the soil's peak strength (shear, compressive, and tensile) [6][7] .

Goofier are generally fibers blended into soils to create an ideal reinforcement system for slope failure repair, pavement subgrade reinforcement, foundation stabilization, and retaining wall backfill improvement. At the same time, geofibers help make a system for reinforcing soil with much better engineering properties [8]. And therefore, they may categorize them into three types (a) natural fibers, (b) synthetic fibers, and (c) waste fibers [9]. When ppf is mixed with soil, it behaves as a composite material [10].

Fiber-reinforced soil behaves as a composite material, with relatively high tensile strength fibers embedded in a soil matrix. Shear stresses in the soil mobilize tensile resistance in the fibers, resulting in increased soil strength [11][12]. Also, Soil tensile brittleness can be reduced by fiber inclusion because of the fiber's bridging effect [13] as shown in Plate (1).

Several authors have studied the shear strength of fiber-reinforced soils and reported increased shear strength and ductility in the sand. According to [14], The peak shear strength of the soil is increased by fibers, while the post-peak decrease in shear strength is limited.[15] They were the first people to search for fibers in the sand that were distributed in a random pattern. According to the results, as the percentage of fibers went up, the peak shear strength went up, and the sand became more flexible.

Polypropylene fiber was used to evaluate the shear strengths of very fine sand. The fiber lengths range from 30 to 35 mm, with 0–1% proportions. The highest improvement value for shear strength was 60%, obtained in fiber content (1%) [11].
Also, [16] performed a direct shear test on the sand. Obtained the highest improvement results, Where the degree of internal friction (ϕ°) increased from (29.8 to 37.1), and the cohesive (c) value increased from (3.5 to 30.9) kPa. When adding (0.9%) ppf
Also, [17] noted that the UCS of fly ash went up from 128 to 259 kPa when the content of polypropylene fibers was raised from 0 to 0.5%.
[18] the effects of randomly distributed polypropylene fiber reinforcement (length 12 mm) on the fine-grained soil were studied. The greatest improvement was obtained in fiber content (0.75 %), where the UCS of the reinforced soil specimen increased by nearly 85 %.[19][20] notice that when the percentage of fiber increases, it leads to a decrease in the maximum dry unit weight significantly while increasing the optimum water content slightly. Though previous studies have shown that geofiber is a



sustainable material for improving the geotechnical properties of a wide variety of soils, the application of geofiber to treat gypseous soil is virtually nonexistent. So, this research looks at what happens to the properties of gypseous soil when polypropylene fiber is added, especially when the soil is wet by carrying out tests in the lab, such as the direct shear test and the unconfined compressive test.

Plate 1: Photo of the so-called bridging effect of fibers across a crack opening (after [13])

2. Materials and Methods

2.1 soil

In this study, three types of disturbed natural gypseous soil were used, obtained from three different sites within the Salah-Aldin Governorate. The depths at which the samples were collected ranged from 0.5 to 2 m beneath the natural surface of the ground. The first one was brought from Tikrit University, which has a gypsum content (56%) and is defined as (soil 1). The second variety is from AL'Dour, has a medium gypsum content (36%), and is known as (soil 2). Finally, the third is from Al 'Alam, but its low gypsum content (21%) is referred to as (soil 3). Fig (1) displays the soil samples' grain-size distribution curve, and The USCS categorizes these soils as "poorly graded sand," which is the lowest soil quality level (SP_SM). Table (1) to Table (3) presents gypseous soils' physical and chemical properties and the test standards.

2.2. Polypropylene Fiber (PPF)

One of the newest members of the family of thermoplastic polymers is polypropylene fiber. This family is expanding at a rapid rate. The technique of melt spinning is used to prepare polypropylene fibers; here, a viscous fluid is forced through a spinneret or multiple die openings, forming a fine-diameter fiber [21]. The main advantages are the low cost, easy mixing, chemically inert, and hydrophobic material that is impossible or difficult to react with or absorb the soil's moisture [9]. Table (4) shows the properties of the (PPF) which was brought from the Sika Company and is depicted in Plate 2.

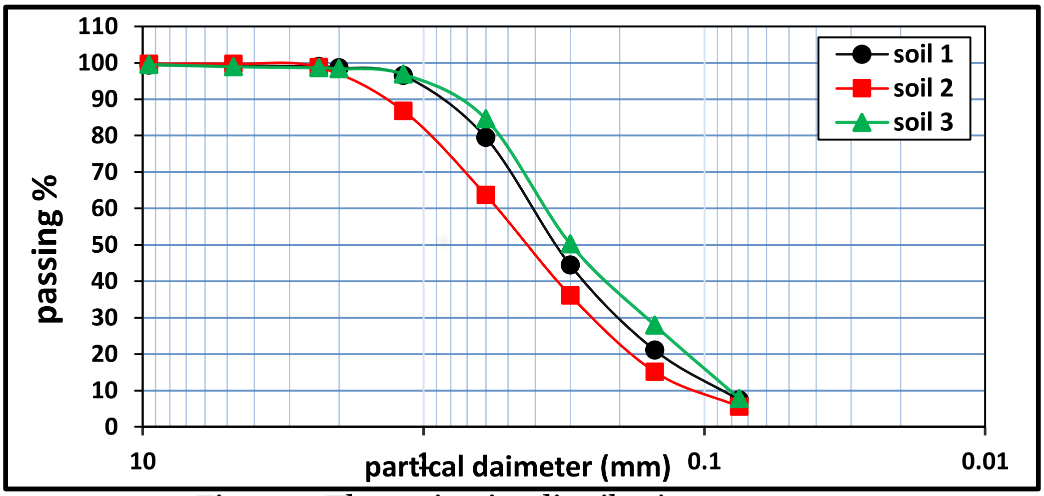


Figure 1: The grain-size distribution curve

Table 1: Gypseous soils tests with their Specification

Property	**Specification**
Grain size distribution	ASTM D422 [22]
Specific gravity	ASTM D854 [23]
(LLand PL)	BS 1377:2A-ASTM D4318 [24] [25]
Compaction test	ASTM D1557 [26]
Field density	ASTM D1556 [27]
Chemical tests	BS 1377-3 [28]

Table 2: Physical properties of gypseous soils

properties	**Soil1**	**Soil2**	**Soil3**
Total soluble salts (T.s.s)%	64.41	37	25.31

Organic matters (O.M)%	0.015	0.048	0.091
PH value	7.88	7.81	7.78
Gypsum content %	57	36	21

Table 3: Chemical properties of gypseous soils

property	value
Colour	transparent fibers
Density	0.91 g/cm3
Length	12mm ± 1mm
diameter	0.032 mm
Tensile strength:	600-700 Mpa
Elastic Modulus	3.000-3.500 Mpa
Elongation	20-25 %
Chemical Base	100% virgin polypropylene
Melt point	160°c
Ignition point	365°c

Table 4: The properties of polypropylene fiber

Soil symbol	**Specific gravity (Gs)**	**Atterberg's limits**		**Grain size distribution**		**Compaction test**		**γ_f KN/m³**
		LL%	PL%	Cu	Cc	$\gamma_{d\ max}$ kN/m³	O.M.C %	
Soil 1	2.36	92.2	N.P	4.86	1.11	17.65	11.75	12.17
Soil 2	2.46	34.2	N.P	5.10	1.07	17.49	13.31	13.34
Soil 3	2.51	32.9	N.P	4.63	0.84	18.91	10.45	14.05

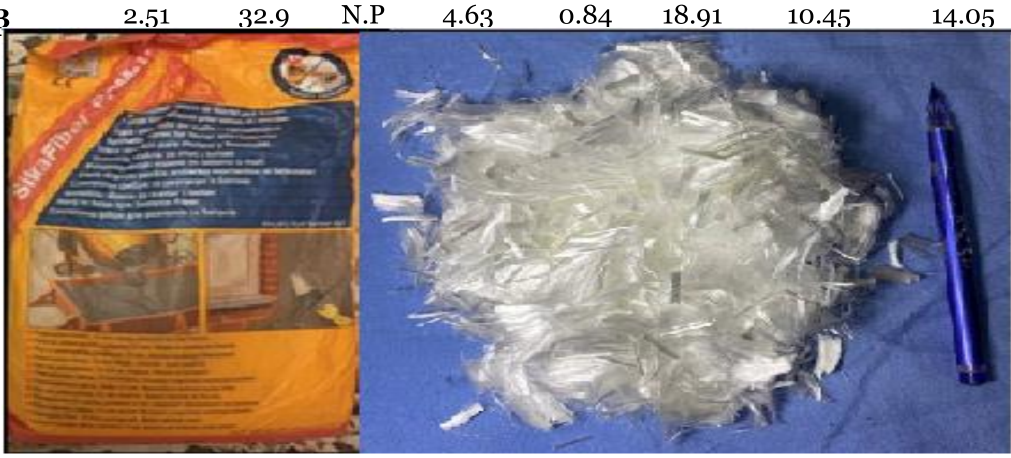


Plate 2: Polypropylene fiber (PPF) used in the present research

3. Experimental program

3.1. Sample Preparation

The prepared soil first passed through No.4 before being oven-dried for 48 hours at 45 °C, then moved to a mixing container. The required amount of water is added to the specimen, and the batter is then carefully mixed by hand to ensure that it is homogeneous.

For fiber-reinforced samples, at this point, the required percentage of fiber is added to the wet soil, expressed as a percent of the total dry weight of soil, and manually mixed into the wet soil in small increments. Because it was observed that if the fibers were mixed into dry soil, it would cause segregation or the floating tendency of fibers, then it was mechanically mixed. Before the tests, the prepared mixtures were kept for 24 hours in airtight bags so that the moisture would be evenly spread throughout the sample.

The field density was used to prepare all specimens for the three types of gypsum soils. In this study, we used (0.25, 0.5, and 1) % ppf ratios.

3.2. Laboratory tests

The three soils' compaction properties (maximum dry density and optimum moisture content) were calculated using a modified proctor test (ASTM D1557). Several direct shear tests were conducted to establish the soil's dry and wet shear strength parameters. (ASTM D3080). The unconfined compression test was carried out according to the (ASTM D2166).

4. Results and Discussion

4.1. Compaction tests

The variations in maximum dry density and OMC with PPF are depicted in Figures (2) and (3), respectively. For untreated gypseous soils, it is noted that soil (3) gave the highest dry density (18.93 kN/m3), followed by soil (1) with its maximum dry density (17.65 kN/m3), while the lowest value of density was for soil (2), which gave 17.49 kN/m3.

According to the findings, increasing the amount of PPF results in a decrease in the maximum dry density while simultaneously leading to an increase in OMC. Using PPF, the density of ppf-treated soil 1 decreased from 17.65 to 17.19 kN/m3, and the (OMC) increased from 11.75 to 12.85% when PPF content increased from 0 to 1%. While in PPF-treated soil (2), it is seen that with a rise in ppf content from 0 to 1%, the (γ_{dmax}) decreases from 17.49 to 16.94 kN/m^3 and the (OMC) increases from 13.31 to 14.18 %. For soil (3), increasing the PPF content from 0 to 1% reduces density from 18.91 to 18.37 kN/m3 while increasing the (OMC) from 10.45 to 11.54%.

As shown above, it can notice that the dry density decreases as the fiber content rises. This behavior may be attributed primarily to fiber having a lower specific gravity value (0.91 gm/cm3) than some of the soil particles it replaces.

However, this is not the only reason; as expected, the fiber can also prevent particles from sliding over each other, leading to a decrease in γ_{dmax} [9] [20]

The OMC increased very little after adding fiber because the PPF did not absorb water. The reason for increasing the OMC is to ensure the uniform mixing of fiber and soil.

The present study's results are consistent with previous studies' results [20][19].

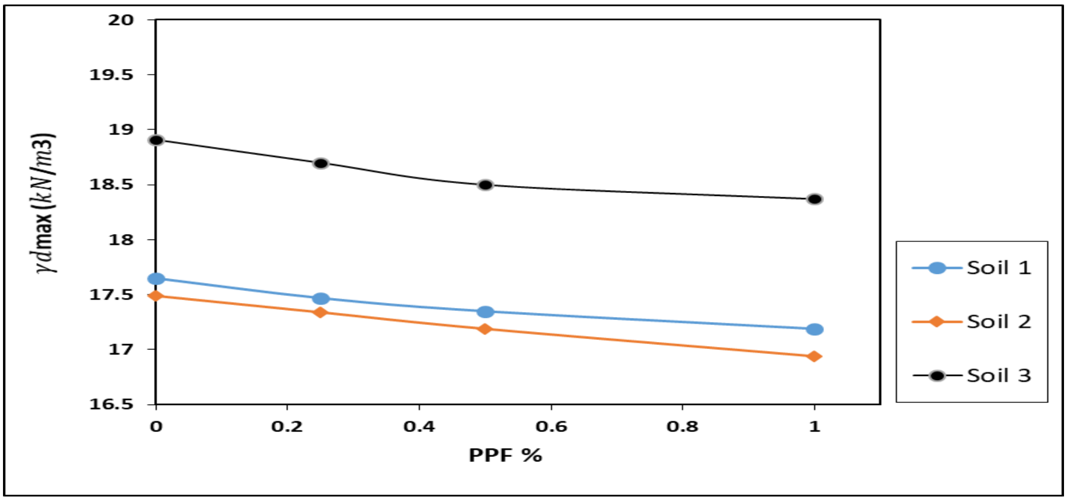


Figure 2: Maximum dry density of PPF-treated soils

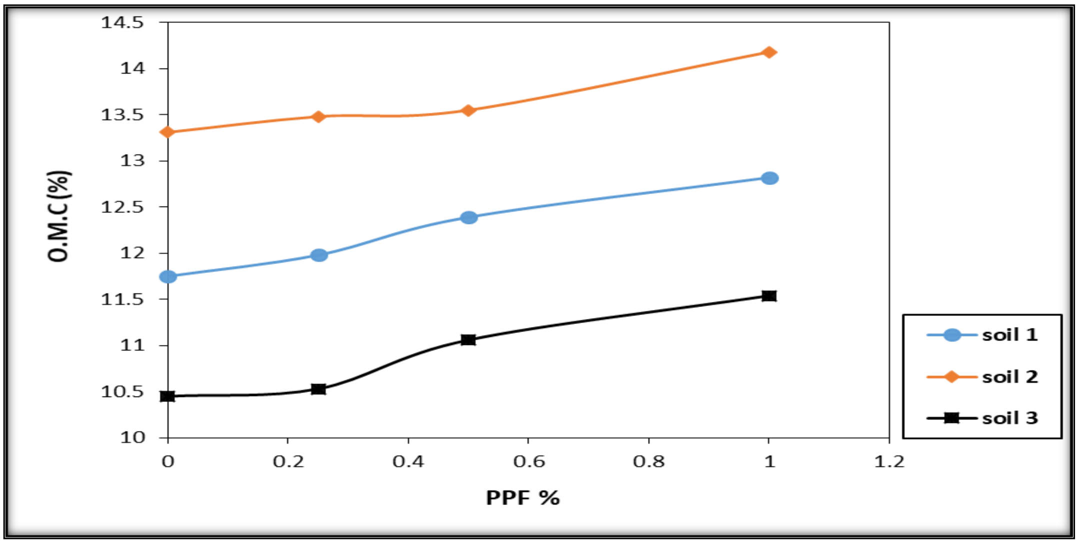


Figure 3: Optimum moisture content of PPF-treated soil

4.2: Direct shear tests

The direct shear tests were conducted in both dry and wet conditions to determine how the PPF content affects the shear strength parameters (c and ϕ°) on (soil 2), with the PPF content (0.5%) using specimens unreinforced and reinforced prepared at various densities (0.83, 0.91, and 100%) from maximum dry density. Figure 4 and Figure 5 show the influence of PPF content on the cohesion of (soil 2) samples prepared at various maximum densities under both dry and soaked conditions. Table 5 summarizes the test results.

Based on direct shear test results, all gypseous soils have a cohesion value; this could due to the cementing action of the gypsum in the untreated gypsum soil and the cementing action of both the gypsum and the fiber in the treated gypsum soil.

Furthermore, as PPF content adding, the cohesion and angle of internal friction increase, as found by [29].

For the dry conditions of PPF-treated soil, the cohesion for soil (2) increased from (43.3, 60.5, and 82.1 kPa) to (59.8, 78.5, and 94.36 kPa) at (0.83% γ_{dmax}, 0.91% γ_{dmax}, and γ_{dmax}) respectively, whereas the value of the angle of internal friction (ϕ°) increased slightly under both dried and soaked conditions.

In the soaked condition, the results for the critical shear strength parameters are reduced, because of the solubility of gypsum in water. However, adding PPF gave higher results because it acted as a reinforcement to bond and protect soaked gypseous soil particles.

For soaked conditions of PPF-treated soil, the cohesion increased to 56.6%, 41.4%, and 36.2% for densities (0.83% γ_{dmax}, 0.91% γ_{dmax}, and γ_{dmax}), respectively.

The increase in soil strength after fiber mixing may be attributed to the larger surface contact area of the soil fiber matrix; the interfacial force and friction resistance between the soil fiber matrixes is more significant. It was also found that hard particles such as sand caused pits and scratches on the surface of PPF due to mixing or loading, and these led to increased bonding between the soil and PPF, increasing cohesion.[29][30].

Table 5: Direct shear test results on samples prepared at various max densities

Soil 2 (36% gups)						
	0% fiber			*0.5% fiber*		
	83% γ_d	*91% γ_d*	*γ_{dmax}*	*83% γ_d*	*91% γ_d*	*γ_{dmax}*
Cohesion (kPa)	43.3	60.5	82.1	59.8	78.5	94.36
Cohesion after soaking (kPa)	11.94	16.4	21.5	18.7	23.2	29.3
Friction angle (degree)	35.6	38.27	40.52	37.17	39.41	41.59
Friction angle after soaking (degree)	29.2	31.4	35.29	31.8	33	36.6

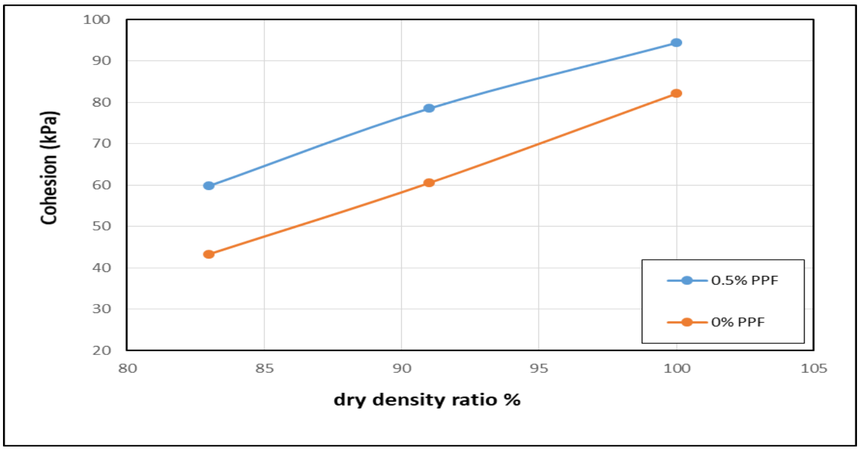


Figure **Error! No text of specified style in document.**: Influence of PPF content on the cohesion of soil 2 samples prepared at various max densities (dry condition)

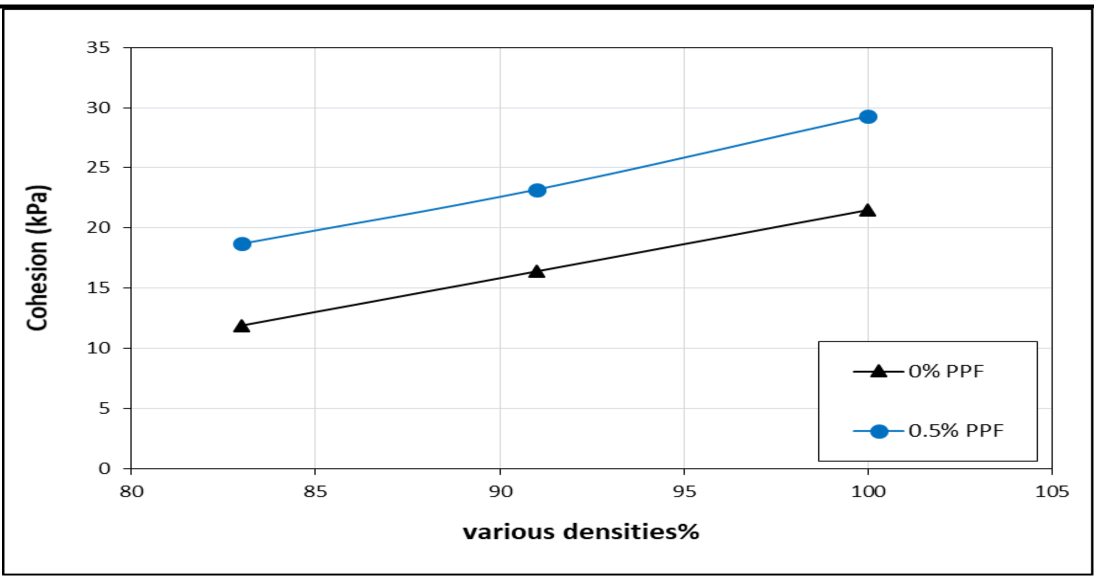


Figure 5: Influence of PPF content on the cohesion of soil2 samples prepared at various percentages from max density (soaked condition)

4.2: Unconfined compression test

The tests were carried out using a cylinder with a length of 89 mm and an inner diameter of 39 mm, using untreated and treated specimens prepared at various densities (0.83, 0.91, and 100 %) from maximum dry density, mixed with the (0.5%) PPF content on soil 2. Figure 6 shows the Influence of various max densities on the UCS of soil (2). A summary of the results is given in Table .6

The unconfined compressive strength of PPF -reinforcement soil2 increased (28%, 18%, and 11%) at (0.83% γ_{dmax}, 0.91%γ_{dmax}, and γ_{dmax}), respectively when added (0.5%) of PPF content One may notice that the increase in the improvement rates was almost linear.

The fiber bridge effect could be to blame for the increase in compression strength. This effect impedes further opening and crack development and can also stop failure planes and soil deformations [30]. The present study's results are consistent with previous studies' results [17][18].

Table 6: Unconfined compression Test Results for soil 2 prepared at various percentages from max densities

PPF%	0			0.5		
percentages from max densities	83%	91%	100%	83%	91%	100%
UCS (kPa)	125	170.1	216.5	160	200.7	240.3

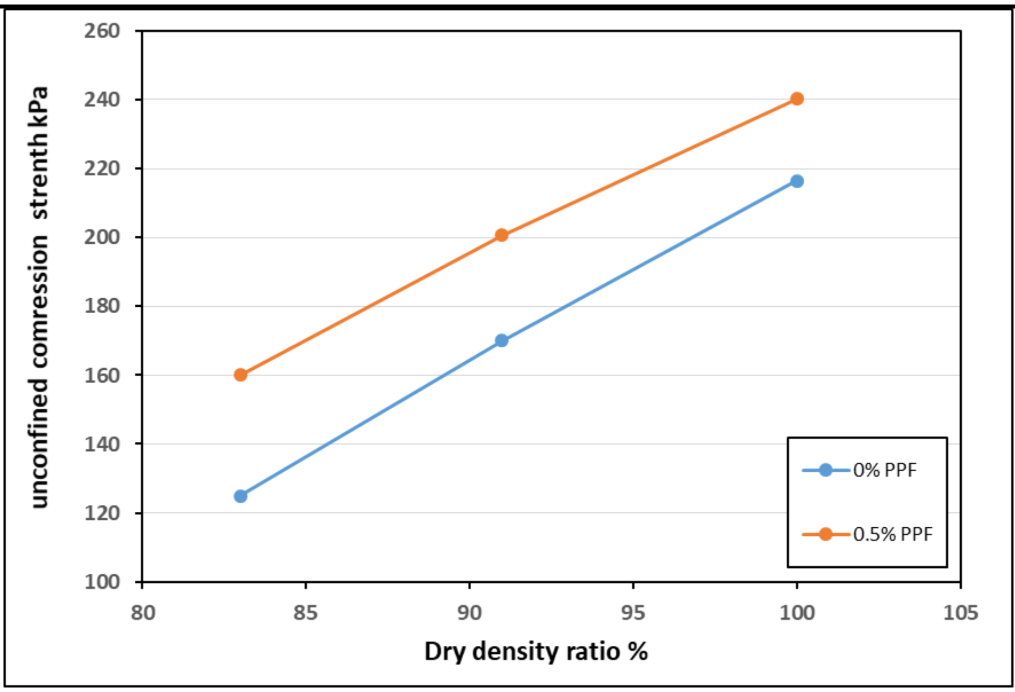


Figure 6: Influence of various max densities on the UCS of soil (2)

5. CONCLUSIONS

This research investigated the effect of polypropylene fibers (PPF) on the behavior of gypsum soils. The following conclusion can be drawn from the obtained results.

1. Increasing in PPF caused a reduction in maximum dry density from 18.91 to 16.94 kN/m3, while the optimum moisture content increased from 10.45% to 14.18%.
2. The friction angle and also cohesion increase as adding (0.5% PPF) under dry and soaked conditions.
3. The addition of the PPF percentage has caused an increase in the unconfined compressive strength by about 11–28 % at 0.5% of PPF addition in samples prepared at various densities.
4. (PPF) is inexpensive and cost-effective, allowing it to improve large areas at a lower cost. On the other hand, it is environmentally friendly because it can solve significant waste disposal problems.

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