Improvement of strength characteristics for sandy soils by polypropylene fibers (PPF)

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Abstract. Sandy soil contains many geotechnical problems, including high permeability, less shear strength, sand dunes, and liquefaction. Therefore, it is necessary to stabilize the sandy soil to improve its engineering properties, either through mechanical or chemical fixations. The mechanical one is done by changing the classification of the soil by mixing it with other types of soils and additives in various gradients. While the chemical fixation is related to the modification of soil properties by adding chemically active substances. In this research, polypropylene fiber PPF with proportions (0.1, 0.3, 0.6, and 1%) was used to study its effect on the physical properties of sandy soils, such as the angle of internal friction $\phi$, shear strength $\tau$, California Bearing Ratio CBR, and permeability $k$. In this paper the value of $\phi$, $\tau$, and CBR for improved sandy soil increases by 24%, 20%, and 182.2% respectively with adding 0.6% PPF, and decrease in permeability which is estimated to be 26% for 0.1% PPF.

Keywords: Polypropylene Fibers, Sand Soil, Permeability, Angle of Internal Friction, CBR.

1. Introduction
Sandy soil is defined as cohesionless soil or as frictional soil because there is no adhesion between their particles. Cohesionless soils have less shear strength, less bearing capacity, don't have containing water, don't have plasticity, and shear strain between their particles is negligible or doesn't exist. Traditional methods of stabilized sandy soil such as fly ash, bituminous, and lime cement often require a long curing period, so the use of polymers to stabilize sandy soils is more extensive in now day because it does not require a long curing time in addition to being chemically stable. Soil improvement by using polymers is not limited to sandy soils only but has also been used in clay soils to improve the physical properties of soils such as increase shear strength, increase bearing capacity, reduce settlement, reduce swelling and reduce all problems related to weak soils. [1] Used two types of polypropylene fibers (40 and 50 mm length ) in four different percentage ( 1, 2, 3, and 4% ) as an additive to increase the angle of internal friction of sandy soil.[2] Showed that the CBR value of sandy soil will increase with increasing the polypropylene fiber (20mm) in five percentage (0.5, 1, 1.5, 2, and 2.5%), the maximum increase in CBR is 113.35% at 2.5% PPF. [3] Mix polypropylene fiber (12mm) in three percentage (0.25, 0.5, and 0.75%) with sandy soil in different relative density (30, 50, and 80 %) and study its effect on shear strength, where it was observed that the shear strength of reinforced soil increases at different relative density.[4] Indicate that the polymer-soil mixture will reduce the permeability and increase shear strength when mix soil with (0.25, 0.5, 0.75, and 1%) PPF (6 and 12mm).[5] polyethylene PE, polyacrylamide PAM, and polyethylene glycol PMA were used to reduce swelling up to 76.75, 78.2% and 71.7%, and increase CBR value by 66.7%, 74.8% and 72.85% of expansive soil with increasing PAM, PE and PMA to 5%, 12% and 7% respectively. [6] showed the effect of adding calcium chloride (2, 4, 8, 10 and 12%) and polypropylene fiber (0.5, 1and 2%) on
the physical properties of expansive soils, the results showed that the liquid limit, plastic limit, plasticity index, swell and shrinkage were decreased with increasing CaCl2 and PPF. [7] studied the physical properties of beach sand when adding polypropylene fiber (0.5, 1.5 and 2\%), the result showed decrease in dilation and increase in shear strength, porosity, and permeability. [8] observed in this paper that the unconfined compressive strength and moisture content was increased while the maximum dry density was decreased when mixed polypropylene fiber (0.5, 1, 1.5 and 2\%) with sandy soil. [9] shows the effect of adding polyurethane (PU) on the properties of modified sand, from the result observed that the compressive strength of soil increased with increase PU polymer varying from (10\% PU (20 kPa) – 100\% PU (500 kPa)).

Recently, various types of polymers have been used to improve the engineering properties of soils and to use them in various construction applications due to their ease of use and availability. This research aims to study the effect of polypropylene fiber on some engineering properties of sandy soils, such as the angle of internal friction, shear strength, permeability, and CBR value.

2. Material Properties

2.1. Soil

The soil used in this research is sandy soil collected from Najaf Governorate, southern Iraq, the engineering characteristics of sandy soil were found through several laboratory tests in the civil engineering laboratories of Al-Nahrain University such as sieve analysis, specific gravity, relative density, direct shear, permeability, and CBR test, as shown in the Table 1.

Table 1. Physical properties of sandy soil.

| Mechanical properties          | Percentage |
|-------------------------------|------------|
| Gravel                        | 0\%        |
| Sand                          | 94.8\%     |
| Fine grain                    | 5.2\%      |
| Water content, Wc             | 5.5\%      |
| Specific gravity, Gs          | 2.68       |
| Angle of internal friction, $\phi$ | 33\%     |
| Permeability, k               | 0.0045 cm/sec |
| CBR                           | 33\%       |

Classification According to Unified Classification System (UCS) SP

2.2. Fiber

In this research, one of the most available type of fibers is used, which is polypropylene fiber (PPF) with a length of 12 mm and a diameter 0.032 mm (Figure 1), different PPF contents (0.1, 0.3, 0.6 and 1\%) were used to investigate its effect on the behavior of reinforced sandy soil by a series of CBR test, direct shear test and permeability test. The physical properties of PPF are summarized in Table 2.
Table 2. Physical properties of polypropylene fiber PPF.

| Property          | Value                               |
|-------------------|-------------------------------------|
| color             | Transparent fibers                  |
| Specific gravity  | 0.91gm / cm³                         |
| Length            | 12 mm ±1                             |
| Diameter          | 0.032 mm                             |
| Shape             | Straight                             |
| Tensile strength  | 600 -700 MPa                         |
| Elastic modulus   | 3000 – 3500 Mpa                      |
| Elongation        | 20-25 %                              |
| Chemical base     | 100 % polypropylene fiber            |
| Melt point        | 160º C                               |
| Ignition point    | 365º C                               |
| Absorption        | No absorption                        |

3. Laboratory Tests

3.1. Direct Shear Test
The direct shear test for soil is determined according to ASTM D3080. The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure and sliding along any plane inside. In the direct shear test a square prism of soil is laterally restrained and sheared along a mechanically induced horizontal plane while subjected to a normal pressure applied to that plane. The normal load used in this is 1, 2, and 4kg.

3.2. Permeability Test
The permeability test is conducted on the natural soil according to ASTM D2434. The coefficient of proportionality k (q=kiA) has been called "Darcy’s coefficient of permeability", permeability enters all problems involving the flow of water through soil, such as drainage of subgrades, seepage under dams, and backfill.
3.3. California Bearing Ratio Test
The CBR test is conducted on soil according to ASTM D1883. The CBR test is used to evaluate the potential strength of subbase, subgrade, and recycled materials for use in road and airfield pavements. 4.5 kg of sandy soil was compacted in the CBR mold in three layers by applying 56 blows with a 24.5 N hammer.

4. Results and Discussions
4.1. Effect of PPF on shear strength
Figures 3 and 4 show the results of the angle of internal friction $\phi^\circ$ and the shear strength $\tau$ for sandy soils after mixing it with polypropylene fiber in proportions (0.1, 0.3, 0.6, and 1%) and under different normal loads, where the angle of internal friction and the shear strength of sandy soils was increased by increasing the PPF. The maximum increase in the angle of internal friction with the addition of 0.3 and 0.6% PPF is estimated to be 18 and 24% respectively.

![Figure 3](image1.png)
Figure 3. The effect of adding PPF on $\phi^\circ$ of sandy soil.

![Figure 4](image2.png)
Figure 4. The effect of adding PPF on shear strength.
This increase in the shear strength behavior of sandy soils due to the characteristics of polypropylene fiber PPF, such as its high flexural strength due to its semi-crystalline nature and higher shear resistance, so when mixed with sandy soils, it reinforces the soil by creating a fiber network and increased a friction at the interface.

4.2. Effect of PPF on permeability of sandy soil

Figure 5 shows the effect of adding different percentages (0.1, 0.3, 0.6, and 1%) of PPF on the permeability (k) values of sandy soil. The figure shows the decrease in permeability at 0.1 and 0.3% PPF, more than 0.3% the permeability of soil increases with increasing PPF content where the maximum decrease in permeability was 26% and 8.8% at 0.1 and 0.3% PPF respectively.

![Figure 5. The effect of adding PPF on k of sandy soil.](image)

Increase the permeability of reinforced soil after 0.3% PPF because polypropylene fiber has a relatively slippery surface and it is difficult to connect to other surfaces in addition to its relatively low density, so when it is increased in the soil than the optimum percentage, it will give the opposite result by increasing the permeability due to the ease of sliding water on its surface.

4.3. Effect of PPF on CBR value of sandy soil

The soil was prepared for the CBR test by first the required soil weight, which is 4.5 kg, as well as fiber, and then the PPF is mixed with the dry soil randomly at a moisture content of 5.5%. The sandy soil was compacted in three layers by applying 56 blows distributed on each layer with a hammer weighing 24.5 N at a free fall. A load of 2.5 kg was seated on the last layer, then the mold is placed under the CBR machine shown in the Figure (8). The penetration plunger is installed in the center of the sample to be in contact with the soil surface. The test was carried out by applying the load through the penetration readings of 0.0, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, and 7.5 mm.

CBR values for sandy soils with and without polypropylene fibers were calculated for the corresponding load penetration of 2.5 and 5 mm under un-soaked conditions. In this paper, it was found that the CBR value when penetrating 5 mm was higher than 2.5 mm. This indicates that the sandy soil reinforced with fiber gives high penetration resistance at large deformations as shown in Figures 5. The maximum increase in CBR value with the addition of 0.3 and 0.6% PPF is estimated to be 172.7 and 182.2% respectively.
5. Conclusion
A series of CBR, direct shear, and permeability tests were carried out to investigate the influence of polypropylene fiber PPF on the mechanical properties of sandy soil, the following conclusion may be made from the results of this tests:
1-The angle of internal friction $\phi^\circ$ and shear strength $\tau$ of sandy soils will increase with increasing PPF and normal load, the maximum increase in $\phi^\circ$ is 24% at 0.6% PPF.

Figure 6. The effect of adding PPF on CBR of sandy soil.

Figure 7. CBR mold of improved sandy soil.

Figure 8. CBR test machine.
2-The permeability of sandy soil will decrease at a ratio of 0.1% and 0.3% and then it will gradually increase again as the percentage of fiber increases, the maximum decrease in permeability is 26% at 0.1% PPF.

3-As for the penetration resistance of sandy soils in CBR test, it was also observed to be increase when the percentage of fiber in sandy soils increased, the maximum increase in the value of CBR is 182% at the percentage of 0.6% PPF.

4- The optimum percentage of adding PPF is found to be 0.6% as it gives the higher increasing in the values of $\phi^\circ$ and CBR with insignificant influence on the value of k.

6. References

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