Evaluating the Use of Polypropylene Polymer in Enhancing the Properties of Swelling Clayey Soil

Duaa Al-Jeznawi¹,a, Tiba N. Jasim²,b, and Qassun S. Mohammed Shafiqu¹,c

¹Department of Civil Engineering, Al -Nahrain University, Baghdad, Iraq.
²Department of Oil Engineering, Al-Farabi University College, Baghdad, Iraq.
³duaa.a.al-jeznawi@ced.nahrainuniv.edu.iq, bTiba208@yahoo.com, cqassun.almohammed@eng.nahrainuniv.edu.iq
*Corresponding author

Abstract. Previous studies found considerable gaps in the knowledge concerning soil stabilization using polypropylene (PP) fiber polymer. Polymer stabilization is considered a recent method used to enhance the mechanical behavior of shrink-swell soils. This research illustrates the effect of adding Polypropylene polymer (PP) on the behavior of the prepared expansive soil through laboratory experiments using different percentages of the intended fiber polymer. Natural soil (from Al-Radhwaniyah City) was mixed with 30% by mass of artificial bentonite to prepare an expansive soil sample, and this sample was treated by reinforcing it homogenously with the PP polymer. Laboratory experiments were performed to demonstrate that the PP polymer had a significant effect on the improvement of expansive soils. Five different percentages (0.4, 0.8, 1.2, 2, and 4% to the natural soil sample) of the PP polymer were used, and two different curing periods (3 and 18 days) were considered. The liquid limit, plasticity index, swelling potential, maximum dry density, and the unconfined compressive strength increased by using 0.4% and 0.8% of PP polymer and continued to increase with curing (3 and 18 days). On the contrary, a significant reduction in these values occurred when increasing the percentages of the PP polymer (1.2, 2, and 4%). Treated soil samples had a considerably reduced swelling potential, which dropped from 19.2% (of prepared soil) to 1.01% (for prepared soil + 4% PP polymer and the sample left for 18 days as a curing time).

Keywords: Polymer; clayey soil; swelling potential; and curing time.

1. Introduction

Shrink-swell soils are found in different regions of the world. These types of soils are known as ‘problematic soils’ [1]. One typical characteristic of this material is the formation of cracks during drying and shrinkage. Al-Jeznawi et al. [2], presented that the main features of the problematic soils were due to the presence of clay particles. These types of deformations aim to enhance soil’s infiltration capability [3]. This phenomenon mobilizes the possibility of dropping the shrinkage or swelling deformations to the lower layers of soil, which may affect the foundations’ performance and leads to the problems of differential settlement [4]. The quality of on-site materials must be enhanced to have a solid and strong sub-base course, which is the main aim of soil stabilization [5]. The use of polypropylene (PP) enhances the properties of swelling clayey soils is the target of the present study.

The literature review performed in this study showed that researchers started to use various types of fiber for soil improvement. Polypropylene is considered as inexpensive as compared with other additives, and it is available in markets. Polypropylene can be mixed randomly and easily with the soil [6]. In this study, artificial bentonite soil was used to obtain an expansive soil sample by mixing it with
natural soil brought from Al-Radhwaniah-Baghdad. Different percentages of polypropylene were used such as 0.4, 0.8, 1.2, 2, and 4% by dry mass of the soil, and different curing times were considered such as instant case, 3 days, and 18 days to investigate the effect of time on the behavior of the prepared soil. In investigating the soil samples, standard compaction tests were performed to obtain the optimum moisture content and maximum dry density, which were used to prepare the main samples. Then, Atterberg limits, free swelling, and compressive strength were performed on these samples. Fig. 1 shows the natural soil, bentonite, and polypropylene fiber polymer.

Figure 1. Materials used in this research.

2. Materials and methods

2.1 Expansive soil samples
Soil samples were collected from the proposed construction site in Al-Radhwaniah City- Baghdad. The samples were taken from a 2 m depth below the natural ground level. Based on the tests performed in the civil laboratory of Al-Nahrain University for the soil sample, the results showed that the soil was classified as clayey soil with low plasticity (CL). These results were obtained by using sieve analysis and hydrometer analysis tests. Other tests were performed to investigate this type of soil's physical and engineering properties, such as specific gravity, free swelling, maximum dry density, optimum water content, and unconfined compressive strength. Table 1 shows the properties of the natural and the prepared soil sample. Soil was prepared by adding 70% of Al-Radhwaniah soil sample to 30% of an artificial bentonite soil by mass. Using this percentage of bentonite soil, the swelling proportion increased from 2.1% (for the natural soil) to 19.2% (for the prepared sample) so that the prepared soil was considered expansive soil.

Table 1. Properties of the Al-Radhwaniah soil sample and the prepared soils.

| Properties                | Liquid limit (%) | Plasticity Index (%) | Specific gravity (GS) | Unconfined compressive strength (kPa) | Maximum dry density (kg/m³) | Optimum moisture content (%) | Free swelling (%) |
|---------------------------|------------------|----------------------|-----------------------|--------------------------------------|-----------------------------|-----------------------------|------------------|
| Natural Soil              | 32               | 12                   | 2.61                  | -                                    | 1634                        | 19.2                        | 2.1              |
| Prepared soil             | 80               | 60.83                | -                     | 170.55                               | 1700                        | 20                          | 19.2             |
| Standard method           | ASTM D4318       | ASTM D4318           | ASTM D                | ASTM D854                            | ASTM D98                  | ASTM D698                    | ASTM D4546       |

2.2 Polypropylene fiber (PPF) polymer
In the current study, the most available type of fibers was used, which is (PPF) with a length of 12 mm. The polypropylene fiber used in this study as shown in Figure 1(c). It has a length of 18 mm, a diameter of 0.034 mm, specific gravity (Gs) of 0.91, the tensile strength of 350MPa, elasticity modulus of 3500MPa, fusion point of 165°C, burning point of 590°C, and excellent dispersibility. Vignesh et al.
2019, stated that polypropylene is the second widely used plastic product, and it is used mainly in the manufacturing of packaging and labeling.

3. Experimental Setup
In brief, the samples were brought from Al-Radhwaniah City, stored in plastic bags to prevent water evaporation while transporting them to the civil engineering laboratories in Al-Nahrain University. An oven set at approximately 110°C was used to desiccate the soil samples, and then the Los Angeles machine was used to pulverize these samples. Firstly, the tests were performed on the natural soil sample to gain insight into the behavior of natural soil (i.e., Al-Radhwaniah soil). Consequently, 70% of the natural soil was mixed with 30% of artificial bentonite to obtain an expansive soil sample. Polypropylene polymer was used with different percentages (0.4, 0.8, 1.2, 2, and 4% by dry mass of the soil) was used. Mixing PPF with prepared soil was difficult as compared with other powder polymers.

The dried prepared soil sample was carefully mixed (by hand) with the PPF, and then the required amount of water was added to reach the optimum moisture content. Thus, the homogenization of soil particles with the fibers was ensured. As for the curing period, the soil samples were stored in transparent seal bags to ensure the initially prepared moisture content (optimum moisture content) was equal (Figure 2). The optimum moisture content and the maximum dry density were obtained via the standard compaction test (according to ASTM D 698-1995) which were used in the free swelling tests and unconfined compression tests. Thus, a total of seven mixtures were made. An odometer device was used to perform the free swelling tests (according to ASTM D 4546-1990), which had a cylindrical mold with a diameter of approximately 49.6 mm and thickness of 19.75 mm.

![Figure 2. Transparent seal bags for storing of soil samples.](image)

4. Results and discussion
Atterberg’s limits, free swell, standard proctor compaction, and unconfined compression strength tests were performed on seven mixtures with zero curing time, five mixtures with 3 days curing time, and five mixtures with 18 days curing time. A total of 17 tests have been conducted.

4.1 Atterberg limits
Atterberg limits (liquid and plastic limits) were obtained in the lab. The Casagrande method was used to determine the liquid limit (LL). As shown in Table 2, adding Polypropylene polymer with two
different percentages, which was less than 1.2%, increased LL and PI. This percentage increased with the increase of polypropylene polymer. On the contrary, adding polypropylene polymer with different percentages equal to and higher than 1.2 (i.e., 1.2%, 2%, and 4%) decreased LL and PI. Consequently, the maximum decrease in the liquid limit and the plasticity index (from 80% to 48.9% and from 60.83% to 30.05%, respectively) was reached by adding 4% of polypropylene polymer to the prepared soil. Fig. 3 shows the relationship between LL and PI and the various percentages of the polypropylene polymer.

Table 2. Results of Atterberg’s limits tests for the natural, prepared, and treated soil samples.

| Sample No. | PP Polymer (%) | LL (%) | PI (%) |
|------------|----------------|--------|--------|
| 1 (Natural soil) | 0 | 32 | 12 |
| 2 (Prepared soil) | 0 | 80 | 61 |
| 3 | 0.4 | 85 | 65 |
| 4 | 0.8 | 86 | 66 |
| 5 | 1.2 | 77 | 52 |
| 6 | 2 | 55 | 32 |
| 7 | 4 | 49 | 30 |

Figure 3. Effect of adding Polypropylene polymer on LL and PI of expansive clayey soil.

4.2 Free swelling test

Free swelling tests were performed on the treated and prepared soil samples. The effects of adding different percentages of PP polymer on the swelling possibility of expansive soil are shown in Figure 4. Adding PP polymer is having a significant impact on the behavior of soil samples during the free swelling test. Swelling potential increased by adding PP polymer less than 1.2% by mass Figure 4. However, a significant reduction was observed by increasing the percentage of PP polymer (1.2, 2, and 4% by mass). This reduction increased with the increase of curing time, accounting for about 19.2% (for the prepared soil sample and zero curing time), and then reached 1.01% (by adding 4% of PP polymer and 18 days as curing time).

4.3 Compaction test (maximum dry density and optimum moisture content)

The effects of adding PP polymer with different percentages have been studied using the standard proctor mold. Table 4 shows the results of the standard proctor tests, which are plotted in Figure 5. Notably, that the maximum dry density increased by adding PP polymer less than 1.2% by mass. On the other hand, a significant reduction of the maximum dry density was observed after adding PP polymer with percentages of more than 1% (i.e., 1.2, 2, and 4%). That’s maybe due to the low density of PP fiber polymer. Samples with curing periods (3 and 18 days), showed that the maximum dry density was
slightly increased with time and different percentages of the PP polymer. For example, the maximum dry density reached 1895 kg/m³ by adding 0.8% of PP polymer, and the sample was stored for 18 days as a curing period. The reduction in the maximum dry density was due to the reduction in the unit weight's value when high percentages of PP polymer were added. Regarding the optimum water content, the results fluctuated and generally decreased by adding less than 1.2% of PP polymer. However, by adding PP polymer with percentages of 1.2% and 2%, the values of the optimum water content were increased to 19.5% when the percentage of PP polymer was 2%, and the soil sample left for 18 days as a curing period.

**Table 3.** Results of free swelling tests for the natural, prepared, and treated soil samples.

| Curing period (day) | Polymer (%) | Free Swelling (%) |
|---------------------|-------------|-------------------|
| 0                   | 0           | 2.1               |
| 0                   | 0.4         | 19.6              |
| 0                   | 0.8         | 20.1              |
| 0                   | 1.2         | 11.3              |
| 0                   | 2           | 5.4               |
| 0                   | 4           | 1.15              |
| 3                   | 0.4         | 19.8              |
| 3                   | 0.8         | 20.5              |
| 3                   | 1.2         | 10.8              |
| 3                   | 2           | 5                 |
| 3                   | 4           | 1.09              |
| 18                  | 0.4         | 20.1              |
| 18                  | 0.8         | 20.5              |
| 18                  | 1.2         | 10.3              |
| 18                  | 2           | 4.2               |
| 18                  | 4           | 1.01              |

**Figure 4.** Effect of adding polypropylene polymer and the curing time on free swelling of expansive clayey soil.
Figure 5. Effect of adding Polypropylene polymer and the curing time on the maximum dry density and optimum moisture content of expansive clayey soil.

Table 4. Results of standard compaction tests for the natural, prepared, and treated soil samples.

| Curing period (day) | Polymer (%) | Max. Dry density (kg/m$^3$) | OMC (%) |
|---------------------|-------------|-----------------------------|---------|
| 0                   | 0           | 1634                        | 19.2    |
| 0                   | 0           | 1700                        | 20      |
| 0                   | 0.4         | 1797                        | 18.9    |
| 0                   | 0.8         | 1887                        | 18.5    |
| 0                   | 1.2         | 1759                        | 19.1    |
| 0                   | 2           | 1648                        | 19.2    |
| 0                   | 4           | 1498                        | 16.8    |
| 3                   | 0.4         | 1799                        | 18.8    |
| 3                   | 0.8         | 1891                        | 18.6    |
| 3                   | 1.2         | 1760                        | 19.5    |
| 3                   | 2           | 1650                        | 19.3    |
| 3                   | 4           | 1502                        | 16.6    |
| 18                  | 0.4         | 1802                        | 19.1    |
| 18                  | 0.8         | 1895                        | 18.5    |
| 18                  | 1.2         | 1764                        | 19.4    |
| 18                  | 2           | 1659                        | 19.5    |
| 18                  | 4           | 1510                        | 16.9    |

4.4 Unconfined compression test
The unconfined compression test was performed to determine the unconfined compressive strength of soil samples. The results of these tests have been presented in Table 5 and plotted in Figure 6. In general, adding 0.4% and 0.8% of PP polymer has a significant effect on the unconfined compressive strength of the expansive soil samples. For the prepared soil sample, the unconfined compressive strength approximately 170.55 kPa, and then it increased to 247.8 kPa after adding 0.8% of PP polymer. This sample was tested directly without curing. Moreover, this value reached 278.1 kPa when 0.8% of PP polymer was used, and the intended sample was stored in seal bags for 18 days as the curing period. Nevertheless, the unconfined compressive strength decreased considerably by adding 4% of the PP polymer Table 5 and Figure 6.
Figure 6. Effect of adding polypropylene polymer and curing time on the unconfined compressive strength of expansive clayey soil.

Table 5. Results of unconfined compression tests.

| Curing period (day) | Polymer (%) | Unconfined Compressive strength (kPa) |
|----------------------|-------------|---------------------------------------|
| 0                    | 0           | 171                                   |
| 0                    | 0.4         | 197                                   |
| 0                    | 0.8         | 247.8                                 |
| 0                    | 4           | 160.3                                 |
| 18                   | 0.4         | 238.92                                |
| 18                   | 0.8         | 278                                   |
| 18                   | 4           | 170.3                                 |

5. Conclusions

This study aimed to the effects of using the PP polymer on the physical and mechanical properties of expansive soils. The results before (0% of PP polymer) and after (0.4, 0.8, 1.2, 2, and 4%) will be discussed in this section. The following conclusions can be drawn from this research:

- Using less than 1% of PP polymer (0.4% and 0.8% by mass of soil) increased LL and PI of expansive soil samples (from 80 and 60.83% for the prepared soil to 86.45 and 66.1%, respectively) and decreased in the plastic limit. By contrast, using higher than 1% of PP polymer (1.2, 2, and 4% by mass of soil) decreased LL and PI (from 80% and 60.45% for the prepared soil to 48.9% and 30.05%, respectively).
- As for the swelling potential, using less than 1% of PP polymer (0.4 and 0.8% by mass of soil) increased free swelling. This increase is higher when the curing period's beings 3 and 18 days. The maximum increase was about 6.8%.
- Using higher than 1% of PP polymer (1.2, 2, and 4% by mass of soil) caused a significant reduction in swelling soil ability. The percentage of soil free swelling reduced by about 94.7% when 4% of the PP polymer was used with 18 days of curing.
- The maximum dry density increased by adding 0.4% and 0.8% of PP polymer. It was about 1700 kg/m$^3$ for the prepared soil, and it became 1895 kg/m$^3$ when 0.8% of PP polymer used, and the mixture left 18 days before testing.
Using 1.2, 2, and 4% of PP polymer significantly decreased maximum dry density, which was approximately 12%. Notably, the maximum dry density of untreated soil sample was approximately 1700 kg/m$^3$ and this value dropped approximately 1498 kg/m$^3$ when 4% PP polymer was added.

The optimum moisture content fluctuated. A considerable reduction of the optimum water content was observed when 4% of PP polymer was used.

The results showed that unconfined compressive strength increased—from 170.55 kPa (for untreated soil) to 278.1 kPa (for treated soil added with 0.8% of PP polymer and stored for 18 days before testing).

Using 4% of PP polymer decreased the unconfined compressive strength. This case could occur without curing.

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