The Impact of Using Recycled Plastic Fibres on the Geotechnical Properties of Soft Iraqi Soils

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Abstract. Soft clay may experience uncontrollable settlement and loss of critical bearing capacity due to the fact that clayey soils possess remarkable plasticity which increases moisture retention and causes decreases in strength, volume changes, and loss of compressive strength. Thus, these types of soils need to be improved before use in construction. A huge volume of waste results from daily human life, which leads to disposal problems and causes environmental contamination and health risks; thus, the usage of such industrial wastes as supporting construction materials could effectively contribute to environmental preservation and minimisation of these harmful effects. In this work, plastic fibre was used as the additive for the soft clayey soils of Baghdad, using different percentage concentrations of 1, 2 and 4% (the proportion of stabilising matter to soil net weight) of the dried soil. This work studied the properties of clayey soil with and without the additives. The studied soil properties were grain size distribution, Atterberg limits, unconfined compressive strength, compressibility, and California bearing ratio. From the laboratory tests results, the effect of plastic fibre content had a remarkable effect on the liquid content, plastic behaviours, and plasticity index. The liquid limits decrease as the percentage of plastic fibre increases while the plastic limit increases, this causes a great reduction in plasticity index. This decrement approached 50% with the addition of 4% plastic fibre to the clayey soil. Inclusion of different percentages of plastic fibre led to noticeable reductions in maximum dry unit weight up to approximately 11% by adding 4% plastic fibre, while the optimum moisture content reduction approached 7.5%. The effect of plastic fibre was also clearly shown on the unconfined compressive strength of soils; the increase in the unconfined compressive strength approached 180% with the addition of 4% plastic fibre. The ratio of compression index (c_c) to recompression index (c_r) reduced as the percentage of plastic fibre increased up to 2%, although it increased after this point. Finally, the California Bearing Ratio (CBR) increased as the plastic fibre content increased, with this increment approaching 210% when adding 4% plastic fibre.

Keywords. soft clay, plastic fibre, Atterberg's limits, unconfined compressive strength, CBR value

1. Introduction
The centre and southern parts of Iraq renowned for their soft clays. These soils are plastic with moderate to high clay fractions and can be identified by their fine-grain particle size. They have high compressibility and low shear strength (generally less than 25 kPa). These soils, from an engineering point of view, are unsuitable for supporting foundations and construction structures due to their poor engineering properties. Many attempts have been made to enhance these soils using ground improvements or replacement techniques, but these methods are expensive. Recycled materials and construction debris may thus provide a vital alternative for engineering if they can enhance soil properties and decrease the total cost.

2. The Aim of the Study
The major goal of this work is to improve the behaviours of weak soil by using local, available, and cheap materials to minimize the cost of construction for any project. Recycled plastic fibre was thus selected as an additive material for study at varying percentages to allow detailed information about its effect on the geotechnical properties of soft clays to be obtained, with the goal of reducing the problem of soil failure in Iraq. In this research, soil improvement aims to achieve the following objectives:

1. To increase both the strength and stability of soil and to reduce the cost of construction by making best use of the available materials in the country.
2. To modify or increase the properties of soil using locally available admixtures.
3. To evaluate the physical properties of these mixtures, including density, expansion, shrinkage, and stability of improved soil samples.

3. Methods of Soil Improvement
There are many techniques for soil improvement, and these can be classified into three main categories:
1. Ground reinforcement.
2. Ground improvement.
3. Ground treatment.
These techniques require skilled man-power and equipment to develop enhancement of the supporting soil. Soil reinforcement is a technique for improving the strength and stability of soft soils. Human beings have learned some of these techniques from nature, by examining animal, bird, and tree root interactions such as those that hold the tree in the soil during the action of heavy rains and winds; the latter is a good example of soil reinforcement provided by nature, as the interaction resulting from both adhesion and friction resists the developing tensile stresses and minimises shear failure. Using randomly distributed discrete fibres also increases the shear strength parameters of soil, similar to the case of reinforced concrete construction.
There are several examples of ancient soil reinforcement, such as the Great Ziggurat of Babylon (woven reed mats) and the Great Wall of China (external soils as reinforcement).

Figure 1. Ziggurat in Iraq

4. The importance of soil reinforcement:
Soil reinforcement is one of the techniques used to improve undesirable characteristics of soils such as issues with shear strength, compressibility, and density. There are several different methods of soil reinforcement, such as using stone columns, adding micro piles, soil nailing, and using reinforced earth (Ling et al 2003)[1]. The most common methods are listed in Figure 2.
Figure 2. Different procedures of soil reinforcement (Hejazi et. al.)

Soil reinforcement is used in the field for geotechnical engineering purposes to obtain the desired properties of soils prior to construction processes. This type of reinforcement has a significant effect on the tensile strength, shear strength, and bearing capacity of soils. Using waste materials to do this also causes a great reduction in cost and controls environmental contamination and health risks.

5. History of fibre use:
As plants can be considered non-polluting and renewable resources “there have been many experimental investigations and increasing interest in using natural fibres and industrial wastes for reinforcement of soil layers such as coconut (coir) fiber” (Babu and Vasudevan)[2]. Prabakara and Sridhar [3], used 0.25%, 0.5%, 0.75%, and 1% sisal (a lingo cellulosed fibre used as reinforcement) by weight of raw soil with four different lengths, 10,15, 20, and 25 mm, to reinforce problematic local soil. They revealed that sisal fibres reduced the soil's dry density. Aggarwal and Sharma [4] experimented with using different lengths of jute fibres (5 to 20 mm) with percentages of about 0.2 to 1% to reinforce soil, with bitumen material used to coat and protect fibres from microbial attack and degradation. The main conclusions of their work were that jute fibres reduced the dry density and increased the optimum moisture content (OMC) of the soil. The maximum CBR value was obtained when 10 mm long jute fibre at 0.8% was used. Hejazi et. al (2012)[5] reviewed the uses and benefits of natural and synthetic fibres, and their main conclusion was that natural and synthetic fibres can be used in six geotechnical engineering fields: pavement layers, earthquakes, soil foundations, protection of slopes, retaining walls, and railway embankments. Kalita et. al., [6] compared the effects of using different types of natural fibre (coconut fibre), synthetic fibre (geotextile , geogrid) and waste materials (waste cement bags). All of these types of fibres were used to improve red loam soil, and the main conclusion drawn was that all types of reinforcement successfully increased the soil strength as the fibre content increased, and that maximum strength was obtained when using 1% by volume of waste cement bags. Furthermore, using this material reduced landfill costs by utilizing waste bags in a cost-effective manner. Salim et.al. [7] studied the geotechnical properties of clayey soil reinforced by nylon carrier bag by-products; the main conclusion drawn by them was that as the percentage of nylon fibre increased, the liquid limit decreased, and at the same time, the plastic limit increased such that the plasticity index decreased. Furthermore, increasing the quantity of nylon fibre decreased the maximum dry density and increased the optimum moisture content. The compression index c decreased as the nylon fibre quantity increased, providing a maximum of 43% when 5% nylon waste material was added. The undrained shear strength also increased as the proportion of nylon fibre increased.

6. Experimental Work
Experimental work was conducted using standard procedures. The untreated samples were tested for their classification and index properties, as well as their consistency properties. The testing programme was carried out on samples of clayey soils, after mixing with varying amounts of recycled plastic strips; tests included Atterberg’s limits, specific gravity, static compaction, consolidation, unconfined compression, and C.B.R. test.
6.1 Soil Used:
The soil sample used for this study was taken from Baghdad city. Figure (3) shows the distribution of grain size of the soil.

![Figure 3. Distribution of Grain size of used soil.](image)

The physical properties of the soil are summarized in Table 1. according to the Unified Soil Classification System; the soil is classified as CL soil.

| No. | Index property                  | Index value |
|-----|---------------------------------|-------------|
| 1   | Liquid limit % (LL)             | 47          |
| 2   | Plastic limit % (PL)            | 25          |
| 3   | Plasticity index % (PI)         | 22          |
| 4   | Specific gravity (G.s)          | 2.69        |
| 5   | Gravel (larger than 4.75mm)%    | 0           |
| 6   | Sand (0.075 to 4.75mm)%         | 4.2         |
| 7   | silt (0.005 to 0.075mm)%        | 29.5        |
| 8   | Clay (less than 0.005mm)%       | 66.3        |
| 9   | Soil symbols (USCS)             | CL          |

6.2 Soil Reinforcement Used

Since the beginning of the current century, the amount of waste has been increasing rapidly due to new life styles and a lack of proper treatment and disposal of materials, which has led to serious problems. In particular, the low recycling ratio of plastic wastes is an issue, despite the fact that many of these can reclaimed while unsuitable ones go for incineration. It is important to use wastes effectively, especially in light of recent developments in engineering fields. The best way to handle plastic waste is to utilize it for engineering applications after shredding in order to conserve scarce natural valuable resources. Waste plastic was collected from nearby disposal sites and made into strips using secateurs and a mill machine of different aspect ratios, as shown in Figure 4.
6.3. *Atterberg's Limits*: The liquid and plastic limits, and plasticity index are used to classify fine soils and to obtain correlations with engineering properties.

6.3.1 *Liquid limit (L.L)*: Liquid limit tests were carried out on clayey samples passing a 0.425 mm (No. 40) sieve using 0, 1, 2 and 4% recycled plastic fibre; Casagrande's liquid limit apparatus was used as shown in Figure (5).

6.3.2 *Plastic limit (P.L)*: The plastic limit tests were carried out on clayey samples passing a 0.425 mm (No. 40) sieve mixed with 0, 1, 2, and 4% recycled plastic fibre, as shown in Figure (6).
6.4 **Specific Gravity:**
The specific gravity (Gs) test was conducted as described in ASTM 854[8], and as shown below in Figure 7.

**Figure 6.** Plastic limit specimens

6.5 **Compaction:**
These tests were performed as described in ASTM 1557[9]. Soil’s degree of compaction influences its engineering properties such as its California Bearing Ratio value, compressibility, permeability, compressive strength, stiffness, shrinkage, and swell potential. Thus, it is desirable to achieve the maximum degree of relative compaction necessary to ensure optimum performance of the soil, as shown in Figure 8.

**Figure 7.** Equipment used for specific gravity test.

6.6 **Unconfined compression strength:**
UCS tests were performed on the samples as described in ASTM D 2166[10], and as shown in Figure 9.

**Figure 8.** Compaction test
6.7 Consolidation:
A standard ASTM D 2435[11] test method for testing the one-dimensional consolidation properties of soils was used. The samples were prepared with static compaction, and the disk employed to fit in the mould for this work was made at an Iraqi industrial market (Shaikh Omar Street). This disk was used to compress the soil into the mold to keep the moisture content fixed and as shown in Figure 10. Based on measured data, the consolidation curve (pressure void ratio relationship) was plotted. This data was very useful in determining the compression index, recompression index, and pre-consolidation pressure for the soil and was also used to calculate the soil coefficients of consolidation and the coefficient of secondary compression.

6.8 California Bearing Ratio (CBR):
The California Bearing Ratio is an indicator of the bearing capacity and strength of the soil. As soft clay may be used as a sub grade under road pavements, the weakness of this layer may cause an increase in pavement thickness, which causes an increase in construction cost. A series of California bearing ratio (ASTM standards D1883-05 for labs)[12] tests were conducted on the soils with and without plastic fibre additives of various percentages 1, 2, and 4%.

Figure 9. Sample under shearing in unconfined compression apparatus
7. Presentation and Discussion of Results:

7.1 Effect of Using Recycled Fibres on:

7.1.1 Specific Gravity:

Table 2 clarifies the effect of using recycled plastic fibre on specific gravity. As the percentage of plastic fibres increases, the specific gravity decreases. This can be attributed to the low values of the specific gravity of plastic fibre used.
Table 2. Effect of recycled plastic fibre on specific gravity

| % of fiber used | Specific Gravity |
|----------------|------------------|
| 0%             | 2.69             |
| 1%             | 2.53             |
| 2%             | 2.4              |
| 4%             | 2.28             |

Figure 11. The effect of plastic fibre content on specific gravity

7.1.2 Atterberg's Limits:
The results of adding recycled fibre to the Atterberg limits are clearly shown in Figures 12 to 14. These figures demonstrate the effects of adding different percentage of recycled fibres (1, 2, and 4%) on the liquid and plastic limits and the plasticity index. It is clear that the liquid limits decrease as the percentage of additive increases, while the plastic limits increase with increase in recycle fibre percentage, which causes a noticeable decrease in the plasticity index. This behaviour ensures that this additive acts as a binder material.

Figure 12. Effect of plastic fibre additive percentage on liquid limit.
7.1.3 Compaction Characteristics:
Table 3 and Figures 15 to 18 show the results of standard compaction tests. The results clearly indicate that with an increase in the percentage of recycled fibre, the maximum dry unit weight will decrease and the optimum water content will decrease; this reduction is attributed to the recycled fibre replacing the soil particles during sample preparation, and compared to the native soil, these have lower specific gravity.

Figure 13. Effect of plastic fibre additive percentage on plastic limit.

Figure 14. Effect of plastic fibre additive percentage on plasticity index.
Table 3. Effects of different percentages of additive on and O.M.C.

| % of Fiber Additive | Max. $\gamma_d$ \( kN/m^3 \) | Optimum water Content \( (O, \omega, C) \) |
|---------------------|-------------------------------|------------------------------------------|
| 0                   | 17.2                          | 21.3                                     |
| 1                   | 16.43                         | 20.8                                     |
| 2                   | 15.81                         | 20.1                                     |
| 4                   | 15.3                          | 19.7                                     |

Figure 15. Compaction curve for untreated soil

Figure 16. Effect of plastic fibre on compaction curve
7.1.4 Unconfined Compressive Strength (CU):
The results of the unconfined compression test on native and improved soils with recycled plastic fibres at 1, 2, and 4% are demonstrated in Table 4, and Figures 19 and 20. The results indicate that adding 1% plastic fibre causes an increase in unconfined compressive strength of about 42%, while this percentage increases to 83% on adding 2% of plastic fibre, and up to 180% by increasing the plastic fibre to 4%.

| Plastic fiber % | Unconfined Compressive Strength $C_u$ (kN/m$^2$) | % of increase in Unconfined Compressive Strength $C_u$ (kN/m$^2$) |
|-----------------|---------------------------------|--------------------------------------------------|
| 0               | 19.61                           |                                                  |
| 1               | 27.94                           | 42%                                              |
| 2               | 35.88                           | 83%                                              |
| 4               | 54.91                           | 180%                                             |

Figure 17. Variation of optimum moisture content with recycled plastic fibre

Figure 18. Variation of the maximum dry unit weight with recycle plastic fibre percentage.
Figure 19. The effect of plastic fibre additive on stress-strain.

Figure 20. The effect of plastic fibre content on shear strength of soil

7.1.5 Compressibility Characteristics:

Figure 21 and Table 5 represent the results of consolidation tests on native and treated soils with recycled plastic fibre additives of different percentages.

Table 5. Results of consolidation tests for native and treated soil.

| Plastic Fiber% | 0%    | 1%    | 2%    | 4%    |
|----------------|-------|-------|-------|-------|
| $c_c$          | 0.157995 | 0.185119 | 0.088435 | 0.104141 |
| $c_r$          | 0.03336  | 0.044138 | 0.039413 | 0.016432 |
| $c_c/c_r$      | 4.736061  | 4.194096  | 2.243803  | 6.337695  |
7.1.6 Effect on California bearing ratio (CBR):
The CBR test, which is simple, fast, and reliable is used to verify the stabilisation of weak soils after the addition of physical and chemical additives (Raymond et al, [13]; Joel Beeghly et al, [14]. Figure 22 shows the test results for CBR using three different percentage of plastic fibre. The results indicate that as the percentage of plastic fibre increases, the CBR of soil increases.

Figure 21. Relationship of e-log p for treated and untreated soils with different percentages of plastic fibre.

Figure 22. The effect of using different percentages of plastic fibre on penetration stress.
8. Conclusions
The use of recycled waste materials has become a pressing issue due to environmental and cost benefits. This paper thus studied the effects of the inclusion recycle plastic fibre as an additive for Iraqi clayey soils. After conducting several tests using different percentages of recycle plastic fibres, the following conclusions can be drawn:

1. Using different percentages of recycle plastic fibres causes a reduction in liquid limits with an increase in plastic limits as the proportion of recycled fibre increases; this causes a reduction in the plasticity index and an increase in workability, which enhances the physical properties of soils.

2. Inclusion of recycled plastic fibres causes a reduction in the maximum dry unit weight and a decrease in optimum water content, which causes the compaction curves to move down and shift to the left.

3. Using recycled plastic fibres to improve soft soil causes a reduction in the specific gravity as the proportion of additive material increases.

4. The unconfined compressive strength is increased to approximately 180% by adding 4% recycle plastic fibale.

5. The CBR increases by about 200% on adding 4% plastic fibre.

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