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Investigating the Effect of Biological Stabilization of Fine-Grained Soils Reinforced with Polypropylene Fibers

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Abstract

The use of a microbiological process to improve soil properties is a cost-effective, non-destructive and environmentally friendly solution for a variety of geotechnical problems that can be used to increase the unconfined compressive strength (UCS) of the soil. In this study, Sporesarcina pasteurii bacteria was injected as a stabilizer to reinforced soil with polypropylene and then the uniaxial strength of the specimens were investigated. The results show that the injection of the bacteria increases the uniaxial strength of fine-grained soil reinforced with the fibers. This increase depends on the duration of treatment, as the duration of treatment increases the effect of stabilization by biological methods.

1. Introduction

In traditional soil improvement method several factor such as high cost of the required devices, low efficiency, uncertainty in performance, consequently, conservatism in design and low influence due to the high concentration of materials and their low permeability provide a new opportunity to use biological methods [1]. The biological solution has a high penetration radius (about 5 m) because of the low viscosity, so it requires less pressure to enter the soil (less than 2 bar). Applying the microbiological process to improve soil properties is a cost-effective, non-destructive and environmentally friendly solution for geotechnical problem such as increase in unconfined compressive strength and toughness of the soil, increase in soil bearing capacity, decrease in land subsidence, decrease in seismicity caused by earthquake, decrease in the potential for inflation under foundation and roads, and increase in the unconfined compressive strength. Also, the use of bio-improvement method is a suitable way for areas where are restricted to apply traditional methods due to topography or high costs [2].

Whiffin (2004) conducted several studies in which P. vulgaris and P. S. Pasteurii bacteria were compared to each other and it was found that S. Pasteurii bacteria is suitable for biological stabilization due to high urea activity, non-pathogenicity and less execution cost. He also considered the infection on the culture effectless up to 50%, and in this way he stated that the method is practical in large and industrial scale [3].

Dejong and et al. (2006) introduced a new method for achieving natural calcite sedimentation in which loose and slush sand are improved and stabilized by using S.Pasteurii bacteria and the necessary culture medium with urea and calcium chloride as a solution of cementation. In this method, three-axial compressive strength test and sandy soil were used to measure soil strength; based on the results of these experiments, the shear strength of the soil is greater 4 times compared to the control state, and also biological sample shows a better performance compared to the modified samples by microbial calcite sedimentation and plaster [4].

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Yasuhara et al., 2012, performed uniaxial strength and permeability test on modified sand soils which resulted in a significant reduction in soil permeability and increase in uniaxial strength from 400 kPa to 1.6 mPA [5].

Jian Li and Chaosheng Tang (2013) presented the research about the effects of reinforcing fibers on the tensile strength of soil. Consolidated soils in geological structures such as dams can cause cracks due to tensile stress which the soil cannot withstand. Mixing the fibers can greatly increase the tensile strength and reduce soil fragmentation and deformation. As a result, when the soil fibers increase from 0 to 0.2 weight percent, tensile strength increases by 56.7%. The use of these fibers is a good way to optimize the soil, and also it has the potential to increase soil resistance against cracking and strengthen the soil. [6].

Nuno Cristelo and Vitor Cunha (2015) studied the effects of discrete fiber response on uniaxial strength and seismic wave velocity of sandstone (Argillaceous sandstone) by stabilized cement. The results show that the addition of fibers cannot have any effect on actual changes in material hardness and seismic wave velocity, so it should be noted that this technique can be used to reinforce soil by the fibers. Moreover, adding fibers increases uniaxial strength for the any amount of cement used for stabilization. However, experiments show that although the results of the fiber increase the resistance results are improved, whereas there is an optimal amount of fiber after which the strength become lower [7].

Anggraini et al. (2014) provided researches about the effect of coconut fibers on tensile and compressive strength on calcareous soft soil. For this purpose, Brazilian experiments were carried out to obtain tensile strength of natural soil and calcareous soil reinforced with the coconut fibers. The results of the experiments show that the highest increase in strength was obtained with a 1% mixing rate. These experiments were also applied to cement cylinders that were used for soil stabilization instead of lime [8].

In this study, the effect of biological stabilization of fine-grained soils reinforced with polypropylene fibers has been investigated.

2. Materials

2.1. Soil

In this research, a clay has been used which was obtained from Zanjanrood area. Grading, specific density, compression and Atterberg limits experiments have been done in order to obtain the technical specifications of the soil. The procedure of experiments to obtain the basic soil specification is shown in figures 1.

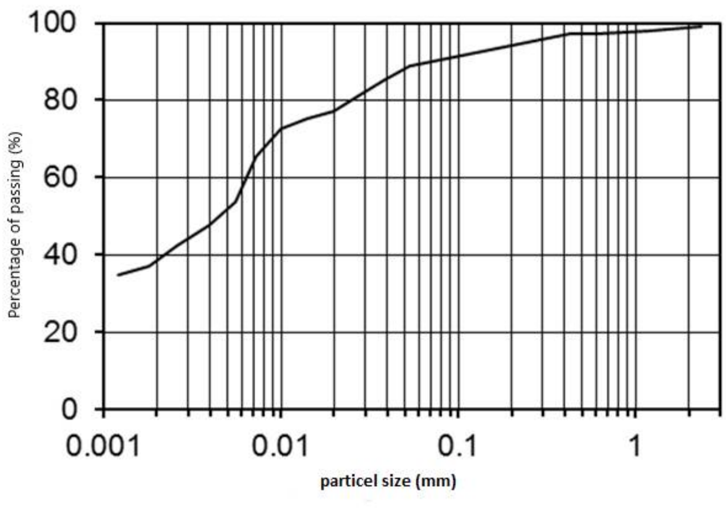


Figure 1. Grading curve of the used clay

The density of soil particles is determined as 2.657, the paste limit 36%, the seismicity limit 20%, the paste indication 16%, the optimum moisture content 11.5%.

2.2. Microorganisms and the treatment materials

The microorganism in this study is from the Bacillus bacteria and has the scientific name of Sporosarcina pasteurii. The strain of this bacteria was prepared by lyophilization from the collection center of fungi and industrial bacteria in

Iran, numbered PTCC 1645 (DSM 33). After activating the strain in the laboratory, the activated bacteria was placed in a suitable culture medium containing yeast extract and Ammonium chloride into an incubator-shaker device. Then, based on the growth curve, bacteria were harvested and separated from the culture medium after 48 h at the end of the growth phase and at the beginning of the lag phase by a centrifuge. The biomass was diluted in normal NaCl solution 0.9, and bacteria concentration adjusted to 1.5 by a spectrophotometer at 600 wavelengths. After this step, the urease activity of both suspensions is measured by testing urea activity. The bacteria are then kept in a covered Erlenmeyer flask inside the refrigerator at 4 °C.

In the experiments, in fact, the Sporosarcina pasteurii bacteria acts as a catalyst in the reaction of calcium and urea, causing the hydrolysis of urea and producing calcium carbonate as sediment. For this reason, urea and calcium solutions should be added to the soil to begin the urea hydrolysis reaction.

2.3. Polypropylene fibers

These fibers, which are produced chemically, are directly prepared from a company called Vand fiber P.P and, used in experiments. The amount of use of this fiber is generally determined as a weight percentage; the 1 weight percent has been selected for these experiments according to previous studies on the effect of this fiber on improving the soil strength behavior, as well as the problems of way of mixing them with soil. The below specifications are presented by the manufacturer. This fiber is used to reduce cracking due to thermal shrinkage in all concrete and also has other uses as mentioned in following [9, 10].

- Concrete of industrial floors, highways, airports
- Shotcrete of shell structures, soil stabilization and lining
- Plaster, cement work and concrete and cement facade
- Repair of all damaged structures, including docks

Based on the information provided by the company, the technical specifications of the polypropylene fibers are as follows:

Table 1. The technical specifications of the polypropylene fibers

Chemical base	Poly propylene
Specific weight	900 kg/m^2
length	12 mm
diameter	About 20 μm
Tensile strength	350 N/mm^2
Melting point	160 ®c

It should be noted that these fibers do not have any environmental effects. Also, these fibers have lower lengths, but due to the fact that the differential stress and as a result shear strength increases by increasing the length and amount of the fibers, and this trend is more evident in reinforced samples with higher amount and longer length (12 mm and 6), a length of 12 mm was used in the tests of this research [11, 12].

Figure 2. Poly propylene fibers (12 mm)

3. Samples preparations

In order to prepare cylindrical samples by diameter of 38 mm and 76 mm in height, the mixture was first prepared in optimum moisture content obtained from compression experiments. Then, the cultured bacteria was mixed with wet soil and pummeled into 4 layers inside the mold. After pummeling each layer, the surface of the layers is scratched to create more conflictive state between the layers. At the end of pummeling and prototyping, the bacteria was injected into the sample and after 24 hours, the mold was rotated and the bacteria was injected into the sample by the other direction. To prepare samples containing bacteria and polypropylene fibers, the fiber was added to the mixture at a 1 weight percent of dry soil. In order to investigate the effect of treatment time, the samples were injected similarly with the same process. The interval time of opening the columns was 0, 7, 14 and 28 days.

4. Uniaxial compressive strength test

Uniaxial compressive strength test was performed according to ASTM D-2126 in order to determine the compressive strength of non-stabilized cylindrical samples and stabilized reinforced samples by polypropylene fibers and bacteria.

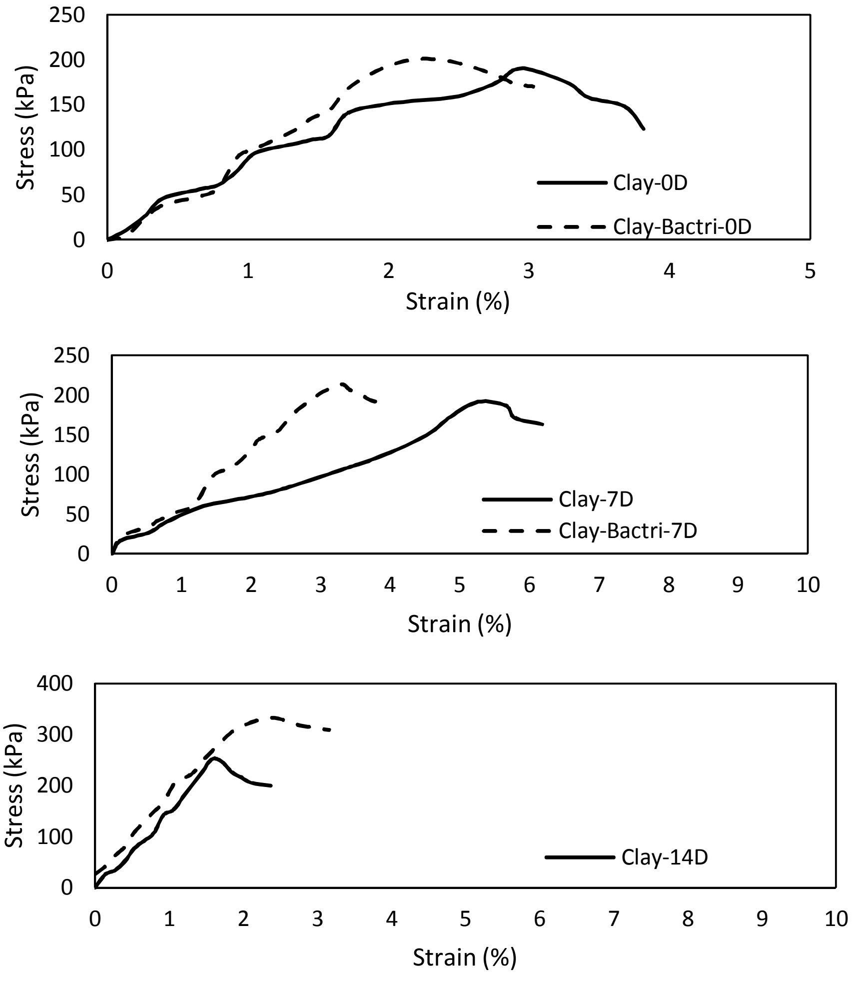
5. Sample storage conditions

The samples made inside the mold, which sealed with four metal holder, are placed inside the nylon and kept at an ambient temperature (18-30 °C) and in still place for fixation.

6. Presentation and interpretation of laboratory results

6.1. The effect of adding bacteria on unconfined compressive strength

In order to investigate the effect of biological stabilization on uniaxial strength, non-stabilized and stabilized samples by the bacteria were prepared and after treatment for 0, 7, 14 and 28 days, they were studied by uniaxial compressive strength test. In figure 3, stress-strain diagrams of non-stabilized and stabilized samples with the bacteria were shown during the treatment days.



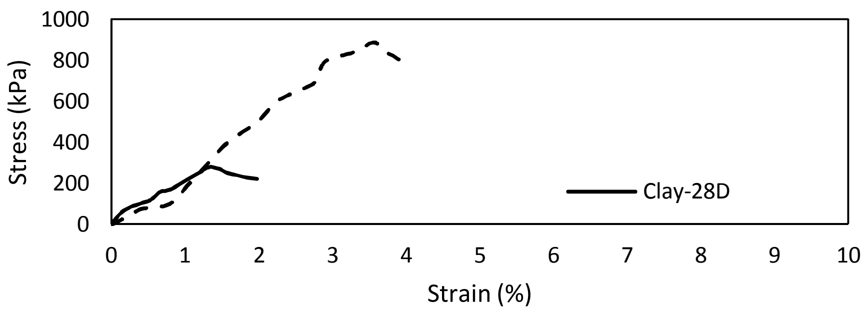


Figure 3. Stress-strain diagram of non-stabilized and stabilized samples by the bacteria during 0, 7, 14 and 28 days of treatment

As seen in the diagrams above, soil stabilization with the bacteria has increased UCS of soil. This increase in strength has continued dramatically due to the passage of time (treatment aging). The cause of this phenomenon can be the formation of chemical bonds between soil particles due to the presence of bacteria. In Figure 4, the final strength variations of samples with and without bacteria are presented at different treatment times.

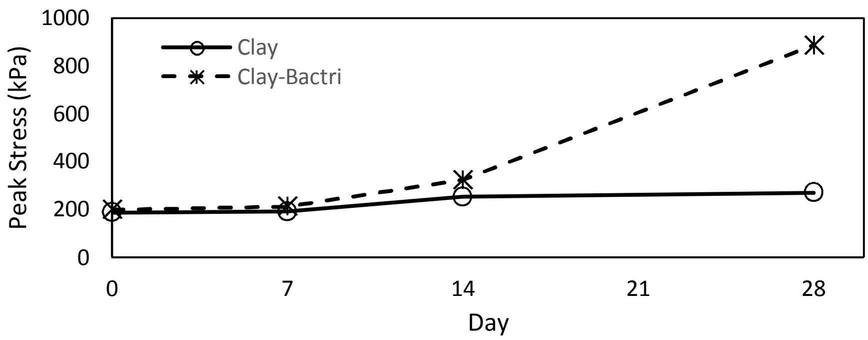
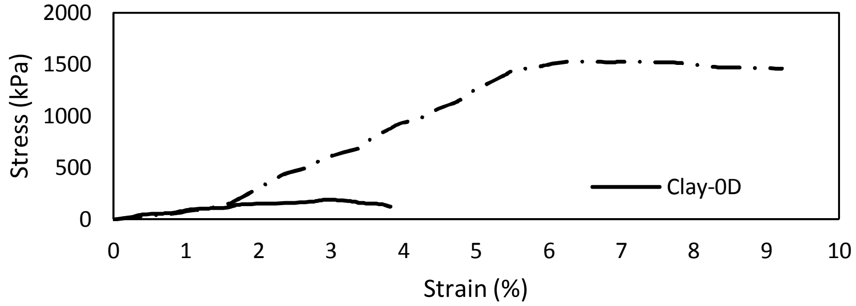


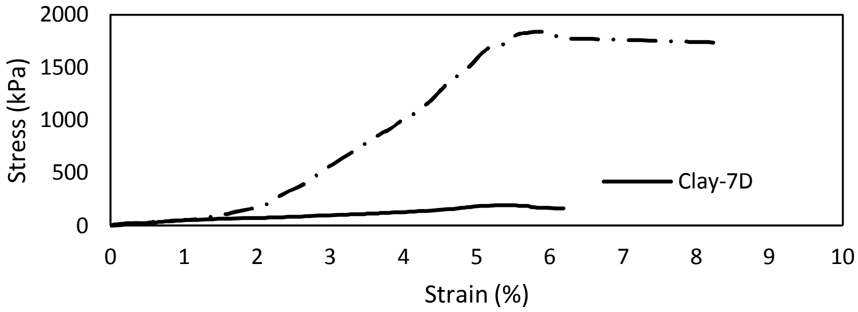
Figure 4. The final strength variation of non-stabilized and stabilized samples by the bacteria at different treatment days

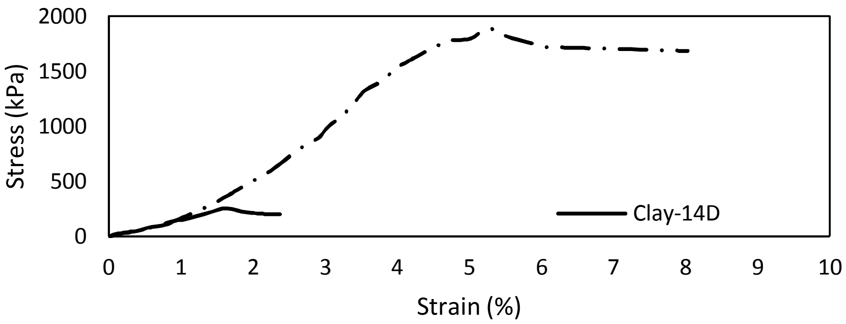
According to the above chart, it can be concluded that the greatest increase in strength due to the presence of bacteria is occurred during the 28-day treatment period. The increase in strength against bacterial stabilization in different treatment times 0, 7, 14 and 28 compared to free-bacteria samples at the same age was 6%, 11%, 30% and 228%, respectively.

6.2. The effect of adding poly propylene fibers on unconfined compressive strength

In order to investigate the effect of soil reinforcement by polypropylene fibers, cylindrical samples were prepared containing 1% polypropylene fibers and they subjected to uniaxial loading. Stress-strain charts of samples without and with 1% polypropylene fibers are shown in figure 5.







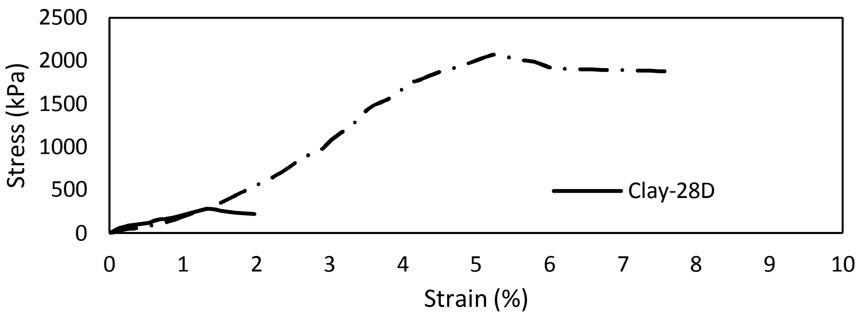


Figure 5. Stress-strain chart of non-reinforced and reinforced samples with% 1 polypropylene fibers during different treatment periods

According to the above charts, it can be seen that the presence of polypropylene fibers is effective in the increase of UCS. The reason for this increase of strength can be expressed in improving the strength behavior due to the interaction of soil and fiber with respect to the high strength of polypropylene fibers against tension, helping to improve tensile strength and ultimately soil compressive strength. Also, due to the high tensile strength of the fibers, the behavior of the sample has been changed from a brittle to a smooth state. In other words, the rapture in deformations has more occurred for the non-reinforced samples. Figure 6 shows the variation in the final strength of the non-reinforced and reinforced samples by polypropylene fibers during different treatment periods.

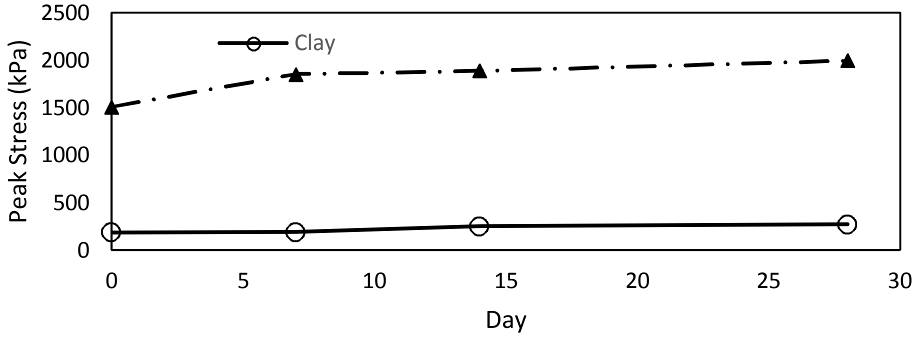


Figure 6. The final strength variation of the non-reinforced and reinforced samples by 1% of polypropylene fibers after 0, 7, 14 and 28 days of treatment

As it can be seen from the above figures, the treatment time has not had a significant effect on the increase in strength. The reason can be seen in the effect of the fibers as a non-chemical substance, which its properties do not change by passing the time.

6.3. The effect of adding polypropylene fibers and biological stabilization on the UCS

In order to investigate the effect of simultaneous stabilization and reinforcement of the soil by the bacteria and polypropylene fibers, the cylindrical samples containing 1% polypropylene and the bacteria were prepared and after 0, 7, 14 and 28 days treatment, they were subjected under uniaxial loading. In figure 7, the stress-strain charts of the stabilized samples with the bacteria containing1 % polypropylene fibers are displayed during different treatment periods.

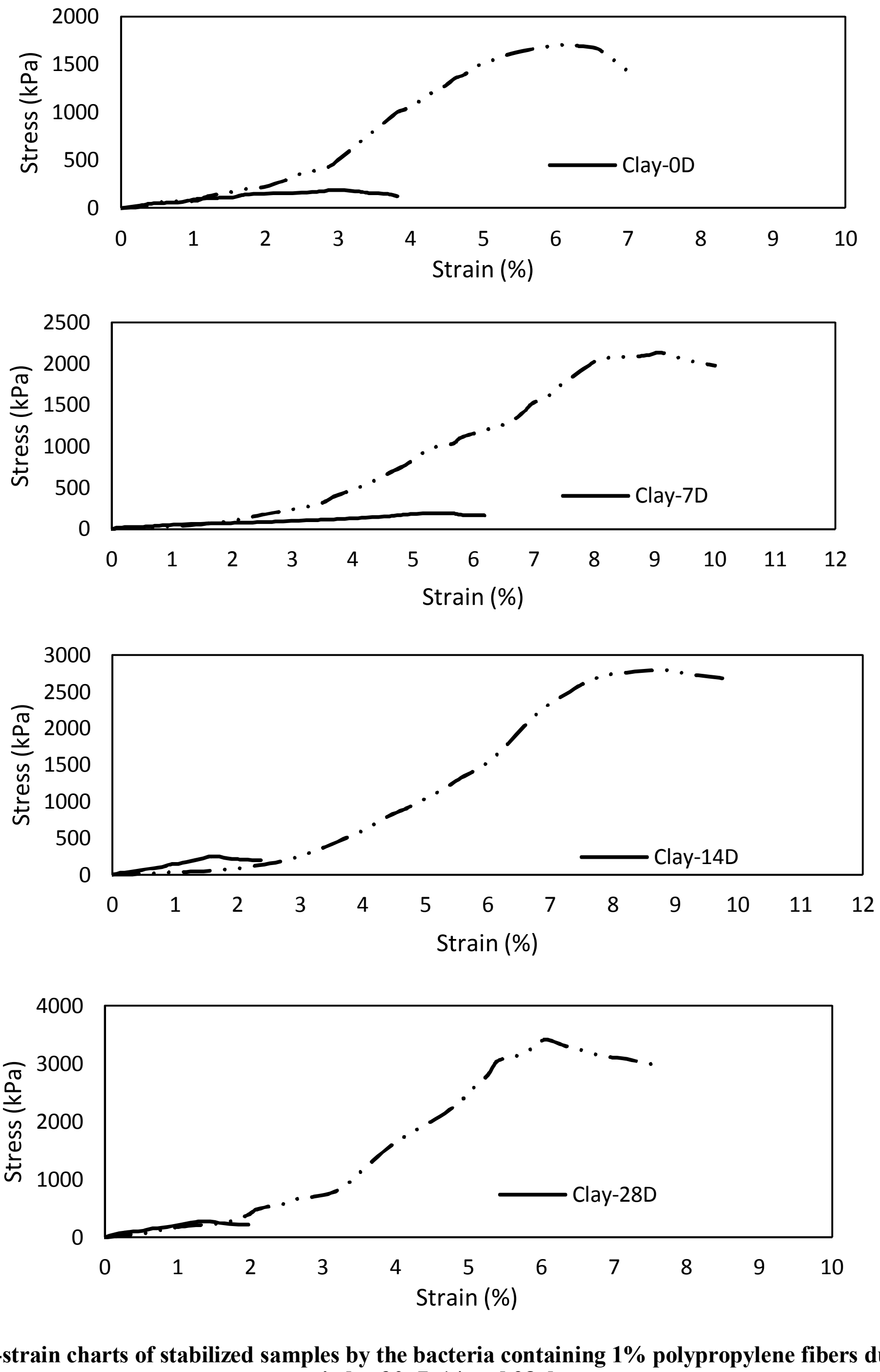


Figure 7. Stress-strain charts of stabilized samples by the bacteria containing 1% polypropylene fibers during treatment periods of 0, 7, 14 and 28 days

As shown in the above charts, the reinforcement of the stabilized soil by the bacteria has greatly increased the UCS. This increase in strength continues by passing treatment time so that the highest strength obtained in the 28-day period. This increase in strength can be attributed to the formation of chemical bonds between soil particles and the bacteria. In Figure 8, the final strength variations of the samples without and with bacterial and polypropylene fibers are shown during different treatment days.

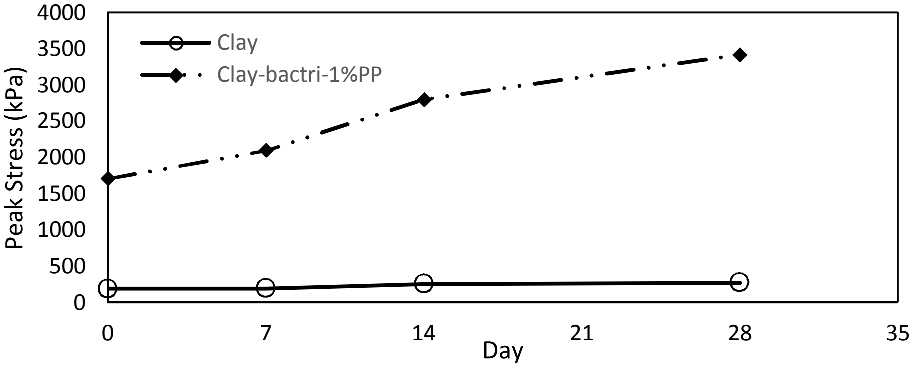
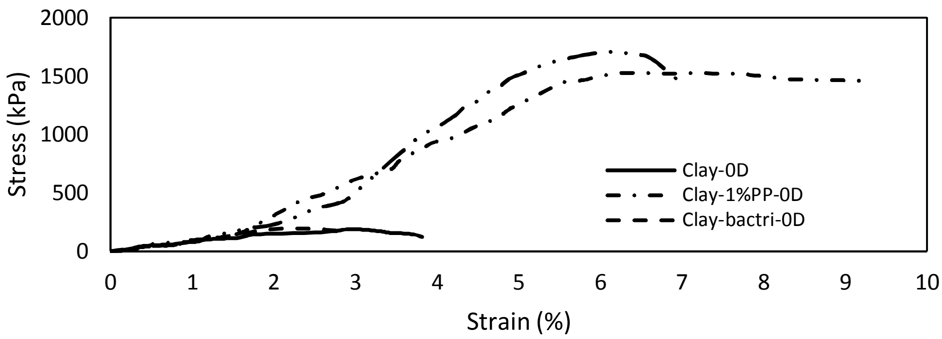


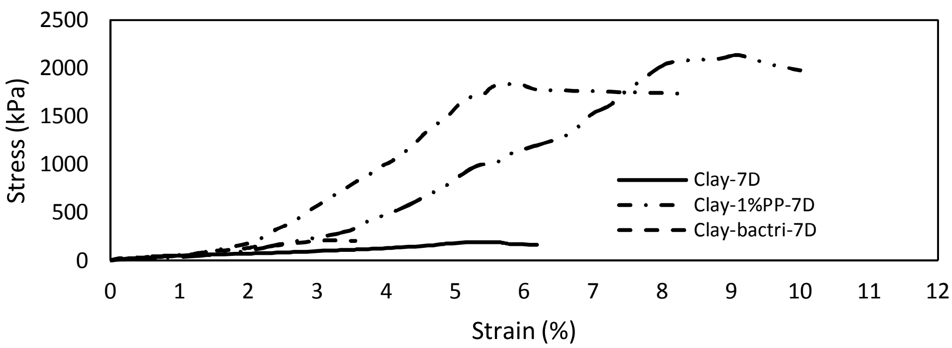
Figure 8. Final strength variation of the samples without and with bacteria and polypropylene fibers after 0, 7, 14 and 28 days of treatment

According to the results of the previous sections, the final strength of the stabilized and reinforced samples by the bacteria and the polypropylene fibers was increased by increasing the duration of treatment. The highest strength is observed for the sample containing the bacteria and polypropylene fibers at the duration of 28 days with the rate of 100% relative to the sample at 0 day treatment time.

6.4. Comparison between the effect of biological stabilization and biological stabilization with reinforcement by polypropylene fibers

In order to compare the effect of soil stabilization with bacteria and the effect of simultaneous use of bacteria as a stabilizing method and polypropylene fibers as the elements of reinforcement, stress-strain charts were drawn for the above mentioned cases. The stress-strain charts of non-stabilized samples, stabilized samples by bacteria, reinforced samples with polypropylene fibers and simultaneous stabilized and reinforced by bacteria and polypropylene fibers are shown in Figure 9 during different treatments periods.





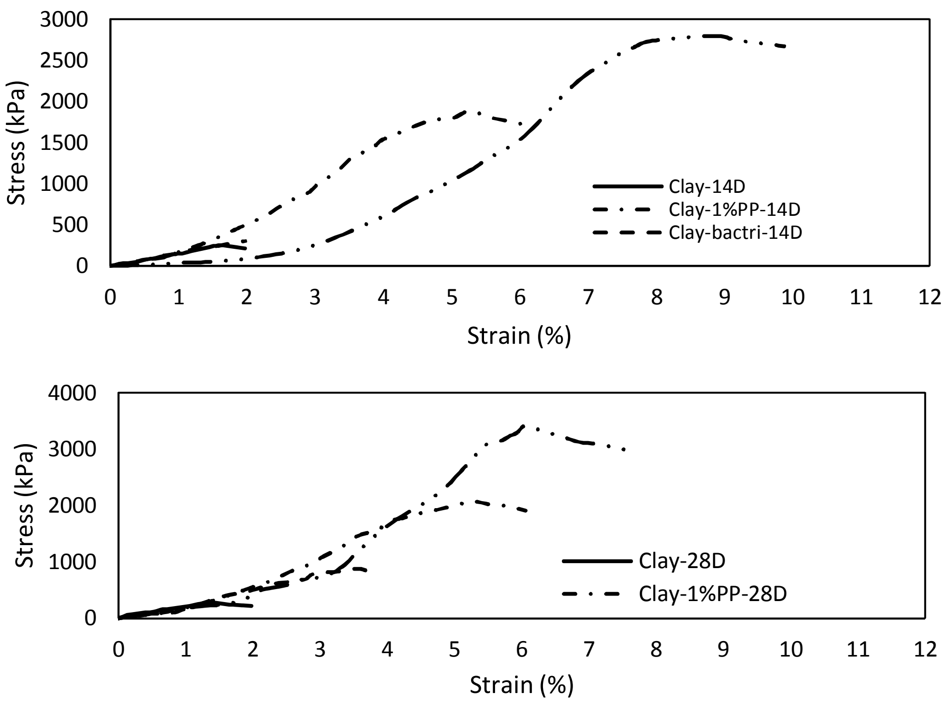


Figure 9. Stress-strain charts of non-stabilized samples, stabilized samples by bacteria, reinforced samples with polypropylene fibers and simultaneous stabilized and reinforced by bacteria and polypropylene fibers during different treatment periods of 0, 7, 14 and 28 days

As it can be seen from the above charts, soil stabilization by the bacteria has increased uniaxial compressive strength. Also, the uniaxial compressive strength has increased significantly due to the addition of polypropylene fibers to the soil containing bacteria. In order to determine the effect of treatment time, the final strength variations of the samples are shown in Figure 10.

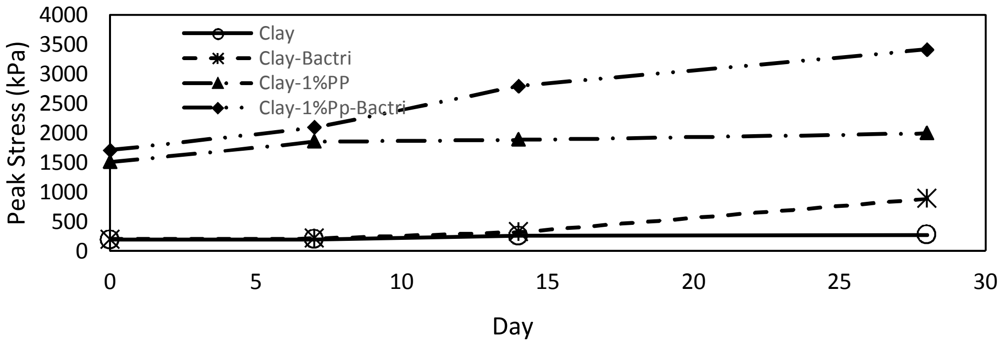


Figure 10. Final strength variations of non-stabilized samples, stabilized samples by bacteria, reinforced samples with polypropylene fibers and simultaneous stabilized and reinforced by bacteria and polypropylene fibers during different treatment periods of 0, 7, 14 and 28 days

As it can be seen from the above figure, the final strength of stabilized and reinforced samples by the bacteria and polypropylene fibers has increased by passing the time. The cause of this phenomenon can be the formation of solid chemical bonds between soil particles, bacteria and polypropylene fibers. The highest amount of final strength in the samples containing the bacteria and polypropylene fibers was observed at 3418 kPa after 28 days, while the final strength for the non-stabilized sample at the same time of treatment was 271 kPa.

7. Conclusions

7.1. Results and suggestion

1. An increase in uniaxial compressive strength was observed by adding the bacteria to the soil. This increase in the strength has also been increasing over the time so that by passing 28 days of the treatment, the sample containing the bacteria has the strength of 888 kPa compared to a non-bacterial sample for which the strength was 271 kPa at the same duration.

2. The presence of polypropylene fibers has increased the uniaxial strength of the soil. The cause of this phenomenon can be seen in the effect of the fiber as a tensile reinforcing element in removing the weakness of the soil's materials against these forces.

3. No significant change was observed in the final strength of the reinforced samples with polypropylene by passing the time. This can be attributed to the function of fibers as a physical substance which does not change over time.

4. The addition of polypropylene fibers has changed the friability behavior of the soil from brittle to smooth state. In other words, the reinforced samples with polypropylene fibers have been ruptured at higher strains compared to the non-reinforced samples.

5. Simultaneous use of the bacteria and polypropylene fibers has significantly increased the uniaxial strength. This improvement in strength has increased dramatically by passing the time. The final strength of the sample containing the bacteria and polypropylene fibers was obtained at 3418 kPa after 28 days of treatment, while the strength of the sample without the bacteria and fibers was 271 kPa at the same duration.

7.2. Suggestions

The following topics are suggested for future research.

- Evaluation of the effect of biological stabilization on clay soil consolidation parameters
- Investigation of the effect of biological stabilization on California loading capacity using CBR test in coarse-grained soil
- Evaluation of the effect of biological stabilization on the shear strength parameters of fine-grained soil using three-axial test

8. Acknowledgment

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