Analysis of Unconfined Compressive Strength of Polypropylene Fiber Soil under Freeze-thaw Cycles

Hongxin Jiang, Yulong He*

School of transportation, Jilin University, Changchun 130022, China

* heyl15@mails.jlu.edu.cn

Abstract

Under the function of freeze-thaw cycles, the strength of soil is greatly changed. A single factor experiment using the clay of a construction in Heilongjiang province, China for research object was designed to research the impact of different water content to fiber soil's unconfined compressive strength in the environment of freeze-thaw cycles. By comprehensive analysis, with the increase of water content, the unconfined compressive strength decreases gradually with the trend of power exponential function. The conclusion can provide reference for the construction of soil structure in seasonal frozen region.

Keywords

Clay, Freeze-thaw cycles, Polypropylene Fiber, unconfined compressive strength.

1. Introduction

In recent years, because the requirements of the soil strength continue to improve in the engineering construction, the phenomenon of strengthening the soil has been very common in the project. The reinforcement measures of adding lime, cement and etc. in the soil are used in the current project. As a kind of reinforced soil, fiber soil has been widely concerned by scholars in recent years because of its low cost, convenient mixing and high strength. Y. Yilmaz studied the polypropylene fiber behavior [1]. The results of Jun Zeng's test show that the unconfined compressive strength of polypropylene fiber soil is 1.18 ~ 2.54 times of plain soil. The unconfined compressive strength of polypropylene fiber soil is related to the fiber content and the fiber length, and the strength grow with the increase of fiber content and fiber length [2]. Han Chunpeng studied the temperature monitoring data of Subgrade in cold region [3]. Chai Shouxi studied the effects of dry density and water content on the strength and deformation of straw reinforced soil. It was found that the strength and anti-deformation capacity of the straw reinforced soil decreased with the increase of water content [4]. The research on the strength characteristics of the fiber soil has made some achievements, but the influence of the different water content on the unconfined compressive strength of the fiber soil under the function of freeze-thaw cycles is still not deep enough. Therefore, in this paper, the clay of a construction site in Harbin was used as the test soil, and the influence of water content on the unconfined compressive strength of the fiber soil was analyzed by single factor test.

2. Experiment Study

2.1 Experiment material

The test soil was taken from a construction site in Harbin, the sampling depth was 1.2~1.5m, and the color of soil sample was brown. According to JTG E40—2007，Test methods of soils for highway engineering［S］[5], the specific gravity test and liquid and plastic limits were carried out to determine the main physical indexes of soil samples (Table1).

Table 1 Physical properties of test soil samples

Soil specific gravity G_S	Water content $\omega/\%$	Density $\rho/(g \cdot cm^{-3})$	Plastic limit $\omega_p/\%$	Liquid limit $\omega_l/\%$	Plasticity index I_P
2.67	4.2	1.68	25.07	38.53	13.46

According to JTG E40—2007， Test methods of soils for highway engineering [5], the optimal water content of plain soil ω_{op} and the maximum dry density ρ_{dmax} were determined by heavy compaction test. The test soil was sifted by 2mm screen. The test equipment adopted TDJ - V multifunctional electric compaction apparatus. The test was carried out on 5 levels, with 27 hits per layer. The compacting curve of plain soil was obtained (Fig.1). From the compacting curve, the optimal water content of test soil is 13.76%, the maximum dry density is $1.76 g \cdot cm^{-3}$

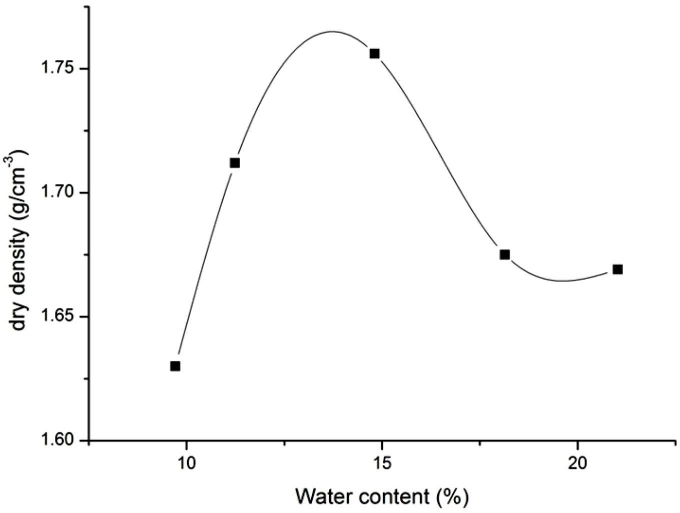


Fig.1 Compacting curve

The fiber for the test was production of engineering use Polypropylene fiber manufactured by Fuzhou City Bot Polypropylene Fiber Products Co., Ltd. Fiber is a long bunchiness, soft texture, white color. The study shows that when the fiber length is 9mm and the fiber content is 3‰, the strengthening effect of soil is the best[6]. In this experiment, soil samples were prepared with 9mm fiber, and the mixing amount of the fiber was 3‰. The main physical and mechanical parameters of the fiber are shown (Table2).

Table 2 Physical and mechanical behaviors of polypropylene fiber

Types	Gravity	Elastic modulus/MPa	Tensile strength/ MPa	Melting point/ ℃	Diameter/μm	Limit tensile	Thermal conductivity
Bunchiness	0.91	3500	368	165	18~48	15%	Very low

2.2 Experiment scheme

Single factor test was adopted in this experiment, in the test process, cycle time of freeze-thaw, freezing and thawing lower limit temperature and other factors remain unchanged, change the water content level, then a single experiment test was designed (Table3). The unconfined compressive strength of fiber reinforced soil was measured under different water content. The unconfined compressive strength of fiber reinforced soil was comprehensively analyzed, and the influence of water content on the strength of reinforced soil under freeze-thaw cycles is obtained.

Table3 Table of single experiment test

Specimens number	A	B	C
Water content/%	15	17	19

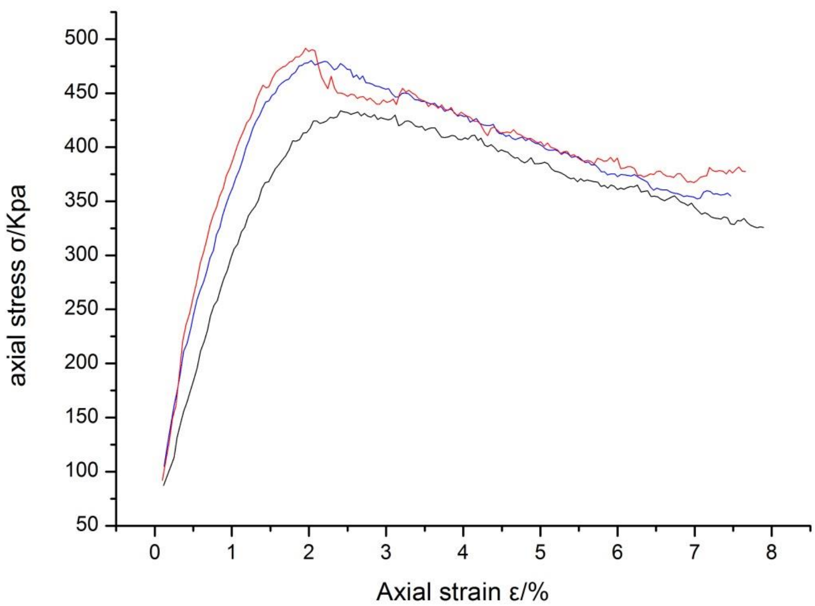
2.3 Experiment method

The test soil was air dried and then grinded. According to the experiment design, the soil and Polypropylene fiber were mixed fully, then sealed at room temperature (14℃~20℃) for 12 hours. The test soil samples were compacted with static pressure to 96% compactness. According to the study of temperature monitoring value of subgrade in cold region [3], the freeze-thaw temperature of soil samples ranges from -15℃ to 15℃. This paper uses the DX-300-40 low temperature test box for freeze-thaw cycle test, setting up a test of soil freeze-thaw temperature of -7℃, freezing time is 12 hours, after the completion of freezing, the soil samples were at room temperature (14℃~20℃) to melt, the melting time is 12 hours, which is 1 time of freeze-thaw cycle, the number of freeze-thaw cycle in this experiment is 1. All the specimens are sealed during the whole freeze-thaw cycle to prevent the moisture loss of the test soil samples. After the freeze-thaw cycle of soil samples, the unconfined compression test of soil samples at room temperature (14℃~20℃) was carried out by LQ-200S unconfined compressive strength tester. The unconfined compressive strength of the reinforced soil was measured. In this experiment, the test soil samples were cylindrical specimens with a height of 81mm and a diameter of 31.8mm [5] was used. The specimens were loaded at 0.1mm/min compression speed, and the experiment was stopped after the inflection point of the curve [7].

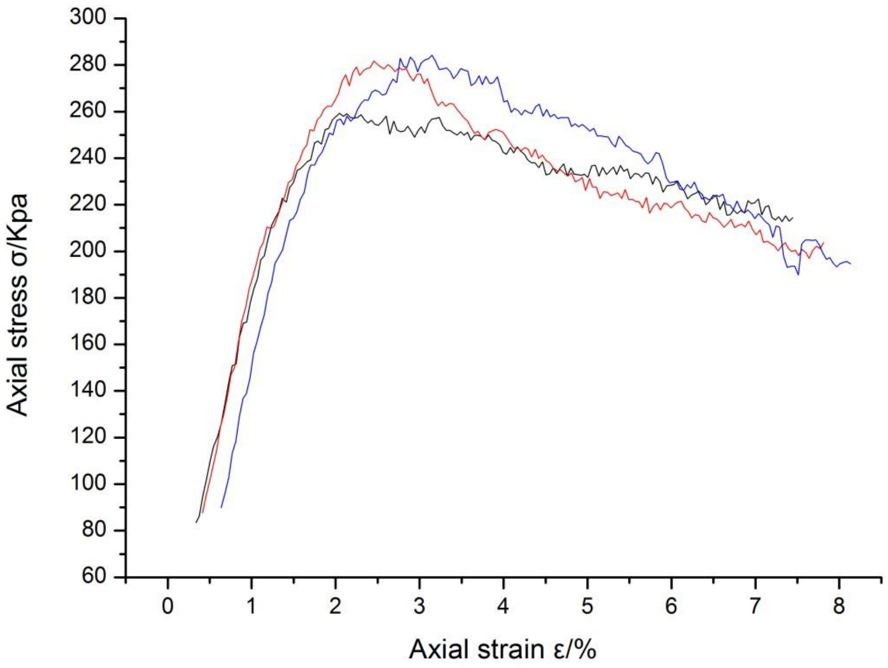
3. Experiment Result Analysis

3.1 Stress-strain curves analysis

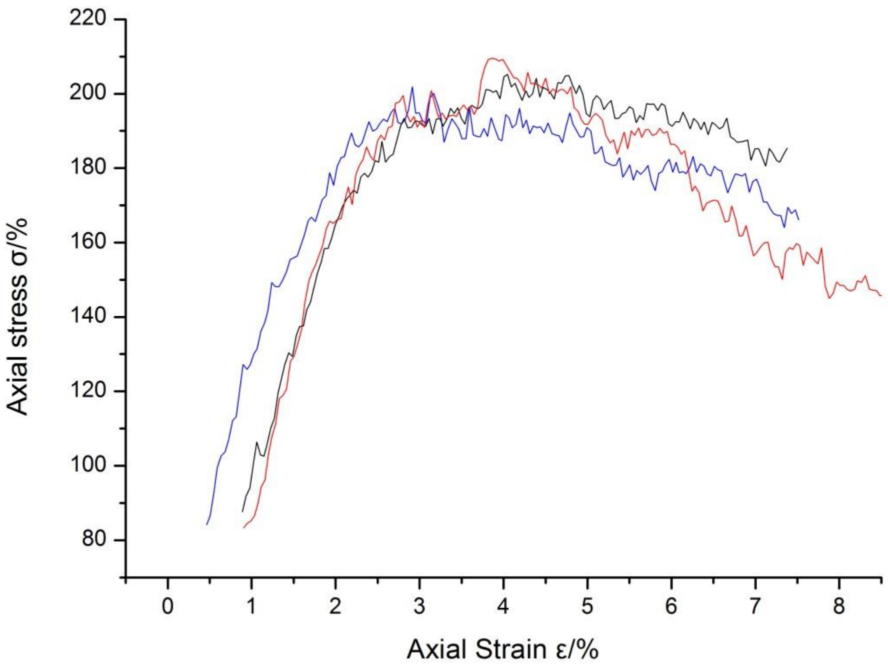
The Stress-strain curves under different water content levels were obtained by the above experimental method (Fig.2).



A. Stress-strain curve when ω=15%



B. Stress-strain curve when ω=17%



C. Stress-strain curve when ω=19%

Fig.2 Stress-strain curve of different water content

As shown in Figure 2, at the beginning, the curve is basically a straight line, and the sample soil is in an elastic deformation stage, the elastic modulus E is numerically equal to the slope of this line segment. With the loading, the strain gradually increases and the curve starts to assume a convex shape, the soil samples yielded, produced bulging, micro cracks. The peak value at which the curve begins to appear is the unconfined compressive strength of the specimens. As the loading continues, the curve begins to show a downward trend, and the specimens produced large cracks, then the specimens were destroyed [8].

From A to C (Fig.2), it can be seen that the stress-strain curves of different parallel specimens of the same group are the same, and the change is small. This result shows that the data have little discreteness, and the experimental data is accurate. At the same time, with the increase of water content, the unconfined compressive strength gradually decreases, the axial strain corresponding to the extreme value of the image increases gradually.

3.2 Fitting curve analysis

The fitting curves of water content-unconfined compressive strength can be obtained by fitting the experimental data (Fig.3).

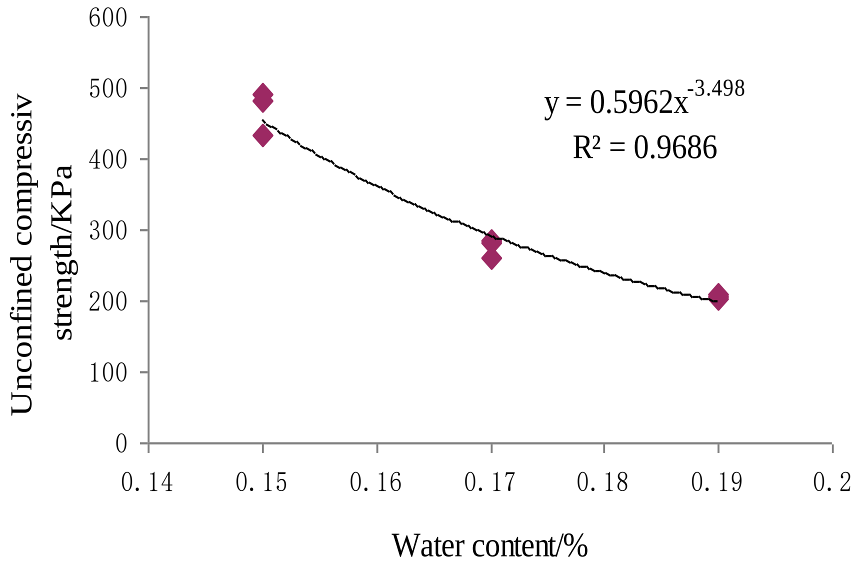


Fig.3 Water content-Unconfined compressive strength curve

By analysis Fig.3, with the increase of water content, the unconfined compressive strength of soil sample decreases gradually. According to the data fitting, the formula can be obtained.

$$y = 0.5962x^{-3.498} \tag{1}$$

When the water content is in the 15%~17% stage, the unconfined compression strength decreases faster, with the increase of water content, the rate of decline gradually decreases. When the water content is large enough, the unconfined compressive strength tends to be stable. With the increase of water content of soil sample, the pore water content of soil sample increases, the pore water content play a role of lubrication and dissolution between soil particles, the internal friction between the soil particles decreases, the cohesion of the soil also sample decreases, therefore, the unconfined compressive strength reduce with the increase of the water content.

3.3 Variance analysis

In order to investigate the significance of the influence of water content on unconfined compressive strength of fiber soil, the significant level α =0.05 was taken and the data were analyzed by variance (Table4).

Table4 Variance analysis: One-way anova

A. Summary

Group	Observation number	Summation	Average	Variance
15%	3	1406.134	468.7113	942.2212
17%	3	825.355	275.1183	189.3963

19%	3	616.603	205.5343	14.63657

B. Variance analysis

Difference source	SS	df	MS	F	P-value	F_{crit}
Between groups	111582.3	2	55791.16	146.0178	8.16E-06	5.143253
Intragroup	2292.508	6	382.0847			
Total	113874.8	8				

As shown in A, Table4, when the water content is 15%, the unconfined compressive strength average is the largest, but the variation degree is great. When the water rate is 19%, the average value of unconfined compressive strength is the minimum, but the variance value is the minimum.

The final analysis of variance is shown in B, Table4, The variation sources of all data are divided into inter - group errors under different water content levels and random errors at the same water content level. In view of the above mentioned variation sources, the square sum (SS), the degree of freedom (DF), the mean square (MS), the F value (F), the associated probability (significant probability, P), and the critical value of F (F_{crit}) are listed in B, Table4. According to the result in A, Table 4, P-value=8.16E-6<0.05, this event is a high probability event. Therefore, the influence of different water content on the unconfined compressive strength of the fiber soil under freeze-thaw cycles is significant. At the same time, $F=146.0178>F_{crit}=5.143253$, therefore, the F value of the data is outside the accepted region of the F distribution. It is impossible to accept the original hypothesis. It can be concluded that the unconfined compression strength of the fiber soil under one freeze-thaw cycle is significantly affected by the different water content. This is consistent with the result of judging by probability.

4. Conclusion

By the analysis above, two conclusions can be obtained. The first one is the stress-strain curves with different water content, and the relation between the unconfined compression strength and the water content. The second one is the significance analysis by the variance analysis.

Under the function of freeze-thaw cycles, the strength of the fiber reinforced soil decreases with the increase of water content. The unconfined compressive strength decreases gradually. The relation between them can be fitted by power exponential function. When the water content is in the 15%~17% stage, the unconfined compression strength decreases faster, with the increase of water content, the rate of decline gradually decreases. When the water content is large enough, the unconfined compressive strength tends to be stable.

According to the analysis of variance, P-value<α, at same time, F value> F_{crit}, the F value of the data is outside the accepted region of the F distribution. Therefore, the influence of water content on unconfined compressive strength of fiber reinforced soil under freeze-thaw cycles is significant.

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