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Effect of Polypropylene Fiber on Frost Resistance of Cemented Soil

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Abstract. *Polypropylene fiber is widely used as a reinforcing material in composite materials of various engineering projects, because it has high strength and corrosion resistance. In this study, with the purpose of examine the impact of discrete polypropylene fiber on frost resistance of cemented soil, cemented soil treated with polypropylene fiber is used as the research sample. Firstly, the impact of curing time, fiber content and length on the strength of cemented soil has been considered. And then, the frost resistance characteristics of cemented soil reinforced by polypropylene fiber with the content of 0.5% have been investigated. The results show that with the development of curing time, the strength of cemented soil increases logarithmically. By adding an appropriate amount of polypropylene fiber, the strength of the specimen may be improved. In this study, cemented soil reinforced by polypropylene fiber 0.1% in content and 3 mm in length has the best reinforcement effect. After 21 cycles of freezing and thawing processes, a sharp decline in strength of cemented soil without fiber, and the strength loss ratio is up to 45%. There are cracks in the specimens, and some of the specimens have broken off. Differently, after 21 freeze-thaw cycles, the strength of the cemented soil with fiber decreased less, and the strength loss ratios are between 1 and 13%, and there are only small cracks on the surface of specimens. The results show that adding discrete polypropylene fiber is a suitable method to prevent the generation and development of internal cracks in the cemented soil during freezing and thawing, thereby improving the frost resistance. These results can be used as a reference for the application of cemented soil reinforced with fiber in seasonal frozen regions.*

Keywords: Polypropylene Fiber, Cemented Soil, Uniaxial compressive strength, Frost resistance

1. Introduction

In last few years, cemented soil has been extensively used as soil reinforcement in various engineering projects. Generally speaking, cemented soil has high compressive strength and rigidity. However, it is a brittle material. Hence, its tensile strength and bending strength are very low [1]. Some studies showed that by adding an appropriate amount of dispersed fiber to cemented soil, its tensile strength and toughness could be improved [2-17].

Polypropylene fiber, as a synthetic fiber, has the advantages of high strength, good ductility, long durability and low price. It has been commonly used as a reinforcing material in composite materials and widely used in reinforced concrete and cemented soil [16, 17]. Studies explained that the compressive strength of concrete or cemented soil may not improve when polypropylene fiber was added. On the other hand, the tensile, crack resistance and bending resistance of concrete or cemented soil were significantly improved [18-20]. It was found that adding fiber could increase ultimate strength, peak strength, decrease toughness and alter the hard property of cemented sand into a flexible one [21]. Jamsawang et al. showed that through laboratory tests, polypropylene fiber could effectively develop the flexion strength of cemented mortar [22]. Vakili et al. showed that by adding and 0.35% polypropylene fiber and 2% lignosulfonate to the dispersed clay reduced the dispersion of the soil significantly, and simultaneously, increased the compressive strength of soil [23-35].

In seasonally frozen areas, due to the changes in season, there may be 1 or more than 1 freeze-thaw cycles per year. Therefore, when cemented soil materials are used in seasonally frozen regions, the impacts of freezing process and melting process on properties of cemented soil cannot be ignored. In

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earlier studies, researchers showed that by adding dispersed fibers to cemented soil improved the frost resistance and reduced the loss of strength of the cemented soil under freeze-thaw cycles [36]. Some researchers found that adding polypropylene fiber showed a progress in strength and displays higher strength at rate of 0.20% of fiber content. Further, to predict strength, an empirical model was proposed while observing the impacts of fiber contents, cement contents, and freeze-thaw cycles [37-45].

In this study, the objective is to determine the impact of freezing process and melting process on mechanical behavior of cemented soil treated by discrete polypropylene fiber. The red sand soil which is a common foundation soil in Changchun City, China, has been used as the research sample, and the polypropylene fiber and cement have been used as the reinforcement materials. Several uniaxial compression tests were conducted with different fiber contents, fiber lengths, curing time, and numbers of freeze-thaw cycles as well.

2. Materials and methods

2.1. Materials

For the experiment, test soil was got from Changchun City, Jilin Province, China. In the laboratory, it was dried and wrecked into small pieces. Figure 1 displays a particle size distribution curve of test soil was used in this study. The ordinary Portland cement (P.O 42.5) was selected in the test. The content of the cement was 10%. Table 1 displays the properties of polypropylene fiber used in this study.

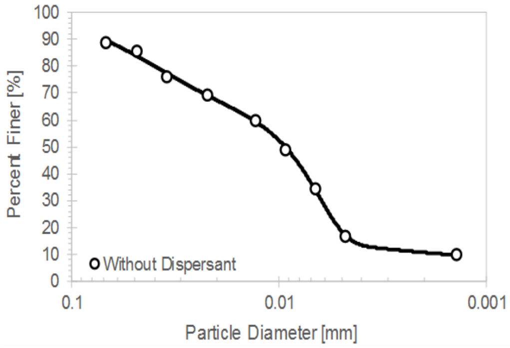

Figure 1. Particle size distribution curve

Table 1. Properties of polypropylene fiber.

Properties	Values
Diameter (µm)	13-21
Length (mm)	3,6,15
Color	White
Strength of Extension (MPa)	900
Elasticity Modulus (GPa)	17
Density (g·cm^{-3})	1.18
Dispersibility	Excellent

2.2. Sample preparation

The soil was treated by cement and polypropylene fibers 3 mm, 6 mm and 15 mm in length, and 0.1, 0.3, 0.5, 0.7, 0.9, and 1.1% in content, respectively. The air-dry soil was mixed with cement, water and fiber, and then the mix was placed into 70.7 mm cubical plastic molds. After shaken on the vibrostand, the molds were sealed and stored in a room for 48 h. The plastic molds were then removed and specimens stored in normal temperature water for 28 days of curing.

2.3. Methods

In this study, the specimens were loaded by the displacement uniform controller. The loading rate was 0.1mm/s. The freezing condition was set to freeze at -15°C for 24h. During the thawing stage, water thawing was selected. All these samples were saved at room temperature water for 24h during the thawing. A cycle consists of a freezing process and a thawing process. The specimens had been subjected to 0, 3, 8, 17, and 21 cycles, respectively.

3. Results and discussions

3.1. Mechanical property of Unreinforced and Fiber-reinforced Cemented Soil

3.1.1. Effect of curing time

Figure 2 shows the relationship between the strength of unreinforced cemented soil (0 mm) and fiber-reinforced cemented soil and the curing time. The fiber content is 0.5%. Figure displays that strength of the cemented soils increases continuously with increasing curing time. All the relationships follow a logarithmic function. At the 7 days of curing time, there is little difference between the uniaxial compressive strengths of unreinforced cemented soil and fiber-reinforced cemented soil. This indicates that the reinforcement impact of fiber is not significant at the early stage (7 days of curing). After 28 days of curing, strength of cemented soil without fiber is significantly lower in comparison with fiber-reinforced cemented soil. It means that the reinforcement effect of fiber is more significant with longer curing time.

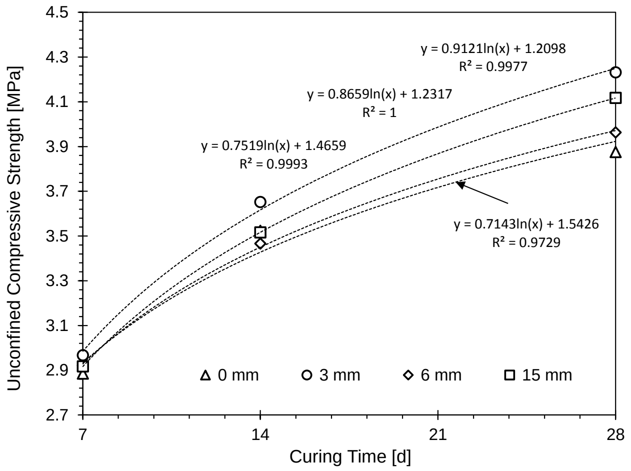

Figure 2. Relationship between strength and curing time (fiber content: 0.5%)

3.1.2. Effect of fiber in different length and content

Figure 3 indicates the strength of cemented soil reinforced with varying contents and lengths of fiber. It can be observed in many cases, the strengths of the cemented soil are higher by adding polypropylene fiber. However, lower are the strengths of the cemented soil with adding 3 mm long polypropylene fiber with contents of 0.7, 0.9 and 1.1%, and 15 mm long polypropylene with content of 0.9 and 1.1%. Because the content of adding fiber in this paper is the weight ratio, the amount of fiber will increase with increasing of the content. If adding short fibers with excessive fiber content can create excessive number of short fibers. This may cause the phenomenon of uneven dispersion, resulting in a weak surface in the cemented soil. Further, excessive fibers may also weaken the bonding of the cement and the fiber. By having too many long fibers, such as 15 mm long, can cause the fibers to lump together and unevenly distributed, which reduces the strength. However, there is no obvious rule between fiber content and length and the reinforcement effect. According to the study results, the cemented soil reinforced with 0.1% and 3 mm polypropylene fiber has the extreme strength.

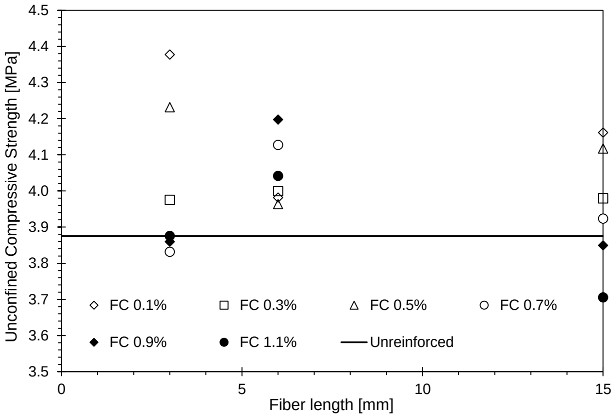

Figure 3. Strength of unreinforced cemented soil & cemented soil with fiber (FC: fiber content)

3.2. Effects of Freezing-Thawing Process

To examine the impacts of freezing process and thawing process on the mechanical properties of cemented soil reinforced with discrete polypropylene fiber, some tests were carried out. The fiber content is 0.5%, and fiber lengths are 3 mm, 6 mm and 15 mm. The cured specimens have been subjected to 0, 3, 8, 17 and 21 freeze-thaw processes, respectively. Figure 4 shows the strength of specimens after subjecting to freeze-thaw cycles. It can be seen that strength of specimens without fiber declines with growing freeze-thaw cycles. The strength decreases sharply after 21 freeze-thaw cycles. On the other hand, as the number of freeze-thaw cycles increase, there results in a small decline in the strengths of specimens with fiber. These results indicate that the fiber addition improves the ability of the cemented soil to repel the decline in strength under the repeated freezing and thawing processes.

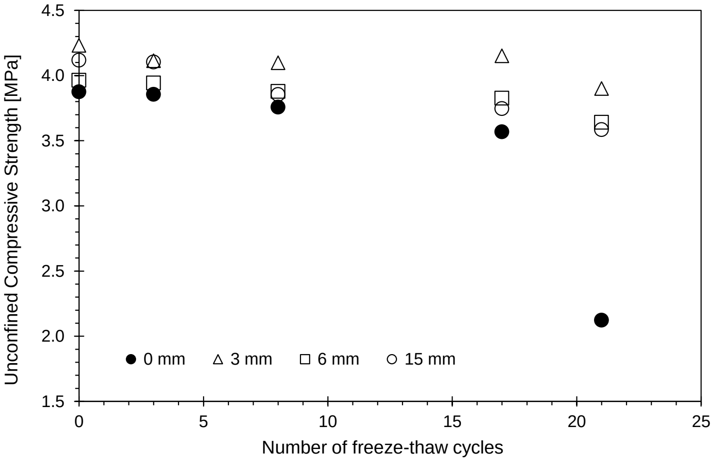

Figure 4. Strength of cemented soil subjecting to repeated freezing and thawing processes

Figure 5 shows a photograph of specimens after 21 freeze-thaw cycles. It shows that there are cracks in unreinforced specimens, and some of specimens have broken off. This phenomenon can be attributed to the water in the pores of the unreinforced specimens. During the process of freezing, the expansion force is generated when the water becomes ice. When the expansion force is larger than the tensile strength of specimens, new cracks are formed. In the process of thawing, water flows into the new cracks. After repeated cycles of thawing and freezing, the cracks expand and penetrate into the specimens, resulting in part of the specimens break off. For the fiber-reinforced specimens, there are small cracks on the surface, but the cracks are small and not obvious after 21 cycles. The phenomenon can be accredited to fibers addition. The anchoring effect of fiber in the specimens improves the tensile strength of specimens, thereby suppressing the formation of cracks caused by the frost heaving force. It also prevents the further expansion of internal crashes in the specimens. Hence, the addition of the fiber can prevent the generation and development of internal cracks in cemented soil subjected to repeated freezing and thawing processes.

Figure 5. Photograph of specimens after 21 cycles of freezing and thawing

3.3. Strength Loss Ratio

The strength loss ratio is defined as follows:

$$\Delta f_n = \frac{f_0 - f_n}{f_0} \times 100\% \qquad (1)$$

where, Δf_n is strength loss ratio; f_0 is unconfined compressive strength prior to freezing and thawing process; and f_n is the unconfined compressive strength after different freeze-thaw cycles.

Figure 6 shows the strength loss ratio of the specimens after 3, 8, 17, and 21 freeze-thaw cycles. It shows that after 21 cycles, there is highest strength loss ratio of the unreinforced cemented soil which is up to 45%, whereas the strength loss ratios of the fiber-reinforced cemented soil are between 1% and 13%. These results indicate that adding fiber to cemented soil can effectually lower the strength loss ratio of the cemented soil under repeated freezing and thawing processes, thereby improving the durability of cemented soil.

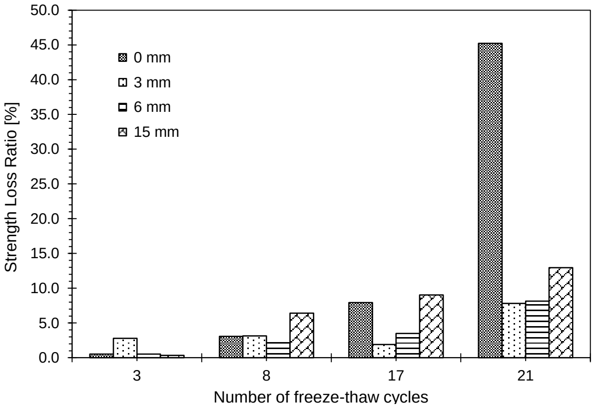

Figure 6. Variations of strength loss ratio of specimens under repeated freezing and thawing processes

3.4. Stress-strain Relationships

Figure 7 depicts the relationships between the strain and the stress of specimens after 0 and 21 freeze-thaw cycles. After 0 cycle, the peak strength of the unreinforced specimen is not markedly change from those of the fiber-reinforced specimens. On the other hand, after 21 cycles as depicted in Figure 7b, peak strength of unreinforced specimens is quite low than those of fiber-reinforced specimens. Further, Figure 7b displays that the rigidity of the unreinforced specimen is considerably lower as compared to the fiber-reinforced specimens.

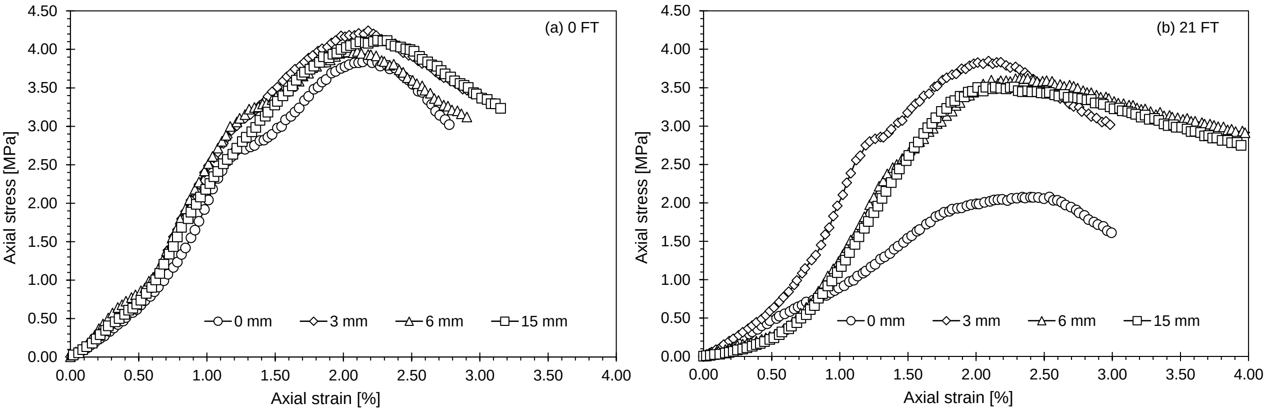

Figure 7. Stress-strain relationships of specimens (FT: freeze-thaw); (a) after 0 freeze-thaw cycle; (b) after 21 freeze-thaw cycles

4. Conclusions

Several experiments were adopted to examine the impacts of discrete polypropylene fiber reinforcement on mechanical behavior of cemented soil under repeated freezing and thawing processes. Important Findings are as follows:

1) As for cemented soil without fiber and cemented soil with fiber, a logarithmic relationship is followed by the strength as it rises with increasing curing time. Moreover, after 28 days of curing, the strength of reinforced cemented soil is significantly higher as compare to the unreinforced cemented soil.

2) By adding an appropriate amount of polypropylene fiber, the strength of cemented soil can be enhanced. Based on the results of this study, cemented soil reinforced with 0.1% and 3 mm long polypropylene fiber gives the best treatment effect.

3) After 21 repeated freezing and thawing processes, there are cracks in unreinforced cemented soil, and some of the cemented soil have broken off. On the other hand, there are some small cracks on the surface of cemented soil with fiber. These results show that polypropylene fiber addition can successfully prevent the generation and development of internal cracks exposed to repeated freezing and thawing processes.

4) After 21 repeated freezing and thawing processes, uniaxial compressive strength of the cemented soil without fiber decreases sharply, and the strength loss ratio is 45%. Dissimilarly, the uniaxial compressive strengths of the cemented soil with fiber decrease less, and the strength loss ratios are between 1 and 13%. These results reveal that adding fiber can effectively lower the strength loss ratio of the cemented soil under repeated freezing and thawing processes, thereby improving the frost resistance of cemented soil.

5) The peak strength and rigidity of the cemented soil without fiber are lower than those of the cemented soil with fiber after 21 repeated freezing and thawing processes.

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