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Strength Characteristics of Clay Mixtures with Waste Materials in Freeze-Thaw Cycles

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Abstract

Waste tires, rubbers, plastic and steel materials, normally produced in every society, enter the environment and cause serious problems. These problems may, to some extent, be reduced by finding applications for them in engineering, for example**,** they can be used for geotechnical applications as backfill material and solving problems with low shear strength soils. Such materials may be subjected to freeze-thaw cycles, resulting in strength reduction. Freeze–thaw cycling is a weathering process which is normal in cold climates. In these cycles, thermodynamic conditions at temperatures below 0^{o}C cause translocation of water and ice which can change the engineering properties of soils. The present study investigates the effect of reinforcing soil with tire chips and steel fibers to reduce the effects of freeze-thaw cycles. To this aim, reinforced kaolinite clay was compacted in the laboratory and exposed to a maximum of 6 closed-system freeze-thaw cycles. The results of the study reveal that adding tires to clay prevents strength reduction due to freeze-thaw cycles. The soil samples which were mixed with 2% of steel fibers and 10% of tire chips were not affected by the freeze and thaw cycles as the pure samples were. These materials can reduce the effects of freeze and thaw cycles especially in cold regions.

Keywords: Freeze thaw cycles; Tire chips; Steel fibers; unconfined strength; Clay.

1. Introduction

Due to the development of industry and growing population, huge amounts of increasingly produced waste materials such as waste tires, rubbers, plastic and steel materials enter the environment**.** Such entrance causes serious problems. It is also harder and more expensive to dispose them safely without threatening human health and environment.

Scrap tires and steel wires are one of wastes for which engineers must find applications. Although some of them are recycled and reused for producing low quality products, the procedure of recycling may have dangerous impacts on environment due to dust production [1]. Therefore, finding applications for them in engineering is highly demanding. For instance, waste tires are used for vibration isolation [2], low strength of ductile concrete [2], reinforcing soft soil in road construction [3-5], controlling ground erosion [6], stabilizing slopes [6,7], and as lightweight material for backfilling in retaining structures [3,7-11], aggregates in leach beds of landfills [12], an additive material to asphalt [4,12,13], sound barriers [14], as limiting for freezing depth [15], a source for creating heat [8], a fuel-supplement in coal-fired boilers [16] and cushioning foams [16].

Many investigators have conducted strength tests through triaxial tests, unconfined compressive strength tests, CBR tests, direct shear tests, and tensile and flexural strength tests on specimens that are reinforced with paper, metal, nylon, and polyester fibers. Steel fibers can improve soils strength but this improvement is less in comparison with other fibers. For instance inclusion of steel fibers with 2 cm length will increase the uniaxial strength of a kaolinite soil [17].

In cold climates, soils are exposed to freeze-thaw cycles. Fine-grained soils influenced by freezing and thawing show changes in volume, strength, compressibility, densification, unfrozen water content, bearing capacity, and microstructure. In the permafrost regions like Canada, it was found that the embankment

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constructed on soil which had never experienced freeze-thaw cycles was damaged in just one year due to the loss of bearing capacity [18]. Therefore, newly constructed highway embankments that are left unpaved for a few years may be damaged by freeze-thaw cycles [19].

Qi et al. [20] reviewed the last efforts done to investigate the influences of freeze-thaw cycles on soil properties. They summarized these influences in two parts: physical properties like density and hydraulic permeability and mechanical properties like ultimate strength, stress-strain behavior and resilient modulus of soils. According to this research, loose soils tend to be densified and dense soils become looser after freeze-thaw cycles. In addition, both loose and dense soils may retain the same void ratio after a number of cycles [21]. With increasing the large pores that are left after the thaw of ice crystals, the soil permeability will increase [22]. These cycles reduce the ultimate strength of soils. All over-consolidated soils exhibit a peak on the triaxial stress-strain curve and this peak is reduced or may even disappear [23]. Resilient modulus, one of the most important factors in pavement designs, will reduce significantly by even a small number of freeze-thaw cycles [24]. Moreover, these cycles considerably decrease the undrained shear strength which is an important factor in fine-grained soil design [23].

All the above-mentioned studies dealt with unreinforced soil and thus the investigation of the influence of freeze-thaw cycles on unconfined strength of reinforced soils is lacking, to the best knowledge of the authors. The main purpose of this study is to investigate the influence of freeze-thaw cycles on unconfined strength of a clayey soil mixed with tire chips and steel fibers in order to find a new solution for reusing the waste materials.

2. Methods

In this study, tests were carried out on a kaolinite clay soil. This soil was selected because fine grained soils are more susceptible to freeze-thaw cycles than coarse soils [20]. The clay, whose characteristics are presented in Table 1, was classified as CH in the Unified Soil Classification System. The grain size distribution which is resulted from hydrometer test is illustrated in Fig. 1. In order to inspect the purity of the soil, two XRD and XRF tests were performed on specimens. These tests are the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by bombarding with high-energy X-rays or gamma rays. The phenomenon is widely used for both elemental and chemical analysis, particularly in the investigation of metals, glass, ceramics, soil and building materials, and research in geochemistry, forensic science, and archaeology. These tests showed that more than 85% of clay is kaolinite.

The specimens were reinforced by 5, 10 and 15% (by weight of dry soil) of tire chips because it was shown that an addition of 10–20% rubber to the soil is optimal to obtain the greatest strength [1] and 1, 2 and 3% of steel fibers as others did before [16]. Tire chips, produced as waste materials in repairing factory of tires, and steel fibers, produced as waste material in building constructions, are shown in Fig. 2 and their characteristics are mentioned in Table 2. In order to add tire chips, it is recommended to pass tire chips from sieve no.20 to get a uniform grain size of tires for a fine grained soil.

Table 1. Characteristics of the soil

G_s	2.61
Plastic Limit	40.6%
Liquid Limit	69.4%
Plasticity Index	28.8%

Table 2. Characteristics of steel fibers and tire chips

Steel Fibers		Tire chips	
Length(mm)	20	Diameter (mm)	0.85
Diameter (mm)	10	Unit Weight (Kg/cm3)	561
Unit Weight (Kg/cm3)	7850		

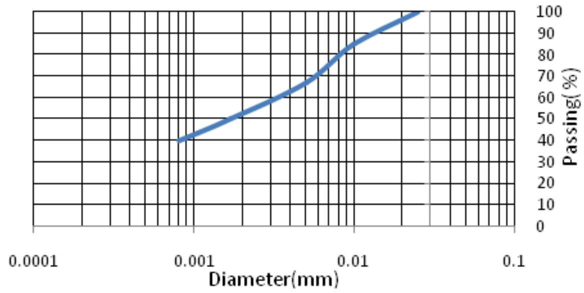

Fig.1. The grain size distribution of the soil

Fig.2. Tire chips and steel fibers

All prepared specimens were cylinder-shaped with 38.5 mm diameter and 77 mm height. Since it led to the best mixture of soil and additives during the sample compaction with different moisture contents, a moisture content of 27% was chosen in specimen preparation. It is worth mentioning that the above mentioned parameter was fixed during the tests and did not affect final results comparison at all. To prepare the reinforced specimens, wet clay and steel fibers or tires were mixed easily. The mixture was divided into four parts which were poured in the mold and compacted. This procedure was repeated to obtain a fully compacted sample.

For freezing and thawing phases, the specimens were placed in a digital refrigerator at -20 °C for 6 hours and then at +20 °C for 6 hours respectively. These temperatures were used in some previous research work [25]. 6 hours is a proportional period after which the alteration of specimen's height would become constant. The cycles were repeated for 4 times. This was chosen because it was shown that most decrease in soil strength would occur in primary cycles and after 5-10 cycles a new equilibrium condition became predominant on samples [26].

Unconfined compression tests were performed on samples according to ASTM D5311-92 in the ambient temperature. The strain rate was kept constant at 0.5 mm/min in all tests.

3. Results

As mentioned in the previous section, several soil samples, with and without tire chips and steel fibers were tested to study the strength of reinforced soil in freeze-thaw cycles. Test results are shown in stress-strain variation. The samples are named X%TC-NC and X%SF-NC as NC stands for the number of freeze-thaw cycle and TC and SF is related to the materials by which the samples are reinforced, i.e., tire chips and steel fibers.

3.1. Unreinforced Ssamples

Before the reinforcement stage, several unreinforced soil samples are tested to compare the behavior of the soil under freeze–thaw cycles. the result of unconfined compression test on pure soil samples subjected to 0, 2, and 4 freeze-thaw cycles, shown in Fig. 3, indicate that as the cycle number increases, the unconfined strength of soil decreases. The most strength reduction is about 29% and occurs after the 4th cycle.

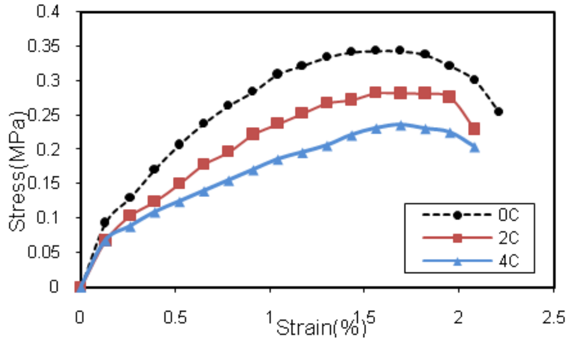

Fig. 3. Stress-strain variation of pure soil

3.2. Reinforced Samples With Steel Fibers

Figs. 4, 5 and 6 represent the stress–strain variation for steel fiber reinforced samples before and after the application of freeze–thaw cycles respectively. Fig. 7 shows the compression strength ratio of reinforced samples versus the number of freeze–thaw cycles for various steel fibers percentages. This ratio is defined as the strength of mixed sample at a given cycle divided by that of a same pure sample which is subjected to the same cycle number. These strengths are denoted by q(N) and q(0), respectively. As clearly shown in the figure, adding steel fibers can increase the ultimate compression strength of soil by about 7% before applying freeze–thaw cycles and 6% after applying freeze–thaw cycles. In fact, with increasing the number of the cycles, the compression strength of reinforced samples is more decreased.

During all of the cycles, the reinforced samples containing 2–3% steel fibers have the greatest strength. This means that even for the reinforced sample, where steel fibers are added, the freeze–thaw cycles still have an effect, i.e. the strength reduction is still observable. The strength of all reinforced samples is reduced by about 25-30% after applying 5 cycles (Fig. 7). This result has also been observed in previous studies in which freeze–thaw cycles decreased the strength of soils subjected to 3–7 cycles [27].

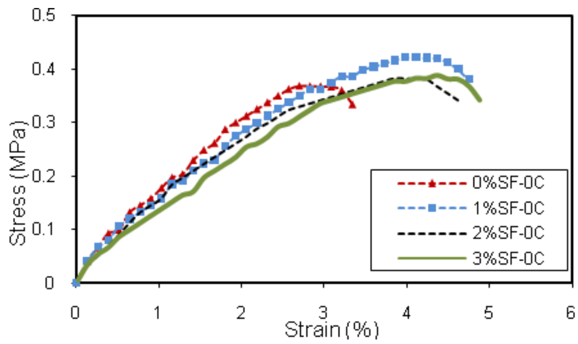

Fig. 4. Stress-strain variation of steel fibers reinforced samples before freeze-thaw cycles

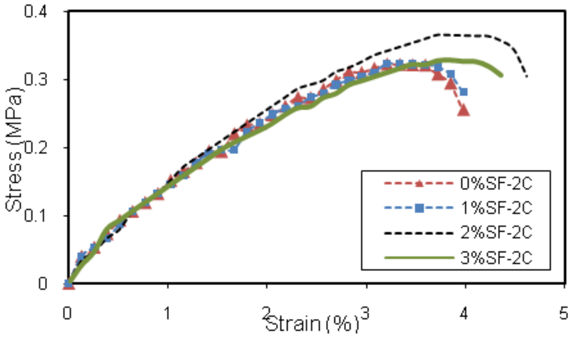

Fig. 5. Stress-strain variation of steel fibers reinforced samples after 2 freeze-thaw cycles

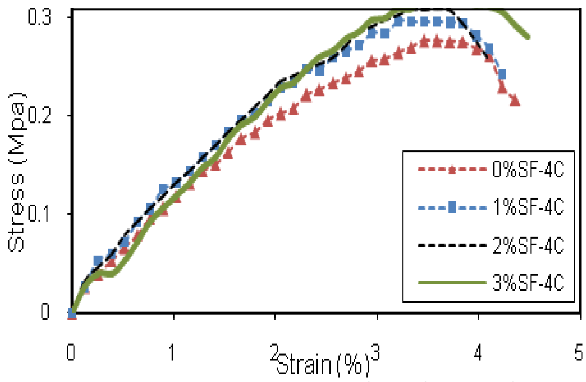

Fig. 6. Stress-strain variation of steel fibers reinforced samples after 4 freeze-thaw cycles

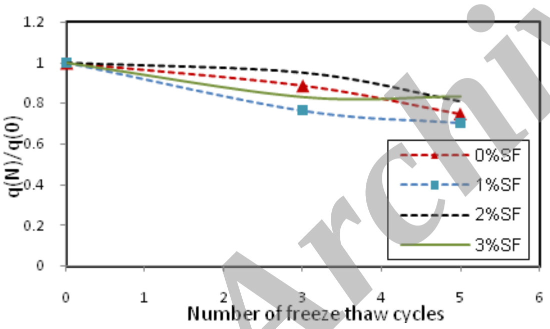

Fig. 7. Ultimate strength ratio for steel fiber-reinforced samples (*q(u)*=unconfined strength after *N* cycles; *q(0)*=unconfined strength with no cycles).

The variation of height change in steel fiber-reinforced samples shows that adding 3% of fibers to the sample reduce the frost heave by about 20% (Fig. 8). This phenomenon is due to the replacement of soil particles by steel fibers which are stronger than soil in freeze-thaw cycles.

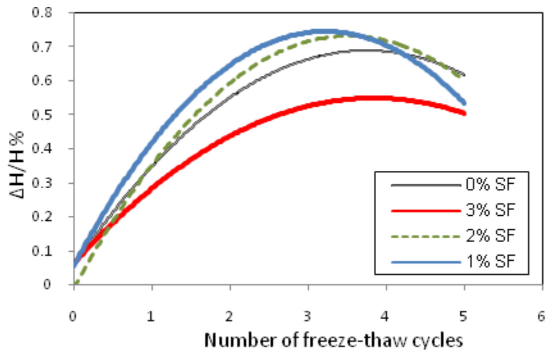

Fig. 8. Height variation of steel fibers reinforced samples after freeze-thaw cycles

3.3. Reinforced Samples with Tire Chips

Fig. 9 and Fig. 10 illustrate the same results for TC samples after applying freeze-thaw cycles. As illustrated in these figures, adding tire chips increases the unconfined compression strength of clayey samples before and after applying freeze–thaw cycles. Applying the freeze–thaw cycles, the unconfined compression strength of mixed and pure soil samples decrease.

Fig. 11 shows the compression strength ratio of clay-chip samples versus the number of freeze–thaw cycles for various chip percentages. It is obvious from this figure that only by inclusion of 10% tire chips, the strength reduction rate caused by freeze–thaw cycles decreases. As depicted, the unconfined compression strength of sample (pure and mixed with 5% and 15% tire chips) decrease by about 50% due to the application of 4 freeze–thaw cycles.

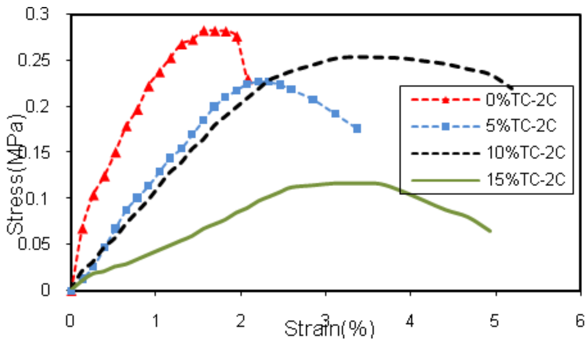

Fig. 9. Stress-strain variation of soil-chips mixtures after 2 freeze-thaw cycles

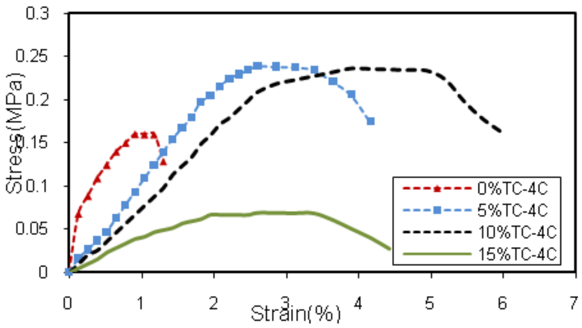

Fig. 10. Stress-strain variation of soil-chips mixtures after 4 freeze-thaw cycles

With adding 5-15% tire chips to soil, the sample height decreases or remains the same. During freezing phase, ice crystals are formed and a frost heave occurs in soil specimens. However, after thawing, the height of samples does not reach the initial amount. This phenomenon leads to an increase in the sample height which is reduced by the inclusion of tire chips especially when 10% tire chips is used.

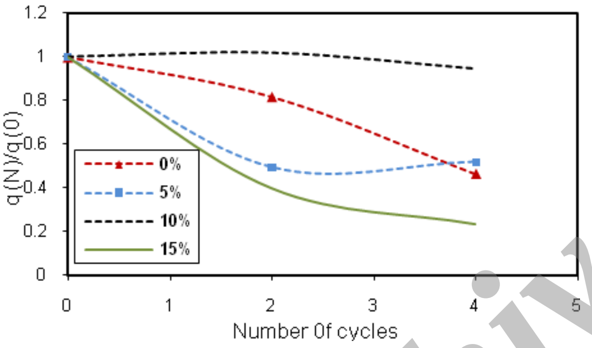

Fig. 11. Final strength variation of soil after 4 freeze-thaw cycles

Fig. 12 illustrates the height variation of soil samples after freeze-thaw cycles. As observed, with the addition of 5-15% tire chips to soil, the sample height decreases or remains the same. During freezing phase, ice crystals are formed and a frost heave occurs in soil specimens. However, after thawing, the height of samples does not reach the initial amount. This phenomenon leads to an increase in the sample height which is reduced by inclusion of tire chips especially when 10% tire chips is used.

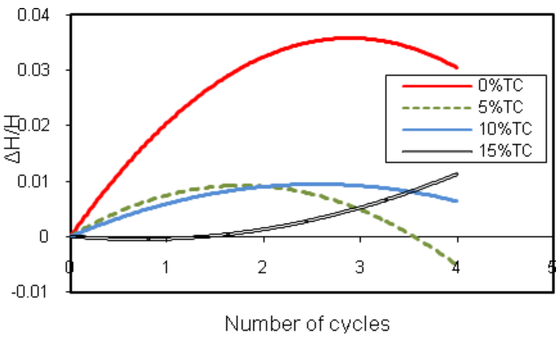

Fig.12. Height variation of samples after freeze-thaw cycles

3.4. Comparison of Tow Additives

Based on the results of this research it can be said that adding tire chips and steel fibers to the soil samples which are affected by freeze-thaw cycles will reduce the frost heave effectively but only tire chips can reduce the decreasing process of strength during the cycles. Fig. 13 illustrates the strength decreasing ratio of all samples after freeze-thaw cycles. It can be seen that just for the samples which are mixed with 10% tire chips the reduction of strength is not noticeable. If the amount of fiber exceeds 10%, the amount of soil particles replaced by tire chips will increase, and since tire chips have negligible cohesion to soil particles, the uniformity of the sample decreases. Since by decreasing the uniformity of soil, it will be more vulnerable during the cycles, the addition of 10% tire chips is far preferable to adding 15% tire chips.

During freezing phase ice crystals are formed, heaved and caused an extra inter pressure to soil particles. This phenomenon can be the reason for strength reduction of soil but it cannot make any changes in steel fibers and tire chips. So when a sample has more tire particles instead of the soil ones it will be more insistent. Having less unit weight in comparison with steel fibers, tire chips occupy more volume in a sample and are more effective than steel fibers are.

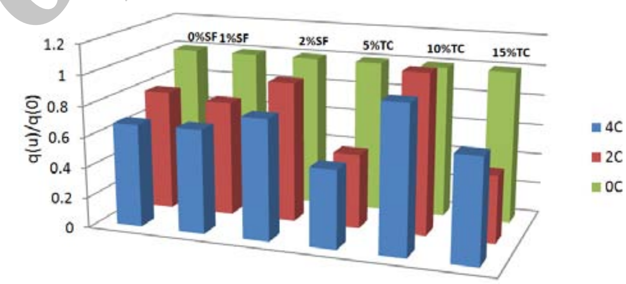

Fig.13. Final strength ratio variation of pure and reinforced samples after 4 freeze-thaw cycles

4. Conclusion

In this paper, unconfined compression strength tests have been conducted to investigate the effects of freeze-thaw cycles on the strength of a kaolinite type clayey soil mixed with tire chips and steel fibers. The results show that:

1) If the number of freeze-thaw cycles increases, the unconfined compression strength of pure samples decreases about 29%.
2) The use of 15% by weight tires in mixtures**,** the unconfined compression strength of samples increases to about 30%.
3) The addition of 3 % of steel fibers increases the unconfined compression strength of soil about 7% and 6% before and after applying cycles, respectively.

4) With increasing the number of freeze-thaw cycles, the height of specimen's increases and addition of 3% steel fibers and 10% of tire chips reduce this phenomenon up to 50%.
5) Although adding steel fibers does not have any noticeable effect on the strength reduction of soil during freeze-thaw cycles, tire chips can reduce this process remarkably.

In general, based on the findings of the study in cold climates where soils are affected by freeze-thaw cycles tire chips are preferable. This preference is more supported due to environmental consideration through suggesting an application for waste materials.

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