Use of homopolymer polypropylene fiber for improving engineering characteristics of cement-stabilized soft clay

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ABSTRACT: Soft clay is a problematic soil that exhibits low bearing capacity and excessive settlement under loading. Chemical stabilization by the addition of lime or cement is commonly used to improve the geotechnical properties of soft clay. Whilst the lime-cement treatment enhances the compressibility and shear strength of soft clay, it decreases the ductility of treated soil, leading to brittle failure. The aim of this paper is to investigate the effects of homopolymer polypropylene fiber in enhancing the engineering characteristics of cement-stabilized soft clay particularly ductility. Homopolymer polypropylene fiber is added with different amounts to cement-treated soft clay and a series of laboratory experiments are carried out to examine the strength (compressive and tensile), stiffness and ductility of the mixtures. The results indicate that homopolymer polypropylene fiber is an effective additive in enhancing the engineering characteristics of cement-stabilized soft clay; however, its level of effectiveness relies on the amount of cement in the treated clay.

1 INTRODUTION

Chemical stabilization by the addition of cement or lime is a proven technique that has been used for decades in stabilization of weak soils by improving soil engineering characteristics such as strength and compressibility. However, chemical stabilization usually results in brittle behavior (Consoli et al. 1998; Sakr et al. 2009), which is undesirable soil property that leads to sudden failure. In order to improve the engineering properties of chemically stabilized soils, conventional geosynthetics (e.g. strips, geotextile, geogrid, etc.) are usually used as soil reinforcement. More recently, randomly distributed fibers are also used which have found to provide more advantages over conventional geosynthetics in terms of workability and simplicity of adding and mixing the fibers with soil. In addition, fibers can limit the potential planes of weakness associated with conventional geosynthetics that may develop parallel to oriented reinforcement (Tang et al. 2006).

There are generally three types of fibers that can be used for soil stabilization, including metal fibers, natural fibers and polypropylene fibers. However, metal fibers have a corrosion problem and natural fibers are biodegradable. In this study, the impact of homopolymer polypropylene fibers in enhancing the mechanical properties (i.e. compressive and tensile strengths, stiffness & ductility) of cement-stabilized soft clay are investigated.

2 MATERAIALS TESTED

The soil used in this study is kaolin clay that has one third of its particle size over 1 micron. The cement used is general purpose ordinary Portland cement. Two amounts of cement (i.e. 3% and 7% by weight) were utilized, as it was demonstrated by Bell (1987) that the desirable lower and upper limits of cement for soil stabilization are 2% and 8%, respectively.

The fiber used is made of 100% homopolymer polypropylene and has a collated fibrillated (network) form, as shown in Figure 1. This fiber is 19 mm long, has a specific gravity of 0.91 and tensile strength of 620–758 MPa. It is classified as medium duty fiber that has long term durability. The fibrillated form of this fiber makes it more workable, which is in contrast to other polypropylene fibers of single form that have a tendency to clump together when water is added to the mixture. Homopolymer polypropylene fiber is mainly used in concrete applications to control temperature/shrinkage cracking; however, to the authors' best knowledge it has not been previously used for soil stabilization. In this study, three different amounts (by weight) of fiber were used (i.e. 0.25%, 0.5% and 0.75%).

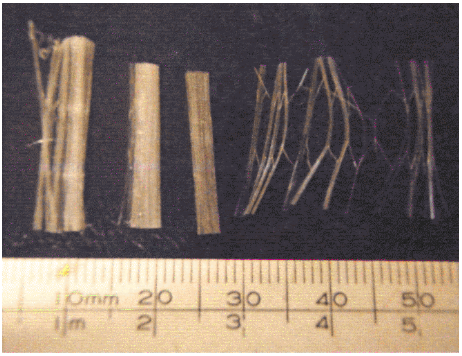

Figure 1. Photograph showing the homopolymer polypropylene fiber

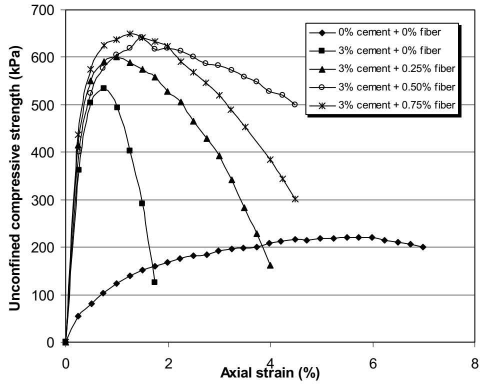

Figure 2. Unconfined compression strength tests for 3% cement-stabilized clay

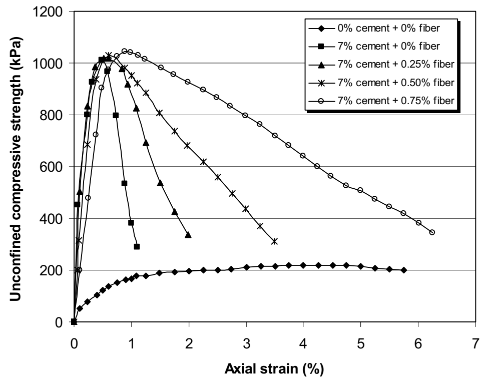

Figure 3. Unconfined compression strength tests for 7% cement-stabilized clay

3 TESTING PROGRAM AND RESULTS

3.1 *Sample preparation*

As mentioned previously, the clay soil specimens used in this study were stabilized with 3% and 7% (by weight of dry soil) of cement, and three different amounts (by weight of dry soil) of fiber (i.e. 0.25%, 0.5% and 0.75%). A series of compaction Proctor tests were carried out on all test specimens in accordance with the Australian Standards 1289 (2007), and the respective maximum dry densities and optimum moisture contents were obtained. In preparation of all specimens for compressive and tensile strength tests, the sample components were mixed using Hobart mixer with the dough mixing attachment. Specimens were mixed for approximately five minutes or until the water was evenly mixed throughout, and the specimens were cured in a curing room for 14 days at a constant temperature of 25^{o}C.

3.2 *Unconfined compression tests*

The compressive strength characteristics of the specimens used were obtained through a series of unconfined compression strength (UCS) tests that were conducted on samples of 100 mm in diameter and 200 mm high. All specimens were prepared at a constant level of compaction equal to 95% of that achieved by the standard compaction Proctor tests. The UCS tests were strain controlled with axial loads applied at a rate of 0.6 mm/min, and the stress-strain curves obtained are shown in Figures 2 and 3 for clay stabilized with 3% and 7% cement, respectively.

It can be seen from Figures 2 and 3 that the addition of cement alone significantly increases the ultimate strength and stiffness (modulus of elasticity) of clay soil, and decreases the deformation at failure. However, it can also be seen that the addition of cement alone exhibits brittle failure with significant loss of post-peak shear strength. On the other hand, it is clearly shown that the addition of homopolymer polypropylene fiber to cement-stabilized clay increases soil ultimate compressive strength and corresponding failure strain, and also increases soil ductility. This is attributed to the reinforcement impact of fiber which provides additional soil strength and ability to restrain soil cracking. The figures also show that stiffness of cement-stabilized clay seems not to be affected by the addition of fiber.

The photographs shown in Figure 4 demonstrate the difference in failure modes (for 7% cement stabilized clay) between the fiber-treated and fiber-untreated soils. It can be seen that fiber-treated cement-stabilized specimen exhibits ductile failure mode, whereas fiber-untreated cement-stabilized specimen shows brittle failure mode.

Figure 4. Different failure modes for 7% cement-stabilized fiber-treated (left) and fiber-untreated (right) soils

Figure 5 illustrates the impact of fiber content on the unconfined compression strength of cement-stabilized clay. It can be seen that compressive strength of cement-stabilized clay generally increases with the increase of fiber content; however, the addition of more than 0.5% fiber does not significantly improve compressive strength. It can also be seen that the influence of fiber in enhancing compressive strength of cement-stabilized clay is more significant for 3% cement than for 7% cement. The addition of fiber has resulted in about 20% increase in the ultimate compressive strength for 3% cement-stabilized clay, whereas the improvement of ultimate compressive strength for 7% cement-stabilized clay was only about 2%.

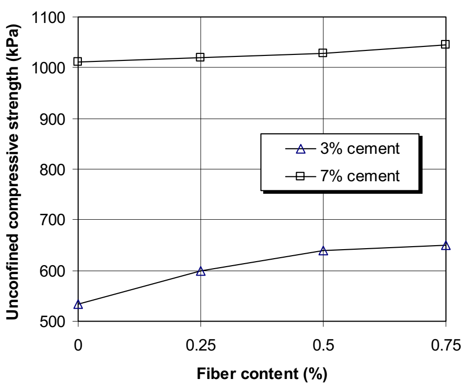

Figure 5. Effect of fiber content on compressive strength of 3% and 7% cement-stabilized clay

3.3 *Tensile strength tests*

A series of indirect tensile strength tests were carried out on samples of 100 mm diameter and 60 mm high. The tests were conducted only for 3% cement-stabilized clay specimens at a loading rate of 0.6 mm/min. The results of the tests are shown in Figure 6, which indicate that the addition of fiber enhances the ductility and ultimate tensile strength of cement-stabilized clay. Again, this is attributed to the reinforcement impact of fiber and its ability to restrain soil cracking. On the other hand, it can also be seen that the addition of fiber to cement-stabilized clay has no effect on the tensile strength modulus of elasticity.

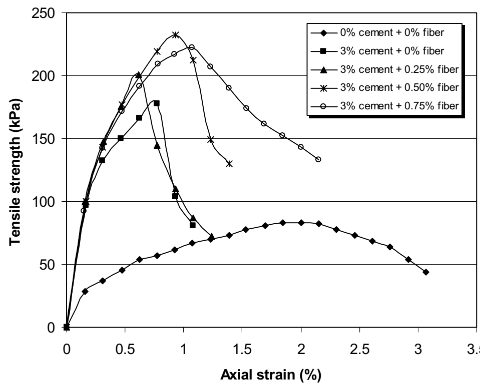

Figure 6. Indirect tensile tests for 3% cement-stabilized soil

Figure 7 above shows the impact of fiber content on the tensile strength of cement-stabilized clay. It can be seen that the addition of fiber generally increases ultimate tensile strength of cement-stabilized clay and that the optimum amount of fiber is 0.5%. It was found that adding 0.5% fiber has resulted in almost 30% improvement in tensile strength of cement-stabilized clay.

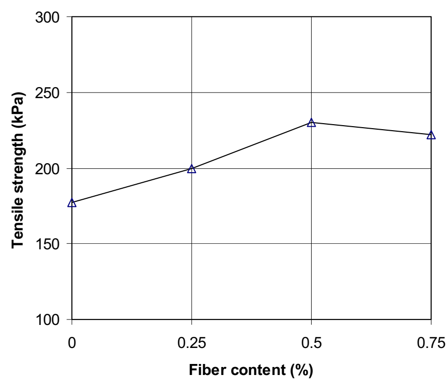

Figure 7. Effect of fiber content on tensile strength of 3% cement-stabilized clay

4 SUMMARY AND CONCLUSIONS

A series of laboratory tests were conducted to investigate the effects of homopolymer polypropylene fiber on the mechanical behavior of cement-stabilized clay. The soil characteristics investigated include the unconfined compression strength, indirect tensile strength, stiffness and ductility. Cement was added in order of 3% and 7% (by weight of dry soil) and fiber was included in order of 0.25%, 0.50% and 0.75% (by weight of dry soil), and experiments were carried out after curing time of 14 days. The study has yielded the following conclusions:

1. The addition of homopolymer polypropylene fiber can increase strength (both compression and tension) and ductility of cement-stabilized clay, but seems not to significantly affect stiffness.
2. The addition of 0.5% (by weight) of fiber homopolymer polypropylene fiber seems to be optimal to achieve satisfactorily improved soil strength and ductility.
3. At low cement content of 3%, the increase of fiber content appears to be more efficient in enhancing strength and ductility of cement-stabilized clay than 7% cement.
4. Overall, the study reveals that the addition of homopolymer polypropylene to cement-stabilized clay can be considered an efficient way of soil improvement.

5 REFERENCES

Australian Standards 1289. 2007. *Method of testing soils for engineering purposes*.

Bell, F.G. 1987. *Ground engineer's reference book*. Butterworth & Co. Ltd., London.

Consoli, N.C., Prietto, P.D. & Ultrich, L.A. 1998. Influence of fiber and cement addition on behavior of sandy soil. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 124(12), pp. 1211-1214.

Sakr, M.A., Shahin, M.A. & Metwally, Y.M. 2009. Utilization of lime for stabilizing soft clay soil f high organic content. *Geotechnical and Geological Engineering*, Vol. 27(1), pp. 105-113.

Tang, C., Shi, B., Gao, W., Chen, F. & Cai, Y. 2006. Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. *Geotextiles and Geomembranes*, Vol. 25(3), pp. 194-202.