Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Reinforcement effects of short geofiber on shear strength and ductility of sandy soil

K. MINEGISHI
M.Eng., Research Associate, Department of Transportation Engineering and Socio-Technology ,
College of Science & Technology, Nihon University, Japan

K. MAKIUCHI
Ph.D., Professor, Ditto

ABSTRACT: For investigating quantitative shear strength characteristics of short fiber-reinforced soils, a series of laboratory shear tests was conducted and the results showed that length, diameter, surface roughness and mixing rate of short geofibers had marked effects on the shearing strength behavior of reinforced soils and the recommended optimum mixing rate of geofibers was presented. Furthermore prominent increase in residual strength or shear strain energy against the shear resistance of fiber-reinforced soils was shown within the wide range of large deformation before failure. This improved ductility or strain-induced toughness can be recognized as an advantageous for fail-safe designing such as earthquake-proof soil structures.

1 INTRODUCTION

A mechanical treatment of soil mixed with short length fibers is classified as one of the fiber reinforced earth construction methods. This short geofiber, as well as continuous long filaments, currently is employed for improving weak embankment slope and poor bearing capacity of foundation grounds, and for increasing the strength of backfill soil in wall-type reinforced-earth. The short geofibers restrain the deformational movement of soil particles and strain-dependent toughness such as the re-use of poor surplus soils produced in the construction sites and stabilizing the steep slopes providing the vegetation base and erosion control. At present, however, insufficient knowledge is available regarding to this reinforcement mechanism and mechanical properties of non-continuous fiber-soil mixture (RIPW, 1997 and Makiuchi *et al.*, 2001).

2 MATERIALS TESTED

2.1 *Soils*

Three types of soils; fine sand, *Kaolin* clay and natural sandy soil were used for this experimental works. Physical characteristics of the fine sand were; particles density ρ_s = 2.64 g/cm^3 ,60 % passing gain diameter d_{60} = 0.2 mm, uniformity coefficient Uc = 2.0, coefficient of curvature Uc' = 1.45, maximum and minimum void ratios e_{max} = 0.97, e_{min} = 0.59, respectively. The properties of clay (CH: high plasticity clay) were; particles density ρ_s= 2.56 g/cm^3, The properties of sandy soil were ρ_s = 2.66 g/cm^3 , d_{60} = 0.2 mm, Uc = 12.7, Uc' = 7.17, optimum moisture content w_{opt} = 19.5 %.

The fine sand as a non-cohesive material was used in the air dry condition in a direct box shear test. The soil employed as a cohesive material in an unconfined compression test was a mixture of the sand and the clay with the mixing rate of 10 % in dry mass. This mixing rate was determined based on the results by pre-compaction test. The sandy soil was compacted in condition of the optimum moisture content.

2.2 *Short geofiber*

Reinforcement short fiber materials tested were nylon fibers for both a box shear test (Test Ⅰ) and an unconfined compression test (Test Ⅱ) and polypropylene fibers for Test- and - . The fibers used in Tests-Ⅰ and-Ⅱ were; one group is L = 10 mm with d = 0.175, 0.33 and 0.66 mm, and another group is d = 0.33 mm with L = 5 to 160 mm. The mixing ratio M of these fibers with the soils was maintained at the constant rate of 1.0 % of fibers in dry mass.

The fibers in Test-Ⅲ was 10 mm in length and two types of the fiber's surfaces were prepared. One had a non-treated smooth surface and another one was a rough surface fiber to which the fine sand particles were adhered with a chemical bond (silicone-sealant 8060). The ribbed fiber in test Ⅳ was 0.25 mm in diameter and 48.8 mm in length with three ribs of 17.5 mm (cross-shaped branches connected in even span).

3 EXPERIMANTAL PROCEDURE

3.1 *Specimen preparation*

In Test Ⅰ and Ⅱ , the air-dried fine sand mixed with the geofibers were used for a box shear test of 6 cm in diameter and 2 cm in height. The sand specimens mixed with the geofibers were compacted under the condition of dry density of 1.43 to 1.45 g/cm^3, *viz.* density index ID between 45 and 55 %.

In Test Ⅱ, firstly sand-clay mixture was mixed and then the specified amount of geofibers were blended uniformly with the mixture. The unconfined compression test specimens of 6 cm in diameter and 14 cm in height and the specimen's dry density of 1.74 g/cm^3 were compacted using a steel mould subjected to the static compression force of 14.7 kN in the condition of the optimum moisture content of 9.5 %. The specimens used in Test Ⅳ were prepared at dry density 1.60 g/cm^3 in the similar way to Test Ⅱ.

3.2 *Direct shear test and unconfined compression test*

The shear stress-deformation relationships and peak and residual stress behavior of fiber-reinforced cohesionless soil were investigated using a standard type shear box device. The shear tests were conducted at the deformation rate of 0.25 mm/min..

The compressive stress-strain relationships and the maximum and residual strength properties of fiber-reinforced cohesive soils were investigated using a uni-axial compression apparatus. The compressive tests were conducted at the compressive strain rate of 1.0 %/min.

4 MECHANICAL CHARACTERISTICS OF SHORT-FIBER REINFORCED SOILS

4.1 *Shearing properties of fiber-reinforced fine sand*

4.1.1 *Improved peak and residual strength*

Figure 1 shows that the effects of fiber's diameter on shear resistance of the reinforced sands under the conditions of M = 1.0 %, L = 1.0 mm and the normal stress σ = 200 kPa, in the box shear test. It is found that smaller the diameter, the higher both the peak strength and the modulus of deformation. This increased peak strength (about 0 to 25 %) is owing to the increased surface area of fibers that are depending to the numbers of fibers in inverse proportion to the diameter of fibers at the constant fiber's mixing rate. No difference of the residual strength, however, can be recognized at large deformation level.

4.1.2 *Mobilized shear resistance*

Figure 2 illustrates the mobilized shear stress increment compared with the non-reinforced soil and it can be seen that the stress increment decrease with the increase in fiber's diameter and will approach finally to almost the same value of non-reinforced sand though some scatters can be seen. The effects of fibers may be caused by interface friction, interlocking and intertwining between the fiber's surfaces and the sand particles. In addition, the high peak and residual strength exhibited in the cases of longer fibers are attributable to the phenomenon of expanding shear zone in proportion to the length of fibers.

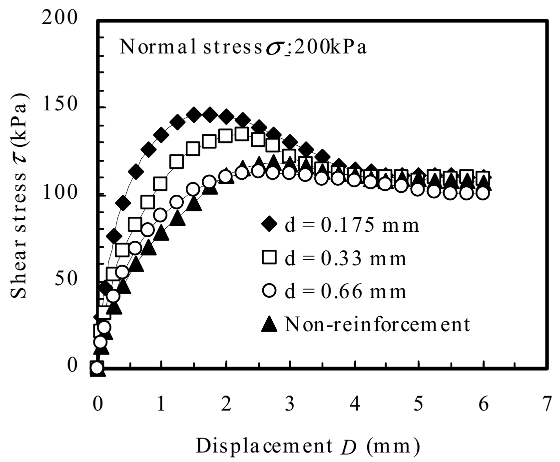

Figure 1. Shear curves in box shear test (sand, L =10mm, M =1.0%).

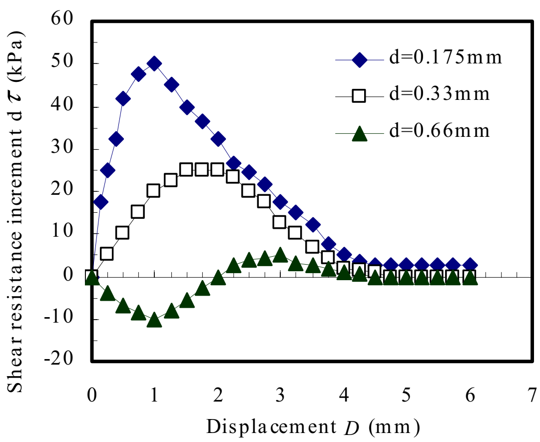

Figure 2. Mobilized shear resistance increment (sand, L =10mm, M =1.0%).

4.1.3 *Effects of fiber's length and diameter*

Figure 3 illustrates that the apparent friction angle obtained from the normal stress and peak shear stress diagrams. It is found form the figure that no cohesion component of shear strength may be supplemented to granular soil particles by means of short fiber's reinforcement.

Figures 4 shows the relationships of the internal friction angles ϕ at the peak strength versus the fiber's length. It can be seen that internal friction angles of the reinforced sands increase gradually with the increase in fiber's length. This is probably due to the friction of each fiber that will expand effectively the confining zone of sand. In order to reinforce the fine sands, it can be seen from the figures shown above that the optimum size concerning length and diameter is supposed to exist at the specified mixing rate and kinds of soil.

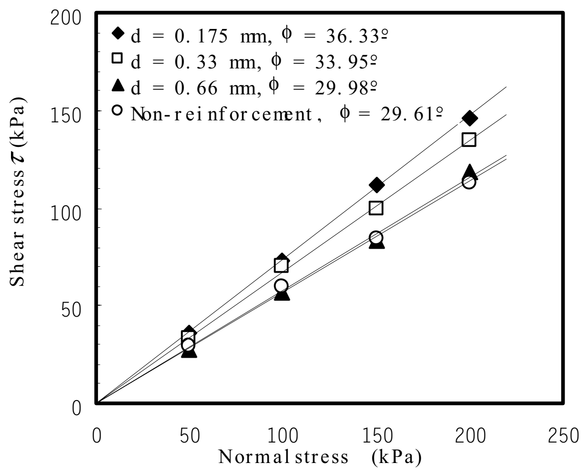

Figure 3. Normal stress - shear stress relations in box shear test (sand, L =10mm, M=1.0%).

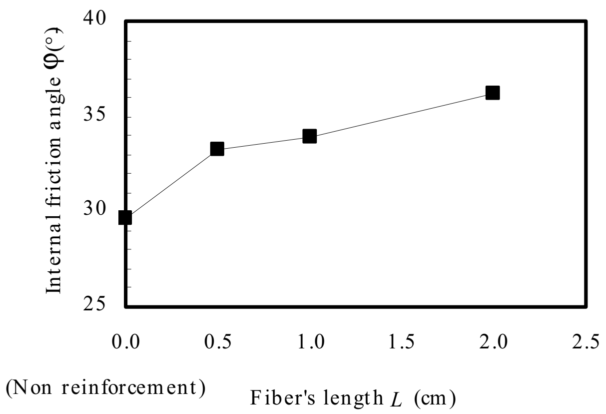

Figure 4. Effects of fiber's length on internal friction angle (sand, M=1.0%).

4.2 *Shearing properties of fiber-reinforced sand-clay mixture*

4.2.1 *Improved peak and residual strength*

Figure 5 demonstrates that the axial stress-strain relations of the fiber-reinforced sand-clay soil. It is found that smaller the diameter, the higher the peak strength (up to about 2 times) and residual strength (increase of up to about 2.5 times at the same strain level). This increased shear resistance is owing to the increased circumferential area of fibers that are depending to the numbers of fibers in inverse proportion to the diameter of fibers at the constant fiber's mixing rate. It must be noted that no noticeable difference of the initial or tangential modulus of deformation can be found among these specimen.

4.2.2 *Total strain energy*

Figure 6 shows the total strain energy *U* up to axial strain of 10 % in an unconfined compression test. Cohesive soils can be extremely improved by the short fiber reinforcement and they have high ductility and toughness for shearing deformation. It is found to be appropriate that fibers of about 10cm are employed as usual in practice.

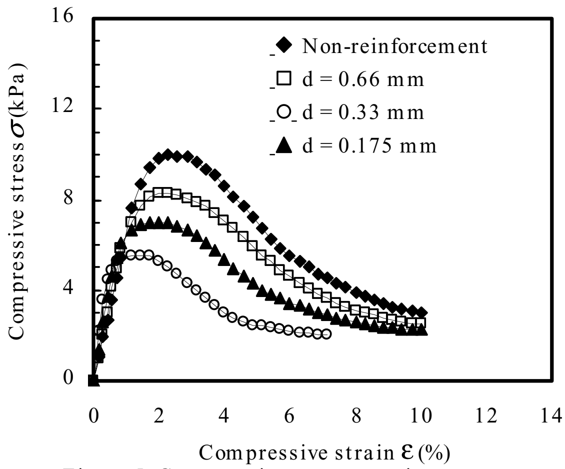

Figure 5. Compression stress-strain cerves (clayey sand, L =10mm, M =1.0%).

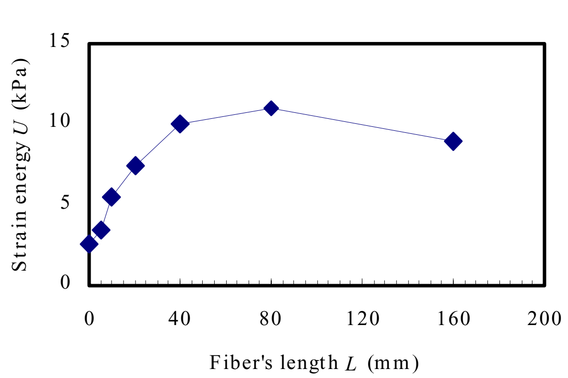

Figure 6. Effects of fiber's length on strain energy (clayey sand, D=0.33mm, M=1.0%).

4.3 *Effects of fiber's surface roughness*

Figure 7 shows that the internal friction angle of reinforced sand by rough surface fiber shows higher resistance than that by the smooth one and the angles increase with in the mixing rate. It must be noted that the smooth surface fiber's reinforcement will not be maintained its residual strength and is consistent with that of non-reinforced soil at larger strain range. The effect may be caused by the mobilized friction and an interlocking action between fiber and sand particles.

4.4 *Shearing properties of ribbed fiber-reinforced sandy soil*

Figure 8 shows the effects of ribbed fiber on axial stress- strain relations in an unconfined compression test. It can be seen that non-reinforced soil demonstrates no residual strength after about 5 % of strain, however, other reinforced soils improve the toughness. Figure 9 indicates the mobilized compressive stress which means the difference between the shear stress of the ribbed fiber-reinforced soils and that of non-reinforced soil. The mobilized resistance increases with the increase in fiber's mixing rate.

Figures 10 and 11 illustrated the total strain energy and the improved compressive peak strength as the similar effects of mixing rate to non-ribbed fiber reinforced soils.

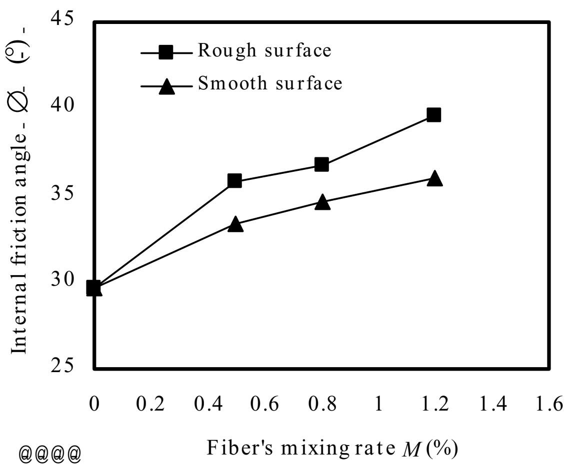

Figure 7. Effects of fiber's surface friction in box shear test. (sand, L =10mm, d =0.33mm)

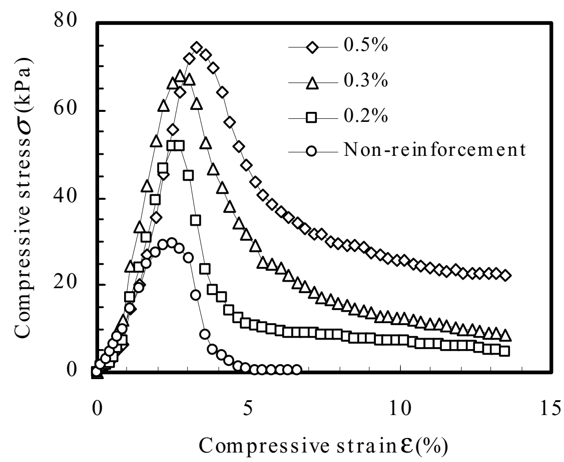

Figure 8. Compression stress-strain curves (sandy soil, ribbed fiber).

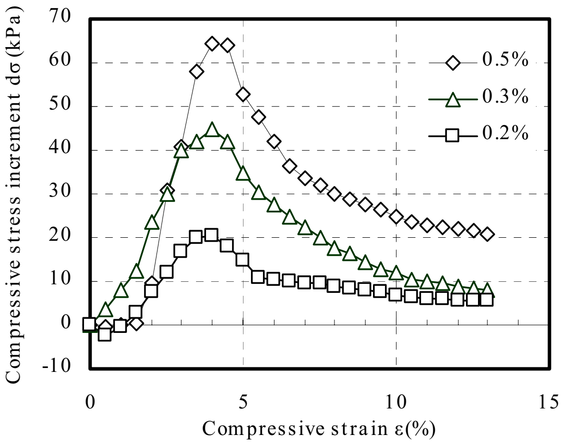

Figure 9. Mobilized shear stress increment (sandy soil, ribbed fiber)

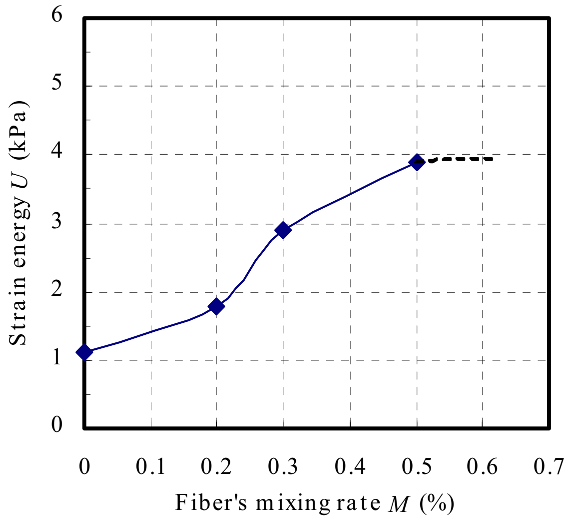

Figure 10. Effects of fiber's mixing rate on strain energy (sandy soil, ribbed fiber).

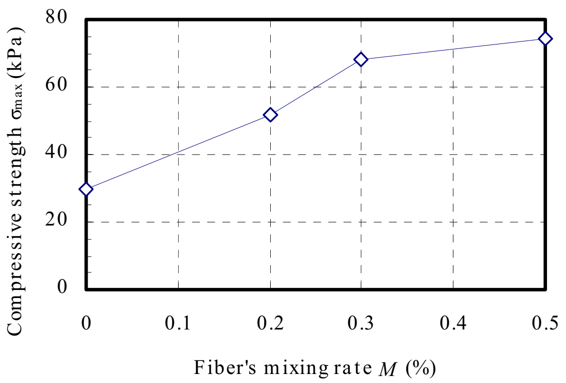

Figure 11. Effects of fiber's mixing rate on compressive strength (sandy soil, ribbed fiber).

5 CONCLUSIONS

From the results under undrained shearing test conditions it was found that the reinforcement effects were influenced by the surface roughness and ribs as well as length, diameter and mixing rate of fibers. The principal findings obtained are as follows:

1) The apparent friction angles of fiber-reinforced non-cohesive sands increase with the increase in fiber's length or with the decrease in fiber's diameter.
2) The marked reinforcement effects on both the peak and residual strength are obtained for cohesive soils
3) The improved total strain energy of reinforced soils indicates its maximum value at fiber's length of around 8 cm. This tendency is consistent with the empirical value of about 10 cm that is supposed to be the optimum length of fibers from the viewpoint of mixing and field construction efficiency.
4) The residual strength are maintained for a very wide range of strain. This means that cohesive soils can be extremely improved by the short fiber reinforcement and they have high ductility and toughness for shearing deformation.

AKNOWLEDGEMENTS

The authors would like to express their gratitude to Mrs. H. Nakahara, T. Watanabe, S. Yamaguchi and I. Hoshino for their assistance in the experimental works in this study.

REFERENCES

K.Makiuchi, K.Minegishi, S.Yamaguchi and I.Hoshino: Shear Strength Characteristics of Ribbed Short Fiber-reinforced Soils, Geosynthetics Engineering Journal, Vol.16, pp.9-12, Japan Chapter of International Geosynthetics Society, 2001 (in Japanese)

Research Institute of Public Works, Ministry of Construction: Joint Research Report of Technical Manual on Application of Earth Reinforcement mixed with Short Fiber, 66pp. 1997 (in Japanese)