Simple Shear Test on Sand Reinforced by Continuous Fibers

J. Kuwano
Tokyo Institute of Technology, Japan

Y. Imamura & K. Ogawa
Science University of Tokyo, Japan

M. Sakurai
Penta-Ocean Construction Co Ltd, Japan

K. Ozaki
Kumagai Gumi Co Ltd, Japan

ABSTRACT: Anisotropy of sand reinforced by continuous fibers is investigated by simple shear tests and box shear tests. Tests are performed on the sand samples mixed with fibers which have different angles of deposition, α, of 0° to 180°. From the simple shear tests it is found that the directions of the minor principal strain to the horizontal converge to about 50° irrespective of the angle of deposition of the specimen. The highest shear resistance is obtained for the specimen with α of 45° to 60°, in which direction the largest tensile strain is induced. Although the strength is highest when α is 90° in the shear box tests, the results obtained by two test series show reasonably good correspondence in terms of the predominant direction of fibers to the failure plane.

1 INTRODUCTION

Sand reinforced by continuous fibers, known as Texsol, has been used for the construction of embankments, retaining walls, slope protection and so forth. Taking advantage of its increased strength, even a ten meter high retaining wall was successfully constructed (Fukuoka et al., 1991). Multiple continuous fibers are mixed with sand by a water jet to improve the shear resistance of sand. Although the fibers are said to be mixed three-dimensionally with sand, they are arranged rather two-dimensionally in the plane of deposition. Therefore this composite material has strong anisotropy as pointed out by Khay et al. (1990).

Anisotropy of continuous fiber reinforced sand was investigated through the use of simple shear tests and box shear tests in this study. Mechanism of reinforcement and shear characteristics of sand reinforced by continuous fibers were studied through these tests.

2 TEST SPECIMENS

Specimens were made in the laboratory by mixing pluviated sand with fibers through the use of the water jet. Thread was spread over the plane of deposition by swinging the nozzle of the water jet as shown in Fig.1. Sand and fibers were placed in the stacked square frames of the simple shear apparatus or in the mold with the different angles of deposition, α, of 0° to 180°, and tamped to get ρ_d=1.6t/m³. The sand used for the tests was Toyoura sand, Japanese standard sand, with D_{50}=0.17mm, U_C=1.7, e_{max}= 0.985 and e_{min}=0.602 as obtained by the JSSMFE method. The fibers are made of polyester, 30 filaments of which are bundled without twist-

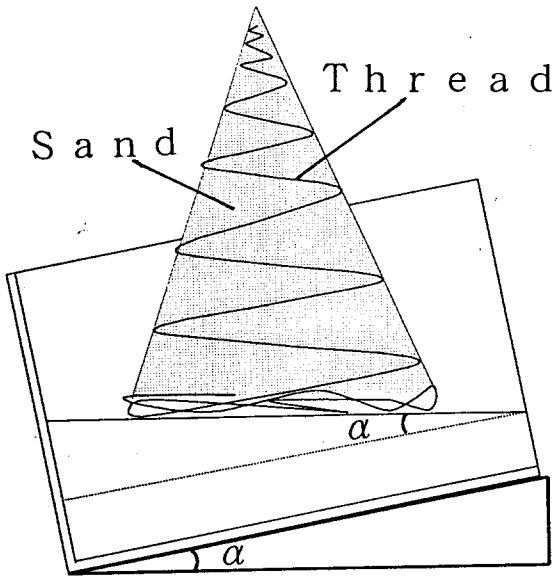

Fig.1 Sample preparation method

ing. Properties of fibers are summarized in Table 1. The amount of fibers mixed with sand was about 0.2 % by weight.

Table 1. Properties of fibers

Material	Polyester
Thickness (D;Denier)	150(≃0.05mm)
Tensile strength per denier (mN/D)	43.5
Number of filaments	30

3 LABORATORY TEST

Simple shear tests were performed on samples of sand reinforced by continuous fibers. The multiple-layer type simple shear test apparatus used in this study is shown in Fig.2. It is composed of nine layers of square frame of 10 cm by 10 cm inside. Rollers are installed between the frames to reduce friction. The total height of the stacked frames is 11 cm.

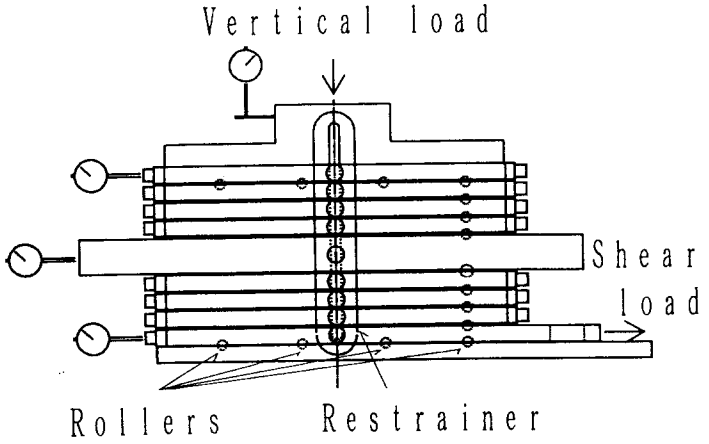

Fig.2 Simple shear test apparatus

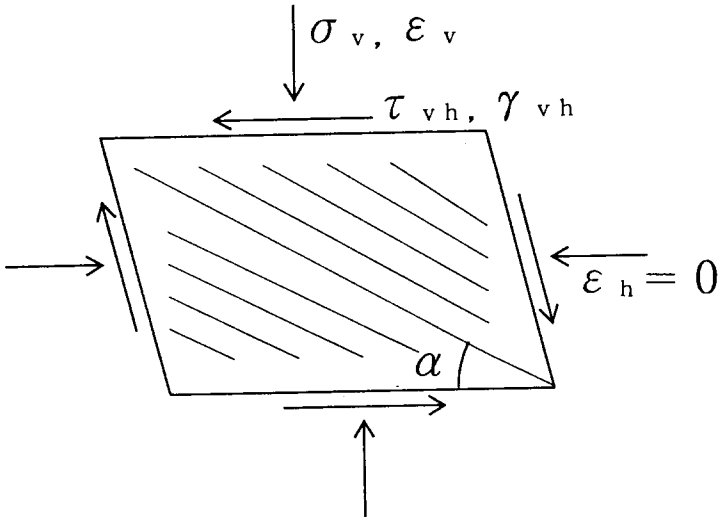

Fig.3 Stresses and strains measured in the simple shear test

The vertical stress, σ_v, and the shear stress, τ_{vh}, are controlled and measured in this apparatus. The vertical strain, ε_v, and the shear strain, γ_{vh}, are measured, and the horizontal strain, ε_h, is zero as summarized in Fig.3.

The specimens prepared as above were then consolidated in the square frames of the simple shear apparatus with the vertical stress of 19.6 kPa. With keeping σ_v constant, they were sheared at the strain rate of 1 %/min.

Box shear tests were also carried out on the continuous fiber reinforced sand samples. Specimen prepared in the mold was set in the shear box with the inner dimension of 30*30*30 (cm). It was consolidated and sheared under the constant vertical stress of 19.6 kPa with the shear displacement rate of 0.25 mm/min.

4 RESULTS AND DISCUSSIONS

4.1 Simple shear tests

It is seen in the stress-strain relationships shown in Fig.4 that the difference in the shear stress, τ_{vh}, among the specimens with different angle of deposition, α, increases with increasing shear strain, γ_{vh}. It seems to be because the reinforcement by fibers works effectively with strain. τ_{vh} of the samples with α=45° and 90°, especially, increase sharply with the shear strain, though the peak values could not be obtained because of the limitation of the simple shear apparatus used in this study.

The direction of the minor principal strain to the horizontal, ξ, was obtained by using Mohr's strain circle as shown in Fig.5 with the

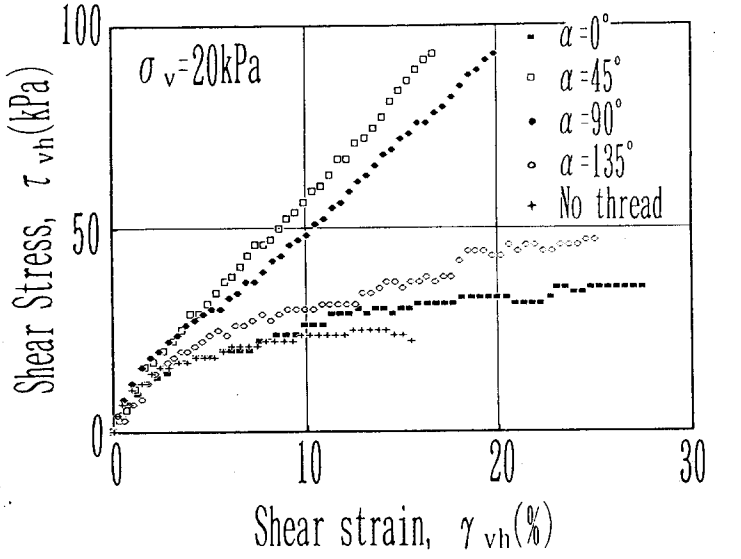

Fig.4 Stress-strain relationships of reinforced specimens with different angles of deposition

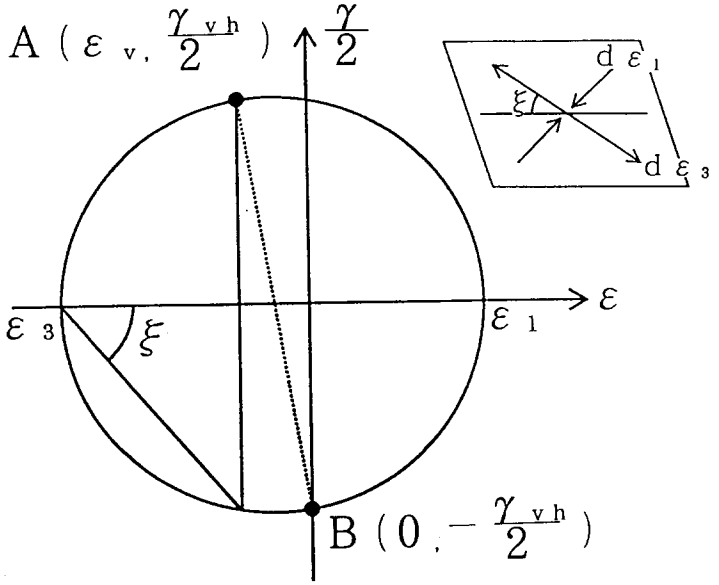

Fig.5 Mohr's strain circle

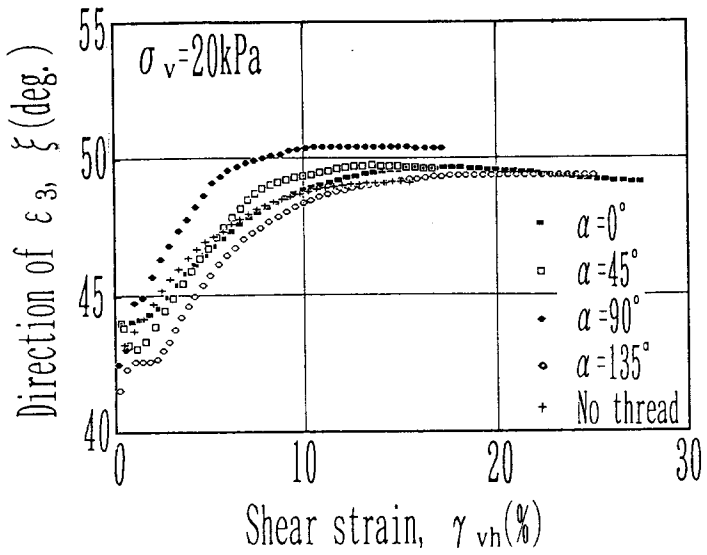

Fig.6 Directions of the minor principal strain

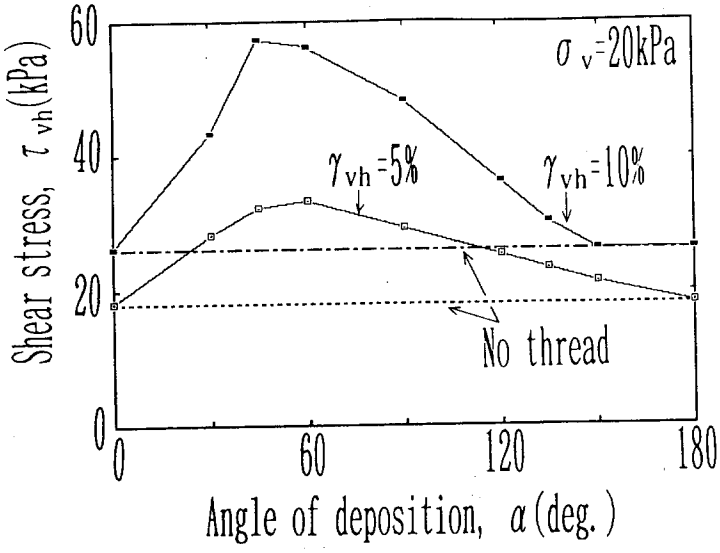

Fig.7 Variations in the shear resistance with α

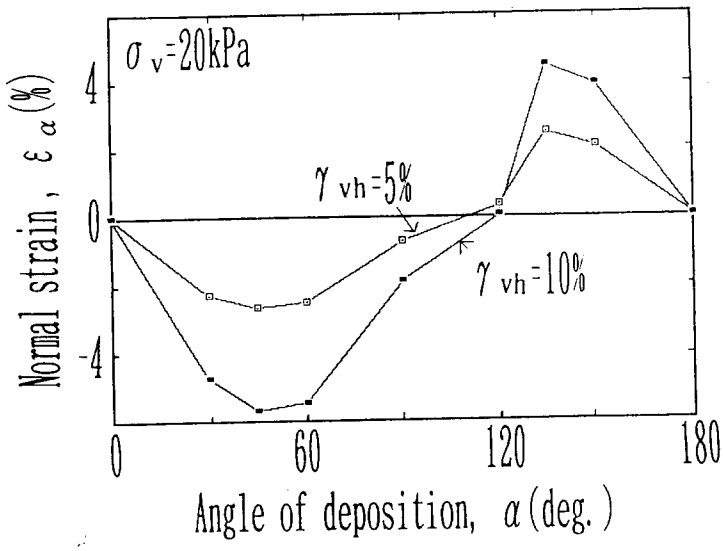

Fig.8 Variations of the normal strain in the direction of deposition

measured values of strain summarized in Fig.3. The direction of the minor principal strain, was about 42 to 45 degrees from the horizontal depending on α of the specimen in the initial stage of shearing as shown in Fig.6. With the shear strain, the angles between the direction of ε_3 and the horizontal increased and converged to about 50° irrespective of the value of α of the specimen. Therefore, the specimens were exposed to the largest extension deformation in the direction of about 50° to the horizontal in all the test cases.

Variations in the shear stress, τ_{vh}, with the angle of deposition of the sample are shown in Fig.7 for the respective strain levels of γ_{vh}=5, 10 %. The highest shear resistance was observed in the specimen with α of 45° to 60°, in which direction the largest tensile strain was induced as shown in Fig.6.

The normal strain induced in the direction of deposition (i.e. in the plane of α) is shown in Fig.8. The tensile strain is observed when α=0° to 120°, and it is highest when α is 45° to 60° which is close to 50° where the direction of ε_3 coincides with the predominant direction of fibers. On the other hand, compressive strain is observed when α= 120° to 180°. The shear resistance of the specimen is, therefore, highest when α=45° to 60°, while it is almost equal to that of pure sand sample when α=120° to 180°.

4.2 Box shear tests

The variation in the shear strength obtained by box shear test with the angle of deposition of the specimen is shown in Fig.9. The strength

was highest when α was 90° as reported by Khay et al. (1990), though the maximum strength was expected to be obtained for the specimen of $\alpha \simeq 45°$ which was obtained by the simple shear test or $\alpha \simeq 60°$ which was predicted by the theoretical approach, e.g. Gray and Ohashi (1983) and Jewell and Wroth (1987).

The failure plane expected in the simple shear test specimen is schematically shown in Fig.10, where $K_o=0.5$ and $\phi=30°$ are assumed for the rough estimation. As discussed above, the shear strength was highest when the predominant direction of thread was normal to the failure plane. The normal is 52° from the horizontal in the case shown in Fig.10. It is close to the direction of $\alpha=45°$ to 60° in the simple shear tests where the highest shear resistance was observed. Therefore, it is to be mentioned that the results obtained by the simple shear tests and the box shear tests show reasonably good correspondence each other.

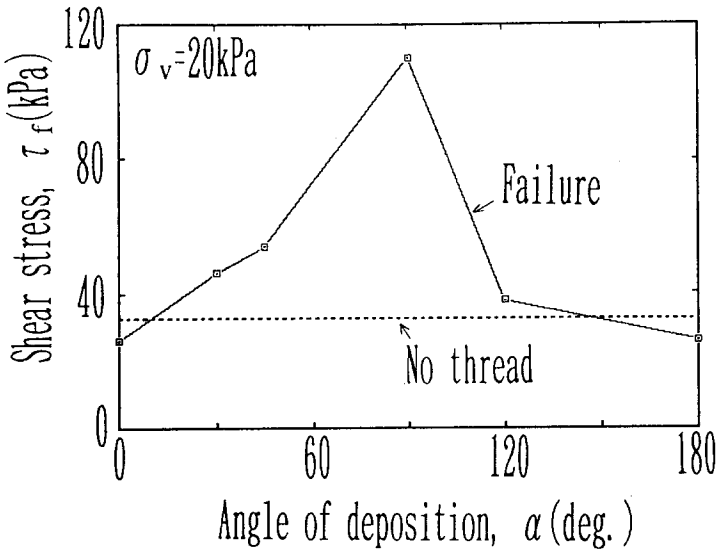

Fig.9 Variation in the shear strength with α

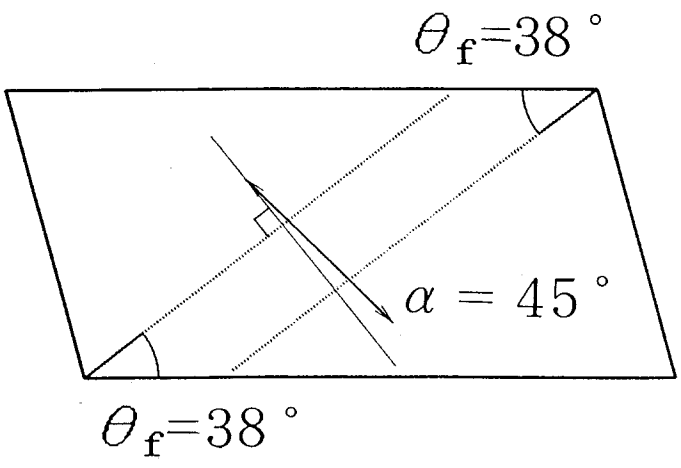

Fig.10 Failure planes in the simple shear test

CONCLUSIONS

From the simple shear tests and the box shear tests on sand samples reinforced by continuous fibers, the following conclusions were obtained:

1) The difference in the shear stress among the specimens with different angle of deposition, α, increased with increasing shear strain.

2) The directions of the minor principal strain to the horizontal converged to about 50° irrespective of the angle of deposition.

3) The highest shear resistance was obtained when α was 45° to 60°. The tensile strain in the direction of deposition was observed to be highest also when α was 45° to 60°.

4) In the box shear tests, the highest shear strength was obtained when α was 90°. It seemed to be reasonably good correspondence with the results obtained by simple shear tests in which the highest shear resistance was observed when the predominant direction of fibers was almost normal to the failure plane.

ACKNOWLEDGEMENT

The laboratory works for this study were performed with the help of Messrs. T.Imanari, T.Kimura, graduate students of Science University of Tokyo. The study was supported by Nittoc Construction Co.,Ltd. The authors wish to express their sincere gratitude to them.

REFERENCES

Fukuoka, M., Nakayama,K., Ihara,S., Okedoi,K. and Ozaki,K. (1991) Stability of Fiber Reinforced Retaining Walls, *Proc. 2nd Int. Conf. on Recent Advances in Geotechnical Earthquake Eng. and Soil Dynamics*, St. Louis, 643-648.

Gray, D.H. and Ohashi,H. (1983) Mechanics of Fiber Reinforcement in Sand, *J. of Geotech. Eng.*, ASCE, 109:335-353.

Jewell, R.A. and Wroth,C.P. (1987) Direct shear tests on reinforced sand, *Geotechnique*, 37, No.1, 53-68.

Khay, M., Gigan,J.P. and Ledelliou,M. (1990) Reinforcement with continious thread: Technical developments and design methods, *Proc. 4th Int. Conf. on Geotextiles, Geomembranes and Related Products*, 21-26.