A Potential Composite Material for Possible Applications in Earth Reinforcement

Hossain, M.Z.
Division of Environmental Science and Technology
Graduate School of Bioresources, Mie University, Tsu, Japan
zakaria@bio.mie-u.ac.jp

ABSTRACT

It is evident that the inadequate frictional resistance and meager cohesion of conventional reinforcements in reinforced earth structures such as geogrids, geosynthetics and wire meshes are serious shortcomings that not only impose constraints in structural designs, but also affect the stability of reinforced earth structures. In this regard, the benefits of earth reinforcing materials in improving the interaction resistances are eminent. For the reinforcement to be effective, two conditions need to be satisfied i.e. it must possess enough strength to withstand tension failure and adhesion failure. This paper highlights some experimental results on the performance behavior of thin cementitious composite elements reinforced by wire meshes under shear tests in soil. It was demonstrated that the use of small stones on the surface of thin cementitious composite elements and making small channels on the surface of thin cementitious composite elements enhanced interaction resistance of thin cementitious composite elements in soil and lead to significant improvement of their structural performance as compared to conventional composite reinforcement in reinforced earth structures. The angle of interfacial friction, a measure of thin cementitious composite elements' frictional resistance, was increased by 1.66, 14.81, 21.57 and 23.78% whereas the cohesion, a measure of bonding phenomena between the thin cementitious composite elements and earth, was increased by 29.15, 69.30, 104.05, 132.04% for thin cementitious composite elements containing stone, 2, 4 and 6 channels, respectively. Comparison of the shear test results of thin cementitious composite elements with other conventional reinforcements such as geogrid, geosynthetics and wire meshes revealed that the thin cementitious composite elements can be used as a potential reinforcing material for earth reinforcement's applications.

Keywords: Composite material, earth reinforcement, potential applications, pullout, shear, cohesion, frictional resistance, Japan

1. INTRODUCTION

It is known that earth reinforcement with various materials still remains an art in its rudimentary level, and ideas are evolving towards assessing the uniqueness of an optimal reinforcement system thus far (Fukuoka 1998 and Jones 1996). Composite reinforcement made of cement mortar reinforced with mesh is gaining much popularity lately for effective application in reinforced earth structures due to adequate frictional resistance and enough cohesion between the interface of earth and reinforcement (Koerner 1994, Murray and Irwin 1981). In a composite reinforcement, two or more different types of materials are rationally combined to produce a new composite that derives benefits from each of two components and exhibits a synergetic response. Composite reinforcement using single steel wire in cement mortar for reinforced soil application is one of the examples (Sivakumar et al 2003). Thin cementitious composite element is a cementitious matrix acting compositely with an elasto-plastic material made of high tensile mesh encased with sand-cement mortar. If properly applied in soil reinforcement, it attains its optimal reinforcing capability owing to the synergetic action of mortar with backfill and mortar with mesh. Thin cementitious composite elements with enough tensile resistance provided by the mesh and enough frictional resistance provided by the interfacial friction between the cement mortar and backfill can be a potential reinforcing material for reinforced earth structures as compared to conventional reinforcements (Hossain and Sakai 2007; Kakao, Shimizu and Nishimura 2001) . This paper deals with the development of various composite reinforcement systems for earth reinforcing material and their comparative study with other conventional reinforcements such as geogrids, geosynthetics and wire meshes, etc. In view of this objective, composite reinforcements with rough surface are made by placing small stone on it and by creating small channels during casting process so that benefits of both interfacial friction and cohesion are, simultaneously achieved. To fully understand the interface shear behavior and optimize the efficiency of reinforcement in a given situation, shear tests of reinforcement embedded in soil are usually performed. In this research work, shear tests of five types of composite reinforcements made with plain surface, rough surface with small stone, rough surface with 2, 4, 6 channels, and another five types conventional reinforcements such as geogrid, geosynthetics and wire meshes were carried out. All the tests were performed under four normal stress conditions such as 80, 120, 160 and 200 kPa and the results of shear tests in the form of interfacial friction and cohesion, as well as a comparison among the obtained parameters were reported.

2. MATERIALS AND METHODS

2.1 Composite Reinforcement

The composite reinforcements were prepared in wooden moulds. The requisite amounts of sand and cement were dry-mixed in a pan, followed by the gradual addition of requisite quantity of water while the mix was continuously stirred. Ordinary Portland cement and river sand passing through No.8 (2.38mm) sieve, having a fineness modulus of 2.33 were used for casting. Both the cement-sand ratio and water-cement ratio were 0.5 by weight. The square mesh obtained from the market was cut to the desired size. The diameter of wire was 1.0 mm with center-to-center opening of 10 mm. The sand-cement mortar layer was spread at the base of the mould on which the first mesh was laid. It was then covered by further application of the mortar. Composite reinforcements with ordinary plain and rough surfaces (thickness of the rough surface was approximately 2-4 mm made of stone and small parallel channels, depth 5 mm and width 15 mm of varying number were prepared. Five types of composite reinforcement along with five types of conventional reinforcement were investigated. The thickness and size of the composite reinforcement were 10.0 mm and 315×380 mm, respectively.

2.2 Properties of Soil

The particle size distribution curve of soil used in this research work (Fig. 1) revealed that nearly 9% of the soil is coarse clay, 7% is fine silt, 6% is coarse silt, 14% is fine sand, 44% is medium sand and more than 20% is coarse sand which means that more than 90 percent of the soil is in the silt and sand fraction.

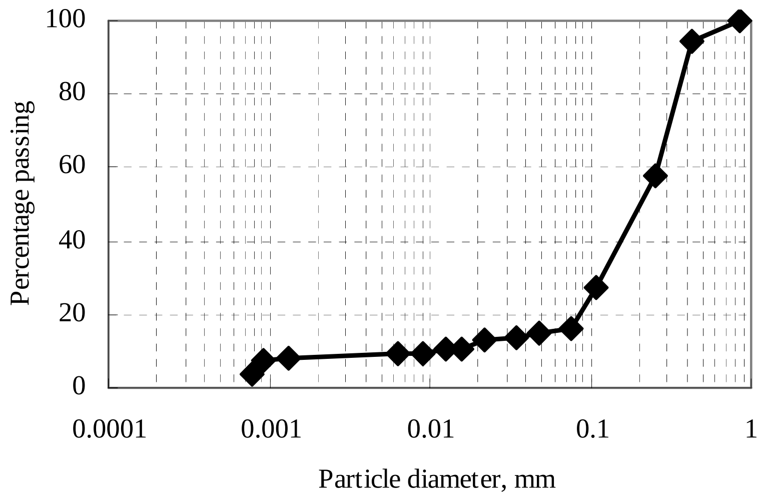

Figure 1. Particle size distribution curve of soil used

According to the unified classification system, the soil is classified as SC. The other properties of soil are depicted in Table 1.

2.3 Test Apparatus

The apparatus used in this study is shown in Figure 2. For convenience of the readers, the important components of the testing equipment are numbered numerically starting from top-left to right-down in ascending manner as the number from [1] to [8], where the number [1] is the normal load application plate for upper box, [2] is the shear stress measuring device, [3] is the upper box filled with soil, [4] is the composite reinforcement panel, [5] is the lower box, [6] is the electrically operated shear jack, [7] is the displacement measuring dial gauge and [8] is the device taking normal load which acted on the upper box.

Table 1. Soil Properties

Component	Parameter	Value
Dry unit weight	γ_d	1.83 t/m^3
Optimum water content	w_{opt}	15.3%
Specific gravity	ρ_s	2.64
Cohesion	c	5.01 kPa
Angle of internal friction	ϕ	32.19^o
Sand, >75μm		78%
Silt, 5-75μm		13%
Clay, <5μm		9%

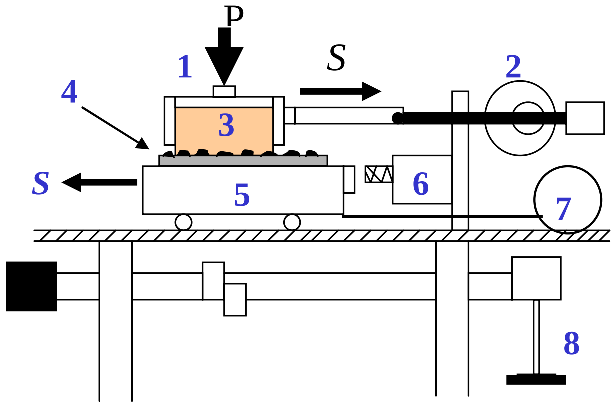

Figure 2. Shear testing apparatus

2.4 Method of Testing

The composite reinforcement panels were made to obtain rectangular pieces of 316 mm by 380 mm in size with 120 mm extended mesh. The specified length of the pieces was selected in order to facilitate clamping with the shear apparatus. The panels were clamped in the box in such a way that the embedded length of the panel was 380 mm in the loading direction and 316 mm in the transverse direction. Water was added gradually to the soil, and thoroughly mixed to obtain desired uniform water content throughout the soil. After embedding the composite reinforcement panel on the lower box, the upper box was set on the panel, and then the soil was filled in the upper box. The shear tests were carried out in the way of pushing out the panel along with the lower box from the soil with constant selected speed of 1.0 mm per minute by means of screw jack under electrically operated constant pressure. The shear forces were measured using a tension load cell with the least count of 5 N. The displacements were measured by means of a mechanical dial gage with least count of 0.001mm. All the shear tests were conducted according to the standard of the Japanese Geotechnical Society (JGS), T941-199X. During the test, the parallel channels on composite reinforcement surface were transverse to the loading direction. The symbols used in this research work are given in Table 2.

Table 2. Description of the symbols used

Symbols	Description
FSS	Composite with smooth surface
FRS	Rough surface composite by stone
FR2	Rough surface composite by 2-channels
FR4	Rough surface composite by 4-channels
FR6	Rough surface composite by 6-channels
GM	Geogrid mesh
SGS	Stabilanka geosynthetic sheet
EMM	Expanded metal mesh
SM10	Square mesh with 10mm opening
CM	Chicken mesh

3. RESULTS AND DISCUSSION

In order to obtain a comprehensible insight of the ultimate shear strength of the composite reinforcements and the other conventional reinforcements for soil reinforcement applications, the ultimate shear strengths corresponding to different normal stresses of the composite reinforcement panels with plain and rough surfaces as well as other conventional reinforcements are depicted in Figures 3-4. It is evident from the figures that the ultimate shear strengths are increased with the increase in the normal stress for all types of composite reinforcement panels and conventional reinforcements.

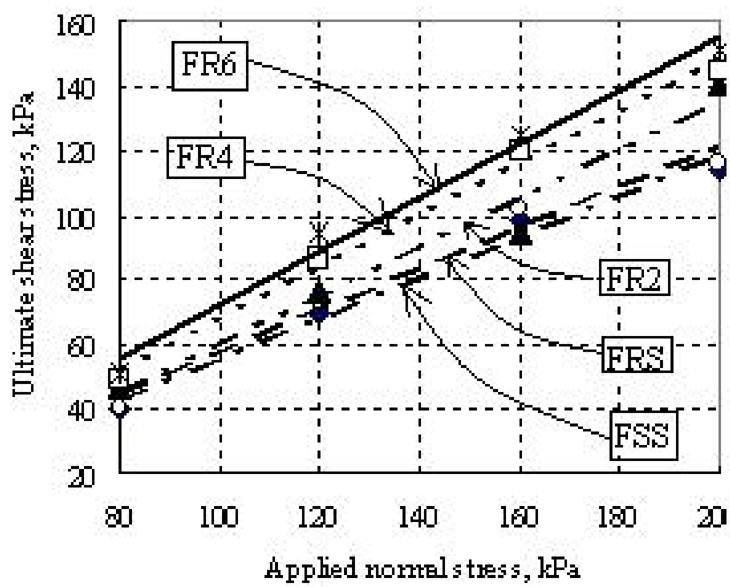

Fig. 3 Shear stress vs. normal stress of composite reinforcements

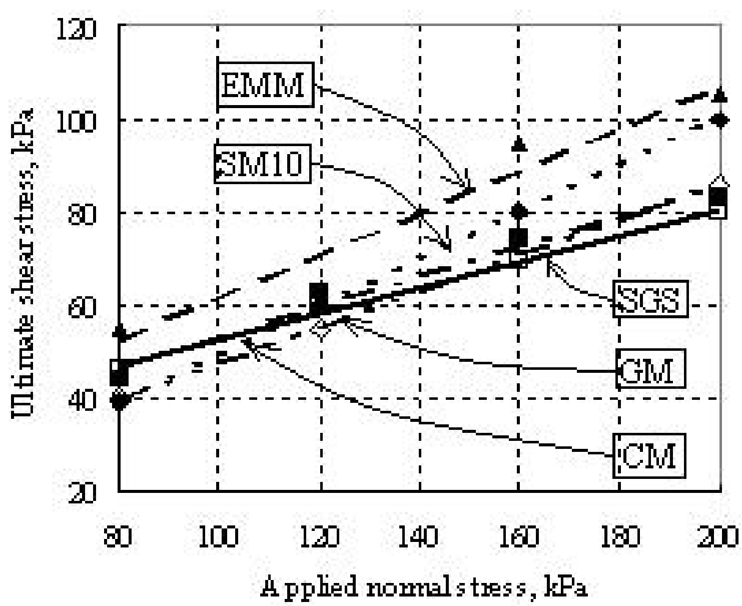

Fig. 4 Shear stress vs. normal stress of conventional reinforcements

However, the rate of increase of the ultimate shear strength for the composite reinforcement panels with rough surfaces is more than that of the composite reinforcement panels with plain surfaces. Furthermore, the rate of increase of ultimate shear strength for composite reinforcement of any type is higher than that of the conventional reinforcement of any type. From the straight lines given in Figures 3-4, the following equations for shear strengths of composite reinforcement and other conventional reinforcement are obtained.

$$\tau_{FSS} = 0.62\,\sigma_{FSS} + 05.18 \quad \text{-----(1)}$$
$$\tau_{FRS} = 0.64\,\sigma_{FRS} + 06.69 \quad \text{-----(2)}$$
$$\tau_{FR2} = 0.74\,\sigma_{FR2} + 08.77 \quad \text{-----(3)}$$
$$\tau_{FR4} = 0.80\,\sigma_{FR4} + 10.57 \quad \text{-----(4)}$$
$$\tau_{FR6} = 0.82\,\sigma_{FR6} + 12.02 \quad \text{-----(5)}$$
$$\tau_{GM} = 0.38\sigma_{GM} + 09.11 \quad \text{-----(6)}$$
$$\tau_{SGS} = 0.45\sigma_{SGS} + 01.40 \quad \text{-----(7)}$$
$$\tau_{EMM} = 0.27\sigma_{EMM} + 11.93 \quad \text{-----(8)}$$
$$\tau_{SM10} = 0.50\sigma_{SM10} + 04.20 \quad \text{-----(9)}$$
$$\tau_{CM} = 0.32\sigma_{CM} + 12.10 \quad \text{-----(10)}$$

where, τ is the shear resistance of reinforced soil on the surface of reinforcement in kPa and σ is the applied normal stress on reinforcement in kPa. Therefore, the angle of friction of the reinforcement-soil interface are calculated as 20.8, 24.22, 15.1, 26.56, 17.74, 24.22, 26.56, 17.74, 20.8 and 15.1degrees, and cohesion are obtained as 5.18, 6.69, 8.77, 10.57, 12.02, 9.1, 11.4, 11.9, 4.2 and 12.1 kPa for FSS, FRS, FR2, FR4, FR6, GM, SGS, EMM, SM10 and CM, respectively. For the comparative study, the frictional angle and cohesion of composite reinforcements and other conventional reinforcements are plotted in Figures 5-6.

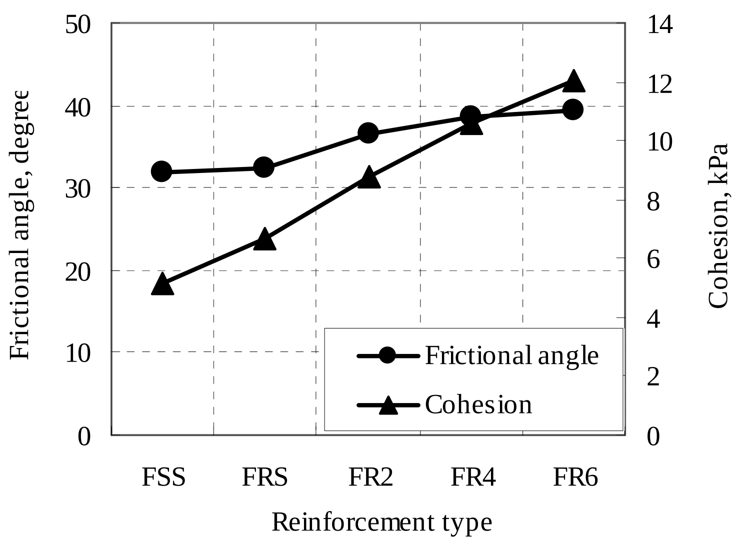

Fig. 5 Frictional angle and cohesion of composite reinforcements

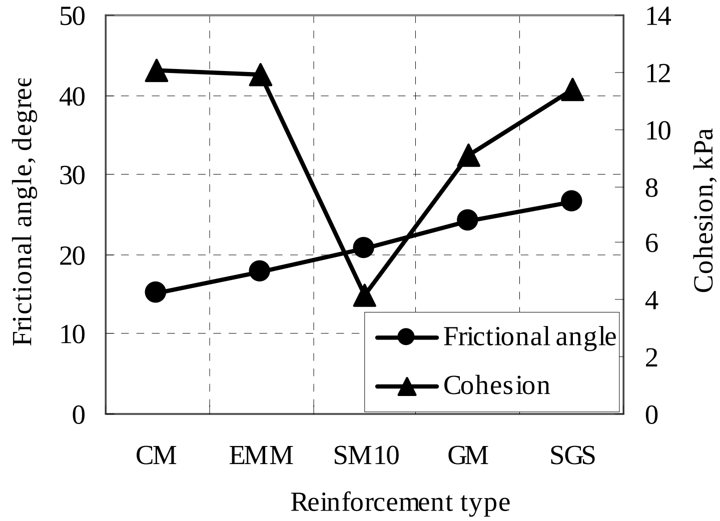

Fig. 6 Frictional angle and cohesion of conventional reinforcements

It is obvious from Fig.6 that the frictional angle, a measure of frictional resistance of composite reinforcement elements, increases significantly due to the presence of stone and small channels on the surface of the composite reinforcement elements. Notice also the general enhancement in the performance of frictional angle owing to the increase in number of channels. The percentages increase in the frictional angle are recorded as 1.66, 14.81, 21.57 and 23.78% for composite reinforcement of FRS, FR2, FR4 and FR6, respectively, as compared to the control specimens (FSS). This also clearly implies that composite reinforcements impart very unique mechanism to the soil – a fact that often remains obscured in the conventional reinforcements. On the other hand, in case of cohesion which is a measure of bonding phenomena between the composite reinforcement and soil, the values are increased by 29.15, 69.30, 104.05, 132.04% for composite reinforcement containing stone, 2, 4 and 6 channels, respectively.

It is evident that creation of small channels on the surface of composite reinforcement can derive significant advantages and that the FR6 is most effective among the composites and conventional reinforcements tested in this research works. The synergy between mortar and soil is already apparent in the case of composite reinforcement especially with small channels for soil reinforcement applications and consequently, the potentiality of the composite reinforcement for earth reinforcement applications was justified.

4. CONCLUSIONS

Studies of interface properties of composite reinforcement elements with soil based on fundamental shear tests are useful in characterization and optimization of composite reinforcement performance for soil reinforcement's applications. The use of small channels on the surface of composite reinforcement elements proves to be highly effective in enhancing the efficiency of the composite reinforcement. Among the five types of composite reinforcement element tested, the FR6 appears to be most effective than others. Based on the comparative study, it is found that composite reinforcement elements can suitably be used as a potential reinforcement material in reinforced soil applications owing to the synergy between mortar/soil and mortar/mesh.

5. ACKNOWLEDGEMENTS

This research was partly supported by the Research Grant No. 18580243 with funds from Grants-in-Aid for Scientific Research given by the Japanese Government. The writer gratefully acknowledges the supports. All they opinions, findings, and conclusions expressed in this paper are those of the authors and do not necessarily reflect the views of the sponsor.

6. REFERENCES

Fukuoka, M. 1998. *Earth Reinforcement-West and East*, Int. Geotech. Symp. on Theory and Practice of Earth Reinforcement, Fukuoka, Japan, pp 33-47.

Jones, C.F.W.B. 1996. *Earth Reinforcement and Soil Structures*, Buterworths Advanced Series in Geotech. Engg., London.

Koerner R.M. 1994. *Designing With Geosynthetics,* Third Edition, Prentice Hall Inc.

Murray R.T. and Irwin M.J. 1981. *A Preliminary Study of TRRL Anchored Earth,* Transport and Road Research Laboratory Report SR 674.

Sivakumar Babu G.L., Shridharan A. and Kishore Babu K. 2003. *Composite Reinforcement for Reinforced Soil Applications,* Soils and Foundations, Vol.43, No.2, pp 123-128.

Hossain, M.Z. and Sakai, T. 2007. *A Study on Pullout Behavior of Reinforcement Due to Variation of Water Content of Soil,* Agricultural Engineering International: the CIGR Ejournal. Vol. IX.

Kakao, B.G., Shimizu, H and Nishimura, S., 2001. *Residual Strength of Colluvium and Stability Analysis of Farmland slope,* Agricultural Engineering International: the CIGR Ejournal. Vol. III.