A COMPARISON OF MESH ELEMENTS AND SHORT FIBRES FOR THE MICRO-REINFORCEMENT OF GRANULAR SOILS

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ABSTRACT: Laboratory testing has been carried out in order to compare the efficiencies of Mesh Elements and Short Fibres for the micro-reinforcement of granular soils. Tests were carried out on soil alone and soil reinforced variously with synthetic polymeric Mesh Elements, two types of synthetic polymeric Short Fibres and Short Fibres of Sisal. The strength tests undertaken on the micro-reinforced soil were CBR and triaxial shear tests. Mixing rates adopted were 0.2 and 0.3 percent of dry weight of soil. The soil used was Leighton Buzzard Sand. It was found that Mesh Elements were more efficient than Short Fibres in reinforcing this granular soil. The synthetic polymeric Short Fibres were found to be only effective at very low strains and low stress levels. The Sisal Fibres were more efficient than the synthetic polymeric Short Fibres. Critical problems with Short Fibres were identified as their lengths and low surface frictional properties. These factors may lead to slippage between the fibres and the soil particles.

1 INTRODUCTION

Mesh Elements and Short Fibres are used in many large and small-scale civil engineering projects. Rapidly growing areas of application are the micro-reinforcement of sports fields, access roads, parking areas and pedestrian access routes.

Extensive laboratory based research has been carried out over the last 25 years on granular soil micro-reinforcement using Mesh Elements or Short Fibres, e.g. Mercer et al (1984), Gray and Ohashi (1983), Hytiris (1986), Sifers and Beard (1993), Bouzza et al (1994), Adi (1996), McGown et al (2002). However, a critical comparison of the influence of Mesh Elements and Short Fibres has not been reported upon. Thus an extensive laboratory study was undertaken in order to make a comparison of their influences and to identify the reasons for any differences in the observed behaviours of Mesh Element and Short Fibre micro-reinforced granular soils.

In this paper, the test materials, test methodologies and analytical techniques used in the study are presented. The results obtained from the test programme are detailed and comparisons made of the performance of the Soil Alone and the Mesh Element or Short Fibre micro-reinforced soils.

2 TEST MATERIALS

The Mesh Elements used were made from polypropylene and produced by the Netlon extrusion process, (NAF Mesh Elements). They have a mass per unit area of 42 g/m^2, mesh pitches of 10 by 10 mm and filament sizes of 0.6 by 0.4 mm. Each Mesh Element was 50 by 100 mm.

Two types of commercially available polypropylene Short Fibres were used. The first type comprised Fibrillated Fibres (Turfgrid) and the second, Staple Fibres, (Fibreturf). The Fibrillated Fibres were used in two lengths, viz. 20 and 35 mm. The Staple fibres were used with a length of 35 mm.

The other Short Fibre used was made from Sisal, which is an algae-like plant from the Agaves family, which was obtained from Malawi. The Sisal Fibres were used with a length of 40mm.

The soil used was Leighton Buzzard sand. This consists mainly of rounded quartz particles with a uniform grading, (D_{10} = 0.62 mm, D_{30} = 0.715 mm and D_{60} = 0.85 mm). It has a specific gravity of 2.67 and a maximum dry density under BS 1377 (1990) standard compaction of 1632 kg/m^3.

3 TEST METHODS AND TESTING PROGRAMME

Uniaxial Constant Rate of Strain (CRS) tests were carried out on 200 mm by 200 mm sheets of the material from which the Mesh Elements were produced. The test methodology was generally in accordance with BS 6906 (1987) with a test specimen size of 200 mm wide by 100 mm long held in specially designed friction clamps which prevented slippage during testing. The tests were carried out at 20 ± 2˚C at a strain rate of 10 percent per minute. Tests were conducted in both the machine and cross machine directions up to 20 percent strain.

Uniaxial Constant rate of strain (CRS) tests were carried out on samples of each of the Short Fibres. The test methodology was generally in accordance with BS 6906 (1987) with a test specimen length of 10mm. Known equal weights of each Short Fibre were held in specially designed friction clamps which prevented slippage of the fibres during testing. The tests were carried out at 20 ± 2˚C at a strain rate of 10 percent per minute.

CBR tests were carried out on dry Leighton Buzzard sand and on mixtures of this sand and the Mesh Elements or the various types of Short Fibres. The tests were carried out on samples compacted to BS 1377 (1990) standard compaction in the CBR mould and undertaken in accordance with BS 1377: Part 4 (1990). The Soil - Mesh Element and Soil - Short Fibre mixtures tested contained 0.2 or 0.3 percent by dry weight of the soil.

Triaxial tests were carried out on dry Leighton Buzzard sand and on mixtures of this sand with the Mesh Elements or the various types of Short Fibres. The tests were carried out on samples compacted to BS 1377 (1990) standard compaction in a split mould of 155 mm diameter and 200 mm height with lubricated end platens to minimise end friction. The Soil - Mesh Element and Soil - Short Fibre mixtures tested contained 0.2 or 0.3 percent by dry weight of the soil. The Soil Alone and Soil – Mesh Element or Short Fibre mixtures were all prepared dry. Cell pressures of 30, 50 and 70 kN/m^2 were used and a rate of strain of 0.5 percent per minute employed.

To establish the Soil Alone, Soil-Mesh Element and Soil-Short Fibre friction/interaction characteristics, a series of shear box tests were undertaken. A 60 mm square shear box was used. The soil was compacted in the shear box to the same density as in the triaxial testing. The Mesh Element sample was fixed at the junction of the two halves of the shear box with soil in the upper and lower halves. The Short Fibres were glued onto a platen and placed into the lower half of the shear box flush with the junction and soil compacted into the top half. The peak and large strain angles of friction / interaction were measured.

4 TEST RESULTS

4.1 *CRS Test Data*

The test data obtained for the Mesh Elements from the CRS tests showed that they had a uniaxial strength of 8.6 MN/kg and were given a relative stiffness at 5 percent strain of 1.0. The Fibrillated Fibres had a uniaxial strength of 32 MN/kg with a relative stiffness of 0.80. The Staple Fibres had a uniaxial strength of 37 MN/kg with a relative stiffness of 0.62. The Sisal Fibres had a uniaxial strength of 15 MN/kg with a relative stiffness of 0.62.

4.2 *CBR Test Data*

The test data obtained from the Leighton Buzzard Sand were CBR [%] at the top of 10 at 2.5mm penetration and 6 at 5.0mm penetration with CBR [%] at the bottom of 17 at 2.5 mm penetration and 8 at 5.0 mm penetration. The data obtained from the Leighton Buzzard Sand and micro-reinforcement mixtures are shown in Tables 1 and 2.

4.3 *Triaxial Test Data*

Typical Deviator Stress – Axial Strain curves obtained from the triaxial testing for the Leighton Buzzard Sand are shown in Fig.1. Typical Deviator Stress – Axial Strain curves obtained from the various micro-reinforced samples are shown in Figs. 2 and 3. The relative pattern of behaviour of the Soil Alone compared to the micro-reinforced soil samples was found to be consistently the same with 0.2 and 0.3 percent of reinforcement by dry weight of soil. This behaviour is represented in terms of mobilised 'pseudo cohesion' and angle of friction as shown in Figs. 4 and 7. The relative behaviours are shown for different strain levels in Figs. 8 to 13.

4.4 *Shear Box Test Data*

The test data obtained for the Leighton Buzzard Sand were at peak an angle of friction of 41.5° and at large strains an angle of friction of 32°. The data obtained from the Leighton Buzzard Sand and micro-reinforcement mixtures are shown in Table 3.

Table 1 CBR Test Data – 0.2 percent fibre content

Mixture with Leighton Buzzard Sand	0.2 percent by dry weight			
	CBR Top		CBR Bottom	
	2.5mm	5.0mm	2.5mm	5.0mm
Mesh Elements	39	28	40	34
35mm Fibrillated Fibres	9	7	23	17
20mm Fibrillated Fibres	9	10	19	15
35mm Staple Fibres	19	18	24	20
40mm Sisal Fibres	26	12	32	25

Table 2 CBR Test Data – 0.3 percent fibre content

Mixture with Leighton Buzzard Sand	0.3 percent by dry weight			
	CBR Top		CBR Bottom	
	2.5mm	5.0mm	2.5mm	5.0mm
Mesh Elements	43	33	48	41
35mm Fibrillated Fibres	22	10	25	12
20mm Fibrillated Fibres	22	10	27	21
35mm Staple Fibres	22	13	27	22
40mm Sisal Fibres	29	24	41	28

Table 3 Shear Box Test Data

Mixture with Leighton Buzzard Sand	Peak Angle	Large Strain Angle
	[°]	[°]
Mesh Elements	44.5	32.9
35mm Fibrillated Fibres	27.0	22.0
20mm Fibrillated Fibres	27.0	22.0
35mm Staple Fibres	29.0	24.0
40mm Sisal Fibres	35.0	31.5

5 ANALYSIS OF TEST DATA

The results of the CRS testing of the micro-reinforcement materials showed that the Mesh Elements exhibited a higher tensile strength and stiffness at 5% strain than all the Short Fibres. Further, that the Staple Fibres were stronger than the Fibrillated Fibres with the Sisal Fibres the weakest. However, the Fibrillated Fibres were stiffer at 5% strain than the Staple or Sisal Fibres.

The CBR testing showed that the Mesh Element reinforcements always significantly increased the CBR value of the Soil Alone at both penetration levels and at the top and the bottom. The Fibrillated Fibres only marginally increased the Soil Alone CBR values, with the longer fibres being slightly better than the shorter fibres. The Staple Fibres showed a fair improvement with the Sisal Fibres intermediate between them and the Mesh Elements.

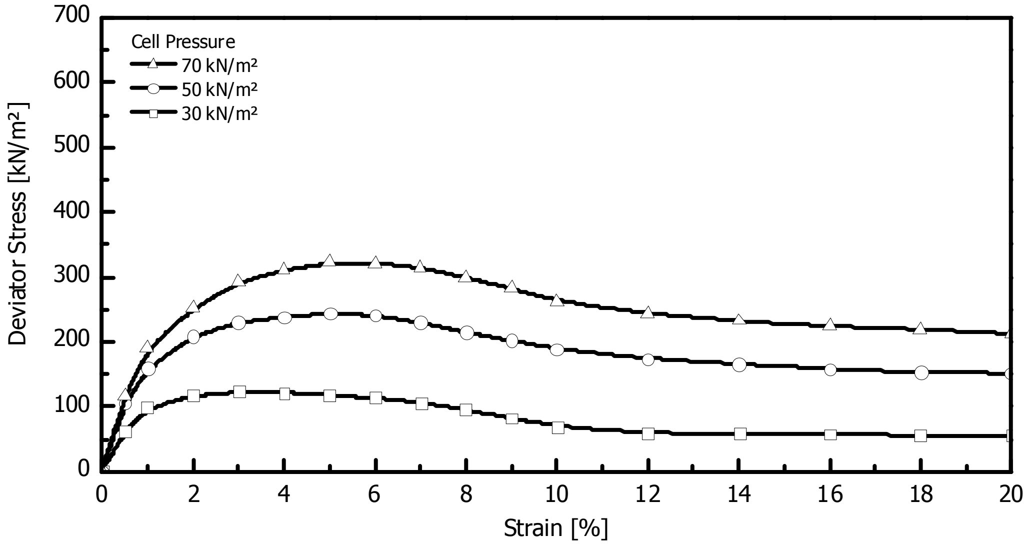

Fig. 1 Stress-strain relationship of Leighton Buzzard sand at different cell pressures

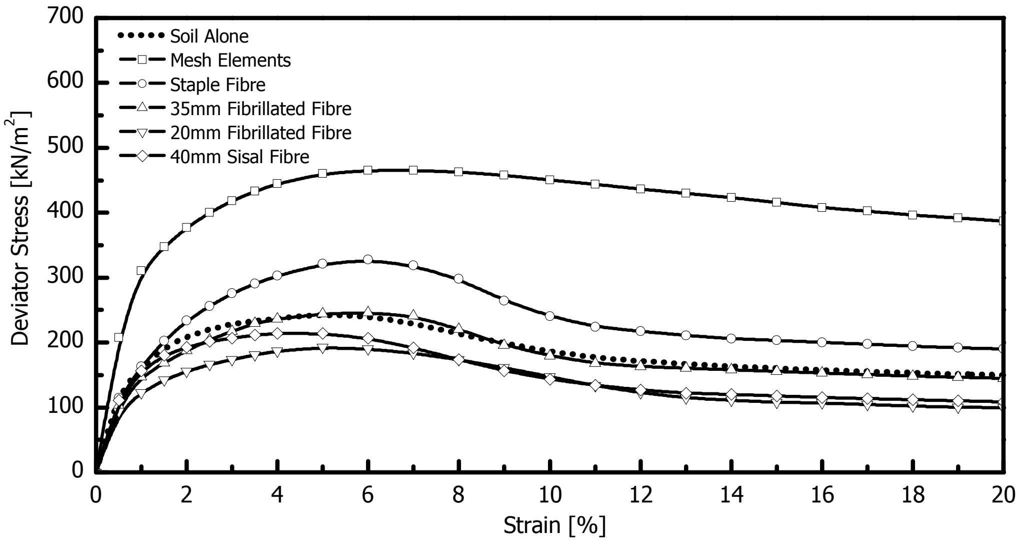

Fig. 2 Triaxial test result for Soil Alone, Mesh Elements and Fibre reinforced soil for 0.2% inclusions at confining pressure of $50kN/m^2$

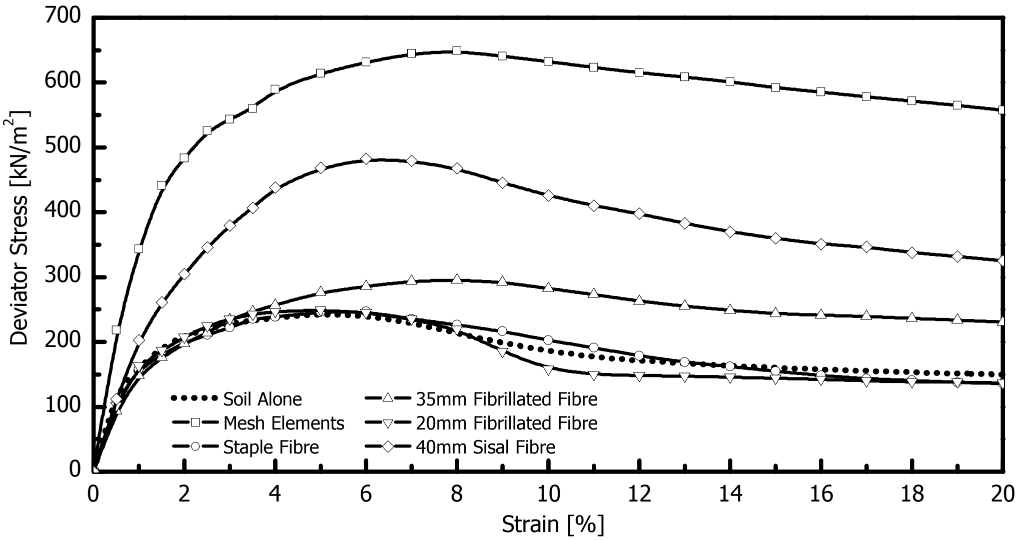

Fig. 3 Triaxial test result for Soil Alone, Mesh Elements and Fibre reinforced soil for 0.3% inclusions at confining pressure of $50kN/m^2$

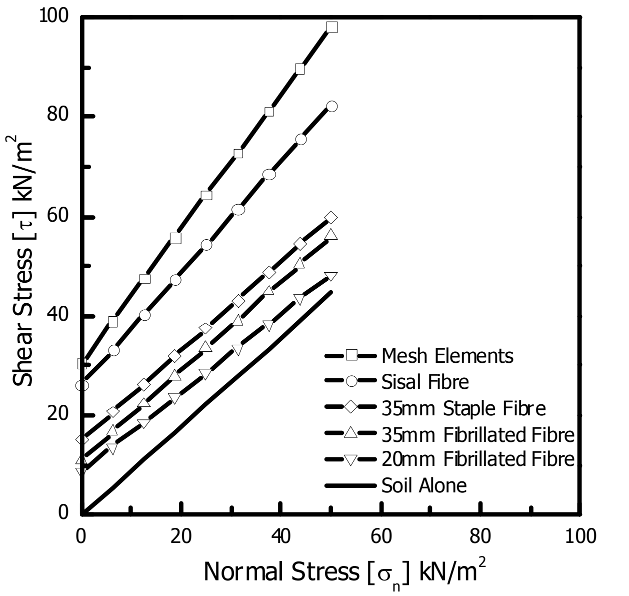

Fig. 4 Strength envelope for Soil Alone and that containing 0.3% of different reinforcing inclusions at strain of 2% in the triaxial test

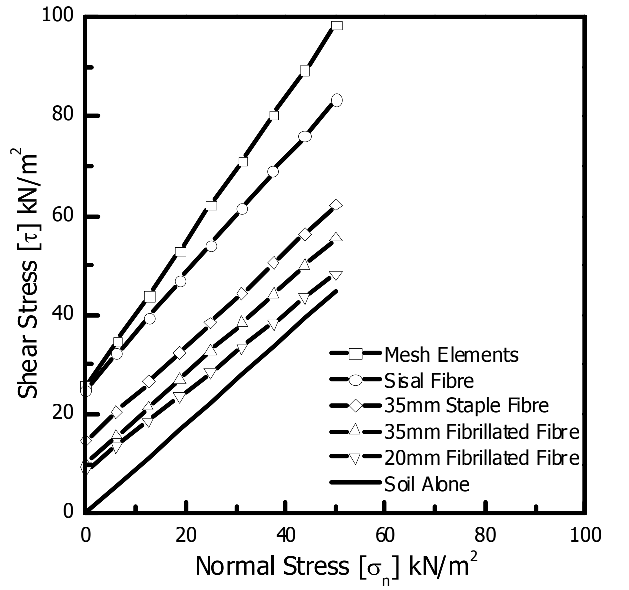

Fig. 5 Strength envelope for Soil Alone and that containing 0.3% of different reinforcing inclusions at strain of 5% in the triaxial test

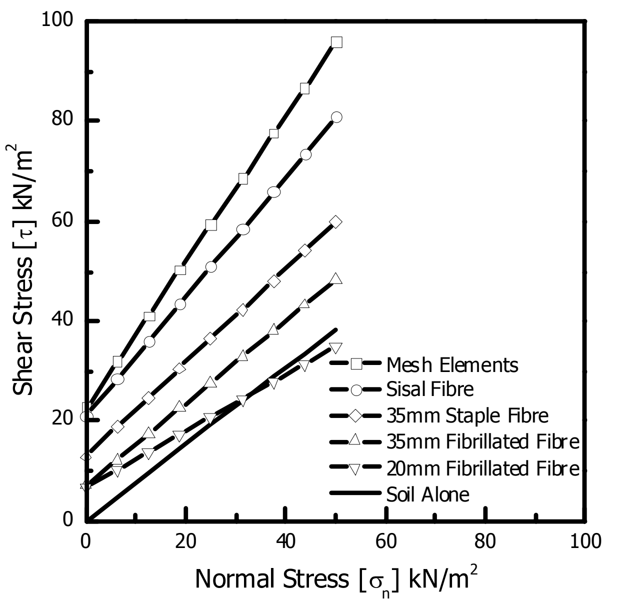

Fig. 6 Strength envelope for Soil Alone and that containing 0.3% of different reinforcing inclusions at strain of 10% in the triaxial test

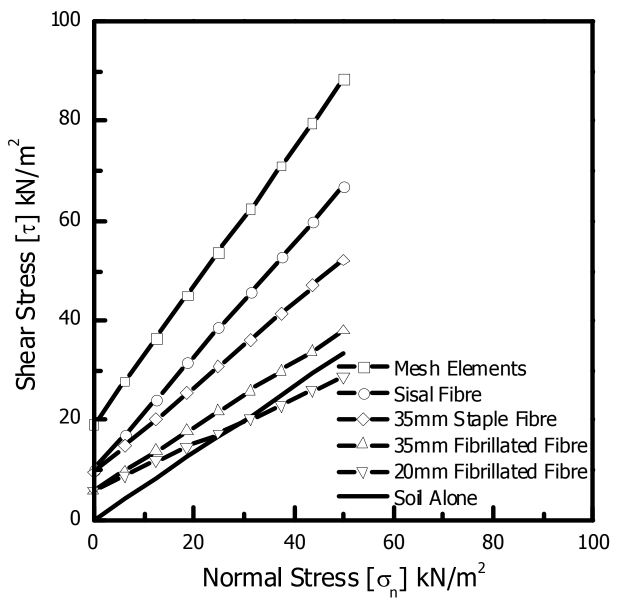

Fig. 7 Strength envelope for Soil Alone and that containing 0.3% of different reinforcing inclusions at strain of 20% in the triaxial test

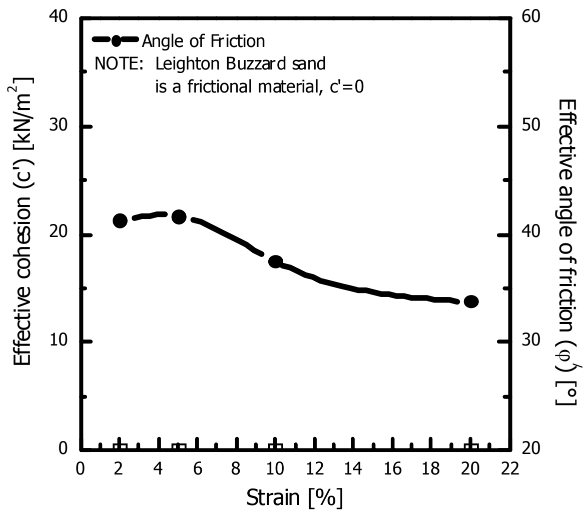

Fig. 8 Variation the effective angle of friction for Sand Alone (Leighton Buzzard sand)

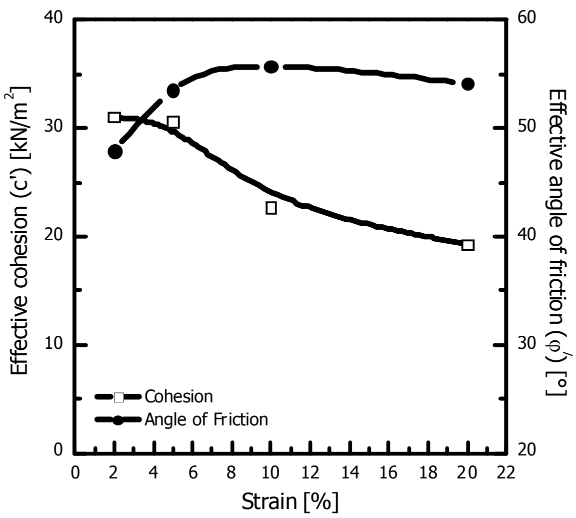

Fig. 9 Variation of effective cohesion and effective angle of friction for Leighton Buzzard sand containing 0.3% Mesh Elements

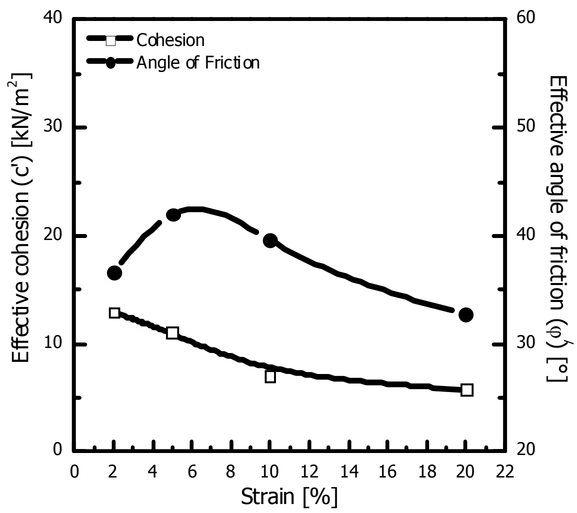

Fig. 10 Variation of effective cohesion and effective angle of friction for Leighton Buzzard sand containing 0.3% of 35mm Fibrillated Fibres

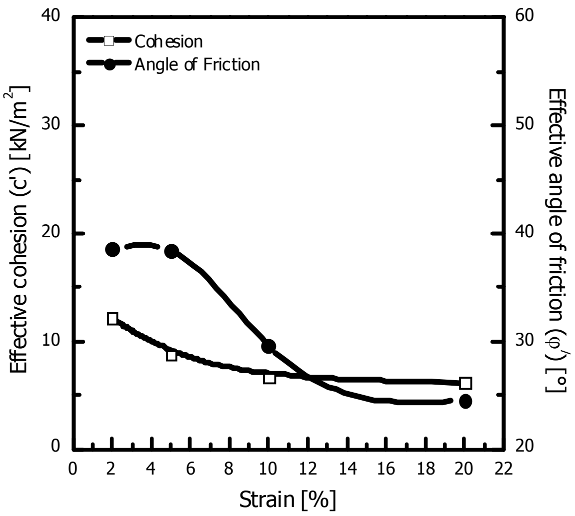

Fig. 11 Variation of effective cohesion and effective angle of friction for Leighton Buzzard sand containing 0.3% of 20mm Fibrillated Fibres

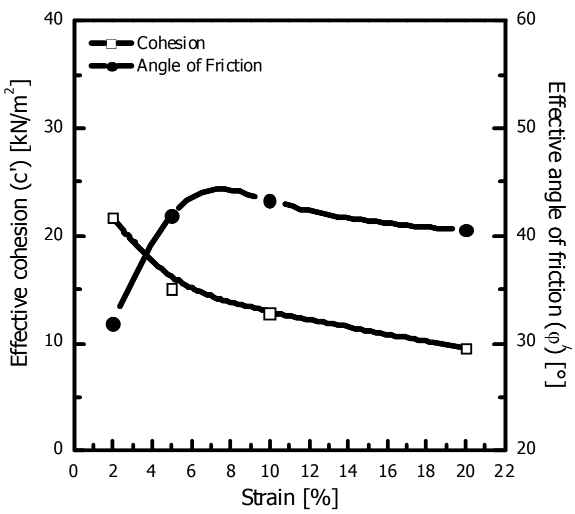

Fig. 12 Variation of effective cohesion and effective angle of friction for Leighton Buzzard sand containing 0.3% of 35mm Staple Fibres

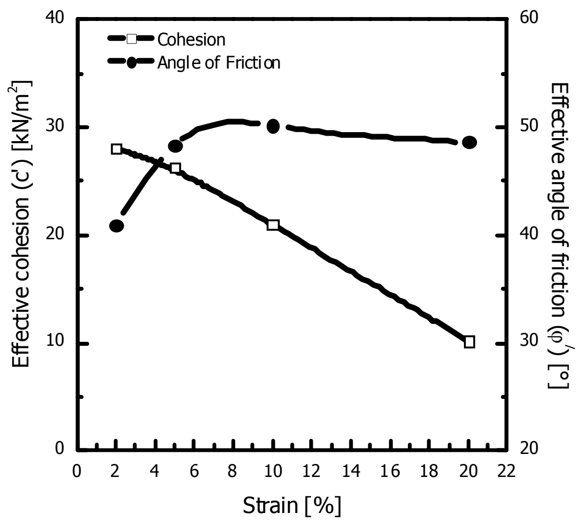

Fig. 13 Variation of effective cohesion and effective angle of friction for Leighton Buzzard sand containing 0.3% of 40mm Sisal Fibres

The triaxial testing showed that with a reinforcement content of 0.2 percent by dry weight of soil, only the Mesh Elements and Sisal Fibres significantly improved the mobilized strength of the Soil Alone, the Fibrillated and Staple Fibres actually tended to reduce the soil strength at higher strains and higher stress levels. At a reinforcement content of 0.3 percent by dry weight of soil, the Mesh Elements and Sisal Fibres once again improved the soil strength with the Mesh Elements providing the greater benefit. The Fibrillated and Staple Fibres improved somewhat the Soil Alone strength and were most effective at low strain and low stress levels, with the Staple Fibre better than the Fibrillated Fibre and the 35 mm Fibrillated Fibre better than the 20 mm fibres. In all cases the main benefit from the use of micro-reinforcements was the development of a 'pseudo-cohesion' whilst maintaining or slightly increasing the angle of friction over that of the Soil Alone.

The shear box testing showed that Mesh Elements had an interaction coefficient with the Leighton Buzzard Sand of unity at peak and at large strains. The Fibrillated Fibres had a coefficient of 0.58 at peak and 0.64 at large strains. The Staple Fibres had a coefficient of 0.63 at peak and 0.71 at large strains. The Sisal Fibres had a coefficient of 0.80 at peak and 0.98 at large strains.

6 DISCUSSION

The test results show that it is a combination of the tensile strength/stiffness and the surface friction/interaction characteristics of micro-reinforcements that controls their ability to improve the strength of a granular soil. However, the testing clearly demonstrates that the surface friction/interaction is the more important characteristic. Thus Mesh Elements with their interaction coefficient of unity are more efficient than synthetic polymeric Short Fibres which have relatively low interaction coefficients. Although the weakest, the Sisal Fibres with their high interaction coefficient provided the greatest improvements of any of the Short Fibres and were approaching the improvement levels gained from the use of Mesh Elements.

The benefits to be gained from Mesh Elements and Sisal Fibres were available at all the stress and strain levels tested. The benefits to be gained from the use of Fibrillated and Staple Fibres were limited to low stress and low strain levels. It is likely that at higher stress and strain levels slippage occurred between these fibres and the soil leading in some circumstances to a weakening of the Soil-Short Fibre mixture compared to the Soil Alone.

7 ACKNOWLEDGEMENTS

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