Investigation of the Suitability of Recycled Carpet Fibre as a Soil Reinforcement Material

F. Anyiko[1], D. Kalumba[2], U. Bagampadde.[3]

[1]Graduate Engineer, Sampar Limited Consulting Engineers, P.O Box 10608, Kampala, Uganda.
Corresponding author email: anyflavie@gmail.com
[2]Senior Lecturer; Dept. of Civil Eng. University of Cape Town, 7701 Rondebosh, and Makerere University, P.O Box 7062, Kampala, Uganda
[3] Senior Lecturer; Dept. of Civil Eng. Makerere University, P.O Box 7062, Kampala, Uganda

ABSTRACT
The textile industry which includes carpet products produces millions of tons of waste material whose disposal has become a dilemma to most consumers. The bulk of carpet waste is generated from post consumer usage as well as the industrial sector. Majority of carpet wastes are non-biodegradable, require a large amount of energy to recycle and occupy large volumes of landfill space. It is such characteristics that have made carpet waste disposal problematic. Inclusion of carpet waste in soil presents an opportunity to alleviate the waste disposal problem. This study reports on the findings from an investigation into the behavior of recycled carpet fibres randomly distributed as internal reinforcement. Composites of a sandy soil and carpet fibres of varying lengths and concentrations were prepared. Fibre lengths of 7.5 mm, 15 mm and 30 mm were used in dosages of 0%, 0.1%, 0.2%, 0.3% and 0.5%. Direct shear tests were carried out on each of the samples and the resulting shear strength parameters determined. Results from the tests revealed an increase in soil cohesion but no significant effect on the friction angle. From these findings, it was deduced that random inclusion of carpet fibres in sandy soil enhances soil strength and load bearing capacity.

Key words: Carpet fibres; Cohesion; Shear strength; Fibre length; Fibre concentration

1.0 INTRODUCTION

The use of carpets for furnishing homes and offices is growing rapidly in many developing countries. This can be attributed to economic growth that has resulted in higher standards of living in these developing countries. To meet these standards, most home and office owners feel the need to redecorate every once in a while and as a result, large amounts of post consumer carpets are discarded for replacement with new carpet coverings. Industry today has a growing concern for the environment and this has prompted recycling efforts in many directions. Earlier, manufacturers only concerned themselves with profit and competition. Today, factors such as government legislation, the increasing cost of landfill space and the growing awareness of the public have encouraged manufacturers to advance towards green engineering and recycling. Much as the carpet industry does not produce waste as hazardous as other industries such as petroleum and oil refining, it still consumes a lot of valuable fossil fuels and produces millions of tonnes of waste material. The rate of carpet disposal is about 2-3 million tons per year in the U.S. and about 4-6 million tons per year worldwide (Wang 2006).
Disposal of used carpet is a dilemma to large apartment complexes and office buildings. These places must find a way to dispose of this carpet waste which usually means land filling. As the cost of land filling waste is increasing due to decreasing landfill space, carpet consumers and manufacturers are scrambling for a solution. Carpets are mainly made from natural and synthetic materials such as wool, polypropylene and nylon among others. The fact that carpets are made from different materials using several processes makes separation and subsequent recycling of the carpet fibers extremely difficult. It is even more difficult to recycle post consumer carpets because of the dirt, cleaning chemicals and other materials that accumulate in the carpet over time. Not only does inclusion of carpet waste in soil improve the soil properties, it also offers additional benefits. These benefits include resource utilization,

low cost of raw materials as well as reduced needs for landfilling. Carpet waste for soil reinforcement only requires a simple inexpensive shredding process and virtually all carpet types are suitable. Sorting costs are therefore eliminated (Wang, 2006). Previous studies have shown that up to 10% by weight of carpet waste can be successfully mixed in clay and substandard soils inorder to enhance soil cohesion, reinforcement and compressive strength (Miraftab and Lickford, 2008). The aim of the study was to therefore investigate the suitability of fibrous carpet waste as a soil reinforcement material. Objectives of the study included; determination of the resulting cohesion and friction angle of the carpet fibre reinforced soil, establishing the effect of fibre length variation on the soil's strength and determination of the effect of variation of fibre concentration on soil cohesion and friction angle.

2.0 MATERIALS AND METHODOLOGY

2.1 Materials

Sand

Sand was selected for its availability. The soil used was brown in colour with a 37° friction angle and sub angularly shaped particles. Figure 1 below shows the gradation curve obtained for the soil sample. According to the Unified Soil Classification system, the soil is poorly or uniformly graded sand.

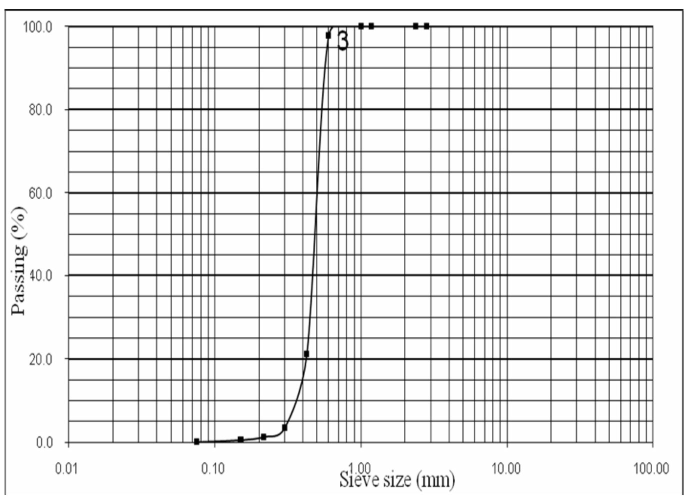

Fig 1: Gradation curve

Carpet fibres

The carpet fibres used as reinforcing material were obtained from local suppliers. Two main fibres were used; the facing fibre which was blue in colour and the white backing fibre. The facing fibres had an average tensile strength of 66.1 MPa and Young's Modulus of 169.3 MPa. The backing fibres on the other hand had an average tensile strength of 82.6 MPa and Young's Modulus of 662.1 MPa. The fact that the backing fibre was stiffer and could not be easily stretched explains the higher values in tensile strength. The facing fibres were made of nylon and tightly packed into a closed loop. The fibres had an average diameter of 0.93mm.

2.2 Methodogy

The carpet was torn apart by hand to separate the facing fibre from the backing fibre. The two fibres were then shredded into pieces of three dimensions; 7.5 mm, 15 mm and 30 mm. The fibre lengths were chosen to fit 0.2 – 0.5% of the dimensions of the shear box so as to control excessive entangling of fibres. Fibre concentrations used were 0.1%, 0.2%, 0.3% and 0.5%

for each of the lengths 7.5 mm, 15 mm and 30 mm. At the selected concentrations it was easier to ensure consistency and even distribution of fibres within the soil sample without clamping of the fibres. The fibres were then randomly mixed with the soil sample contained in a shallow dish by hand and care was taken to ensure that the mix was consistent.The sample was then ready for placing in the shear box. The sample was placed in the shear box in three equal layers, each subjected to uniform compaction by tamping twenty times with 1.5kg hand tamper. Compaction was done to eliminate air voids within the sample. The compacted soil/carpet fibre sample was confined in a 60mm square shear apparatus and the direct shear test conducted according to BS 1377: Part 4 1990. Direct shear tests were carried out at normal pressures (P) of 60 kPa, 90 kPa and 120 kPa. These tests were repeated for varying fibre concentrations and lengths. is attributed to the fact that the fibres are lightweight but occupy large volumes.

3.0 RESULTS AND DISCUSSION

3.1 Shear stress, horizontal displacement and normal stress relationship

In all samples, peak stresses were mobilized at similar displacements as shown in figures 2a and 2b. This is probably due to the uniform gradation of the sand used in the study. For the sand on sand samples, peak stresses attained were seen to increase with increasing normal pressure. The same observation was made for the samples containing reinforcing elements. The backing fibre however, depicted higher peak stress values as compared to the facing fibres. This can be explained by the fact that the facing fibres were smoother than the backing fibres and hence friction between the sand and facing fibre was greater than with the backing fibre. Increased friction is a hindrance to interlocking between the sand and fibres. As the length of fibres increased, the peak stress reached also increased. Although peak stress was observed to increase with increasing fibre concentration, the greatest increase was noted at 0.2% and 0.3% concentrations. Peak stresses at 0.5% concentration, the highest concentration used in the study, were generally lower. This reduction in peak stress is attributed to increased concentration of fibres leading to entanglement of fibres with each other instead of the soil particles.

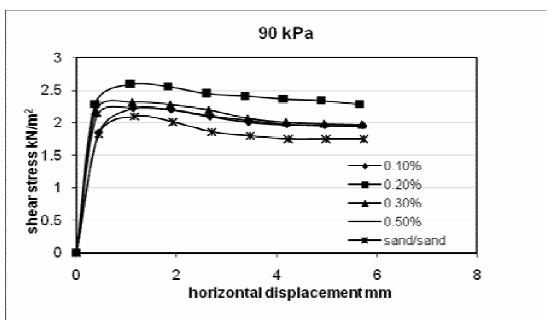

Fig 2a: Facing fibre stress-displacement relationship

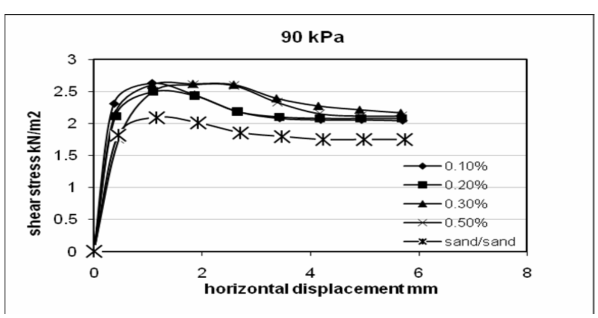

Fig 2b: Backing fibre stress-displacement relationship

3.2 Effect of fibre length on cohesion

The values of cohesion against fibre length for a given concentration were plotted in Figures 3 and 4 and on the whole, it was observed that addition of fibres in a soil sample increased the soil cohesion. Composites of sand and 7.5 mm length fibres showed an increase in cohesion of as much as 14.8% and 27.7% in the facing fibre and in backing fibre composites respectively. Also, for a given fibre length concentration, cohesion of the soil increased with an increase in fibre length. This is attributed to increased area of contact between the fibres and sand. The backing fibre however registered higher values in cohesion due to less friction and more adherance of sand particles.

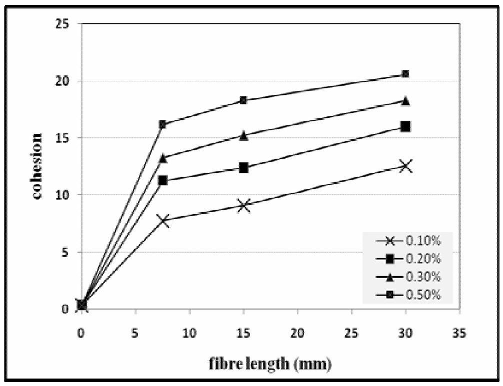

Fig 3: Effect of facing fibre length on cohesion

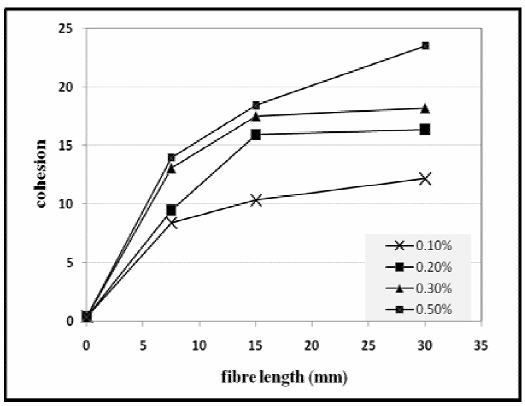

Fig 4: Effect of backing fibre length on cohesion

For both facing and backing fibres, it was observed that an increase in fibre concentration enhanced soil cohesion (Figures 5 and 6). The greatest increase in soil cohesion was noted between 0.1% and 0.2% concentrations in both fibres.

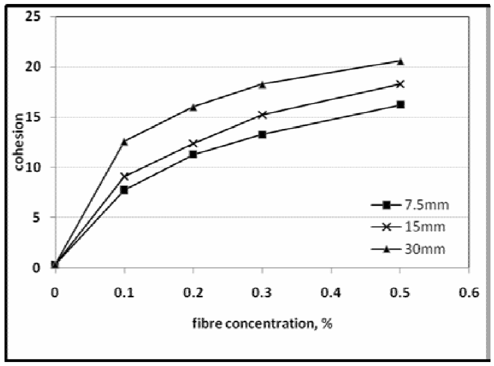

Fig 5: Effect of facing fibre concentration on cohesion

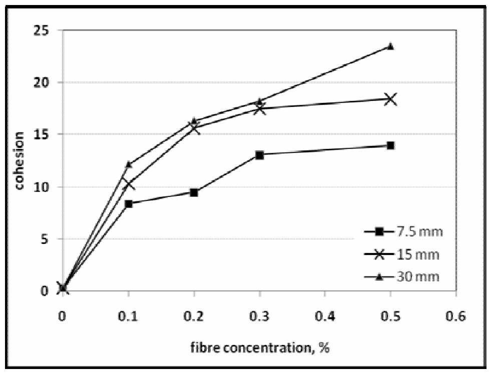

Fig 6: Effect of backing fibre concentration on cohesion

3.3 Effect of measured parameters on friction angle

It was observed from figures 7 and 8 below that inclusion of fibres in the sand reduced the value of the soil's friction angle by as much as 6%(facing fibres) and 3% (backing fibres). The friction angle reduced as fibre concentration increased but beyond 0.3% (facing fibre) and 0.2 %(backing fibre), an optimum value was maintained.

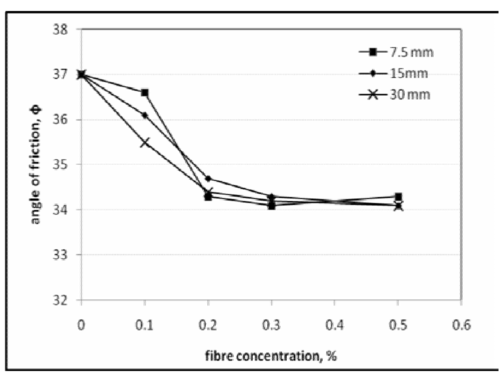

Fig 7: Effect of facing fibre concentration on friction angle

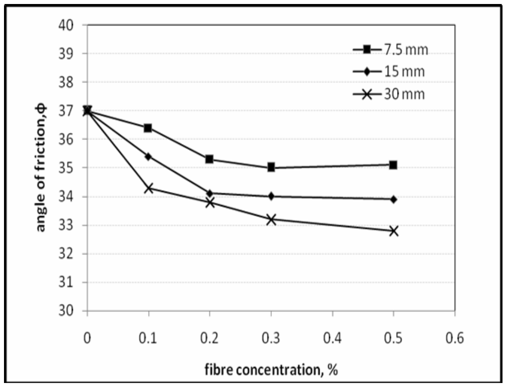

Fig 8: Effect of backing fibre concentration on friction angle

Considering that the fibres are stronger and stiffer than the soil, stretching of fibres during shear provides resistance to soil deformation and thus improves the strength retention of the soil. Since the friction angle of soil is dependent on interaction between the soil particles, the decrease in friction angle observed from this study can be explained by the interaction with fibres. The soil particles mould around the fibres and this reduces the particle to particle interaction. The much higher cohesion achieved from reinforcing sand with the fibres compensated for the reduction in friction angle. This resulted in higher overall shear strength within the tested range.

4.0 PRACTICAL APPLICATION

Ideally, structures should be founded on solid rock but because of the great depth at which these rocks lie, foundations must be designed to rest on the material between the structure and the underlying rock. Internal reinforcement of this material by inclusion of carpet fibres could be a means of increasing the bearing capacity of the foundation bed.

The tables 1 and 2 below show the resulting bearing capacity of a foundation bed after reinforcement by random distribution of 15mm facing and backing carpet fibres.

Table 1: Facing fibres as reinforcement

Fibre conc., %	Unit weight of reinforced soil, γ	Cohesion	Friction angle, Ø	Bearing capacity, q_{ult} (KN/m^2)
0.0	16.77	0.3431	37.0	1434.5
0.1	22.24	9.0687	36.1	2111.9
0.2	18.22	12.389	34.7	1868.2
0.3	18.24	15.219	34.3	1979.9
0.5	18.27	18.283	34.1	2118.1

Table 2: Backing fibre as reinforcement

Fibre conc., %	Unit weight of reinforced soil, γ	Cohesion	Friction angle, Ø	Bearing capacity, q_{ult} (KN/m^2)
0.0	16.77	0.3431	37.0	1434.5
0.1	24.55	10.33	35.4	2026.4
0.2	21.84	15.647	34.1	1987.8
0.3	19.68	17.512	34.0	2085.1
0.5	19.72	18.429	33.9	2148.4

Figure 9 shows the relation between bearing capacity and fibre concentration. The value of bearing capacity is seen to increase as reinforcement is incorporated into the soil. Peak values are attained at 0.1% concentrations of both facing and backing fibre. Bearing capacity increased by as much as 47 %(facing fibre) and 41 %(backing fibre). Between 0.1% and 0.2% concentrations, the value of bearing capacity reduces by 30% and thereafter steadily increases with fibre concentration. This implies that facing and backing fibres give nearly the same improvement in strength for the same soil conditions and any addition of fibres after peak strength is reached tends to residual strength. The Bearing capacity of a soil is dependent on its cohesion, friction angle and unit weight. Much as the friction angle of the soil decreased, there was an increase in soil cohesion and unit weight after adding carpet fibres. As a result, there was an average net increase of 44% in bearing capacity. Reinforcing sand with carpet fibres is therefore a practical mode of increasing the bearing capacity. For instance, this could be achieved onsite by using mixers and spreading the resulting soil composites onto the founding bed of structures, road bases and embankments among others.

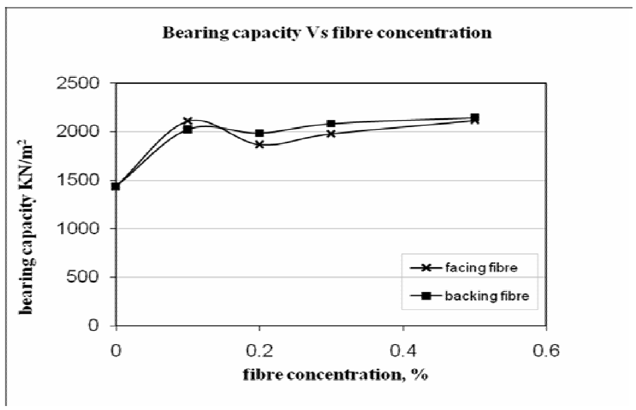

Fig 9: Bearing capacity against fibre concentration

5.0 SUMMARY AND CONCLUSIONS

From the experiments conducted and analysis of results thereafter, the following conclusions were made. Inclusion of carpet fibres within the sand sample increased soil cohesion by as much as 27%. Soil cohesion increases with increasing fibre length and concentration although the backing fibre presents a greater increase in soil cohesion than facing fibre. On the other hand, inclusion of the reinforcement has no significant effect on the friction angle of sand. This method of soil reinforcement can be employed to improve the bearing capacity of foundation beds such as road bases and embankments. This reuse of carpet waste would reduce on material volumes destined for landfills.

6.0 REFERENCES

Bateni F. and Ahmad F., (2009), "*Performance of Oil Fibres on Improvement of Soil Strength*", GIGSA GeoAfrica 2009 Conference.

Miraftab, M. and Lickford, A. (2008), *"Utilization of Carpet Waste in Reinforcement of Substandard Soils"*, *Journal of Industrial Textiles*, pp 167- 174.

Marandi S.M., Bagheripour M.H., Rahgozar R., Zare H., (2008), *"Strength and Ductility of Randomly Distributed Palm Fibres Reinforced Silty – Sand Soils", American Journal of Applied Sciences,* Technology Publications.

Mohammad Shariful Islam and Kazuyoshi Iwashita, (2009), *"Performance of Composite Soil Reinforced with Jute Fiber"*, Adobe2009- Abstract, Adobe Association of the Southwest.

Wang Y., (2006), *"Utilization of Recycled Carpet Waste Fibres for Reinforcement of Concrete and Soil"*, Recycling of Textiles, chap. 14.