Palm leaf geosynthetics

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ABSTRACT
Previous research has shown that vegetable fibres can be used to manufacture 'Limited Life Geotextiles' which should satisfy theoretical requirements for their use as soil reinforcements in situations where the shear strength of the ground will increase with time. Currently, laboratory studies are being undertaken to assess the viability of using geotextile mats constructed, by 'cottage industry', from palm (Borassus and Buruti) leaves within an EU-funded Research Project (BORASSUS) - the project involves 10 countries in Africa, Europe, South America and South-East Asia.

RÉSUMÉ
Des recherches précédentes ont montré que des 'Limited Life Geotextiles' fabriqués des fibres végétales pourraient être utilisés comme des renforcements des sols dans les situations géotechniques òu la résistance au cisaillement augmentera avec le passage du temps. Cet article concerne des essais laboratoires des grilles géotextiles, composées des feuilles du palmier (Borassus et Buruti), afin de déterminer leurs caractéristiques techniques. La recherche présentée ici était entreprise comme une partie du projet BORASSUS (financé par le UE) qui a des participants dans 10 pays en Afrique, en Europe et en Asie.

1 INTRODUCTION

Since the development of man-made polymeric fibres, perceptions that natural fibres have low apparent tensile strength and very short life (particularly when in contact with soil and water) have led to the virtual demise of their use in construction. However, when correctly designed, natural fibre materials can compete with synthetic materials and sometimes they will even have superior performance (Sarsby, 2006). The key to developing geosynthetics from natural fibres is the concept of designing by function, i.e. identify the functions and characteristics required to overcome a given problem and then manufacture the product accordingly. There are a significant number of ground engineering situations where the critical case for stability or functionality is either immediately (or very shortly) after construction and beyond this stage the stability of the system is constant or increases with time or the need for full functionality declines with time (Sarsby, 1997).

As a part of the EU-funded BORASSUS project (INCO-CT-2005-510745) the tensile strength properties of palm mat geotextiles, manufactured in the Gambia and Brazil from Borassus and Buruti palm leaves using low-tech, 'cottage-industry' manufacturing techniques, have been investigated with a view to using them as engineering materials for soil reinforcement. The rate at which the engineering properties of the palm mat geotextiles decline once they have been buried in soil is a vital parameter and geotextiles have been buried in a sandy soil, but with different moisture conditions, and then tested/examined to quantify any change in tensile strength with time.

2. VEGETABLE FIBRE GEOSYNTHETICS AS SOIL REINFORCEMENT

It has been shown that the basal reinforcement requirements for an embankment built on soft clay can be satisfied by vegetable fibre geotextiles (Pritchard, 1999; Mwasha, 2005). It has been proposed (Sarsby, 2006) that for practical purposes the design time-strength-envelope of such basal reinforcement can be represented by an equation of the form,

$$H = H_{(t=0)} - S(T_v)^n \qquad [1]$$

where $H_{(t=0)}$ is the force required prior to any consolidation and S and n are factors which relate to slope angle, strength properties of the embankment fill and the foundation soil, T_v is the consolidation time factor.

The strength properties of vegetable fibres depend on various factors such as source, age, species, processing parameters, chemical constituents and internal structure (Satyanarayana et al., 1986). Pritchard (1999) found that vegetable fibre geotextiles have superior soil reinforcement properties when compared to mid-range synthetic geotextiles, when considering average tensile strength between 100-200 kN/m at approximately 10% failure strain and frictional resistance. However, although numerous standards exist for conventional geotextiles and geosynthetics, and even though many types of coir geotextiles are produced by the coir industry, a standard method for characterization of their tensile properties has yet to be developed (Subaida et al., 2008).

Little information has been published with regard to the biodegradation of natural geotextiles when used in geotechnical engineering. This biodegradation and resultant degree of damage depends on various factors, e.g. ambient temperature, relative humidity and moisture content of the surrounding material and natural ageing of the material, presence/type of micro-organisms in the ground. Existing official and national standards, such as British (BSI), French (AFNOR), German (DIN) and American (AATCC), describe methods of testing for the determination of resistance of textile materials themselves to deterioration by the action of micro-organisms but do not cover geotextiles (materials used in intimate contact with soils which are often manufactured using textile processes).

All geotextiles exhibit some inherent variability during manufacturing process - this differs from manufacturer to manufacturer and depends primarily on the geotextile type and manufacturing technology utilized (Narejo et al., 2001). The resulting property values, called product specifications, are published along with a qualifier – MARV (Minimum Average Roll Value) – implying that the product would meet the claimed value 97.5% of the time. MARV is applicable to a geotextile's intrinsic physical properties such as weight, thickness and strength (Shukla and Yin, 2006). If $X_1, X_2, X_3, ..., X_N$ are individual property values in a sample of size *N*, then the foregoing qualifiers and standard deviation can be determined as follows (Narejo et al., 2001).

$$\text{MARV} = \bar{X} - 2 \times S \qquad [2]$$

$$\text{Minimum} = \bar{X} - 3 \times S \qquad [3]$$

$$\text{Maximum} = \bar{X} + 3 \times S \qquad [4]$$

Standard deviation:

$$S = \sqrt{\frac{(X_1 - \bar{X})^2 + (X_2 - \bar{X})^2 + \cdots\cdots + (X_N - \bar{X})^2}{N-1}} \qquad [5]$$

The use of natural material magnifies the variability of product properties. With vegetable fibre geotextiles, variation in the product may result from climatic conditions, disease, country of cultivation, etc, rather than just manufacturing aspects.

3. PALM LEAF GEOSYNTHETICS

Two types of palm geotextiles have been studied, i.e. Borassus aethiopum (manufactured in the Gambia) and Buruti Palm (manufactured in Brazil), and they are shown in Figures 1 and 2 respectively.

Small cottage workshops were established in The Gambia (West Africa) and Brazil to harvest palm leaves and to manufacture the mats. Palm leaf fibres were obtained by drying cut fronds in the sun over four weeks, stripping out the thick central spine and cutting the vegetation into 1.5m lengths (and approximately 20 mm wide). Mats were manufactured using a 0.5 m x 0.5 m wooden template to which the outer edge strip of the mat was sewn using leaf fibre waste. Further strips (vertical and horizontal) were then attached at 50 mm intervals to the edge strip and were woven into a grid pattern and tied together using slipknots at approximately 50 mm intervals.

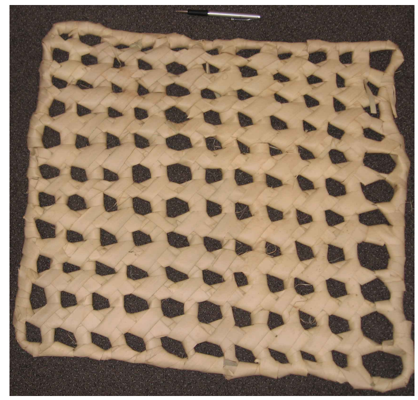

Figure 1. Example of a Borassus mat

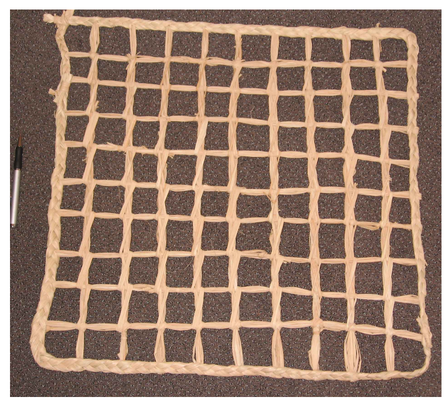

Figure 2. Example of a Buruti mat

4. PROPERTIES OF PALM LEAF GEOSYNTHETICS

4.1. Geometry

Numerous measurements have been made of mat dimensions, size and distribution of mat apertures, rib dimensions and mass per unit area. The aperture size is one of the key factors in soil reinforcement design as it directly influences efficiency of transfer of shear between soil and reinforcement. The aperture width variation along the edge of a mat is a very important factor when joining several mats to form large geotextile sheets. If the aperture variation is large, it will make overlapping or joining of these mats very difficult, because of non-alignment of holes and this will severely disrupt on-site work.

The apertures of the Borassus mats varied from 10mm x 10mm to 40mm x 40mm approximately and their variation followed a normal distribution curve with a mean of 1443mm^2 and standard deviation of 327mm^2. The MARV value was equal to 790mm^2, i.e. 97.5% of apertures were larger than 790mm^2. The aperture variation for the Buruti mats fitted a 3-parameter lognormal distribution curve and openings varied from 20mm x 20mm to 50mm x50mm approximately, i.e. apertures in Buruti mats are generally about twice the size of those in Borassus mats.

Figure 3 shows that the variation of aperture width along the edges of Borassus mats fits a normal distribution curve with a mean value of 29mm and standard deviation of 9mm. The aperture width varied widely, from 5mm to 55mm, and potential patterns of variation of rib and aperture width along mat edges are illustrated in Figure 4. This illustration demonstrates that problems would be encountered when overlapping or joining Borassus mats to form continuous geotextile sheets in a construction project.

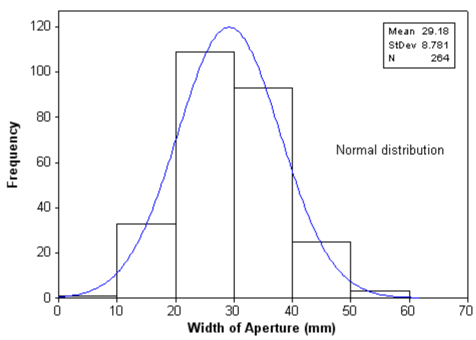

Figure 3. Aperture width along the edges - Borassus mats

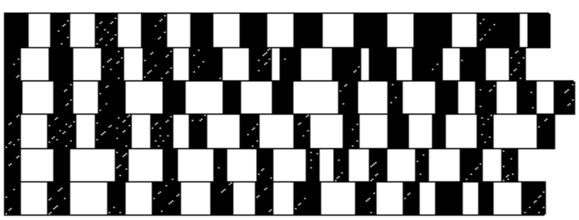

Figure 4. Edge rib and aperture patterns -Borasssus mats

The variation of aperture width along the edge of Buruti mats also fits a normal distribution (with a mean of 38mm and standard deviation of 7mm) but the Buruti mats have significantly less variation along their edges than Borassus mats so that when overlapped to form continuous sheets they could be more easily joined on-site

4.2. Tensile strength testing

The tensile properties of mats were measured by incrementally applying a tensile force and recording the resultant extension until rupture occurred. International Standards such as BS EN ISO 10319 (1996) describe an established test method for determination of the tensile properties of geotextiles and related products, using a wide strip. In this method the specimen is generally rectangular (200mm wide with a 100 mm 'free' length between the clamps applying tensile load) and it is applicable to most geotextiles and geogrids. However, this test method was found to be unsuitable for assessing palm mat geotextiles as the internal structure of a particular palm fibre mat has a large influence on strength measurements due internal non-uniformity. The weaving pattern for the palm mat edge is different from that for internal ribs and cutting the mat will affect the mat fibre formation pattern and dimensional stability. Consequently, tests have to be carried out on complete palm mats.

A standard Hounsfield tensometer was modified to accommodate mats (approximately 0.5m x 0.5m in plan) and clamps were fabricated to take account of some degree of irregularity of mat shape. Different types of end-fixing condition were tested to investigate the effect of rigidity of clamping on tensile strength and to determine if one type of testing is preferable. With very flexible end-fixing conditions the lateral edge elements are only fastened at their mid-points so that the elements deform and extend but are held back by longitudinal ribs which are therefore subjected to tensile load. With rigid end-fixing conditions the lateral mat elements are fastened along their whole length with a pair of steel plates so that tensioning of all internal ribs occurs from the start of a test.

4.3. Initial strength properties of Buruti mats

Typical stress-strain curves for mats with different end-fixing conditions are presented in Figures 5 and 6 and Table 1 gives typical tensile properties of equal weight mats with different end-fixing conditions.

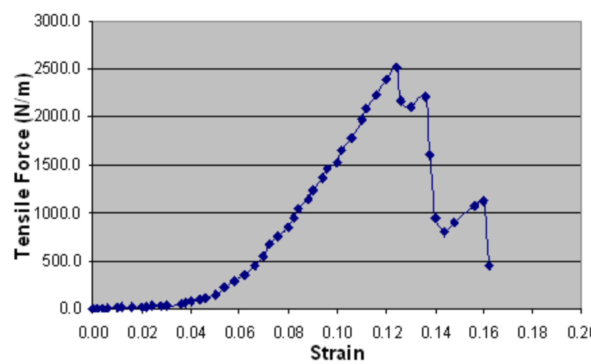

Figure 5. Tensile test with very flexible end-fixing

Mats underwent significant strain before resistance to tensile deformation was developed - this is denoted as the strain to load 'take-up', strain developed after load 'take-up' until failure occurred is denoted as strain to mobilise failure. With rigid end-fixing the percentage strain to failure after load take up was in the range of 1 to 3%. This range is appropriate for design of slopes under limit equilibrium analysis with peak soil shear strength (Hinchberger and Rowe, 2003). The deformation modulus cited in Table 1 relates to the essentially linear part of the stress-strain curve after load take-up. Cyclic loading tests showed that once the initial slackness was eliminated there was a unique load-deformation relationship even if loading was applied in stages - the loading, unloading and reloading paths were close and could be accurately represented by a single value of deformation modulus (180 to 195 kN/m). The tensile tests gave only small variation in failure loads and even less variation in total strains at failure, despite the variation that would be expected with natural material.

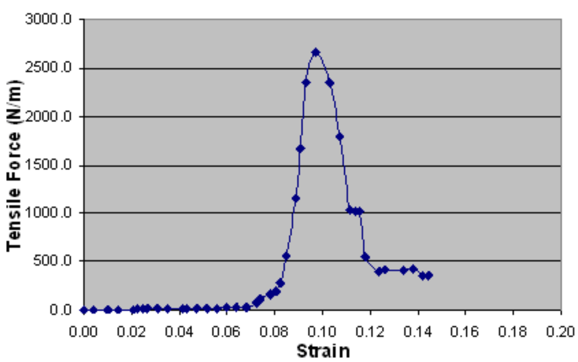

Figure 6. Tensile test with rigid end-fixing

Table 1. Typical tensile properties of 'fresh' Buriti mats

	End-Fixing Condition		
	Flexible	Intermediate	Rigid
Tensile strength (N/m)	2560	2520	2650
Strain to load 'take-up'	0.045	0.05	0.08
Strain at tensile failure	0.12	0.105	0.095
Strain to mobilise failure load	0.075	0.055	0.015
Deformation modulus (kN/m)	35.0	45.8	176.7

Trials undertaken to investigate the effect of mat length on failure load showed that short samples had a very different strength from full-length mats, i.e. 800 N/m as opposed to around 2500 N/m, and also totally different deformation moduli, i.e. 2.9 kN/m as opposed to of 35 to 177 kN/m. The reasons for these differences are believed to be the inherent variability and extensibility of the natural fibres so that there was significant non-uniformity of tensile loading within a short mat. When a sample was installed in the tensile testing apparatus some fibres were tensioned but some were slack. When testing a short mat some fibres would reach their ultimate load capacity and fail before other fibres carried significant load.

The ideal clamping arrangement would be a deformable grip which allows uniform lateral stress on all elements of the specimen and a uniform stressing of all elements in the test direction (Müller-Rochholz and Recker, 2000). From the results of the Authors' tensile tests it has been concluded that employing rigid end-fixity to test a complete mat produces an acceptable approximation to the ideal test method.

Since the palm mats are natural fibre products the measured tensile strengths were expected to show a wide scatter, particularly because mat weight was highly variable. Figure 7 shows the weight variation of 55 randomly selected Buruti mats - the weight distribution follows a lognormal frequency.

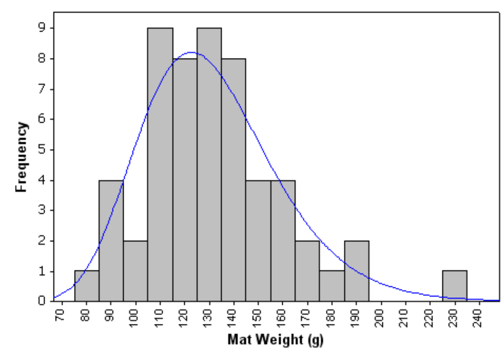

Figure 7. Weight variation of as-manufactured Buruti mats

The relationship between tensile strength and mat weight (for 25 mats) is plotted in Figure 8. The strength clearly increases as a function of mat weight and is probably attributable to variations in the number of leaf fibres involved in a particular tensile test. With few exceptions there is a direct relationship between mat strength and mat weight for weight in the range of 50g-250g. This relationship can be used to find the average expected tensile strength (T_e) of a mat before burial in the soil:

$$T_e \text{ (in N/m)} = 47.9 \times W_m \text{ (in g)} - 1751 \qquad [6]$$

The minimum strength value is a manufacturing quality control tool whereby, for the product in question, manufacturers publish strength values that are certain to be met or exceeded. From the laboratory data the expected minimum tensile strength ($T_{e.\ min}$) for Buruti mats can be calculated using the following equation:

$$T_{e.\ min} \text{ (N/m)} = 44.4 \times W_m \text{ (g)} - 2500 \qquad [7]$$

In order to be able to determine the proportion of tensile strength lost during mat burial it is also necessary to define a relationship which predicts the maximum initial tensile strength ($T_{e.\ max}$) that a mat could have due to the initial weight of material that it contains, i.e.

$$T_{e.\ max} \text{ (N/m)} = 50 \times \text{Mat weight (g)} - 1500 \qquad [8]$$

The correspondence of the equations for T_e, $T_{e.min}$ and $T_{e.max}$ and the actual data is shown in Figure 8.

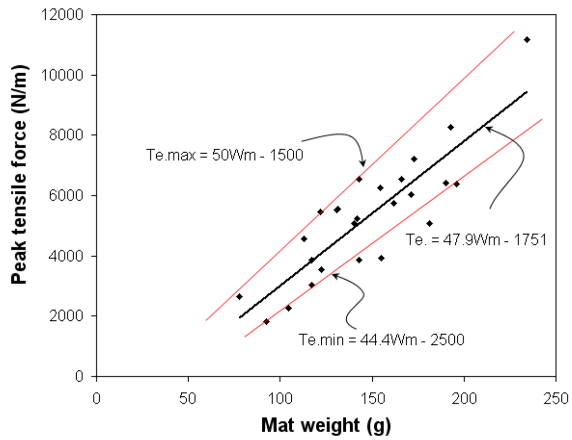

Figure 8. Correlation of initial tensile strength and weight (Buruti mats)

4.4. Initial strength properties of Borassus mats

The tensile stress-strain curves for Borassus mats varied considerably from one mat to another for the same mat weight and so did the associated deformation modulus and peak strength values. Both of the latter parameters were very much less than those for Buruti mats, e.g. the deformation modulus was between 3.2 and 12.6 kN/m as compared to the Buruti range of 180 kN/m to 195 kN/m. This is probably due to the way in which the internal strips were attached to the edge strip of a mat. With Borassus mats the internal strips (and thus the actual leaf fibres) were wrapped diagonally around the edge strip whereas with Buruti mats the internal leaf strips were straight and continuous up to the edge strip. Mat properties are summarised in Table 2. Because of the low tensile strength and high variability of Borassus mats it was decided that they would be unsuitable for use as soil reinforcements and so further testing was not undertaken.

Table 2. Characterization of palm mats

	Buruti	Borassus
Approximate mat size (mm x mm)	500 x 500	600 x 600
Mat weight (g/mat)	77.5 - 234	332 -454
Rib thickness (mm)	10 -15	20 - 25
Percentage open area	48% - 62%	19% -28%
Tensile strength (kN/m)	2.6 – 11.1	0.4 – 0.9
Strain to load 'take-up'	0.04% - 0.08%	0
Deformation modulus (kN/m)	180 - 195	3.2 – 12.6

4.5. Post-burial strength of Buruti mats

Buruti mats were buried within fully-saturated and partially-saturated sand (contained within large tanks) and to date testing/examination has been carried out after 1,2,3,6 and 12 months burial. Since it is not possible to test a particular mat to find both its initial tensile strength and strength after in- soil burial the strength after burial has been compared with predicted initial strength. This prediction has been undertaken using the previously-described correlations between mat weight and tensile strength. When the initial tensile strengths were predicted using equation (6) in some cases the predicted values were less than measured post-burial strengths as shown in Figure 9 (for mats under fully-saturated conditions). Normally the strength of a natural fibre is reduced by an increase in water content and so the upper and lower bound values of initial strength were also predicted using equations (7) and (8).

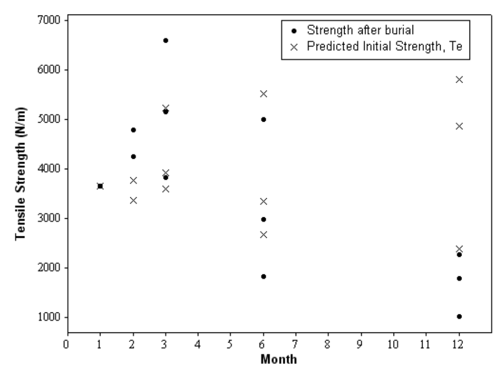

Figure 9. Actual strength and predicted initial strengths

For short burial times the 'theoretical' upper bound to tensile strength apparently exceeds 100% because the initial strength prediction from mat weight is not precise. However, the trend of strength variation with time should still be correct in fact the gradients of the upper and lower bounds are similar and indicate an approximately linear decrease of strength with time. For practical purposes the retained strength can be represented by the equation;

$$T = T_i(1-0.05t) \quad [9]$$

where T_i is the initial strength and t is the burial time in months.

For mats buried in partially saturated sand the strength loss with time was essentially exponential (Figure 10) and the strength remaining could be represented by the equation;

$$T = T_i(1-0.5t^{0.333}) \quad [10]$$

The rate of strength loss was very high for burial in partially-saturated soil and significantly greater than that which occurred under fully-saturated conditions. In fact, after only 9 months burial in partially-saturated sand the Buruti mats were totally decomposed whereas after 12 months of burial in fully-saturated sand they still retained approximately 40% of their initial strength. This behaviour agrees with the observation of Peacock (1996) that for undyed natural textile fabrics (cotton, linen, silk and wool) soil burial was more aggressive than prolonged soaking (and sandy loam more aggressive than peat as a burial medium). Under conditions of partial saturation there is more opportunity for movement of air through a soil and the enhanced oxygen availability will provide the opportunity for biodegradation by both aerobic and anaerobic micro-organisms.

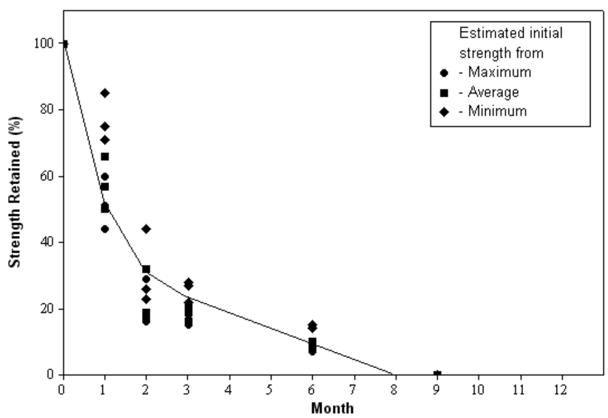

Figure 10. Loss of strength with time – Buruti mats in partially-saturated soil

5. CONCLUSIONS

The palm mat geotextiles do have the potential to provide short-term strengthening of temporary access roads and may be useful in prolonging the working life of low-cost, unbound rural roads in developing countries.

The findings from the research indicate that palm mat geotextiles are not suitable for use as soil reinforcement for major ground strengthening applications, for the following reasons:

- Such fibre geotextiles have low tensile strength when compared to other vegetable fibre geotextiles and polymeric geosynthetics. Furthermore, their tensile strength is highly variable due to the 'cottage-industry' mode of manufacture and the variability of growing conditions.
- The rate of loss of strength of a buried palm mat geotextile is very high - for Buriti mats buried in partially-saturated soil there was total loss of tensile strength within 9 months. This working life would be insufficient for any significant increase in the shear strength of a foundation due to consolidation.

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REFERENCES

BS EN ISO 10319.1996. Geotextiles – Wide-width tensile test. *British Standard Institute*, London.

Hinchberger, S.D., Rowe, R.K., 2003. Geosynthetic reinforced embankments on soft clay foundation: predicting reinforcement strains at failure. *Geotextiles and Geomembranes* 21, pp151-175.

Müller-Rochholz, J. and Recker, C. 2000. Tensile Strength and clamping of Geogrids. Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379, P.E. Stevenson, Ed., *American Society for Testing and Materials*, West Conshohocken, PA, pp28-36.

Mwasha, A.P. 2005. Limited Life Basal reinforcement for an embankment built on saturated soft clay. Ph.D. Thesis, The University of Wolverhampton.

Narejo, D., Hardin, K. and Ramsey, B. 2001. Geotextile Specifications: Those Vexing Qualifiers. *Geotechnical Fabrics Report*, IFAI, Roseville, MN, USA, pp. 24-27.

Peacock, E.E. 1996. Characterization and Simulation of Water-degraded Archaeological Textiles: a Review. *International Biodeterioration & Biodegradation*, pp35-47.

Pritchard, M. 1999. Vegetable fibre geotextiles. Ph.D. Thesis, Bolton Institute.

Sarsby, R. W. 1997. Vegetable fibre geotextiles, Presentation to the Ministry of Agriculture, Fisheries and Food, April, London.

Sarsby, R.W. 2006. Limited design life in geosynthetic materials. Geosynthetics in civil Engineering. *Woodhead publishing Limited*, Cambridge, England.

Sarsby, R.W. 2007. Use of 'Limited Life Geotextiles' (LLGs) for basal reinforcement of embankments built on soft clay. *Geotextiles and Geomembranes* 25, pp302-310.

Satyanarayana, K.G., Ravikumar, K.K., Sukumaran, K., Mukherjee, P.S., Pillai, S.G.K. and Kulkarni, A.G. 1986. Structure and properties of some vegetable fibres. Part 3 Tailpot and palmyrah fibres. *Journal of materials science* 21, pp 57-63.

Shukla, S.K. and Yin, J.H. 2006. Fundamentals of geosynthetic engineering, Taylor & Francis Group, London, UK.

Subaida, E.A., Chandrakaran, S., and Sankar, N. 2008. Experimental investigations on tensile and pullout behaviour of woven coir geotextiles. *Geotextiles and Geomembranes* 26, pp384-392.