CHARACTERISATION OF OPEFB SHEETS AS A SOIL REINFORCING MATERIAL

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December 2011

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by

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in fulfilment of the requirements for the degree of

Master of Science

Universiti Sains Malaysia

December 2011

ACKNOWLEDGEMENTS

This dissertation would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study. It is a pleasure to convey my gratitude to them all in my humble acknowledgment.

In first place, I would like to express my sincere gratitude to my supervisor Prof. Fauziah Ahmad, whose encouragement, supervision and support from the preliminary to the concluding level enabled me to develop my MS.c. study and research. I will be always thankful of her for all she did for me to obtain this degree.

My parents need to figure in here somewhere; I owe my success to my parents because of their unflinching encouragement and utmost support. Beside all they have lost in this way, they have been so patient till I get through this success. I am so grateful of both of them for my whole life.

Special thanks to Ministry of Science, Technology and Innovation (MOSTI) of Malaysia for their supports and providing the equipments.

Last but not least, I would like to extend my acknowledge to Mr. Farshid Bateni for his valuable helps and advices.

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LIST OF ABREVIATIONS

Abbreviation	Description
ABS	Acrylonitrile Butadiene Styrene
HDPE	High Density Poly Ethylene
MEK	Methyl Ethyl Ketone
OPEFB	Oil Palm Empty Fruit Bunches
PVC	Polyvinyl Chloride
SW	Well graded Sand
USCS	Unified Soil Classification System
UV	Ultra Violet

LIST OF SYMBOLS

Symbol	Definition
c	Cohesion
C_c	Coefficient of curvature
C_i	Interaction coefficient
C_u	Coefficient of uniformity
D_d	Relative density
F	Breaking force
G_s	Specific gravity
J	Tensile modulus
L	Embedded length of reinforcement
P	Pullout force
W	Width
ϵ_p	Elongation
α	Interface shear strength coefficient
γ_d	Dry density of soil
γ_{dmax}	Maximum dry unit weight of soil
γ_{dmin}	Minimum dry unit weight of soil
σ_n	Normal stress
τ	Shear strength
τ_{max}	Maximum shear strength
Ø	Internal friction angle

PENCIRIAN KEPINGAN OPEFB SEBEGAI BAHAN TANAH BERTETULANG

ABSTRAK

Geosintetik merupakan salah satu bahan untuk kaedah pembaikan tanah yang digunakan secara meluas pada masa kini. Beberapa jenis geosintetik seperti geotekstil, geomembran, geogrid dan geokomposit telah dibangunkan selama beberapa dekad. Kesedaran persekitaran dan kos yang tinggi bagi membangunkan produk yang berasaskan petrolelum mendorong penyelidik untuk mencari pangganti bagi bahan-bahan tersebut melalui sumber alam semulajadi. Berbagai jenis serat terdiri dari sumber alam seperti sabut kelapa sawit tandan buah kosong (OPEFB), serat sisal, tali rami dan lain-lain terdapat dikawasan panas dan lembab. Penggunaan bahan asli yang di kitar semula dapat membantu negara yang sedang membangun melalui pengurangan kos pembinaan awam dan seterusnya dapat memastikan kelestarian persekitaran.

OPEFB adalah sisa serat industri kelapa sawit yang terhasil dari sebahagian besar industri bekalan minyak sawit dunia, Ciri kekuatan kepingan OPEFB ini diuji di makmal dengan menggunakan ujian kekuatan tegangan, ujian ricih terus dan ujian tarik keluar (pull out). OPEFB disaluti dengan bahan polimer bagi mengukuh kekuatannya dan menahan dari biodegredasi serat semulajadi tersebut.

Tiga perbezaaan peratusan bahan ‘Acrylonitrile Butadiene Styrene’ (ABS) iaitu, 5%, 10% and 15% digunakan untuk salutan tikar OPEFB. Dalam rangka mengoptimumkan pola penyalutan, empat masa rendaman yang berbeza iaitu 1,15,30 dan 60 minit dikaji. Keputusan dari ujian ketegangan menunjukan peningkatan tempoh rendaman menyebabkan kekuatan menurun. Didapati penggunaan ABS untuk tikar OPEFB, meningkatkan kekuatan dalaman dan kekuatan tarik keluar yang

tinggi bagi penggunaan salutan perendaman salama 15 minit. Perbezaan di antara polimer lain yang di kaji menunjukkan kekuatan OPEFB adalah yang terbaik dari semua aspek kekuatan yang di perolehi.

Ujian ricih terus diuji untuk megkaji peranan antara muka salutan tikar OPEFB dengan tanah pasir. Keputusan menunjukan dengan penanaman salutan tikar OPEFB terdapat peningkatan sudut geseran puncak dan baki. Selain itu kekuatan ricih spesimen bertetulang didapati lebih besar berbanding dari kekuatan ricih spesimen tanpa tetulang.

Bagi memahami kelakuan sebenar bahan tikar OPEFB sebagai bahan tetulang di dalam tanah, model tembok tanah bertetulang dengan menggunakan bahan tikar OPEFB dikaji dengan menggunakan ujian tarik keluar. Ujian tarik keluar yang digunakan paling ialah 5.1, 5.9 dan 6.6 kPa, untuk mengkaji interaksi di antara tikar OPEFB dengan tanah berpasir. Didapati bahawa sudut geseran puncak adalah lebih besar dari keputusan ujian ricih terus. Keputusan ujikaji menunjukkan, dengan kenaan tegasan normal meningkat ke atas model tarik keluar, kekuatan tarik keluarnya akan meningkat. Ini menunjukkan bahawa bahan ini masih kukuh kerana kegagalan yang berlaku adalah bukan kegagalan sebenar.

Keputusan ujian ricih terus dan tarik keluar untuk salutan tikar OPEFB boleh dianggap tercapai dan efektif dengan adanya ikatan dalaman dan penyatuan di antara butiran pasir. Sebagai kesimpulan tikar OPEFB boleh digunakan sebagai tetulang dan juga seperti fungsi geotekstil yang lain seperti pengasingan, pemisahan dan penyaliran. Selain itu penggunaan OPEFB akan mengurangkan masalah alam sekitar yang berkaitan dengan pelupusan bahan-bahan sisa.

CHARACTERISATION OF OPEFB SHEETS AS A SOIL REINFORCING MATERIAL

ABSTRACT

Geosynthetics have been one the widely used methods of ground improvement. Environmental awareness and high costs of petroleum-based products stimulated researchers to look for substitutions through the natural products. Various types of natural fibres such as coir, oil palm empty fruit bunches (OPEFB), sisal, jute and etc. are available in hot and humid regions of world. The novelty of utilising natural products could assist the developing countries to reduce the expenses of civil works and ensure the sustainability of their environment.

OPEFB is one of the waste produce by oil palm industry in Malaysia, where very large volumes of this fibre is available annually. This study is to characterise the OPEFB sheets and determine their potentials to be used as a soil reinforcing material. Tensile test, direct shear test and pullout test were chosen to investigate the characteristics of OPEFB sheets under this test mechanism. OPEFB sheets were used as a coating solution to strengthen the material as reinforcement and also to protect it from biodegradation.

Three different percentage of Acrylonitrile Butadiene Styrene (ABS), 5%, 10% and 15% were used to coat the OPEFB sheets. It was found that there is an increment of tensile strength and the highest strength was experienced for 15% ABS coated OPEFB sheets. In order to optimise the coating design thickness, four different soaking durations of 1, 15, 30 and 60 minutes were tested. The results showed that by increasing the soaking duration, the tensile strength of sheets decreased.

Direct shear tests were implemented to study the interface behaviour of coated OPEFB sheets against the sandy soil. The results concluded that embedment of coated OPEFB sheets increased the peak and residual friction angles. Also the shear strength of reinforced specimens was found to be greater than the shear strength of unreinforced specimens.

A model of reinforced soil walls were tested under a pullout forces conditions to study a more realistic application of OPEFB sheets inclusions. The pullout stresses used were in the lowest range of 5.1, 5.9 and 6.6 kPa, in order to study the interaction between OPEFB sheets and sandy soil. It was found that the peak friction angle under pullout tests were greater than results obtained from direct shear test. The results showed that by increasing the normal stress, the pullout capacity was also increased.

The results of direct shear and pullout test interpreted that the coated sheets are able to make a sufficient and effective interlocking and bonding with sand particles. Therefore the OPEFB sheets is capable of sustaining the function as a reinforcement. Application of OPEFB sheets would reduce the environmental problems of functionless abandonment.

CHAPTER 1
INTRODUCTION

1.1 Background of the study

The rapid growth in number of population of world and associated civil developments has resulted in the scarcity of good sites for construction. Scarcity of good sites forced to concentrate on lowland areas which are susceptible to differential settlements, low strength and high compressibility. Construction of structures on such lands is risky and ground improvement methods must be applied to decrease or eliminate the possible hazard. Through the past six decades, several methods of ground improvement have been established for the variety of soil and rock conditions.

Soil reinforcement is one of the widely used ground improvement methods. Several types of materials such as wood, metal and several types of polymeric materials have been used for reinforcement purposes. Planar products which are using for reinforcement purposes are generally called geosynthetics. Geosynthetics had a rapid growth and strong influence on geotechnical engineering. In 1970s just five or six types of geosynthetics were available in whole world, while today more than 600 different types of geosynthetics are being traded through the construction industry (Chen and H. S. Ang, 2009). It is believed that the worldwide annual consumption of geosynthetics is about $1.5\times 106\ m^2$ and it probably costs around US$$3\times10^6$ (Chen and H. S. Ang, 2009).

Polymeric geosynthetics have been posed interests since they have uniform properties and they are reproducible at the same quality. The application of geosynthetics increased whilst they have the disadvantages of high cost and being petroleum based, which is not eco-friendly. The environmental awareness and high costs of petroleum products have encouraged researchers in developing counties to investigate the possible utilisation of natural products. Natural products are becoming as a challenging rival for polymeric products since they are cheap and large volumes of them are abundantly available. The natural products have two key advantages. First one is the required low degree of industrialisation for manufacturing; the required energy for production of them is small and consequently, their costs are low (Silva et al., 2010). Second advantage is that natural fibres are from renewable resources.

Several types of natural fibres such as coir, sisal, oil palm empty fruit bunches, jute, bamboo and etc. are available in all around the world. Most of these plants grow in tropical and subtropical countries like Malaysia, Indonesia, India, Mexico and Brazil. Large volumes of such fibres are available abundantly every year and only small portion of them are consuming for traditional products and supplies. Most of these fibres are being disposed functionless in environment to get rid of them.

Through the past decades several studies have been conducted to study the tensile properties of natural fibres. Following researches investigated the effects of discrete fibres inclusion though the geotechnical tests. Such kinds of studies are useful for fibre-reinforcement solutions which do not need to be designed and the discrete fibres are just simply added and mixed randomly with soil. Another possible and useful method of using natural fibres is reinforcing sheets. Different methods of manufacturing could be enhanced to make planar sheets by using natural fibres. This type of research has not been investigated recently; quite limited numbers of literatures about the characterisation of natural sheets are available. Natural sheets could be used for the applications where not the strongest fibres are required; rather a fit-for-purpose solution would be satisfactory.

There are several aspects of reinforcing sheets that must be evaluated. Over the past decades, experiences with the behaviour of slopes and their failure have led to development of soil reinforcement methods and aspects. Tensile strength is one the most important design parameters that must be established when reinforcement is going to be embedded in soil (Subaida et al., 2008). Interface behaviour and shear resistance of reinforcement against the soil are also important and must be determined before application.

In Malaysia and Indonesia oil palm is one of the largest crops where they produce 83% of world’s supply (E.Gunawan et al., 2009). Oil palm empty fruit bunches are the waste of oil palm industry. It is believed that every hectare of oil palm plantation annually produces about 55 ton of fibrous biomass (Shinoj et al., 2011). The waste of oil palm fruit is called oil palm empty fruit bunches (OPEFB). The nonwoven-randomly-oriented OPEFB sheets are commercially available in Malaysia. These sheets have been chosen to be studied through this research in order to evaluate their characters for future applications.

1.2 Objectives of study

The objectives of characterisation of OPEFB sheets as a soil reinforcing material are:

1. To evaluate the tensile strength of OPEFB sheets at different coating percentages.

2. To evaluate the interface behaviour of OPEFB sheets against sand.

3. To evaluate the interaction behaviour of OPEFB sheets against sand.

1.3 Statement of problem

The abundant of OPEFB fibres in nature could contaminate the environment and the freshwater's ecosystem. Evaluating the potentials of OPEFB sheets for using in soil works, could assist in ensuring the sustainability. Utilisation of OPEFB sheets could also cause to save noticeable amounts of money in civil works. Based on interaction mechanism of reinforced soil embankements, three characters of soil reinforcing materials must be measured; tensile strength, shearing resistance and pullout capacity.

Although the tensile strength of OPEFB fibres have been determined in previous works, it could not be applicable for designing purposes since tensile strength of OPEFB sheets as a single matrix is required. Furthermore, the interfacial behaviour of OPEFB sheets against the soil particles must be evaluated. Interlocking and bonding of fibres and soil particles under different stress levels is an important feature that must be determined. Direct shear test and pullout test are the appropriate test to investigate the mentioned behaviours. Since reinforcement is subjected to pullout forces under operational conditions, pullout test has been believed to be a more realistic model to study the interfacial behaviour.

1.4 Structure of the thesis

This thesis comes in five chapters. Current chapter, Chapter 1, is a brief introduction and scope of research and includes the objectives of this study and statement of problem. Chapter 2 is about the review of previous works and the recent developments on utilisation of natural fibres as reinforcement for soil works. The enhanced materials, tests and methodology for this research is presented comprehensively in Chapter 3. In Chapter 4, the results of experiments are presented by details. The results are compared with the results that have been reported by other researchers to evaluate the performance of OPEFB sheets as a reinforcement. The last chapter, Chapter 5, presents the conclusions of this research and recommends the researchable areas for further studies on utilisation OPEFB sheets.

CHAPTER 2
LITERATURE REVIEW

2.1 Fundamentals

Within this chapter the history, fundamentals, applications, materials and methods of ground improvement concept will be reviewed through the past published literatures and text books. This chapter contains five major sections. First section reviews the generals of geosynthetics as a ground improvement method; and also definitions, general specifications and functions of most common reinforcing materials will be presented. Second section deals with the natural fibres, and clarifies the large available volumes of some eco-friendly and economical natural fibres like oil palm empty fruit bunches, coir, sisal, etc., as renewable resources. Since the natural fibres are biodegradable, in third section the importance of protecting the natural fibres through the chemical treatments is reviewed. Fourth section, presents the previously used methods and standards of evaluating the soil reinforcing materials. Also the review of past researches on natural fibres in term of soil reinforcing material is provided in fourth section. The last section, fifth section, is the summary of whole chapter and specifies the point view of this research.

2.2 Ground improvement

From the very early dates of the history, when human were living in caves, improvement and stabilisation of residency areas were always have been concerned. By the increase in the number of people, the need for residing new places is becoming more vital. The scarcity of suitable grounds for civil works, makes ground improvement as one of the most important and useful choices. Through several years, several ground improvement techniques, such as cement grouting, soil fracturing, in situ soil mixing and geosynthetics, have been established and developed widely. Based on the type of structure, ground, available material, topographical and geographical situations and climate, proper improvement method can be chosen and applied. In this section geosynthetics will be reviewed and discussed thoroughly.

2.2.1 Geosynthetics

The prefix of “geo” refers to applications associated with improving the efficiency of civil engineering projects involving earth, ground and/or soil and the suffix of “synthetics” refers to man-made material (Shukla and Yin, 2006). Geosynthetic is a general term used to describe a range of all synthetic materials used along the soil, rock and/or any other civil engineering related materials as a reinforcement part of a structure (Shukla, 2002). Cost-effective applications of geosynthetics brought a worldwide acceptance over the past three decades for them and they have been used as an efficient alternative of conventional solutions of civil engineering problems (Shukla, 2002).

The earliest historical examples of using fabrics as an aid for road construction date back to ancient Romans (Shukla, 2002). Casagrande proposed the modern concept of soil reinforcement using membrane for the first time (Koerner, 1998; Shukla, 2002).The first use of cotton fabrics in reinforcing roads was attempted by south Carolina Highways Department in 1926 (Shukla, 2002; Shukla and Yin, 2006).

After the disastrous flood of 1953 in Netherlands, hand-woven sheets made of extruded Nylon 6, strips of about 10 cm width and almost 1 mm thickness was produced in Netherlands (Santvoort, 1994). At that time, the application of geotextiles was to protect the banks and beds against erosion were happening in

Holland (Santvoort, 1994). In 1960s, Rhone-Poulenc Textiles in France used nonwoven needle-punched geotextiles as beds for highway and railway track support systems (Shukla and Yin, 2006). By the next decade, France used geotextiles in a dam as a filter for the aggregate downstream drain (Shukla and Yin, 2006). Through the time between 1975 and 1980s, several researches had been conducted about the application of fabrics as a soil reinforcing material for the foundations (Santvoort, 1994). Four field tests of Zevenhoven (Netherlands), RW 12 highway (Netherlands), Cuxhaven (Germany) and Almere (Netherlands) were carried out to understand how and to what extent reinforcing fabrications can take place in stability of earth fills constructed on low bearing capacity soils (Santvoort, 1994). By 1990s, American Society of Testing Materials (ASTM) published many standards on geosynthetics (Shukla and Yin, 2006).

Geosynthetics can be used for performing five major functions; separation, reinforcement, filtration, drainage and containment. The materials consumed in manufacturing geosynthetics are basically synthetic polymers which generally derived from petroleum products (Shukla and Yin, 2006). The most common types of geosynthetics are:

- Geotextiles
- Geogrids
- Geonets
- Geomembranes
- Geocomposites
- Geonaturals

The types of geosynthetics do not limit to only six above types. Webs, grids, nets, meshes, and composites, which are not technically textiles, are being used in combination with or in place of geotextiles; such products are called geotextiles related products (Shukla and Yin, 2006). Geocells, geofoams, geomats, geomeshes, geopipes, geospacers and geostrips are instances of geotextiles related products. Next paragraphs present the definition, characters, functions and applications of six above mentioned geosynthetics.

2.2.1.1 Geotextiles

Geotextiles are defined as planar, permeable, flexible, polymeric textile sheets that act compositely with soils and rocks (Koerner, 1998; Shukla, 2002; Shukla and Yin, 2006).

Geotextiles were first used in erosion control applications and were as an alternative to granular filters (Koerner, 1998). The polymeric materials which are being used in producing the fibres of geotextiles are mostly polypropylene, polyester, polyethylene and polyamide (Koerner, 1998). The accurately formulated polymers are made into fibres by melting and forcing them through a spinneret. The resulted fibres then hardened or solidified by one of wet, dry or melt methods. Most of geotextile fibres are produced by melt process; through this method fibres will be hardened by cooling and simultaneously or then after they will be stretched. Stretching reduces the diameter of fibres and makes the molecules to arrange themselves in an orderly fashion. The result of this rearrangement are an increase in fibre’s strength, decrease in theirs elongation at failure and modulus increases (Koerner, 1998). By variation in fibres diameter, wide range of stress versus strain values can be achieved (Koerner, 1998). The manufactured monofilaments can also be twisted together to form a multifilament yarn. Denier is a unit which is used to characterise the fibres and it is defined as the weight of 9000 m of yarns in gram. The other type of fibres is called staple fibres; they are manufactured by continuous filaments of certain denier in a large rope-shape bundle which is called tow. The bundles are then crimped and cut into short lengths of 25 to 100 mm; then after, short fibres of staple are twisted or spun into long yarns for fabric manufacturing (Koerner, 1998). The last type of fibres is called slit (or split) film or tapes. They are produced from a continuous sheet of polymer that is cut into fibres by knives or lanced by air jet. The resulted ribbon-like silt-film monofilaments can also be twisted together to make a silt-film multifilament (Koerner, 1998). Figure 2.1 illustrates the structure of several types of polymeric fibres which are using for geotextiles.

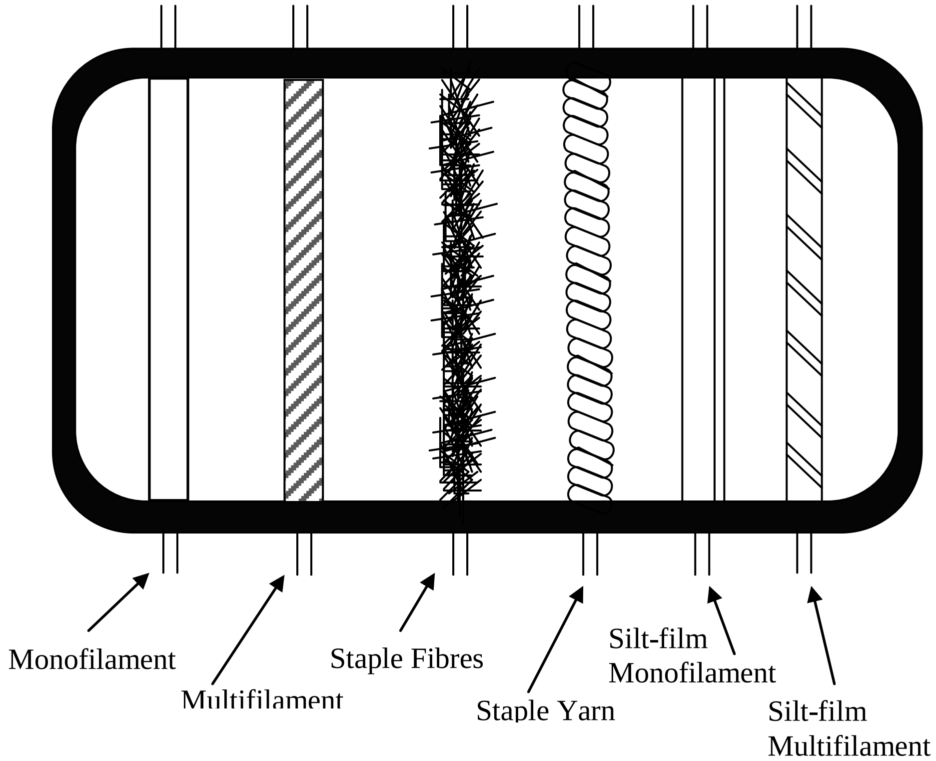

Figure 2.1: Types of polymeric fibres for manufacturing the geotextiles (Koerner, 1998)

Based on fabrication process and style, Shukla and Yin (2006) categorized geotextiles in four groups:

- Woven geotextiles: including geotextiles manufactured by interlacing, usually at right angles, two or more sets of yarns or other elements using a conventional weaving process with a weaving loom.
- Nonwoven geotextiles: including geotextiles fabricated from directionally or randomly oriented fibres into a loose web, bonded by partial melting, needle-punching or chemical binding agents like glue, rubber, or latex.
- Knitted geotextiles: including geotextiles produced by interlooping one or more yarns with knitting machine.
- Stitched geotextiles: including geotextiles in which fibres or yarns or both are interlocked by stitching or sewing.

Geotextiles could be used for functions of geotextiles are separation, reinforcement, filtration, drainage and containment. Geotextiles are rarely serves only one function, but one specific function predominates. A few remarks of geotextiles applications are as below (Bergado, 2005):

As separator:

- Geotextile placed between subgrade soil and an aggregate layer to form an unpaved road.
- Geotextile placed between fine-grained foundation soil and an embankment constructed with coarse granular soil.
- Geotextile placed between underwater mud and material placed to construct a dyke or the fill between two dykes.

As reinforcement:

- Embankment constructed on poor foundations with geotextile layers incorporated at the bottom
- Embankment constructed on good foundation with steep reinforced slope.
- Vertical embankment or wall with soil reinforced with several layers of geotextile.
- Reinforced embankment on subsiding areas.

As filter and drainage:

- Geotextile filter between natural retained soil and free-draining fill.
- Geotextile filter between stream or canal bank and riprap or mattress protection.
- Gravel filled trench drain wrapped with geotextile.

2.2.1.2 Geogrids

Geogrids are planar high-density-polymeric products, consisting of mesh or net-like regular open networks of intersecting tensile-resistant elements which are called ribs and are integrally connected at the intersections. Based on connection type, extrusion, bonding or interlacing, geogrid will be called extruded geogrid, bonded geogrid or woven geogrid, respectively (Shukla and Yin, 2006). Extruded geogrids includes two types of uniaxial geogrids and biaxial geogrids. Uniaxial geogrids manufactured by the longitudinal stretching of a punched sheet; they have higher tensile strength in longitudinal direction than transverse direction (Shukla and Yin, 2006). Biaxial geogrids manufactured by stretching in both longitudinal and transverse direction of a punched polymer sheet; the tensile strengths of both directions are equal (Shukla and Yin, 2006). Woven geogrids use polyester for strength component and are coated with any of a number of materials such as PVC, latex and bitumen (Koerner, 1998). This coating is for dimensional stability and to provide protection for the ribs during protection (Koerner, 1998).

The key feature of geogrids is that the apertures, openings between the longitudinal and transverse ribs, are large enough to let soil strike-through from one side of geogrid to the other side. The ribs of geogrids are quite stiff compared to the fibres of geotextiles. Not only ribs, also junction strength is important in geogrids; the reason is the soil strike-through within the apertures resists against the transverse ribs, which transfers the force to the longitudinal ribs via junctions (Koerner, 1998). Geogrids are relatively high-strength, high-modulus, and low-creep-sensitive polymers with near-square apertures varying from 10 to 100 mm in size (Koerner, 1998).

Separation can be the function of geogrids, if very coarse gravels and/or large particle size material are supposed to use. Otherwise, geogrids function focuses on reinforcement applications (Koerner, 1998). Theirs applications include:

- To reinforce embankment fills and earth dams.
- To repair slope failures and landslides.
- To reinforce landfills to allow for vertical and lateral expansion.
- As gabions for erosion control structures.
- As basal reinforcement over soft soils.
- As asphalt reinforcement in pavements.

2.2.1.3 Geonets

Geonets are planar polymeric products, consisting of regular dense network of integrally connected and extruded parallel sets of ribs at acute angles to another ones (Koerner, 1998; Shukla and Yin, 2006). Almost all geonets are made of polyethylene and depending on the used classification system, they are in the upper range of medium-density or lower range of high-density products. The only additives in geonets are carbon black and processing/antioxidant package (Koerner, 1998). The ingredients are mixed and forced through and extruder, that ejects the melt into a die with slotted counter-rotating segments. The polymer melt flows at angles, forming discrete ribs in two planes. The semisolid mass is pushed over an increasing diameter core, which separates the ribs and diamond-shaped apertures form. After absolute cooling of geonet and realizing its full diameter, the geonet will be quenched in a water bath; then after, they will be cut along its manufactured axis and will be rolled for shipment (Koerner, 1998).

Their design function is to perform the in-plane drainage of liquids where they are needed to convey liquids. Few remarks of their applications are:

- Water drainage behind retaining walls
- Water drainage beneath building foundations
- Polluted water drainage beneath highways
- Underdrain systems beneath landfills

2.2.1.4 Geomembranes

Geomembranes are planar, relatively impermeable, synthetics sheets produced from polymeric or asphaltic or combination of those two materials (Koerner, 1998;

Shukla and Yin, 2006). There are several methods for manufacturing various types of geomembranes; the common procedure in all methods, starts with the production of the raw materials that include the polymer resin itself and adding number of additives such as antioxidants, plasticizers, fillers and carbon black to process the geomembrane sheets in various widths and thicknesses (Koerner, 1998).

A wide range of applications of geomembranes in environmental, geotechnical, hydraulic and transportation activities have been conducted to perform containment function, and control the fluids migration in projects (Koerner, 1998). Few remarks of applications are as below:

- Liners for reserve water.
- Liners for solar ponds.
- To waterproof liners within tunnels.
- To control expansive soils.
- To conduct water flow into preferred paths.

2.2.1.5 Geocomposites

Geocomposites include the products which are assembled or manufactured from composition of two or more material which one at least is a geosynthetic (geotextiles, geogrid, geonet, geomembrane or any other type) (Shukla and Yin, 2006). These products perform specific function(s) more effectively than when used separately. The key philosophy behind these products is to combine the best features of different materials in such a way to solve specific problems, in the optimal way (Koerner, 1998).

2.2.1.6 Geonaturals

Environmental awareness and high costs of petroleum-based synthecis stimulated concerns about development of alternative materials (Ahmad et al., 2009; Lekha and Kavitha, 2006; Methacanon et al., 2010; Prabakar and Sridharb, 2002; Rawal and Anandjiwala, 2007; Sarsby, 2007). Utilisation of natural based products such as jute, coir, sisal, oil palm empty fruit bunches (OPEFB), bamboo, cotton, wool have been investigated in several countries such as Malaysia, India, Brazil and Mexico (Ahmad et al., 2009; Beena and Babu, 2008; Ghavami et al., 1999; Silva et al., 2008). The use of natural fibres poses an exciting challenge to the construction industry, since they are cheap, and large volumes of them are readily available and only need a low degree of industrialisation for manufacturing (Silva et al., 2010). Such products, which are called geonaturals, are different from geosynthetics in several material characteristics and compositions. The chemical compositions of some natural fibres are provided in Table 2.1.

Due to the environmental-friendly concept of geonaturals, researchers probe new applications, where not always the strongest fibres are needed, but rather a fit-for-purpose solution is looked for (Defoirdt et al., 2010). Nevertheless, generating an employment for huge volumes of natural fibres prevents the environmental pollution, which would be caused by leaving these material in environment without any particular purpose (Satyanarayana et al., 2007). A higher economy can be saved by utilising natural fibres for geotechnical purposes, instead of manufacturing and importing of the polymeric geosynthetics (Ghavami et al., 1999). Geonaturals can be a complementary companion of geosynthetics because of some common application areas (Shukla and Yin, 2006).

Table 2.1: Chemical Composition of some natural fibres (John and Anandjiwala, 2008)

Fibre	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Waxes (%)
OPEFB	65	-	29	-
Coir	32-43	0.15-0.25	40-45	-
Sisal	65	12	9.9	2
Jute	61-71	14-20	12-13	0.5
Banana	63-64	19	5	-
Pineapple	81	-	12.7	-

2.3 Natural fibres

Through the recent years, jute, coir, sisal, OPEFB and bamboo fibres have been arisen lots of interests between the researchers (Ahmad et al., 2009; Bateni et al., 2011; Beena and Babu, 2008; Defoirdt et al., 2010; Ghavami et al., 1999; Silva et al., 2010; Virk et al., 2009). Following paragraphs present a brief introduction of these fibres.

2.3.1 Coir Fibres

Coir is the thick fibrous part (mesocarp) of coconut fruit, extracted from the husk. Coconut is from Cocos Nucifera specie of fruit family (John and Anandjiwala, 2008). This fruit grows extensively in tropical countries like India, Indonesia and Philippines. The length of coir fibres ranges between 150 mm up to 280 mm and the diameter varies between 0.1 to 0.5 mm (Beena and Babu, 2008). Based on higher amounts of lignin, coir fibres are more durable than jute fibres; as underwater, coir fibres retain their strength for about eight to ten years (Beena and Babu, 2008).

2.3.2 Sisal Fibres

Bundles of sisal fibres are extracted from the leaves of sisal plants, which originated in Mexico, Brazil, Indonesia and East African countries. Sisal plant is a member of leaf family and specie of Agave Sisilana (John and Anandjiwala, 2008; Satyanarayana et al., 2007). The size of sisal leaves varies between 6 and 10 cm in width, and contains 700-1400 technical fibres in length of 50 to 250 cm, depending on species, climate and plantation's soil (Ghavami et al., 1999; Satyanarayana et al., 2007; Silva et al., 2010).

2.3.3 OPEFB Fibres

Oil palm belongs to the species of Elaeis Guineensis, under the family of Palmacea, and originated in the tropical forests of West Africa. OPEFB fibres are the wastes of oil palm industry. The fibres have various lengths and their diameter varies from one end to another where the largest amount is located around the middle of length (E.Gunawan et al., 2009). Oil palm has been considered as one of the largest crops in Malaysia and Indonesia; where the 47% of world's supply is being produced by Malaysia and Indonesia produces 36% of that supply (Abdul Khalil et al., 2011; E.Gunawan et al., 2009; Sreekala et al., 1997). In Latin America and India cultivation of this plant is increasing, where India is looking forward to become self-sufficient in oil production (Bateni, 2009). One hectare oil palm plantation annually produces about 55 ton of fibrous biomass while yielding 5.5 ton of oil (Shinoj et al., 2011). Oil palm industry has to dispose about 1.1 ton of OPEFB per every single ton of oil produced (Karina et al., 2008).

Fibres are extracted from empty fruit bunches through the retting process. The available retting processes are mechanical retting (hammering), chemical retting (boiling with chemicals), steam/vapour/dew retting and water/microbial retting. Albeit water retting method is the most popular process (Raju et al., 2008), but the mechanical extraction is eco-friendly whereas the other methods pollute water bodies (Shinoj et al., 2011).

OPEFB fibres are hard, tough, non-hazardous and biodegradable materials. The diameter of fibres varies between 0.15 and 0.5 mm (see Table 2.2) and as other naturals fibres the tensile properties of them could differ based on the origin, surrounding climate, harvest period, the date of harvesting, maturity at harvesting and cultivation soil (Bateni, 2009; Defoirdt et al., 2010; Sreekala et al., 1997). Scanning electron microscopic (SEM) images of OPEFB fibres clarified that the fibres has void areas inside, which their size depend on the diameter of fibre (E.Gunawan et al., 2009); and porous surface morphology has been cited in literatures (Shinoj et al., 2011; Sreekala et al., 1997).

Table 2.2: Physical properties of OPEFB fibres (Bateni, 2009)

Parameter	Value
Diameter (mm)	0.15-0.5
Density (gr/mm3)	0.7-1.55
Linear density (denier)*	2150
Tensile strength (MPa)	100-400
Young’s modulus (MPa)	1000-9000
Elongation at break (%)	14
Microfibrillar angle (°)	46

* 1 denier = 1/9000 g/m

2.3.4 Bamboo Fibres

Bamboo fibres are extracted from the culms of bamboo plants, of grass family. Through the literatures it has been mentioned that bamboo plants have more than

1250 species around the world (John and Anandjiwala, 2008). Bamboo plant is considered as one of the most fast growing plants, where it grows in most of tropical regions of world. Since geonaturals contains a large portion of natural polymers such as lignin and cellulose, they also can be considered as polymeric materials (Shukla and Yin, 2006).

2.4 Protection of natural fibres

Since natural fibres are biodegradable, it is necessary to protect them from any circumferential agents and to ensure their long-term performance (Ahmad et al., 2009). Existence of hydroxyl groups in cellulose and lignin make the natural fibers potential for changes and modifications. Chemical treatments of cellulosic materials could change the physical and chemical structures of the fibre's surface. Such modifications reduce the hydrophilic nature of the fibre and decrease the rate of biodegradation (Rahman et al., 2007).

2.4.1 Acrylonitrile Butadiene Styrene

Acrylonitrile butadiene styrene (ABS) terpolymer is a widely used engineering thermoplastic due to its desirable properties which include good mechanical properties, chemical resistance, toughness, dimensional stability, good surface appearance, and easy processing characteristics (Martins et al., 2010; Owen and Harper, 1999).

ABS comes from acrylonitrile, butadiene, and styrene; acrylonitrile is a synthetic monomer which is obtained from ammonia and propylene; butadiene is a petroleum hydrocarbon from butane; and styrene monomers are derived from benzene and ethylene of coal and are commercially available. The chemical structure of ABS is shown in Figure 2.2. The OPEFB fibre contains high amounts of cellulose. The reported FTIR results were shown that OPEFB fibres have reaction with ABS. The adhesion-strengthening mechanism may result from interactions between the OH groups in the cellulose and the C≡N groups in the ABS (Sreekala et al., 1997).

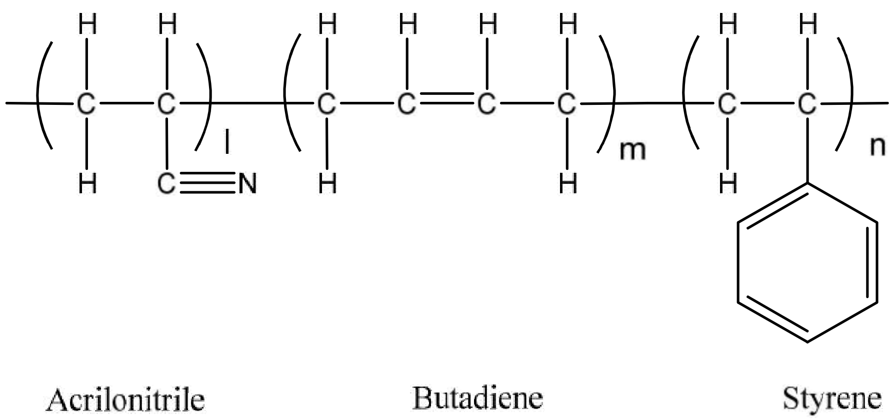

Figure 2.2: Chemical structure of ABS (Bateni, 2009)

Ahmad et al. (2009) and Bateni et al. (2011) dissolved ABS in methyl ethyl ketone (MEK) and used the solution for coating the OPEFB fibres. Bateni et al. (2011) found that by coating the OPEFB fibre by ABS, the water absorption ration decreased and consequently the biodegrading ratio of fibres decreased too. Ahmad et al. (2009) reported some improvements in shear strength of silty sand, reinforced by coated OPEFB fibres. The ABS was found to be absolutely soluble in MEK solvent and no noticeable gel-forming reactions observed during the solving process (Bateni, 2009).

Bateni (2009) conducted biodegradability test for untreated and ABS coated sheets. He tested the specimens in silty sand, peat soil, and over sand with contact of moisture and fungus for three months. The weight loss results indicated that almost

50% improvement was experienced for coated sheets. The coated sheets lost about 18% of their weight while the untreated sheets lost almost 37%.

2.5 Evaluation of Reinforcing Material

In reinforced soil-slopes, the soil-reinforcement interfaces are usually the weakest portions of system (Anubhav and Basudhar, 2010). In order to take into account the real behaviour of reinforced structures by extensible reinforcement, it is necessary to obtain information on tensile properties of reinforcing material and soil-reinforcement interaction. The force that develops in the reinforcement is a tensile stress which results from the shear stress between the reinforcement and soil (Abdelouhab et al., 2010; Gurung and Iwao, 1999; Lee and Manjunath, 2000; Moraci and Gioffrè, 2006; Palmeira, 2009; Sieira et al., 2009; Teixeira et al., 2007). Figure 2.3 shows some possible failure or deformation mechanism of a reinforced soil wall depending on the region and loading conditions considered:

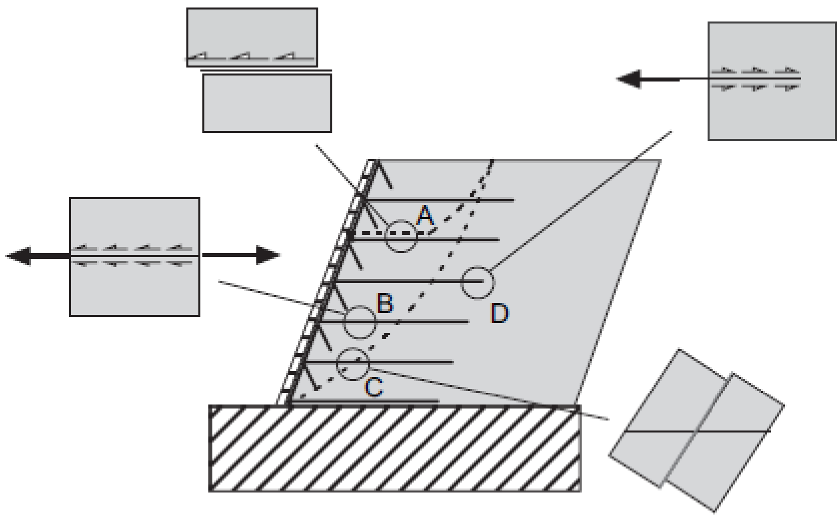

Figure 2.3: Interaction mechanism in a geosynthetic reinforced soil wall (Palmeira, 2009)

In region A (Fig. 2.3) sliding of the soil mass on the reinforcement surface can occur, which direct shear test can be employed to quantify soil-reinforcement bond under these circumstances. In region B, soil and reinforcement can deform laterally, and reinforcement undergo tensile strain as it transfers the load from unstable portions of soil mass into stable zones (Teixeira et al., 2007); so a plane strain test can be used in this case. Region C shows a condition where soil and reinforcement are sheared, so the direct shear test with the reinforcement inclined to the shear plane can be employed. In region D the reinforcement is being pulled out, so pullout test would be applicable (Palmeira, 2009). Rather than tensile strength which is mostly evaluated by manufacturer, direct shear test and pullout test are the appropriate and required tests which must be executed to study the interface mechanism (Goodhue et al., 2001; Gurung and Iwao, 1999; Liu et al., 2009; Lopes and Silvano, 2010; Subaida et al., 2008; Tatlisoz et al., 1998; Teixeira et al., 2007).

2.5.1 Tensile properties

Since the polymeric synthetics are highly homogenous, the tensile behaviour of such products is mostly consistent for the entire outcome of mill. For this reason, the tensile strength of polymeric geosynthetics is usually measured by the manufacturer to proffer it to their customers and convince them it term of quality and property of their product. This section is focused on works which studied the tensile behaviour of natural fibres.

Through the past decade, limited numbers of studies have been conducted on the tensile strength of natural fibres. Triphathy et al. (2000) published a paper about the mechanical properties of jute fibres. They ran tensile test for four types of jute fibres, untreated jute filament, silver jute filament, bleached jute filament and mercerized jute filament. Their results indicated that the mean tensile strength was found to be highest for untreated jute fibres, and followed by bleached jutes, mercerized jutes and silver jutes; approximate amounts of tensile strength were 700, 660, 580 and 540 MPa, respectively (Tripathy et al., 2000).

Tensile strength of coconut husks of different varieties and maturities have been investigated by Van Dam et al. (2006). They concluded that only slight differences could be observed between mature coconut husks (coir fibres) of different origins; the weakest type of fibres experienced the tensile strength of 75 MPa and two types experienced the maximums of 105 and 114 MPa. Rao and Rao (2007) studied the tensile properties of a few natural fibres which were using as fillers in polymeric matrixes. They ran the tensile test on five specimens and took the average of results for determining the tensile strength, strain percentage and tensile modulus. The result of tensile strength for sisal fibres, coir fibres and two types of bamboo fibres were reported as 567, 500, 503 and 341 MPa, respectively; average tensile strains were as 5.45, 20, 1.4 and 1.73 per cent, and average tensile modulus were 10.4, 2.5, 35.91 and 19.67 GPa, all in the same order. Rao and Rao (2007) also mentioned that the process of chemical extraction reduces the tensile strength and modulus, but increases the amounts of strain. Subaida et al. (2008) did experimental investigations on tensile behaviour of coir fibres, yarns and woven geotextiles at different gauge lengths and strain rates. Based on their results, they found that the tensile properties of coir yarns and woven coir geotextiles vary significantly based on gauge length and strain rate.

Tensile properties of coir fibres were found to vary depending on their origin (Subaida et al., 2008). In their research, consistent values of tensile strength and