

INVESTIGATION OF TENSILE AND SOIL-GEOTEXTILE INTERFACE STRENGTH OF KENAF WOVEN LIMITED LIFE GEOTEXTILES (LLGs)

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ABSTRACT: Most geotextiles are made from polypropylene or polyester polymers formed into woven and nonwoven fabric. Recently, new type of geotextile called Limited life Geotextiles (LLGs) made of natural fibers are utilized. Natural fibers are renewable fibers that can be sustainable into woven geotextiles for various geotechnical engineering applications. Geotextiles have been widely used to improve short term stability of embankments on soft clay by two functions: tensile reinforcement and as a drainage element. The paper presents the results of experimental investigation from the suitable pattern of woven Kenaf LLGs for soil reinforcement. Three patterns of weaving Kenaf LLGs were obtained, namely: plain, knot-plain, and hexagonal patterns. Tensile strength tests were conducted in warp and weft directions to select the most appropriate pattern for soil reinforcement application. The plain pattern of woven Kenaf LLGs is the most appropriate pattern due to its high tensile strength. Moreover, large scale direct shear tests were carried out to find the interface strength of Kenaf woven LLGs with sand backfill material as well as the sand backfill materials under different normal confining pressures of 40, 80, and 120 kPa. The important variables for LLGs reinforcement structure design and analysis were investigated. Furthermore, pullout tests were performed using normal confining pressures of 20, 40 and 60 kPa which cover the range of possible applied confining pressures in the field applications. Slippage failure occurred below the normal confining pressure of 40 kPa and tensile failure occurred at higher normal confining pressures.

Keywords: Geotextile, Fiber, Pullout, Direct shear, Interface.

INTRODUCTION

Environmental concern has increased in geotechnical field application all over the world. Natural fiber geotextiles known as “Limited Life Geotextiles (LLGs)” have emerged in applications of temporary reinforcement and biological soil stabilization (Sarby, 2007). New types of natural fiber reinforcing materials have been introduced recently in geotechnical applications; for example, jute, coir, sugarcane bagasse. Natural fibers can be manufactured into woven geotextiles and used in geotechnical engineering applications and generally classified as Limited Life Geosynthetics (LLGs). The LLGs were studied by many researchers (eg. Sarsby, 2007; Lekha and Kavitha, 2006; Dinu and Saska, 2007; Chattopadhyay and Chakravarty, 2009; Mwashu, 2009a,b; Mwashu and Pertersen, 2010, Vinod and Bhaskar, 2012) for soil reinforcement, erosion control and drainage. For geotechnical applications, the suitable natural fibers were investigated in this year in order to select the most appropriate pattern

and natural fibers. The effect of normal pressures and displacement rates of the kenaf LLGs were investigated by direct shear and pullout tests.

BACKGROUND

Polymer geotextiles have been used for soil reinforcement and soil erosion control. Due to growing environmental concerns new geotextiles known as “Limited Life Geotextiles (LLGs)” derived from natural fibers have emerged. The LLGs are reinforcing fabrics that are only required to perform short term applications in geotechnical engineering such as temporary roads over soft ground as basal embankment reinforcement (Sarsby, 2007).

Methacanon (2010) have investigated the chemical properties of four kinds of natural fibers namely: sisal, roselle or Kenaf, reed, and water hyacinth. Though, these natural fibers are one of the most natural fibers widely used in ropes, twines, rugs, mats, mattresses, and handcrafted bags, these economic and renewable

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resources are still under-utilized. The lengths of the fibers were determined using optical microscope as shown in Fig. 1.

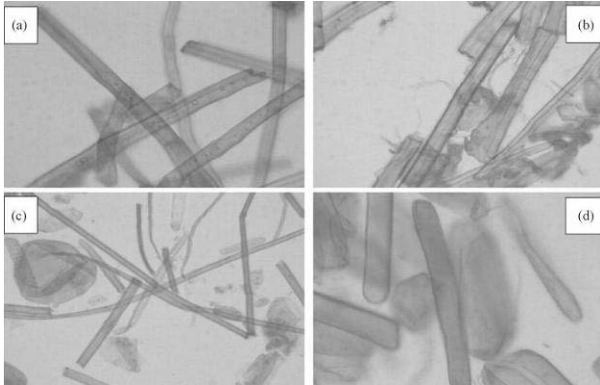


Fig. 1 Optical micrographs of single cells of: (a) sisal, (b) roselle, (c) reed, and (d) water hyacinth (Methacanon, 2010)

From the properties of the four studied fibers, they can be classified into two groups, namely: long fibers such as sisal and roselle (Kenaf), and short fibers such as reed and water hyacinth. The tensile strengths at dry and wet conditions for sisal and roselle (Kenaf) were significantly higher than that of reed and water hyacinth fibers. The elongation of all studied fibers with the exception of water hyacinth was not significantly different as shown in Fig. 2.

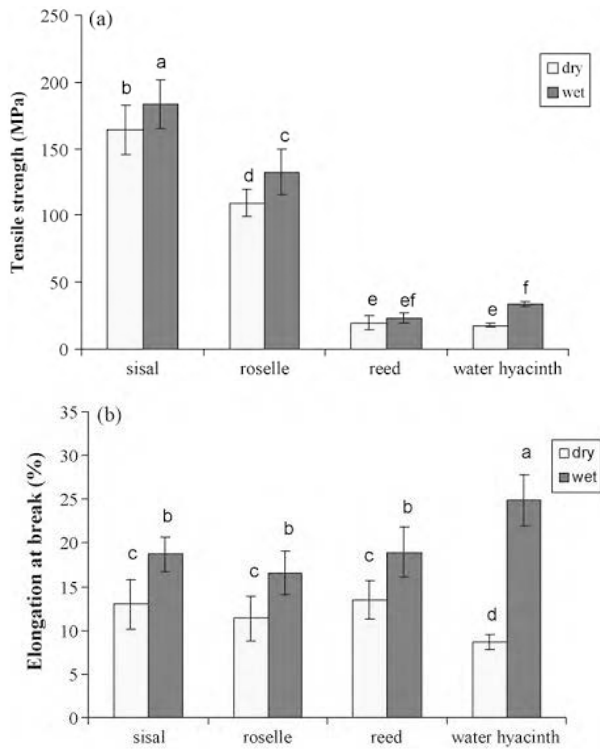


Fig. 2 Mechanical properties of the studied natural fibers: (a) tensile strength, and (b) elongation at break (Methacanon, 2010)

The water hyacinth fibers absorb the most amount of moisture. Moreover, when the fibers are wet, their elongation increased. The unique properties such as low moisture absorption and high strength of roselle (kenaf) fibers were similar to those of sisal, which would provide a good geotextile for soil reinforcement.

Natural fiber materials

Natural fibers used in this study consist of Kenaf or roselle (*Hibiscus sabdariffa* var *altissima*) fibers as illustrated in Fig. 3. Kenaf fiber yarns were woven to dimensions of 300 mm by 300 mm with 3 mm opening size including hexagonal, plain and knot-plain patterns as shown in Fig. 4. The objective is find the best suited pattern of woven LLGs made from Kenaf fibers for earth reinforcement. In considering the aforementioned specimens for geotextiles, the mass per unit area (ASTM D5261) and thickness (ASTM D5199) of the samples are tabulated in Table 1.



Fig. 3 Roselle or Kenaf fibers

Table 1 Physical properties of kenaf LLGs pattern

Patterns	Mass per Unit Area (g/m ²)	Thickness (mm)
Knot-plain	2117	9.89
Plain	1157	5.27
Hexagonal	1700	8.00

Tensile strength test

Wide width tensile strength tests of the LLG specimens were conducted 200mm wide specimens with separation of 100mm between clamps following ASTM D4595-86 Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method at a speed of 10 mm/min. The temperature in the testing room was 22 °C. The test set-up is shown in Fig. 5.

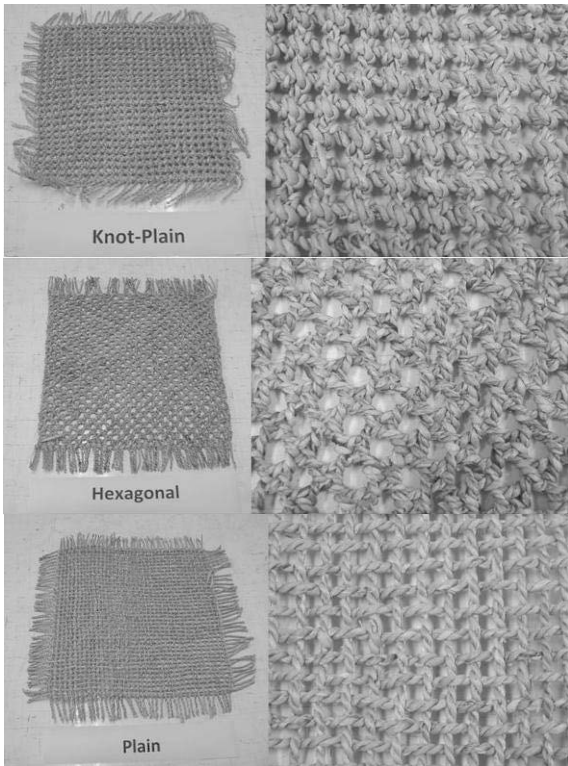


Fig. 4 Patterns for tensile test



Fig. 5 Tensile test machine

Tensile Strength Test Results

The tensile strength of knot-plain pattern was 7.72 kN/m for machine direction and 6.42 kN/m for cross machine direction. While tensile strength of hexagonal patterns were larger at 19.99 kN/m for machine direction and 16.43 kN/m for cross direction, respectively. For plain pattern, the results were highest at 22.79 kN/m and 21.26 kN/m for both machine and cross machine directions having similar results in both directions. The comparison of tensile strengths and elongations for all patterns is plotted in Fig. 6. The plain pattern had the highest tensile strength, followed by hexagonal pattern

and knot-plain. Thus, the plain pattern was recommended for earth reinforcement respectively.

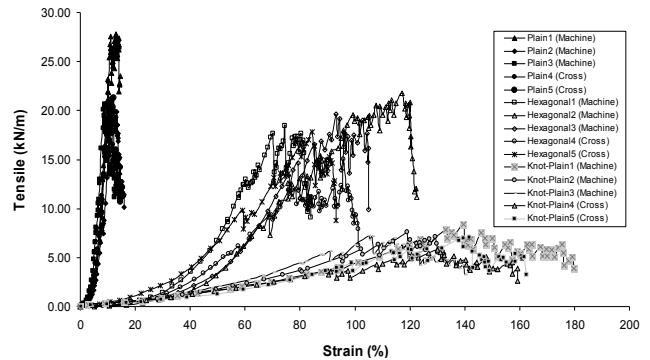


Fig. 6 Comparison of tensile strength of Kenaf LLGs for all pattern

TESTING PROGRAM TO OBTAIN INTERFACE PARAMETERS

In considering the properties of natural fiber, plain woven pattern of Kenaf LLGs which has dimension of 3 mm opening size was selected for this study due to its highest tensile strength. Thus, this type of woven LLGs were tested further to investigate its interface behaviour with silty sand backfill soil.

Backfill Material

The local silty sand with a specific gravity of 2.65 was used for pullout and direct shear tests. Based on standard Proctor compaction test, the maximum dry unit weight was 18.1 kN/m³ and optimum moisture content was 10%. The water contents before the test were maintained within ± 1 % of the desired optimum water content. Consequently, the backfill samples for pullout and direct shear tests were kept in plastic containers for 24 hours before tests to achieve uniform distributions of moisture contents. The backfill soil for both large scale direct shear and pullout tests were compacted to 95% of maximum dry density measured by sand cone method.

Large scale direct shear test

Direct shear testing apparatus was modified to be used as the interface shear equipment in accordance with ASTM D 5321 (Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic Friction by the Direct Shear Method). The tests were carried out up to high relative displacements to evaluate the residual shear resistance. The inner dimensions of rectangular shear boxes were

300 mm long, 300 mm wide, 50 mm deep for upper and lower box. This direct shear apparatus has movable lower shear box with horizontally supported upper box and a rigid load plate to apply the normal stress. The normal and shear stresses were computed after the area of the contact surface between the tested materials has been corrected. Two dial gauges were used to measure the horizontal displacement and a dial gauge installed at the top of the loading plate measured the vertical displacement. The bottom shear box was moved relative to the fixed upper shear box under a constant normal compressive stress. A photograph of device is shown in Fig. 7.

The large-scale direct test conducted for evaluating the friction between backfill soil only and between kenaf LLGs and backfill soil. The backfill sand only being tested was used initially as the substrate in the lower and upper box. Normal loads were applied to the backfill sand specimen and the specimen sheared across the pre-determined horizontal plane between the two halves of the shear box. The displacement rate 1 mm/min was used for all the tests. The normal loads applied in the direct shear tests for this study are 40 kPa, 80 kPa, and 120 kPa, respectively. The shearing was carried out until a

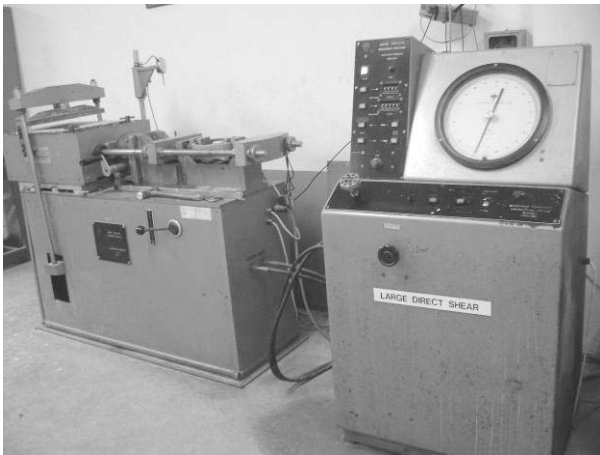


Fig. 7 Large scale direct shear apparatus

displacement of 50 mm was achieved. Measurements of shear load, shear displacement and normal displacement were recorded.

Kenaf LLGs was prepared by dimension of 300 mm by 500 mm and it was folded at one end and placed between compacted backfill soils which compacted to optimum moisture content in the upper and lower direct shear box, as shown in Fig. 8. During the shear tests, the soil is forced to slide along a Kenaf LLGs under a



Fig. 8 Kenaf LLGs folded with sand backfill in shear box

constant rate of displacement, while a constant load is applied normal to the plane of relative movement. The normal and shear forces applied to determine the point of failure. The test was repeated under three different normal pressures at 40 kPa, 80 kPa, and 120 kPa, respectively.

Pullout Test

Pullout test was conducted to determine displacement and structure of LLGs reinforcement layer needed to achieve active limit state in order to exploit reinforcement's load capacity properly. In this study, normal pressures 20, 40 and 60 kPa were applied to cover the range of possible reinforcement failures (i.e. slippage and breakage).

The pullout machine was composed of 15.9-mm thick steel plates around the pullout box and 12.7 mm thick steel plate at the bottom. These plates are welded together to form the channel section. Moreover, there are

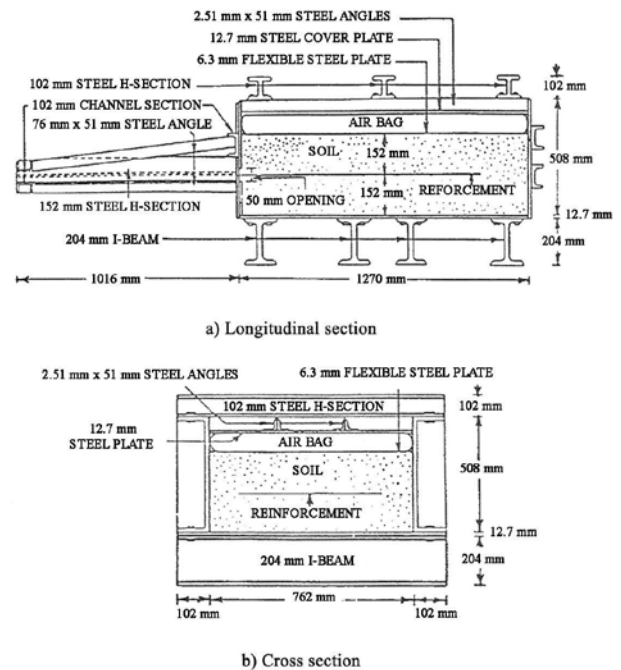


Fig. 9 Dimensions of pullout test apparatus (Bergado *et al.*, 1996)

additional 12.7 mm thick steel plates were used as removable back and front walls and 102 mm steel channels were used to support the pullout box. The inside dimension of pullout box were 1270 mm long, 760 mm wide and 508 mm high (Fig. 9). The front wall was composed of two parts, the upper and the lower one; there was a 50 mm slot between them.

A 225 kN capacity electro-hydraulic controlled jack was used to transmit pullout force through the steel reaction frame in front of the pullout box. The pullout clamp with dimensions of 100mm x 600mm x 12.7mm which is composed of two steel plates with grooves was used to grip the Kenaf LLGs reinforcement. The longitudinal bars of the steel grids were kept between the upper plate and the lower plate to prevent slippage of reinforcement during pulling procedure. The load cell attached between the pullout jack and reinforcement was

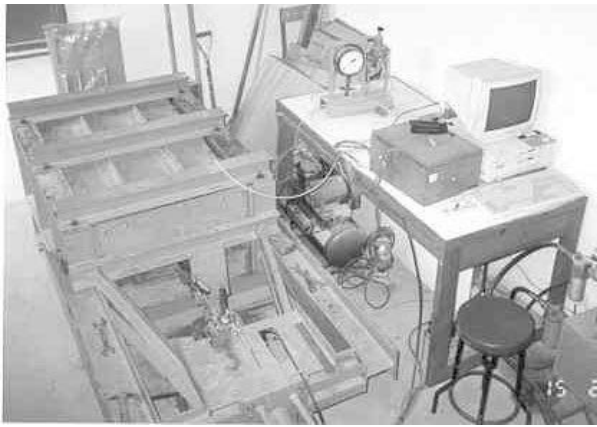


Fig. 10 Pullout machine

used to measure pullout force.

The inflated air bag was placed between the flexible steel plate and the top cover of the pullout box was used to apply the normal pressure. The top cover consist of a 12.7 mm thick steel plate reacted by the steel angles. The pressure regulator valve was connected between the air compressor and the air bag was used to adjust the normal pressure maintained constant during the pullout test. A



Fig. 11 LVDT and dial gage for measuring the horizontal displacement in front

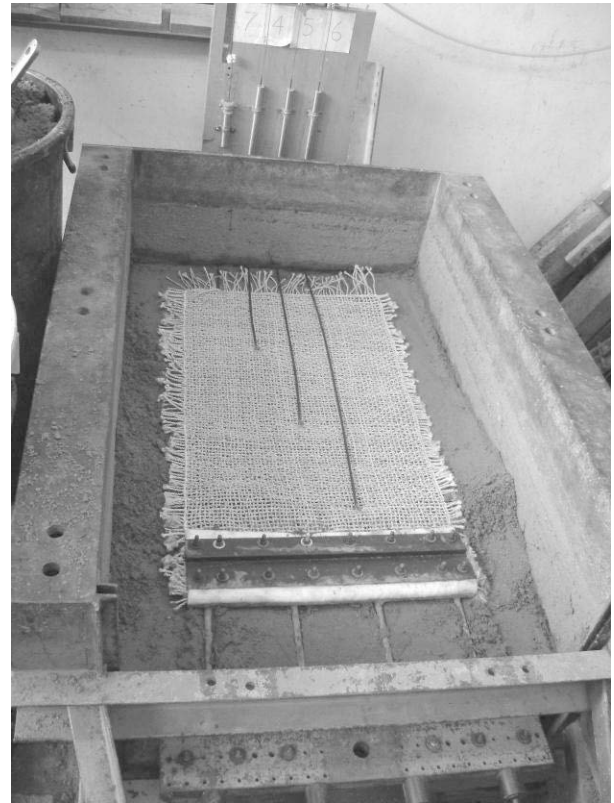


Fig. 12 Positions of LVDTs attached on the woven kenaf LLGs

pullout machine is shown in Fig. 10.

Pullout force was measured by a load cell connected to the data logger. The displacement of the woven Kenaf LLGs was recorded by a LVDT and a dial gage in front of the pullout box (Fig. 11). High strength wires were connected to the longitudinal bars and the other ends were connected to the LVDTs to measure the displacement at different positions on the longitudinal bars (Fig. 12).

Pullout tests on Kenaf LLGs

The backfill soils was put into the pullout box then compacted into three layers with the height of 0.15 m for each. The required density for each layer is 95% of the maximum dry density which was obtained from the result of Standard Proctor Test. Sand cone test was used to check the density and water content of each layer. The woven Kenaf LLGs specimen with the size of 0.5 m x 0.9 m was connected to the clamp at one end then placed in the middle position of the pullout box. After that, the upper front cover plate was placed and the next soil layers were poured above the sample. The requirements for density and water content of the latter layers were the same as that of the first layer. When compaction was completed, steel plate was placed above the sand and then the air bag was installed. Finally, the top cover was

installed and three bolted beams were placed to act as reaction equipment.

The normal pressures were applied using the air bag. To ensure that the pressure was transmitted uniformly on the filling material, this normal pressure was kept one hour before applying the pullout force. The pullout rate of the test was controlled at 1 mm/min. The data logger was used to record the pullout resistances and pullout displacements. The tests stopped when the sample has been pulled 150 mm (Shivashankar, 1991).

TEST RESULTS AND DISCUSSIONS

Direct shear test results

In this study, large scale direct shear tests were carried out to determine the value of friction angel (ϕ) by shearing Kenaf LLGs with sand backfill material and only sand backfill material. The tests were conducted under three different normal pressures at 40 kPa, 80 kPa, and 120 kPa, receptively. The tests were ended at maximum displacement of 150 mm. After the tests, the relationship between shear stress and horizontal displacement were plotted in Fig. 13 for sand backfill only and Kenaf LLGs with sand backfill. From the result of only silty sand backfill specimen, the peak friction angles was 35.63 degrees and cohesion was 11.33 kPa. In case of Kenaf LLGs with silty sand backfill, the peak friction angle was found to be 27.66 degrees and

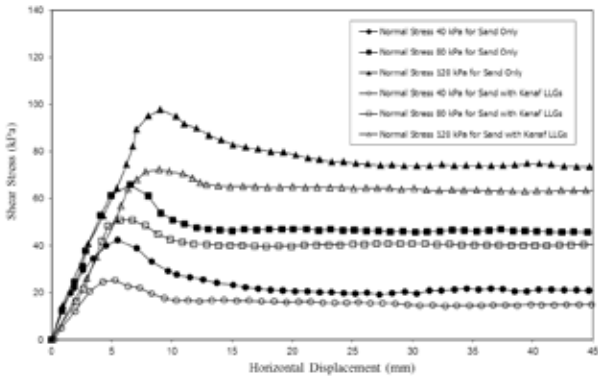


Fig. 13 The relationship between shear stress and horizontal displacement from direct shear tests

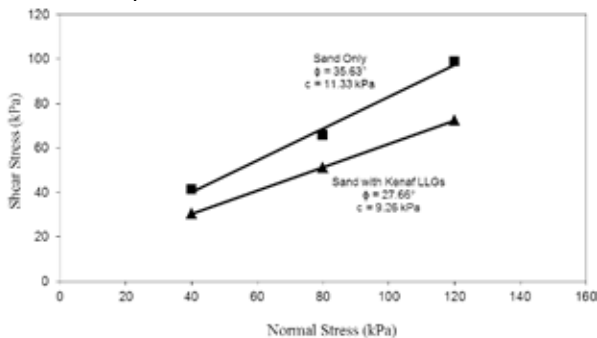


Fig. 14 The relationship between shear stress and normal stress from direct shear tests

cohesion was 9.26 kPa. The relationship between shear stress and normal stress is shown in Fig. 14.

Pullout test results

Pullout tests on woven Kenaf LLGs were conducted at normal pressures at 20 kPa, 40 kPa, and 60 kPa, receptively in order to evaluate the contribution of the interface frictional resistance to the overall pullout-resistance. Pullout resistance was measured by the load cell connected to the data logger and the pullout displacement was measured by the dial gage in front of the pullout box. The relationship between the pullout resistances and pullout displacements of Kenaf LLGs

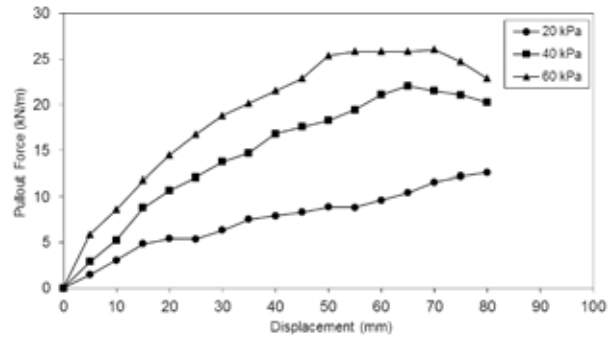


Fig. 15 Pullout displacement of Kenaf LLGs at different normal pressures

reinforcement during the pullout test at different normal pressures are shown in Fig. 15.

In general, the pullout resistance increases when normal pressure increases resulting from the increase of confinement on the woven Kenaf LLGs reinforcement. Moreover, the pullout resistance has been observed to increase rapidly at small pullout displacement. After the peak values of pullout resistance at small displacement, the pullout resistance continues to increase very slowly to the maximum pullout resistance. The test was terminated when a maximum displacement of 80 mm was reached for three values of normal pressures. The maximum pullout resistances observed at the end of the test were 12.57 kN/m, 22.04 kN/m, and 26.03 kN/m for normal pressures of 20 kPa, 40 kPa, and 60 kPa, respectively. Furthermore, the relationships between

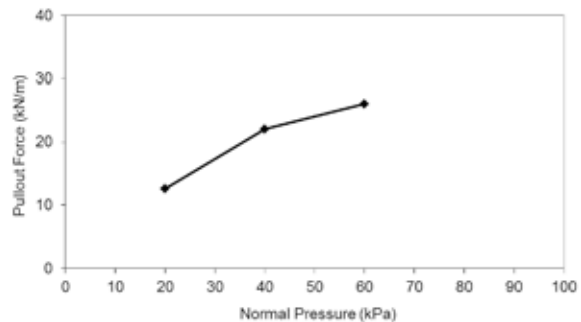


Fig. 16 the relationships between maximum pullout resistance and normal pressure

maximum pullout resistance and normal pressure for woven Kenaf LLGs are plotted in Fig. 16.

The failure mode of woven Kenaf LLGs reinforcements can be divided into two modes, namely: slippage failure and tension failure, depending on the magnitudes of the applied normal stresses. At lower normal stresses of 20 and 40 kPa, the failure modes of Kenaf LLGs reinforcements were slippage failure with no visible damages in the reinforcement. The pullout force increased with displacement as shown in Fig. 15. In contrast, the Kenaf LLGs were damaged at normal stress of 60 kPa because the failure mode was tension failure. Due to tension failure of the reinforcement, the pullout force reduced with displacement as shown in Fig. 15.

Interaction between soil and Kenaf LLGs reinforcement

Shear parameters from soil to reinforcement were obtained from the direct shear and pullout tests. The efficiency values of Kenaf LLGs reinforcement by the direct shear test on cohesion and on friction could be determined by using the following equations (Bergado and Chai, 1994):

$$E_c = \left(\frac{c_i}{c} \right) \times 100 \quad (1)$$

$$E_\phi = \left(\frac{\tan \delta}{\tan \phi} \right) \times 100 \quad (2)$$

where E_c is the efficiency of Kenaf LLGs reinforcement on cohesion; E_ϕ is the efficiency of Kenaf LLGs reinforcement on friction; c_i is the adhesion between soil and Kenaf LLGs reinforcement; c is the cohesion between soil and soil; δ is skin friction angle between soil and Kenaf LLGs reinforcement from shearing resistance test between Kenaf LLGs and sand backfill material and ϕ is friction angle between soil and soil. The aforementioned parameters were obtained from large scale direct shear test results as plotted in Fig. 14. From this study, the efficiency of Kenaf LLGs reinforcement on cohesion, E_c can be calculated as 81.73% and the efficiency of Kenaf LLGs reinforcement on friction, E_ϕ can be calculated as 73.11%.

The interaction coefficients at direct shear interfaces which denoted as R_i and defined as the ratio of the shear strength of backfill material-structure interface to the corresponding shear strength of the backfill as follows:

$$R_i = \frac{\sigma \cdot \tan \delta + c_i}{\sigma \cdot \tan \phi + c} \quad (3)$$

where σ is the applied normal stress; δ is the skin friction angle between backfill and reinforcement; and the rest of the terms have been defined previously. The interaction coefficient at direct shear interfaces is found to be 0.812.

The interaction coefficient from pullout test represents the efficiency of geosynthetic reinforcements embedded in the soil backfill. The interaction coefficients are used in the design of reinforced earth structures to determine the required embedment length of reinforcements to prevent the pullout of the reinforcements. The pullout interaction coefficient (C_i) was defined by Bergado and Chai (1994) which is expressed in the following equation:

$$C_i = \frac{P_{(\text{pullout})\text{ult.}}}{2WL(\sigma_n \tan \phi + c)} \quad (4)$$

where $P_{(\text{pullout})\text{ult}}$ is the ultimate pullout resistance that can be measured from a pullout test; W is the width of reinforcement; L is the embedded length of reinforcement and σ_n is the applied normal stress or confining stress. The pullout interaction coefficients (C_i) for Kenaf LLGs are 1.11, 1.07 and 0.88 for applied normal load as 20 kPa, 40 kPa and 60 kPa, respectively.

CONCLUSIONS

Based on the results of tensile test, direct shear test and pullout test, respectively. The conclusions of the study were summarized as followed:

1. Plain pattern is the most appropriate pattern for soil reinforcement application due to the highest tensile strengths.
2. The peak friction angle of sand backfill only and Kenaf LLGs with sand backfill were 35.63 and 27.66 degrees with the corresponding cohesion values were 11.33 and 9.26 kPa, respectively.
3. The efficiency of Kenaf LLGs reinforcement on cohesion and on friction are 81.73% and 73.11%.
4. The interaction coefficients at direct shear interfaces is found to be 0.812 which can be applied for simulate the behavior of Kenaf LLGs reinforcement.
5. The pullout resistance on woven Kenaf LLGs increased with increasing normal pressure. Slippage failure occurred below the normal pressure of 40 kPa and tension failure occurred at the normal pressure of 60 kPa.
6. The pullout interaction coefficients for Kenaf LLGs are 1.11, 1.07 and 0.88 for applied normal load as 20 kPa, 40 kPa and 60 kPa, respectively. Interaction coefficients for Kenaf LLGs decreased as increasing the normal stress.

7. Based on the results of the interaction between the Kenaf LLGs reinforcement and backfill soil, the direct shear and pullout resistances indicate that the Kenaf LLGs can be used for temporary soil reinforcement applications.

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