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Structural and Hydraulic Performance of Polypropylene Fibre Reinforced Clay

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Abstract

Conventionally, clay is the material of choice for construction of earth dam cores/ embankments dues to its low hydraulic conductivity. Also, undrained behavior of composite clays in its natural or compacted state e.g., core material of embankment dams has a great importance for the geotechnical engineers. A series of tests on unreinforced and reinforced clay specimens on direct shear box, split tension strength, and hydraulic conductivity tests were carried out to investigate the structural and hydraulic performance of polypropylene fibre reinforced clay. Samples were tested with addition at nine different percentages (0, 0.05, 0.1, 0.15, 0.2, 0.25, 1, 2 and 3%) fibre content by weight of soil. The test results were clearly showed that the shear strength parameters (c, φ) of soil has improved when addition in fibre content as well as in splitting tensile strength. Also, the tests result, revealed that hydraulic conductivity K decreased as the fibre content increased. The reinforcement gain increased with an increase in fiber contents.

Keywords: Polypropylene fibre, red coffee clay, reinforcement, direct shear, splitting tensile, hydraulic conductivity.

1. INTRODUCTION

Associated with its design and construction. This indicates that there is a need for a careful assessment of the cost involved. The use of an earth dam instead of some other type would usually reduce the cost, as an earth dam can be built at less than half the cost of the concrete dam with equal capacity and height.

However, the soil reinforcement technique is well set up and is utilised in variety of applications like improvement of permeability, bearing capacity, filter and drainage control, shear strength, among others. Reinforced soils can be extorted by either incorporating continuous reinforcement inclusions within a soil mass in a defined mixing discrete fibre randomly with a soil fill. The concept and principle of soil reinforcement was first developed by Vidal in 1969[1]. He found out that the introduction of reinforcement elements in a soil mass increases the shear resistance of the medium. The primary purpose of reinforcing soil mass is to improve its stability, increase its bearing capacity and reduce settlements and lateral deformation [2]. In this study, discrete fibres are introduced to be added and mixed with dam embankment soil. Inclusion of fibre is expected to improve soil mechanical behaviour, increase soil tensile strength and improve soil hydraulic performance by filling up voids restricting the seepage flow within some pore channels, which were partially blocked by fibres as well as through providing tensile resistance against soil piping and erosion.

2. EXPERIMENTAL STUDY

2.1. Soil Material

The used soil was clay materials (red coffee soil) which is abundant in most parts of Kenya collected around Juja with grain size distribution curve as shown in figure 1a. The results of standard proctor compaction test indicated a maximum dry density (MDD) and optimum moisture content (OMC) of soil of 1.515 g/cm^3, 27% respectively. Figure 1b shows the relationship between optimum moisture content and dry density as compaction curve of the soil. Some of soil engineering properties are given in table 1.

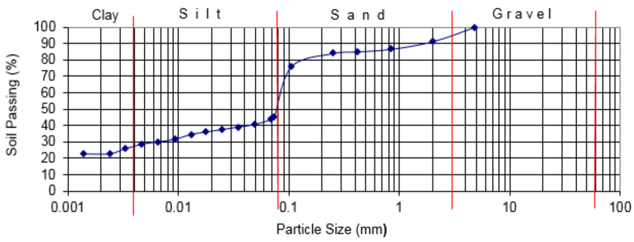

Figure 1a. Particle size distribution

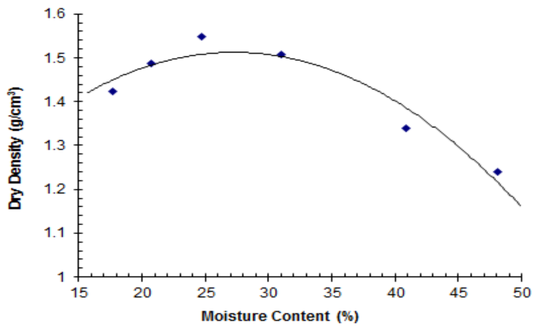

Figure1b. Compaction curve for clay

Table 1. Summary of test soil properties

Property	*value*
Specific gravity	*2.39*
Atterberg limit	
Liquid limit (%)	*66*
Plastic limit (%)	*32.60*
Plasticity index (%)	*33.4*
Particle size distribution	
Gravel (%)	*4*
Sand (%)	*20*
Silty (%)	*30*
Clay (%)	*46*
Soil classification	*CH*
Compaction characteristic	
Maximum dry unit (g/cm^3)	*1.515*
Optimum moisture content (%)	*27*
Shear strength	
Cohesion (kg/Cm^2)	*0.95*
Internal friction angle (degree)	*28*
Hydraulic conductivity K (m/s)	*4.67 x 10^{-7}*

2.2. Polypropylene fibre

Polypropylene (PP) fibre was used in this study. PP fibre is the most widely adopted synthetic fibre for soil reinforcement [3]. [4] reported that PP fibre performed better than polyester (PET) fibre in increasing seepage resistance, because the PET fibre has a specific gravity higher than the PP fibre. For the same fibre content, a greater specific gravity implies a lower fibre volume and a lower number of fibres, and hence reduces the benefit of improving the piping resistance of a soil.

Short discrete polypropylene fibre (PPF, 6 mm in length), figure 2 was used as the reinforcement material. The physico-mechanical parameters of the PP-fiber provided by manufacture are given in Table 2. The PPF shows a very good dispersibility. It is easy to mix with soil and obtain uniform mixture.

Table 2. Mechanical and physical properties of fibre

Property	*value*
Material	*100*
Fibre type	*Bunchy monofilament*
Density	*0.91*
Acid and alkali	*High*
Melting point	*About 160*
Conductivity for heat	*Very low*
Containing moisture	*0.1*
Elongation at break	*30*
Specification	*6 mm*
Tensile strength	*> 400 MPa*
Young modulus	*> 3.5 GPa*
Fibre diameter	*0.026 mm*
Burning point	*580*
Safety	*Non-toxic material*
Ageing resistance	*Anti-ageing resistance*

Figure 2. Polypropylene fibre

3. TEST METHODOLOGY

3.1. Shear box test

The direct shear was employed to determine the shear strength of the tested specimens in accordance with BS 1377-4:1990[5]. The shear box has dimensions of 20 × 20 ×10 cm as shown in figure 3. Three specimens were carefully mixed by hand [6] and tested at each different percentage of fibre. The soil fibre mixture was moisturised by adding water to allow specimen to settle in the shear box and then loaded at three different vertical stresses (2 Kgf, 3 Kgf, 5 Kgf). The laboratory testing program was performed in the Pan African University hosted in JKUAT/ Kenya, Soil Mechanics Laboratory.

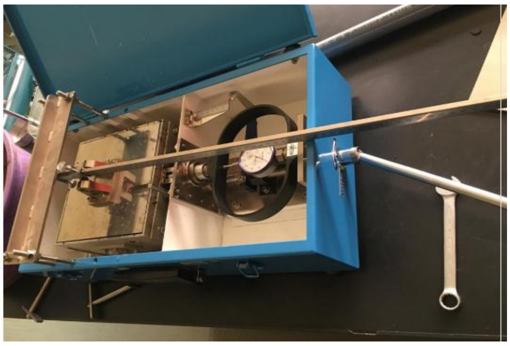

Figure 3. Direct shear machine

3.2. Tensile splitting strength

A compressive testing machine was used for the tensile splitting test as shown in Figure 4. The tensile splitting test were conducted in accordance with BS 1377-4: 1990. To investigate the influence of water content on tensile strength, sample were air dried (at the same condition in climatic chamber) to avoid loose of moisture and then tested after 48 hours[7]. The load were applied continuously at a steady rate of 0.05 N/ mm^2/s up to failure of the specimen , and tensile splitting strength recorded. Equation (1) was used to determine the splitting tensile strength (T in MPa) of cylindrical specimen(127 mm of height and 100 mm of diameter). In the equation (1), P is the maximum applied load (N), d and L are diameter and length (in m) of the cylinder, respectively.

$$T = \frac{2P}{\pi l d} \quad (1)$$

Figure 4. Crushing of specimens

3.3. Hydraulic Conductivity

The falling-head test can be used for all soil types, but is usually most widely applicable to materials having low permeability as clay. The hydraulic conductivity (Permeability) were conducted in accordance with BS 1377-5:1990[5]. Different seepage tests were carried out to evaluate the influences of soil and fibre on the hydraulic conductivity.

For the aim of hydraulic conductivity, seepage test system Figures 5a; 5b, consisting of a falling head device were used in this study. The hand mixing method has been commonly adopted by various researcher (K-H yang, W.M Adilehou, 2017) [8]. The soil-fibre mixture was moisturised by adding water (10 of total weight) to avoid soil-fibre segregation before being compacted in the mould (127 mm of height and 100 mm of diameter).

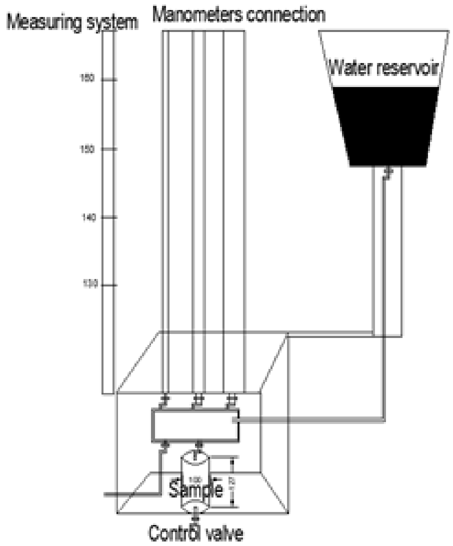

Figure 5a. Seepage system test

Figure 5b. Overview Photo

4. RESULTS AND DISCUSSION

4.1. The effects of fibre inclusion on the shear strength

The effects of fibre inclusion on the shear strength parameters are compared using the test results of the direct shear test on unreinforced samples. The shear stress-horizontal displacement curves obtained from the tests for reinforced and unreinforced soils at normal stress and vertical stress. The settlement is recorded after the sample is loaded. Shear stress was recorded as a function of horizontal displacement up to a total displacement of 50 mm in order to observe the post-failure behaviour. It is observed that an increase in shear strength as a result of increasing the fibre content for all normal stress as

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shown in figure 6a. Therefore, with the increase of fibre content, the internal friction angle and cohesion of soil improved a little, as illustrated (figures:, 6b, and 6c). Also, with 3% of fibre content, there was an increase of 48.71% of specimen reinforced with fibre over the unreinforced one.

Table 3. Summary of test results for unreinforced and reinforced soils

Fibre content (%)	Cohesion (kg/cm^2)	φ (degree)	MDD (g/cm^3)
0	0.95	28	1.515
0.05	1.00	33.42	1.515
0.10	1.15	33.5	1.515
0.15	1.20	33.69	1.515
0.20	1.25	34.5	1.515
0.25	1.50	40.17	1.515
1	1.62	42	1.515
2	1.70	42	1.515
3	1.95	45	1.515

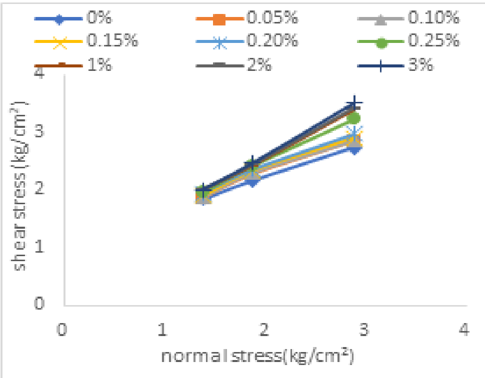

Figure 6a

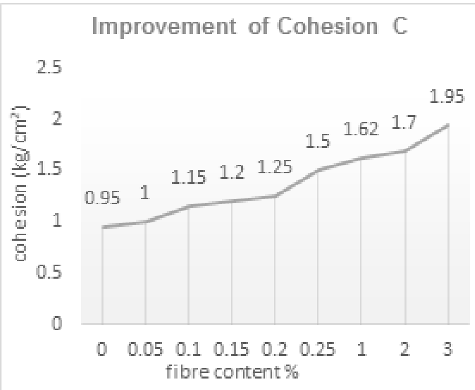

Figure 6b

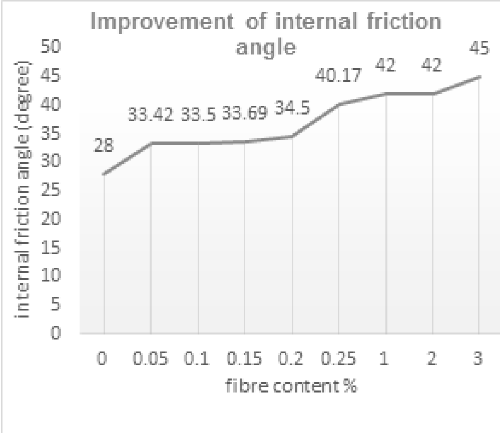

Figure 6c

4.2. Consequence of fibre on split tension

The splitting tensile strength was used to assess the tensile strength of brittle materials, because direct tensile test cannot be performed on such types of materials. The summary of the splitting tensile strength test result is presented in Figure 7. The result showed that the splitting tensile strength increased with increase of fibres content but after 1 % fibre content it start decreased. The strength decreased because the high content of fibre in the cylindrical specimens made a balling up which caused the specimens to loose strength. For both unreinforced and reinforced specimens, it was observed that the fibre had significantly improved the tensile strength. In Figure 7, it is observed that with 1 % of fibre content there was an increase of 11.03 % of specimens reinforced with fibre over the unreinforced one. These findings indicated that the optimum fibre content based on splitting tensile value is 1%.

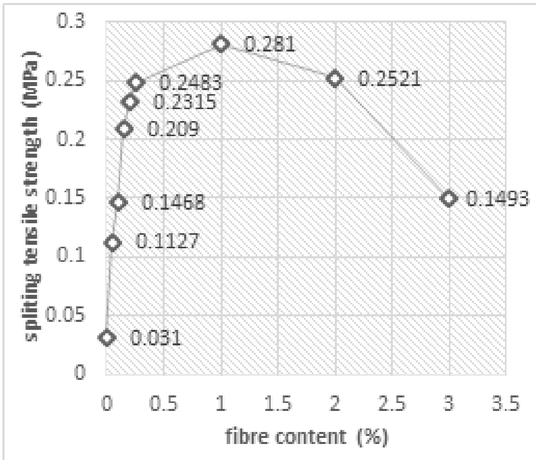

Figure 7. Variation of strength of specimen on tensile

4.3. The effect of fibre on the hydraulic conductivity

The variation of k with fibre parameters was quantitatively evaluated using the k ratios, defined as the ratios of the hydraulic conductivity of PPFRS to those of unreinforced clay. The k ratios serves as indices for assessing the reduction of seepage velocity and improvement of soil piping resistance. Figure 8 shows that the influence of fibre content on hydraulic conductivity k, and Table 4 lists seepage test and the associated k ratio values. A clear trend of decreasing k with increasing fibre content can be observed. For example, for PPFRS, the k decreases from 4.67×10^{-7} to 9.01×10^{-8} m/s (k ratio decreases from 1 to 0.192) as the fibre content increases from 0.05 to 3%. These results suggest that hydraulic conductivity decreases significantly when adding 0.05 % of fibre and continuesly after adding 0.25% of fibre to the soil. These findings indicated that the optimum fibre content based on hydraulic conductivity values is 0.25.

Table 4. Summary of seepage test

Fibre (%)	*K (m/s)*	*K ratio*
0	*4.67 x 10^{-7}*	*1.000*
0.05	*1.82 x 10^{-7}*	*0.389*
0.1	*1.22 x 10^{-7}*	*0.261*
0.15	*1.20 x 10^{-7}*	*0.256*
0.20	*1.17 x 10^{-7}*	*0.250*
0.25	*1.14 x 10^{-7}*	*0.244*
1	*1.06 x 10^{-7}*	*0.226*
2	*1.02 x 10^{-7}*	*0.217*
3	*9.01 x 10^{-8}*	*0.192*

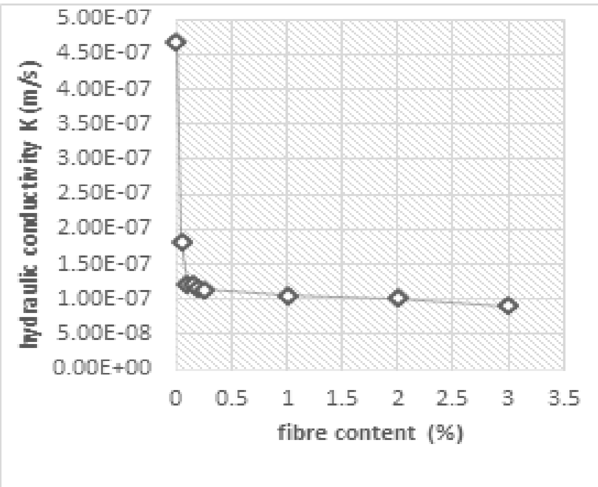

Figure 8. Effect of fibre on the hydraulic conductivity

5. CONCLUSION

This study was undertaken to investigate the hydraulic and structural performance of polypropylene fibre and fibre content on the shear strength parameters (c and φ), tensile strength, hydraulic conductivity of randomly distributed fibre-reinforced soil. The results of this study conduct forth the following conclusions:

- Benefit of physical and engineering properties of clay (red coffee clay);
- Optimum polypropylene fibre content;
- Peak shear stresses are significantly affected by fibre content;
- Inclusion of fibre are provided tensile resistance against soil erosion, and restricting the seepage flow within some pore channels, which were partially blocked by fibres.

ACKNOWLEDGEMENTS

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NOTATION

MDD maximum dry density

OMC Optimum moisture content

PPFS polypropylene fibre reinforced soil

P maximum applied load

L length

D diameter

K hydraulic conductivity

BS british standard

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