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Study on the Strength of Lightly-Cemented Soil Reinforced with a Synthetic Fibre and a Natural Fibre

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ABSTRACT

Strength response of a lateritic soil reinforced with one natural fibre (sisal) and one synthetic fibre (polypropylene strips-PPS) was examined in this work. The soil belongs to USCS class of clayey sands (SC), which is fairly good as a pavement material. However, the need to improve the strength and ductile behaviour of soils under load culled the need to stabilize the soils with three (3) percent cement and then reinforce them with varying percentages of sisal fibre and PPS (0.25, 0.5, 0.75, 1, 1.5 and 2). Maximum UCS was achieved at 2% sisal fibre and 0.5% PPS for LAT 1. For LAT 2, maximum UCS was achieved at 2% sisal and 1.5% PPS. The response of sisal fibre to soil reinforcement was uniform across both soils but the response of PPS seems to be affected by the nature and type of soil in use because significant improvement was observed in the strength of soil in LAT 2 when compared to LAT 1. Analysis of variance was used (at 95% confidence level) to examine the effect of variation of fibres on soil strength. The results show that the variation of fibre content was significant when the soils are first stabilised with cement.

Keywords: Sisal fibre, polypropylene fibre, unconfined compressive strength, soil reinforcement, soil stabilization

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1. INTRODUCTION

Interest in the use of fibres in geotechnical applications began with the work of Vidal in 1969 who found that adding reinforcing elements in a soil mass increases the shear resistance of the medium (Gowthaman et al, 2018). Fibres are broadly classified into natural fibres and synthetic fibress. Natural fibres are broadly classified as plant fibres, and animal parts containing protein and minerals. Based on availability and applicability, plant fibres are preferred over other classes (Gowthaman et al, 2018). There have been widespread research in the use of synthetic fibres which are mostly bye-product of the petroleum industry because they can easily be processed. Besides this advantage, they are affordable and their elastic modulus per density is high. Recently, the use of natural fibre reinforcement as sustainable stabilizer/binder in geotechnical engineering has gained interest among researchers. The reason for this is due to various advantages associated with natural fibres such as favourable strength, sustainability, stiffness, low energy consumption, economical, eco-friendliness and high prospects over synthetic materials (Gowthaman et al, 2018). Researches have shown that synthetic fibres consume more energy and are more costly when compared to natural fibres. Fig. 1 shows the fibre properties and the role of soil in fibre-soil reinforcement technology.

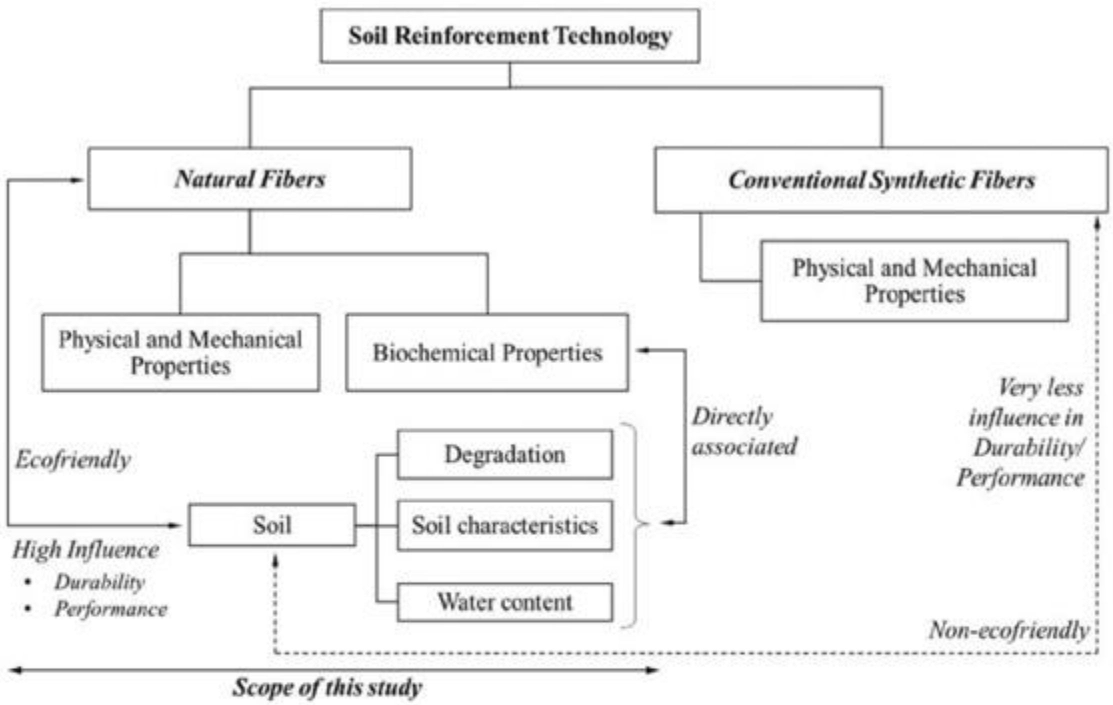

Fig. 1; Fibre properties and the role of soil in fibre-soil reinforcement (Gowthaman et al, 2018).

According to Sharma et al (2012), natural plant fibres such as banana, coir, sisal and jute have been used to make composites which are used in consumer goods, low cost housing and other civil structures. This use is attributable to excellent advantages associated with natural fibres such as appreciable strength, good thermal and acoustic properties, low density, affordability, biodegradability, renewability, good insulation properties, high strength, resistance to fracture and high stiffness etc. The reinforcing efficiency and behaviour of natural fibers are attributed to the natural cellulose and its crystallinity (Gowthaman et al, 2018). Table 1 shows some of plant fibres and their biochemical composition.

Table 1; Some plant fibres and their biochemical composition (Gowthaman et al, 2018)

Source of Fiber	Species	Fiber Origin	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Bamboo	(>1250 species)	Culm	40–55	18–20.8	15–32.2
Jute	*Corchorus capsularis*	Stem	56–71	29–35	11–14
Coir	*Cocos nucifera*	Fruit	32–43	21	40–45
Palm	*Elaeis guineensis*	Fruit	32–35.8	24.1–28.1	26.5–28.9
Sugarcane Bagasse	*Saccharum officinarum*	Stem	32–44	25	19–24
Water hyacinth	*Eichhornia crassipes*	Stem	43.58–47.38	19.77–22.23	9.52–13.08
Rice	*Oryza sativa*	Husk	59.9		20.6
Sisal	*Agave Sisiana*	Leaf	57–71	16	11–12
Flax	*Linum usitatissimum*	Stem	62–72	18.6–20.6	2–5
Banana	*Musa indica*	Leaf	60–65	25	5–10
Hemp	*Cannabis sativa*	Stem	67–78.3	5.5–16.1	2.9–3.7
Kenaf	*Hibiscus cannabinus*	Stem	70	3	19
Pine	*Pinus lambertiana*	Straw	67.29		11.57
Barely	*Hordeum vulgare*	Straw	33–40	20–35	8–17
Wheat	*Triticum aestivum*	Straw	30	50	15

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Higher cellulose composition (>50%) reflects the strength of a fibre. Among the higher strength fibres is sisal with cellulose content within 57 – 71% which is among the highest. In a typical fibre, the orientation of cellulose is usually along the length of the fibres. This behaviour enhances some mechanical properties of the fibre such as the flexural strength and the tensile strength. The lignin content of the fibres helps to ensure their durability in a reinforced mass. Fig. 2 shows a structure of the fibre cell and the contents.

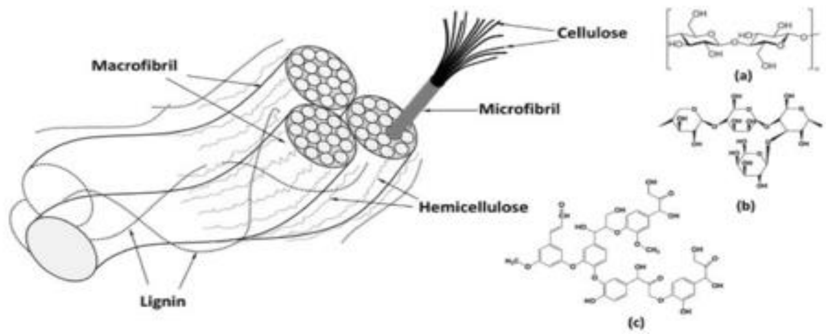

Fig. 2; Fibril matrix of a plant fibre with its chemical composition. 2 (a) represents the cellulose composition while 2(b) and 2 (c) represent the hemicellulose and lignin composition respectively (Gowthaman et al, 2018).

Sisal (*Agave sisalana*) which is in the class of plant fibres is the lignocellulosic plant which is found in America, Africa, and Asia (Fig. 3). A sisal plant produces 200-250 leaves (of about 2 m length) before flowering and its leaves contain approximately 700-1400 fibre bundles which are about 0.5-1.0 m. Within the leaf three basic types of fibres are there: structural, arch and xylem fibres (Suresh, 2011).

Fig. 3; Diagram of sisal plant

The sisal fibre constitutes of 65.8% cellulose, 12% hemicellulose, 9.9% lignin, 0.3% wax, and some water soluble compounds. In recent years plenty of research has been focused on the potential of sisal fibre reinforced composites. One of such is in soil reinforcement. To effectively use the fibre composites in many applications it is necessary that it had some mechanical properties such as flexibility, good tensile strength, and should have less wear property. Table 2 shows the typical mechanical properties and physical properties of common plant fibres. Previous researches have shown that the fibre increases the toughness of polymer than increasing the strength and modulus, and it is noted that sisal fibre composite had maximum toughness than other fibre that is about 1250 MNm^{-2} and its strength is about 580 MNm^{-2} (Pavithran et al, 1987; Sharma et al, 2012).

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Table 2; Typical mechanical and physical properties of common plant fibres (Gowthaman et al, 2018)

Fiber	Density (kg/m^3)	Young's Modulus (GPa)	Ultimate Tensile Strength (MPa)	Elongation at Break (%)	Moisture Absorption (%)
Bamboo	715–1225	33–40	400–1000	-	40–52.45
Jute	1300–1450	10–30	393–860	1.5–1.8	12
Coir	1390–1520	3–6	100–225	12–51.4	130–180
Palm	463	26–32	100–400	19	1–10
Sugarcane Bagasse	1250	15–19	66.29–290	1.1	-
Water hyacinth	800	-	295.5–329.5	13.6	32
Rice Husk	-	-	-	-	-
Sisal	700–1330	9–20	400–700	3.64–13	56–230
Flax	1500	27.6–80	345–1500	1.2–2.7	7
Banana	1350	27–32	711–779	2.5–3.7	-
Hemp	1140–1470	30–70	690–920	16	8–9
Kenaf	1040	136	1000	-	307
Pine	813	-	61.65	10.68	-
Barley	870	-	-	-	400
Wheat	868	-	-	-	280–350

Polypropylene strips (PPS) (Fig. 4) belong to the class of synthetic fibres. According to Gupta et al (2012) PPS often identified as polypropene strips, belongs to the class of thermoplastic polymers which have common usage in packaging and other fields.

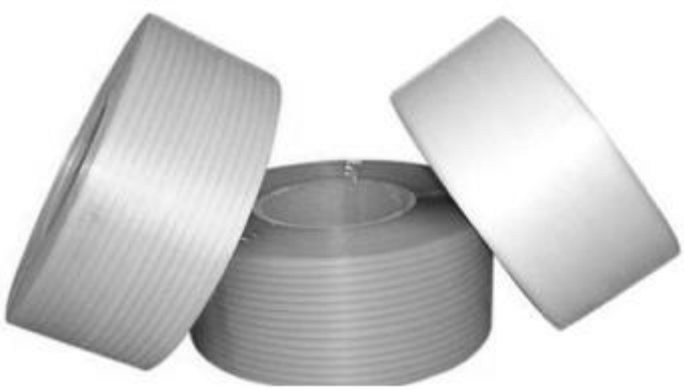

Fig. 4; Typical polypropylene strips

Fig. 5; Typical polypropylene fibre (Rawat and Gayan, 2018)

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Global market reported that the production of polypropylene since 2013 stands at 55 million tonnes (Gupta et al, 2017). In synthetic fibres, polypropylene is the world's second widely available product after polyethylene. Chemically, polypropylene is denoted as C_3H_6. The benefits of PP or PPS include some physical properties such as its lightness, with a density of 0.91 gm/cm³. It has an average diameter of approximately 0.034 mm and average length of 12 mm. The excellent chemical properties include its hydrophilic properties, chemical resistance to alkalis and acids and low thermal conductivity in comparison to other fibres. Its disadvantages are low melting temperature and high creeping rate (Gupta et al, 2017). PPS have many applications and it is recently used in reinforcing soils.

According to Rawat et al (2018), the inclusion of fibres causes an increase in peak shear strength and reduction in the loss of post-peak stress. He opined that the graphical relation of shear to amount of fibre is linear to some point, then approaches an asymptotic upper limit governed essentially by confining stress and fibre aspect ratio. Besides increasing the shear strength, inclusion of fibres sometimes change the stress–strain behavior from strain softening to strain hardening. He outlined the benefits of using fibres in soil reinforcement as follows: prevention of the formation of the tensile cracks, increment in hydraulic conductivity and liquefaction strength, reduction of the thermal conductivity of building materials, decrement of the density of building materials, elimination of the high potency of expansive soils to alternate swelling and shrinkage, and reduction of soil brittleness. Past literatures show that using natural and/or synthetic fibres in geotechnical engineering is applicable in six major fields including pavement layers (road construction), retaining walls, earthquake engineering, railway embankments, protection of slopes; and soil-foundation engineering. Some of the literatures reviewed are as follows

Rahman and Gayan (2018) stabilised soil with polypropylene strip and observed an increase in unconfined compressive strength from the initial values of 43.87% and 258.70% at 0.10% and 0.20% PPS respectively.

Sharma et al (2012) observed that to have less wear in fibre reinforced composite, the fibre content should be 60% in the composite.

Rawat et al (2018) opined that research on the use of fibres with cohesive soils has been more limited. Further research in this area is necessary especially with the use of chemical binders. This is necessary because chemical binders have the propensity of reduction of the brittleness factor of composite soil through the stability of the soil and improvement of its ductility.

Kalita et al (2016) stabilised poor soil with one synthetic fibre (glass fibre), one natural fibre (coconut coir) and waste cement bag. They carried out unconfined compressive strength (UCS) tests and undrained shear strength (USS) tests on the stabilised soils and discovered that 1% waste cement bag impacted most strength on the soil.

Based on the findings of previous researchers and shortcomings in the research on soil reinforcement using natural fibres, the objective of the study is to examine the properties of two lateritic soils stabilised with two fibres, a natural and a synthetic fibre in order to examine how the interaction between fibre properties and quantities affect the UCS of the reinforced composite. The inclusion of fibres is usually more effective in enhancing the tensile properties of soil-cement. However, the absence of proper tensile test facility affected this decision but based on the work of past researchers who tested UCS, the results would be examined in line with their findings.

2. MATERIALS AND METHODS

Sections 2.1 and 2.2 shows the materials used in the research work and the methods adopted respectively.

2.1 Materials

The materials used for this work are two tropical laterites, two fibres (sisal fibre and polypropylene strips) and cement. Two tropical laterites obtained from two different locations were used in the study. The soil samples were gotten from Okpuno and Nawfia in Enugu and Anambra states of Nigeria respectively. These locations were chosen because they have large stock of borrow pits. The samples were collected as disturbed soils samples, kept safe and dry in polythene bags and transferred to the Geotechnics laboratory of Nnamdi Azikiwe University for tests. LAT 1 is for Okpuno sample and LAT 2 is for Nawfia sample. Okpuno is located on Latitude 6^0 13^1 22^{11}N and longitude 7^0 3^1 13^{11}E while Nawfia is located on latitude 6^0 12^{11} 22^{11}N and longitude 7^0 1^{11} 33^{11}E. The fibres were gotten from the market. PPS has force at peak of 75.051N, elongation at peak of 1.781mm, tensile strength of 0.56495 kN/mm², elongation at peak of 17.811%, area of 0.133mm² and guage length of 10mm. There was no evidence of tensile tests on the sisal fibre as this work was drawn from an undergraduate project work. The cement brand used is one of the popular Portland Limestone Cement (PLC) brands available in Nigeria. Specifically, the cement brand is Dangote 42.5R cement.

2.2 Methods

Index property tests were carried out on the natural (unstabilised) soils according to BS 1377-2:1990 to classify the soils. Compaction energy tests were carried out for both stabilised and unstabilised soils according to BS 1377-4:1990 for British Standard Heavy and British Standard light compaction methods and according to Ola (1987) for West African Standard method. The three compaction energies enumerated above were used to examine the properties of the natural soil. The British Standard Light (BSL) an equivalent of Standard Proctor method involves the compaction of the soil in three (3) equal layers while giving each layer 27 blows of 2.5kg rammer that falls through a height of 3048mm. British Standard Heavy (BSH) an equivalent of Modified Proctor method involves the compaction of the soil in five (5) equal layers using a 4.5kg rammer that gives 27 blows to each of the layers. West African Standard (WAS) method involves the compaction of the soil in five (5) equal layers with 4.5kg rammer that gives 10 blows to each of the soil. The compaction characteristics of the cement-modified soil randonmly reinforced with sisal and polypropylene fibres were examined using only BSL method test results. BSL only was adopted because the paper was drawn out of undergraduate project work and these work usually have a very limited time to accomplish. Therefore, including many tests many stretch the time available for the students beyond acceptable range. UCS tests was also carried out on both unstabilised and modified/reinforced soils according to BS 1377-7:1990. Even though split tensile test may have been more appropriate when dealing with fibres, the unavailability of the necessary equipment for the test and the time available for the tests affected the decision. However, it is possible to correlate the relationship between compressive and tensile strengths of cement-modified-fibre-reinforced soils. Owing to afore-mentioned reasons, the findings in this research work is limited. However, they can be aid for further research in the field.

3. RESULTS AND DISCUSSION

Soil classification was done according to American Association of State Transportation and Highway Officials (AASHTO) method and USCS (Unified Soil Classification System). The results of the index properties show that LAT 1 and LAT 2 belong to soil group A-2-4(0). Based on USCS, both soils belong to SC – sandy clay. This is as shown in Table 3 below.

Table 3: Index properties of the lateritic soils

Samples / Index properties of natural soil	LAT 1	LAT 2
Natural moisture content (%)	8.2	10.2
Fines content (%)	25.36	24.13
Sand content (%)	74.64	75.87
Gravel content (%)	Nil	Nil
% Retained on No. 40 sieve (0.425mm)	27.41	31.78
C_u	Nil	Nil
D_{10}	Nil	Nil
D_{50}	0.21	0.2
Specific gravity	2.6	2.6
Liquid limit (%)	33	32
Plastic limit (%)	22	21.3

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Plasticity Index (%)	11	10.7
Maximum dry unit weight (kN/m³)	18.7	17.2
Optimum moisture content (%)	13	15
Colour	Reddish brown	Reddish brown
AASHTO	A-2-4(0)	A-2-4(0)
Subgrade rating	Excellent - good	Excellent - good
USCS	SC- clayey sand	SC- clayey sand

The fines content (that is the percentage of the soil finer than 75µm) of all the samples are less than 35%. Soil description guide by Federal Ministry of Works and Housing, Nigeria (1997) opines that samples having percentage of particles finer than 75µm and less than 35% can be used as sub-base course and base course materials in road construction (Bello and Adegoke, 2010). Thus, it is expected that the two soil samples would be suitable for pavement material since they fall into this category even though these two are not the only quality criterion. Due to increasing pressure of vehicles on roads as a result of rate of growth of vehicular movement, the strength of natural soils are most times no longer adequate to sustain the roads for the design period. Constant reconstruction and maintenance continues to deplete scarce soil resources. It is necessary that natural soils should be improved with sustainable materials that can help it sustain loads longer. Fibres have been found useful in this situation. The discussion of the results would show the effect of sisal (natural fibre) and PPS (synthetic fibre) on the dry density and moisture content behaviour of natural laterite stabilized with 3% cement. Generally, soil type, properties and state affects their relation to reinforcement (Babu, n.d.). The discussion is seeking to understand how the two fibres perform on the same state and what could constitute the differences observed.

3.1. Effect of increasing strip content on cement-stabilised soil

Figs. 6 to 8 shows the effect of increasing fibre content on LAT 1 and LAT 2.

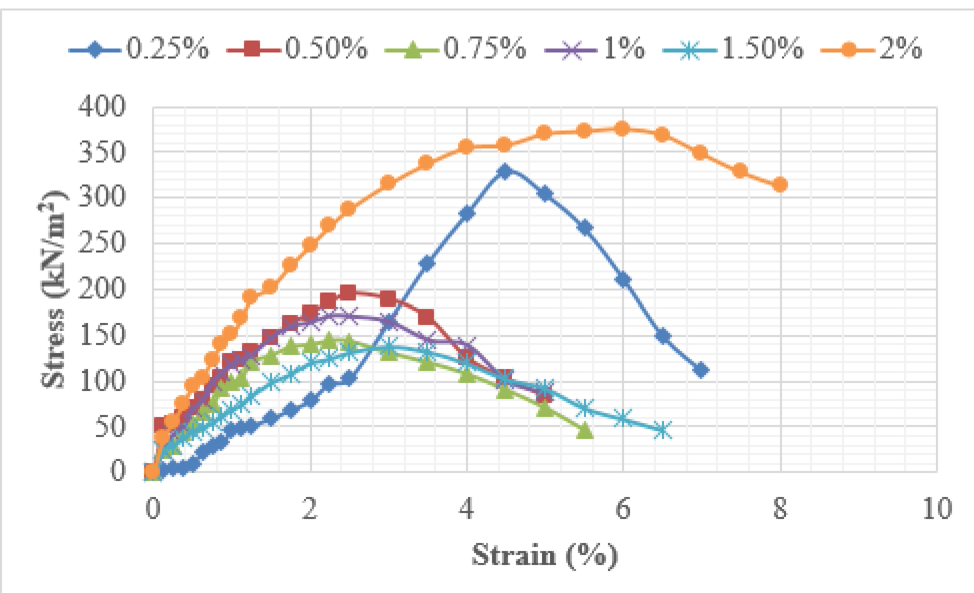

Fig. 6. Stress-Strain curve for sisal fibre with LAT 1

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The maximum UCS was achieved with 2% fibre. The value of the stress fall between 350 and 400 kN/m². This shows that increasing the sisal fibre in soil increases its strength. Since our limit is 2%, we do not yet know the optimum fibre content and it is necessary to study it beyond 2% to obtain the optimum fibre content.

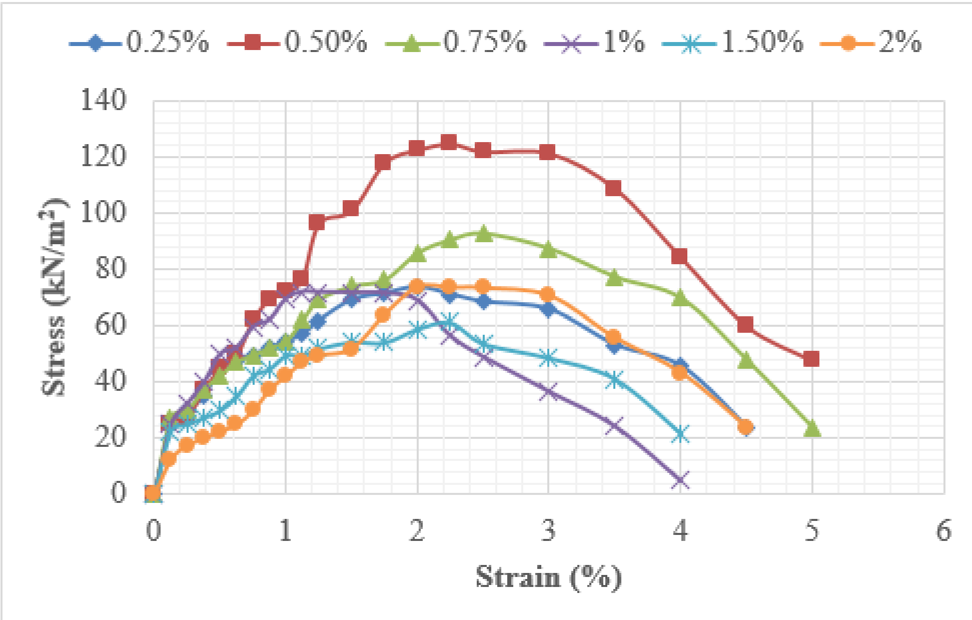

Fig. 7. Stress-Strain curve for PPS with LAT 1

The maximum UCS was achieved with 0.5% fibre even though fibre content was increased up to 2%. The value of the stress fall between 120 and 140 kN/m². This is in line with the findings of (Remya and Varghese, 2016; Gupta et al 2017) who shows that strength gain reverses at higher amounts of PPS. Malekzadeh and Bilsel (2012) Gupta et al (2017) also found out in their work that PPS increases ductile behaviour of soils due to the increment in the ratio of tensile strength to compressive strength of the soils.

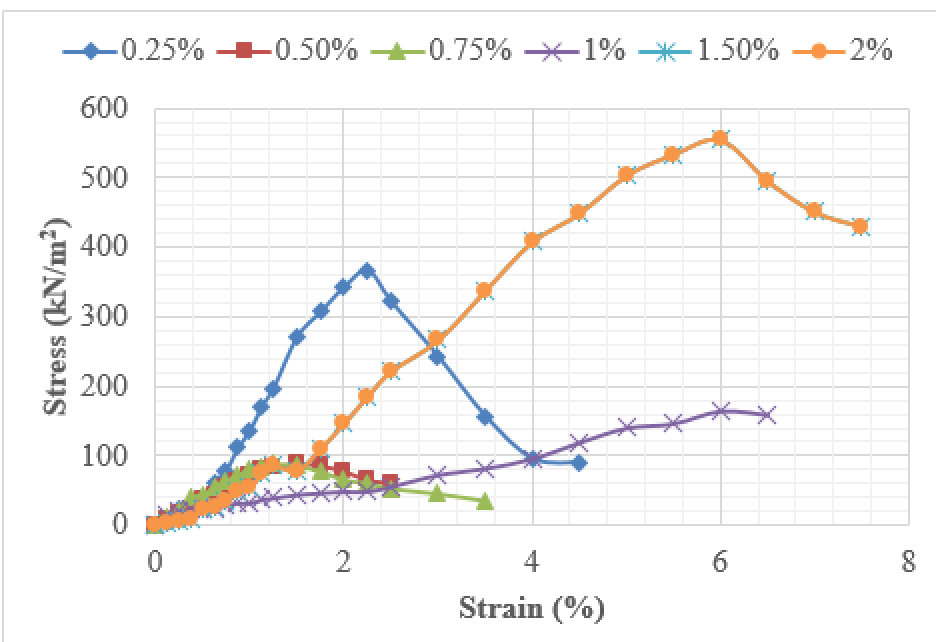

Fig. 8. Stress-Strain curve for sisal fibre with LAT 2

The maximum UCS was achieved in Fig. 8 at 2% sisal fibre and the value falls between 500 and 600 kN/m². The value obtained here is more than the value obtained when using the same fibre on LAT 1. Since the percentage of cement used here is the same as that used in LAT 1 (Fig. 6), the differences in values obtained could be attributed to the differences in the properties of the two soils.

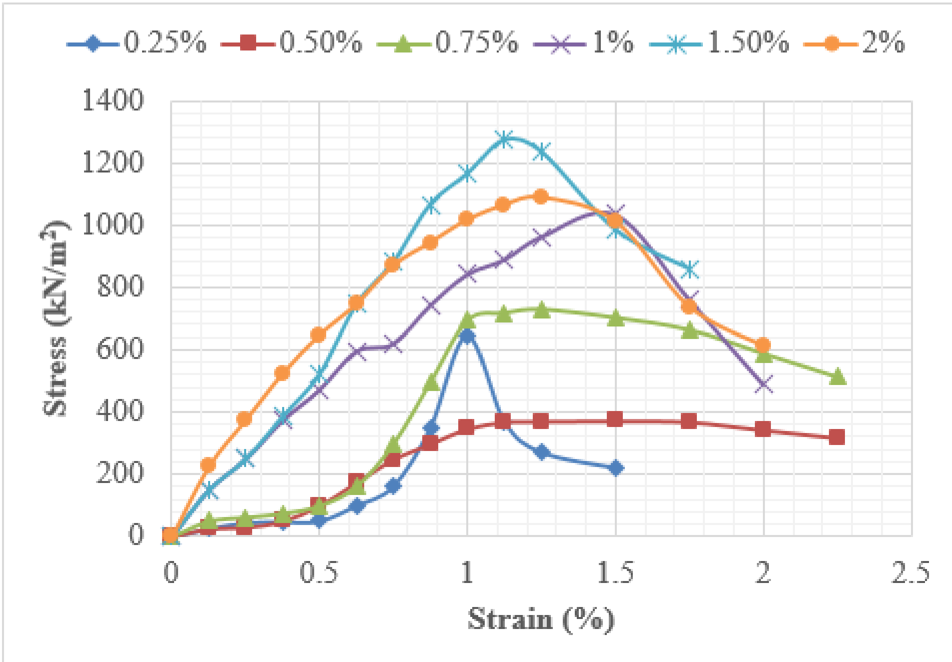

Fig. 9. Stress-Strain curve for PPS with LAT 2

The maximum UCS was achieved with 1.5% fibre even though fibre content was increased up to 2%. The value of the stress fall between 1200 and 1400 kN/m² about 900% increase from the value in Fig. 7. This is quite different from the trend observed in Fig. 7 even though the soils were modified with the same percentage of cement before incorporating fibre. This show that there must be an inherent property of soil affecting the performance of fibres. Since fibres does not interfere with the soil mineral composition but its fabric, it is important to know how soil fabric affect the behaviour of fibres.

3.2 Comparison of reinforcement with different fibres

The behaviour of the stress-strain curve of the soil samples at different states was examined with the Figures 10 to 21 below. The states include: unstabilised, modified at 3% cement, reinforced at various percentages of fibre only, modified with 3% cement plus various percentages of fibre.

3.2.1 Comparison of modified soils reinforced with different fibres for LAT 1

Figs. 10 to 15 shows the comparison of different states of LAT 1. The states are unstabilised, modified with 3% cement only, reinforced with PPS only (0.25, 0.5, 0.75, 1, 1.5, 2), reinforced with sisal only (0.25, 0.5, 0.75, 1, 1.5, 2), modified with 3% cement + PPS only (0.25, 0.5, 0.75, 1, 1.5, 2), modified with 3% cement + sisal only (0.25, 0.5, 0.75, 1, 1.5, 2). The values of maximum UCS values observed in each case are summarized in Table 4.

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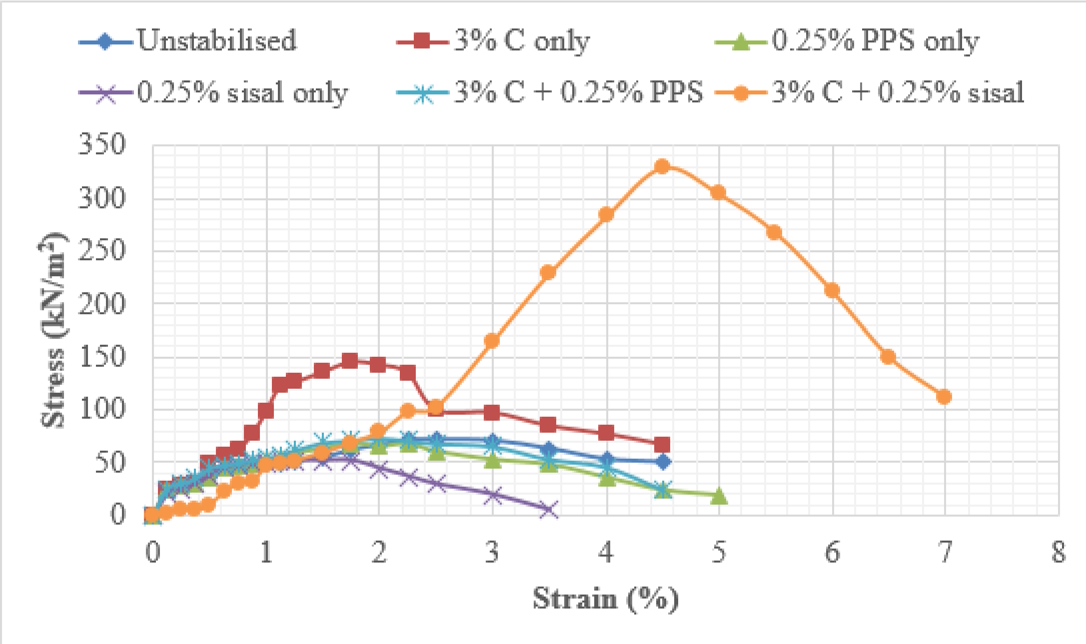

Fig. 10. Stress-Strain curve of LAT 1 reinforced with 0.25% sisal and PPS

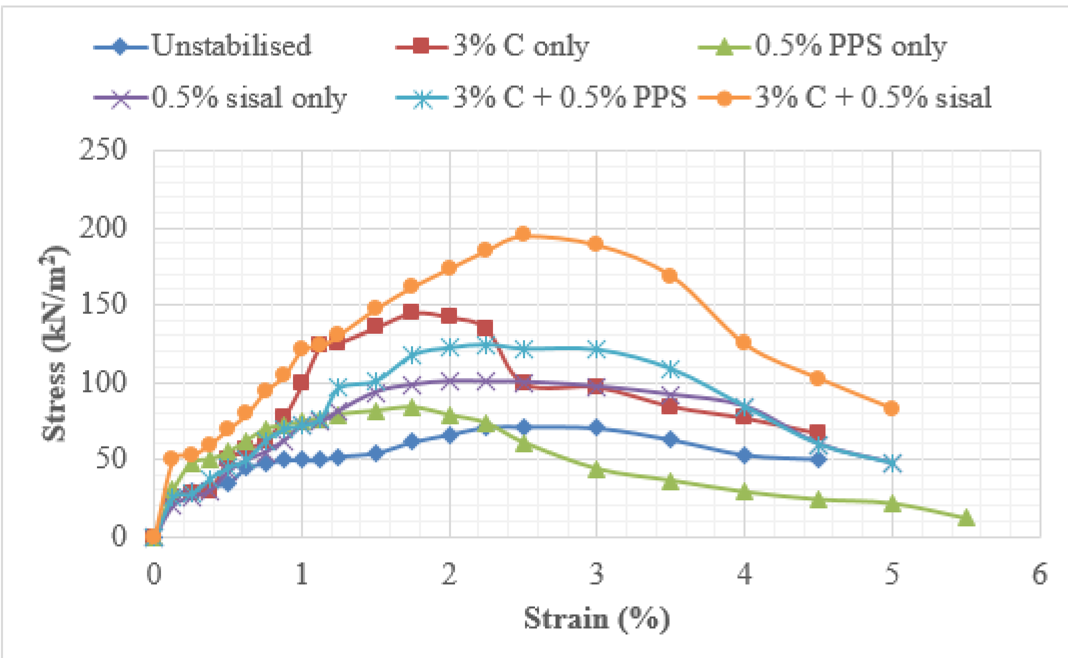

Fig. 11. Stress-Strain curve of LAT 1 reinforced with 0.5% sisal and PPS

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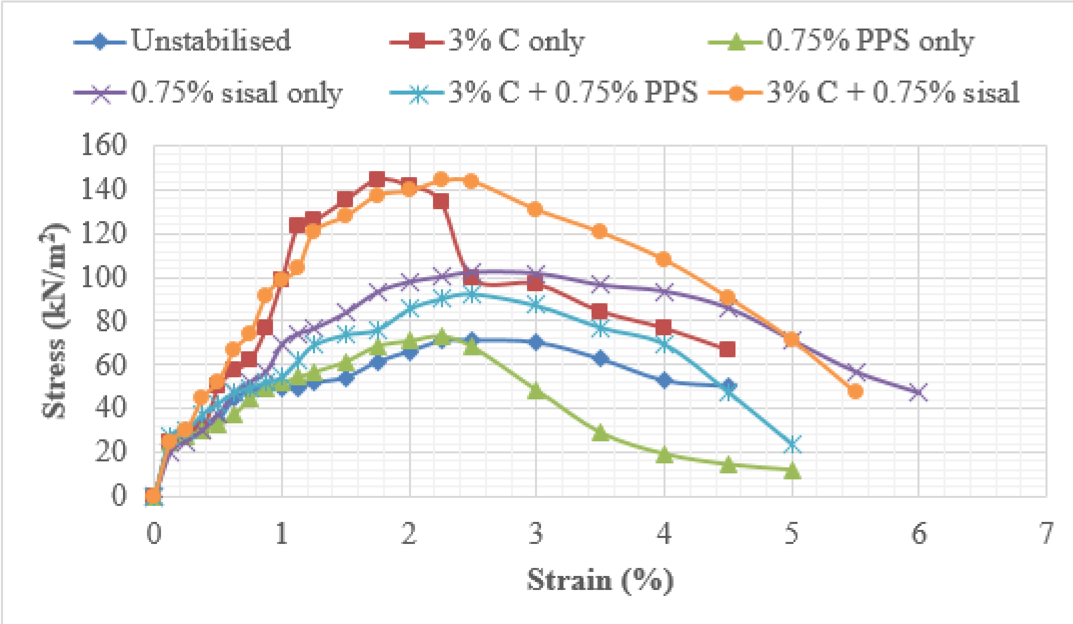

Fig. 12. Stress-Strain curve of LAT 1 reinforced with 0.75% sisal and PPS

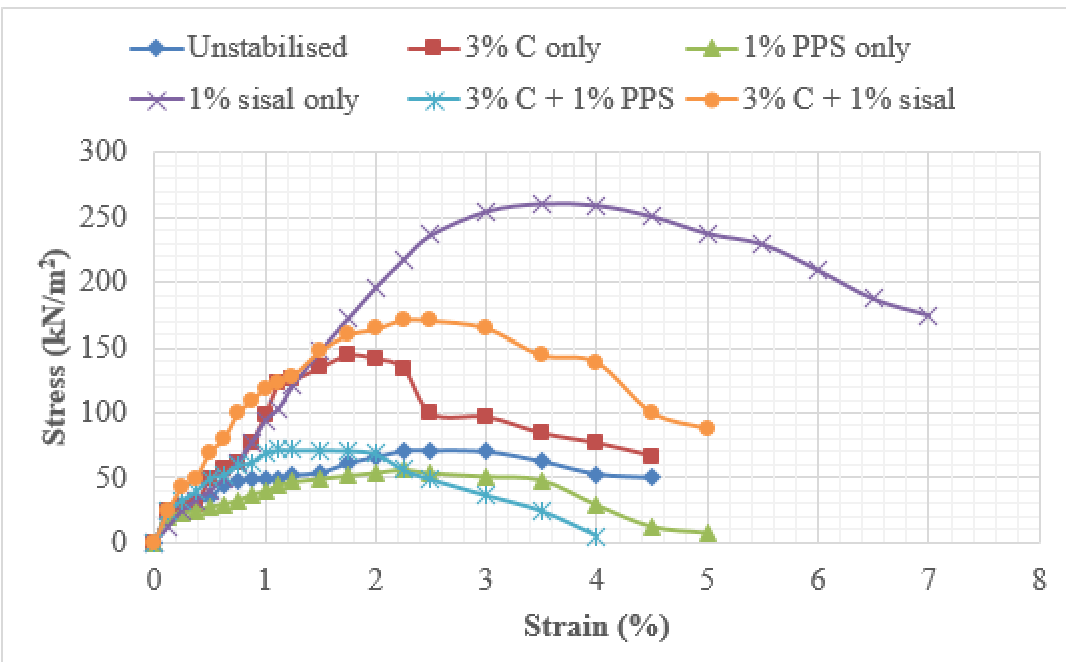

Fig. 13. Stress-Strain curve of LAT 1 reinforced with 1% sisal and PPS

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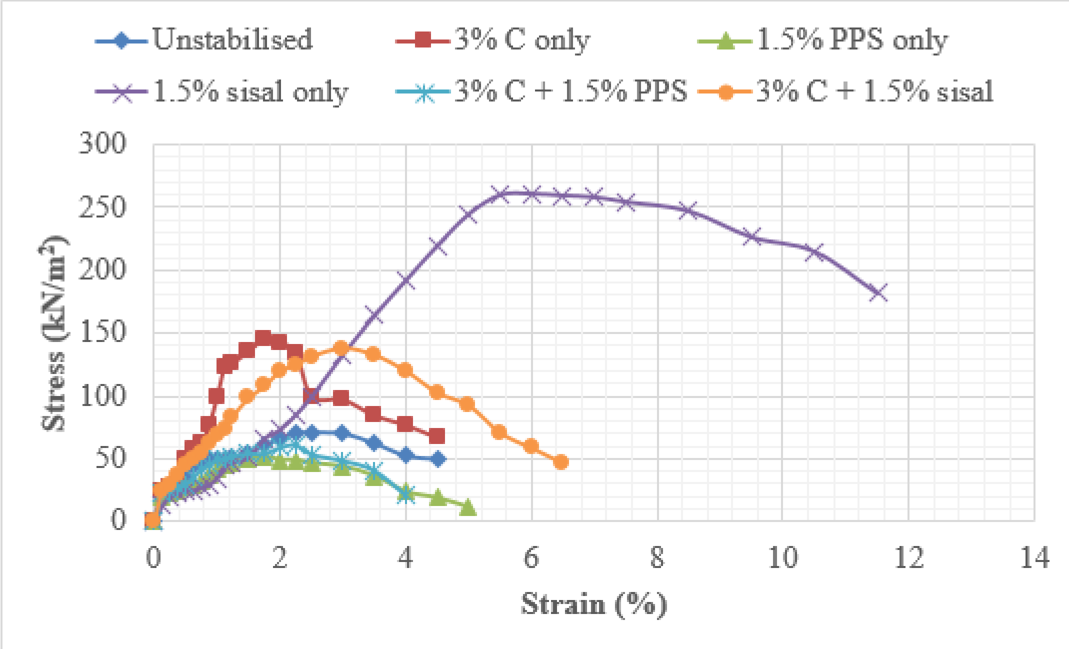

Fig. 14. Stress-Strain curve of LAT 1 reinforced with 1.5% sisal and PPS

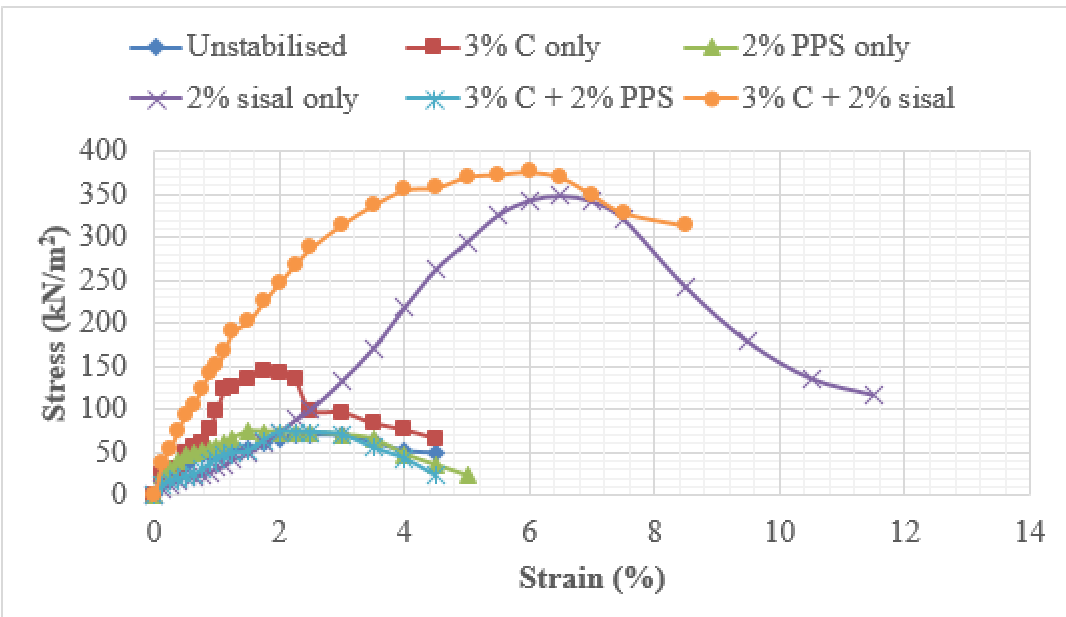

Fig. 15. Stress-Strain curve of LAT 1 reinforced with 2% sisal and PPS

In each of the Figs above, maximum UCS was obtained while reinforcing with sisal fibre alone or modifying with cement before reinforcing with sisal fibre. At 0.25%, 0.5% and 0.75% sisal fibre, better results were obtained when the soils were modified with 3% cement before adding fibre. At 2% sisal fibre, better results were obtained when the soil was modified with 3% cement before incorporating fibre. Sisal fibre would not be beneficial when used together with cement at higher fibre percentages. It is better to use sisal fibre in conjuction with 3% cement to modify soils at 0.25% fibre or less. However, to ensure improvement in the compressive strength of the reinforced soil, more cement may be required to stabilize the soils before the addition of fibres.

Table 4; Summary of maximum UCS of LAT 1 in different states

Fibre content (%)	Maximum UCS (kN/m²)					
	Unstabilised	+3% C	PPS only	Sisal only	PPS +3% C	Sisal + 3% C
0.25	72	146	68	52	74	333
0.5			84	100	126	196
0.75			74	104	94	144
1			56	260	72	172
1.5			52	260	62	136
2			75	350	74	380

3.2.2 Comparison of reinforcement with different fibres for LAT 2

Figs. 16 to 21 shows the comparison of different states of LAT 2. The states are unstabilised, modified with 3% cement only, reinforced with PPS only (0.25, 0.5, 0.75, 1, 1.5, 2), reinforced with sisal only (0.25, 0.5, 0.75, 1, 1.5, 2), modified with 3% cement + PPS only (0.25, 0.5, 0.75, 1, 1.5, 2), modified with 3% cement + sisal only (0.25, 0.5, 0.75, 1, 1.5, 2). The values of maximum UCS values observed in each case are summarized in Table 5.

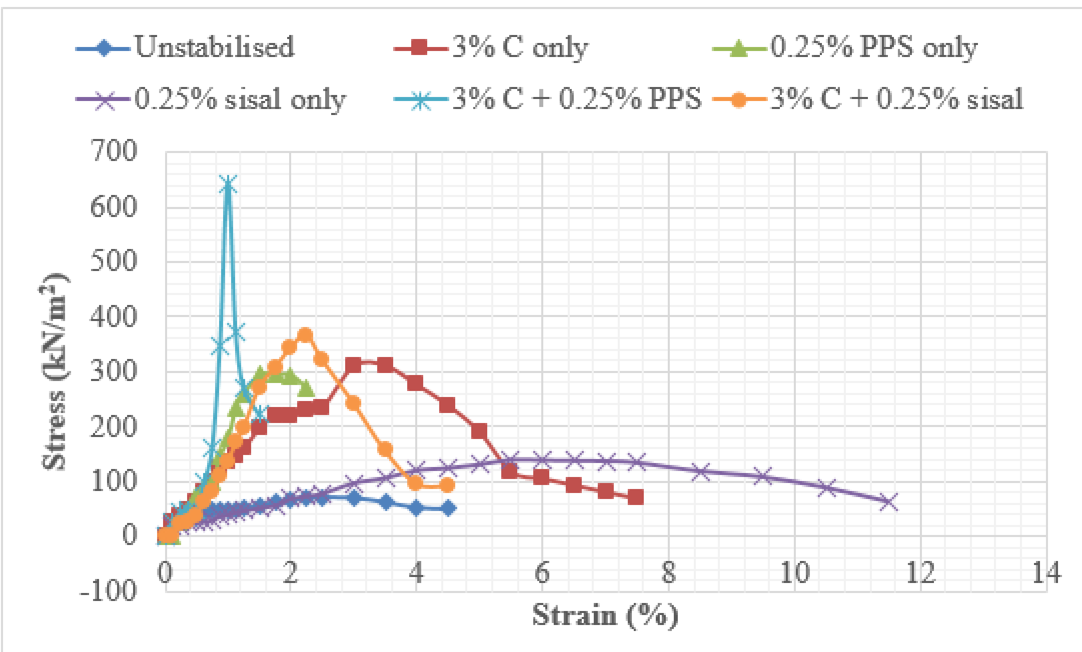

Fig. 16. Stress-Strain curve of LAT 2 modified with 0.25% sisal and PPS

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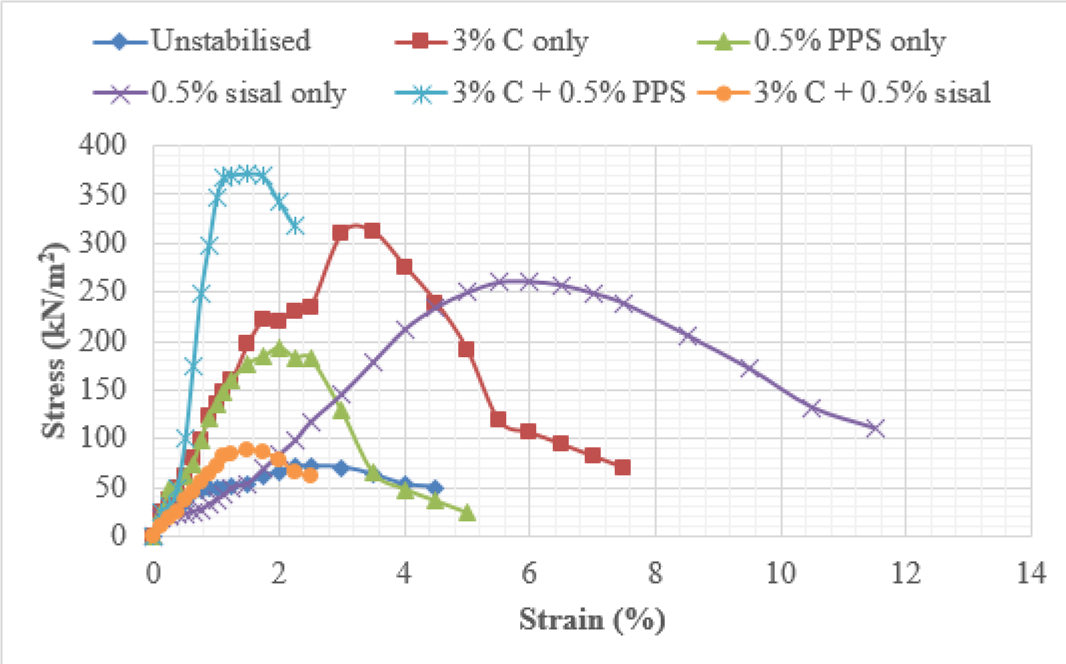

Fig. 17. Stress-Strain curve of LAT 2 modified with 0.5% sisal and PPS

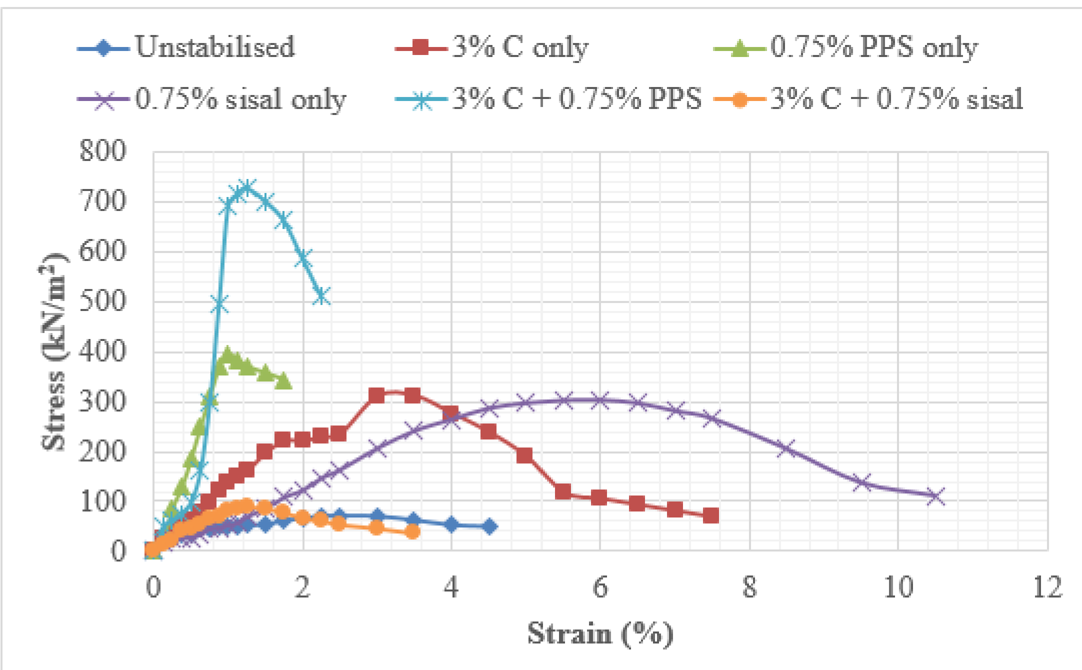

Fig. 18. Stress-Strain curve of LAT 2 modified with 0.75% sisal and PPS

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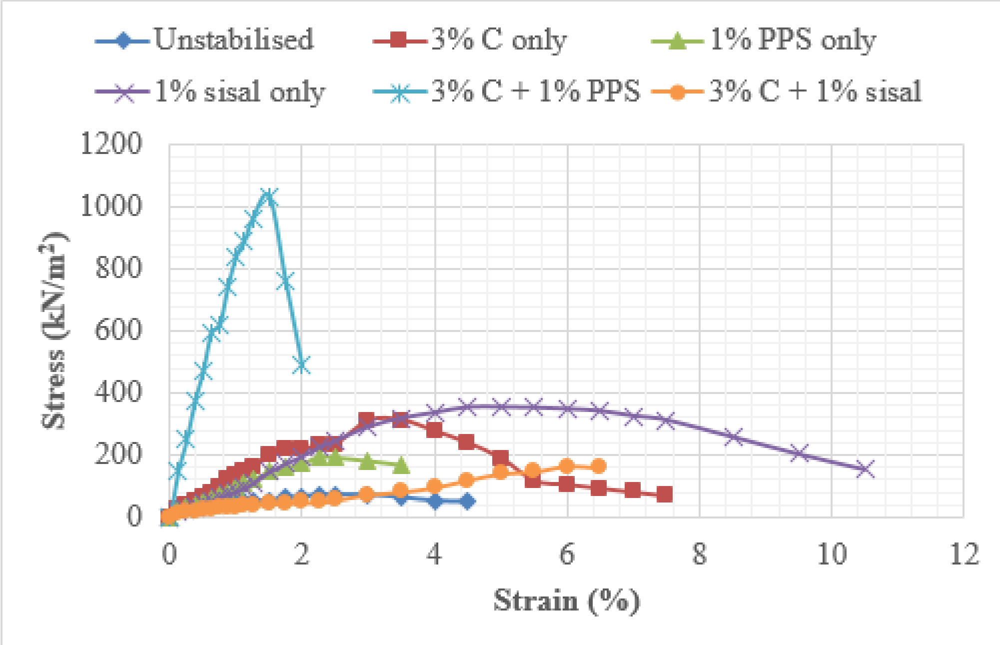

Fig. 19. Stress-Strain curve of LAT 2 modified with 1% sisal and PPS

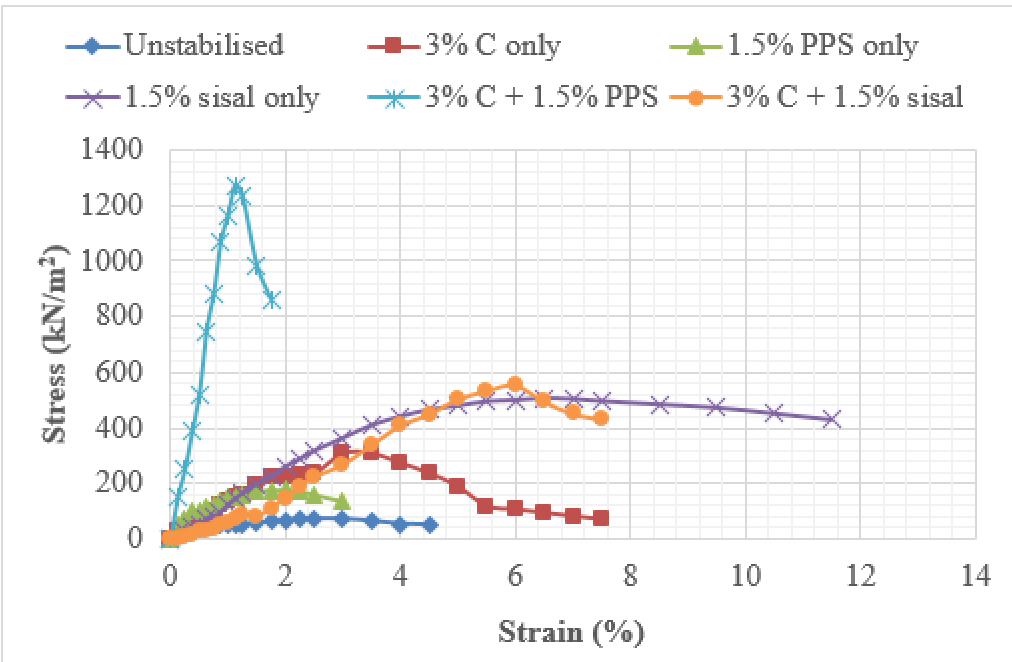

Fig. 20. Stress-Strain curve of LAT 2 modified with 1.5% sisal and PPS

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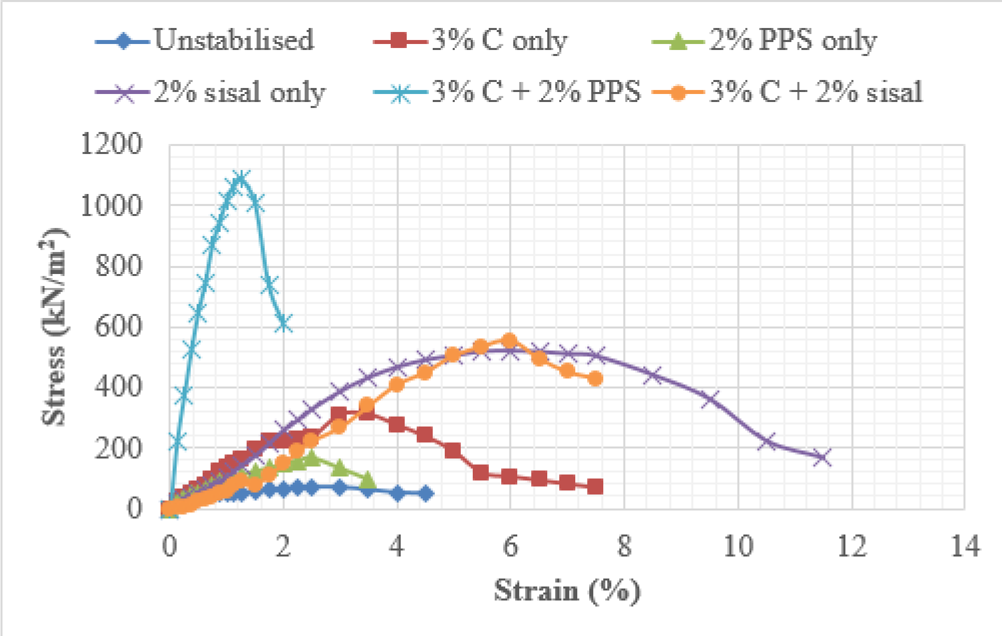

Fig. 21. Stress-Strain curve of LAT 2 modified with 2% sisal and PPS

Table 5; Summary of maximum UCS of LAT 2 in different states

Fibre content (%)	Maximum UCS (kN/m²)					
	Unstabilised	+3% C	PPS only	Sisal only	PP +3% C	Sisal + 3% C
0.25	72	315	300	140	642	355
0.5			195	260	370	90
0.75			390	305	730	85
1			195	350	1040	168
1.5			175	520	1280	560
2			170	520	1100	560

The results of the findings here does not agree with the work of Correia et al (2015) who observed in their work that increase in binder content increases the stiffness and compressive strength of the soft soil used in the work but have lower effect on the specimen reinforced with fibres (PPS). According to them, addition of a low quantity of fibres to the stabilised soft soil originates a decrease in the stiffness, compressive and direct tensile strength, a reduction of the loss of strength after peak and a change in behaviour, from brittle to more ductile. The deviation may be attributable to the nature of the soil or fibre materials used. Contrary to the findings of Correia et al (2015) that addition of fibres increases compressive strength, maximum UCS was achieved when the soil was modified with 3% cement and reinforced with varying percentages of fibre. These irregular properties could be attributed to the type of soil, quantity of modifier, mechanism of fibre inclusion and quantity of fibre as this same trend was not observed in LAT 1.

3.3 Analysis of variance (ANOVA) on maximum unconfined compressive strength (UCS)

ANOVA was carried out to examine the influence of fibre addition on the maximum UCS of the soils.

Table 6; ANOVA on Sample 1 without addition of cement

Source of Variation	df	F	P-value	F crit
UCS	5	0.85342	0.566921166	5.050329058
Fibre content	1	5.61953	0.063908742	6.607890974

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The P-value is not significant at 95% confidence level because the value is more than 0.05. This shows that the variation of fibre content does not have much effect on the UCS of the soil.

Table 7; ANOVA on Sample 1 with addition of 3% cement

Source of Variation	df	F	P-value	F crit
UCS	5	0.86403	0.56175	5.05033
Fibre content	1	10.1447	0.0244	6.60789

The P-value is significant at 95% confidence level since the value is less than 0.05. This shows that the variation of fibre content have effect on the UCS of the soil stabilized with 3% cement.

Table 8; ANOVA on Sample 2 without addition of cement

Source of Variation	df	F	P-value	F crit
UCS	5	0.32809	0.87666088	5.050329058
Fibre content	1	1.64228	0.256223424	6.607890974

The P-value is not significant at 95% confidence level because the value is more than 0.05. This shows that the variation of fibre content does not have much effect on the UCS of the unstabilized soil.

Table 9; ANOVA on Sample 2 with addition of cement

Source of Variation	df	F	P-value	F crit
UCS	5	4.76347	0.0559	5.05033
Fibre content	1	32.8751	0.00226	6.60789

The P-value is significant at 95% confidence level since the value is less than 0.05. This shows that the variation of fibre content have effect on the UCS of the soil modified with 3% cement.

From the ANOVA analysis, it was observed that the response of fibre addition in the soils would be significant when the soils are first modified with 3% cement.

4. CONCLUSION

Gowthaman et al, (2018) argued in their work that natural fibres would be better in reinforcing soils because of the potentials of natural fibres in biochemical transformation of soils. Addition of sisal fibre usually improves the ability of soil to be plastically deformed without fracture. However, this addition does not usually improve the compressive strength of the soil. This trend was observed in both LAT 1 and LAT 2 because of the nature of post-peak stress-strain curve. The behaviour of PPS with soil on the other hand was observed to be irregular. In LAT 1, the compressive strength of PPS with the soil was very low, but in LAT 2, there was significant improvement in compressive strength accompanied by high brittle failure. This could be attributed to the nature of the soil. Babu ('n.d.') said that the dimensions of the reinforcement are very important in fibre addition to soil and the length, thickness and diameter, should be obtained and optimized for soil reinforcement. Besides these, the location, spacing and orientation of fibres in the soil also affect the behaviour of the reinforced soil and it is better that the reinforcement is placed in the direction of the tensile strains. The fibres used in this study were randomly distributed and would definitely have effect on the soil strength. From the analysis, it can be deduced that soil properties influences the performance of fibres. While PPS performed poorly with LAT 1, it performed very well with LAT 2. PPS does not perform well in ordinary state but when combined with cement, it increases the UCS of the soil significantly but develops high brittleness as well. Sisal have high ductile properties even in the presence of cement. It is necessary to determine the soil properties that influence the performance of these fibres to know where and when to use them. It would be expedient, too, to study how the two fibres would perform when combined together in one mix.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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