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Strength and Durability Study on Banana Fibre Reinforced Lime Stabilized Kuttanad Soil

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Abstract: Soft soils can be improved with reinforcement in the form of randomly distributed fibers of natural and synthetic types. In Alappuzha district in Kerala, the soil is very weak and plantain tree trunks are used conventionally inorder to improve the soil. In this context, a detailed study is undertaken to investigate the strength behaviour of the soil reinforced with randomly included banana fibres. The samples were reinforced with untreated and rubber coated banana fibres. The optimum percentage of fibres was added to soil in addition with lime also. The banana fibre reinforced soil samples are then subjected to compaction tests and unconfined compressive strength tests to study its strength behaviour. Tests were also done to study the effect of alkaline medium (calcium hydroxide) and fresh water on the durability of untreated and rubber coated banana fibres.

Keywords: Banana fibre, Kuttanad soil, unconfined compression test, rubber coated, durability.

I. INTRODUCTION

Soil has been used as a construction material from time immortal. Being poor in mechanical properties, it has been putting challenges to civil engineers to improve its properties depending upon the requirement which varies from site to site. Works done on strength-deformation behaviour of fibre reinforced soil states that, there are improvements like greater extensibility, small loss of post peak strength, isotropy in strength and absence of planes of weakness. Fibre reinforced soil has been used in many countries in the recent past and further research is in progress for many hidden aspects of it.

Reinforced soil is a set of theories, principles and application methods and it is one of the branches of geotechnical science to stabilize and improve soil engineering properties such as strength, hardness and deformability. Reinforced soils can be obtained by either incorporating continuous reinforcement inclusions (e.g., sheet, strip or bar) within a soil mass in a defined pattern (i.e., systematically reinforced soils) or mixing discrete fibres varyingly within a soil fill (i.e., varyingly reinforced soils). In comparison with systematically reinforced soils, varyingly distributed fibre reinforced soils exhibit some advantages that they can be easily prepared by simply adding the fibres much like cement, lime or other additives. Also the randomly distributed fibres offer strength isotropy and limit the potential planes of weakness that can develop parallel to oriented reinforcement. The main advantages of using natural fibres as reinforcing elements are they are locally available and are very cheap. They are biodegradable and hence do not create disposal problem in environment. Processing of these materials into a usable form is an employment generation activity in rural areas of these countries. If these materials are used effectively, the rural economy can get uplift and also the cost of construction can be reduced, if the material use leads to beneficial effects in engineering construction.

In Alappuzha district, most of the low lying areas mainly in Kuttanad Taluk, plantain tree trunks are used to reinforce the soil. In this context a detailed investigation is carried out to study the effect of banana fibre as a reinforcement material in Kuttanad soil. The study is intended to investigate the strength behaviour of the soil reinforced with random inclusions of banana fibres.

Surface modification (rubber coating) was given to the natural banana fibres inorder to improve its moisture resistance and tensile strength. Also the optimum percentage of untreated and bitumen coated fibres were added to soil in addition with lime. The samples were reinforced with both untreated and rubber coated banana fibres.

The strength characteristics of reinforced soil samples were determined by conducting a series of compaction tests and unconfined compression tests. Durability study was also carried out to study the effect of alkaline medium (calcium hydroxide) and fresh water on the durability of untreated and rubber coated banana fibres.

II. EXPERIMENTAL PROGRAMME

A detailed experimental study was undertaken to determine the strength and durability characteristics of Kuttanad soil reinforced with untreated and rubber coated banana fibres.

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A. Materials used

The materials used for the study are Kuttanad soil, raw banana fibres, rubber latex and lime.

The soil used for the study is collected from Kuttanad region in Alappuzha district. The soil was partially air dried before the commencement of the experiments. The properties of the soil are shown in Table I.

Natural rubber is chemically modified in order to improve their workability. The fibres were coated with rubber latex and kept for air drying under shade. The properties of rubber used for the present study are given in Table II.

The banana fibres were air dried to remove the moisture from it. The fibres used for the study is shown in Fig. 1 and the properties of banana fibres are given in Table III.

The lime used for the study was locally available and the properties of which are given in Table IV.

Untreated fibres   Rubber coated fibres

Fig. 1 Banana fibres used in the study

TABLE I. PROPERTIES OF SOIL

Properties	Results
Clay content (%)	30
Silt content (%)	70
Liquid limit (%)	66
Plastic limit (%)	38
Plasticity index (%)	28
Optimum Moisture Content (%)	29
Maximum dry density (kN/m^3)	12.6
Unconfined compressive strength (kN/m^2)	34.01

TABLE II. PROPERTIES OF RUBBER

Chemicals	Amount (%)
ZDC	6g/kg
ZMDT	6g/kg
Antioxidant (TQ)	6g/kg
RGS powder	22g/kg
Zinc oxide	22g/kg
Dispersal fluid	6g/kg

TABLE III. PROPERTIES OF BANANA FIBRES

Properties	Untreated fibres	Rubber coated fibres
Average diameter (mm)	0.5	0.6
Average tensile strength (N/mm^2)	11	19.08
Fibre density (g/cc)	0.62	0.93

TABLE IV. PROPERTIES OF LIME

Components	Amount (%)
Calcium hydroxide $Ca(OH)_2$	90
Silica	1.5
Ferric oxide	0.5
Magnesium oxide (MgO)	1
Alumina	0.2
Carbondioxide	3.0

B. Preparation of samples

The samples were prepared with banana fibres of 10, 20 and 30 mm length added in percentages of 0.25, 0.50, 0.75 and 1%. Samples were also prepared by mixing varying length of untreated and rubber coated fibres with soil. The soil was also reinforced with fibres in addition with lime.

C. Test performed

Unconfined compression tests were conducted on the prepared samples to study the strength and durability characteristics of banana fibres as reinforcing element. Water absorption test on banana fibres was also done. The tensile properties of fibres were determined after conducting durability studies. The various tests performed are explained below.

1) Water Absorption Test:

The water absorption capacity of the naturally dried fibres under study was established using the equation

$$W = \frac{P_h - P_d}{P_d}$$

in which W denotes the water absorbed and P_d and P_h, denote the weight of air-dried and soaked fibres in drinking water respectively. The measurements were carried out at specified intervals till the weight of soaked fibre became a constant.

2) Unconfined Compression Test:

The test was conducted in accordance with IS2720-Part 10. The samples were prepared at their corresponding maximum dry density and OMC.

3) Durability Test:

Durability studies on fibres were carried out by immersing the fibres in two different mediums, namely,(i) in clean and fresh water (pH = 7.0) and (ii) lime solution

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[$Ca(OH)_2$] and determining the changes in the chemical composition of fibre after a specified period. Fibres of random length were kept immersed in airtight containers containing the above mediums. At 24h time intervals, the fibres were taken out, washed with plenty of water and dried at room temperature and then replaced in the same bottle. This alternate wetting and drying operation were repeated for 30 cycles (i.e. for a total of 60 days), in order to evaluate the performance of fibres subjected to alternate wetting and drying cycles, separate set of fibres were kept continuously immersed up to 60 days in airtight containers. At the end of the above exposure period, the fibres were taken out and their tensile strength and the UCC of soil reinforced with these fibres was determined.

D. Results and discussions

1) Water absorption test on fibres:

The fibres immersed in water absorb water with time and it was found to be more during the commencement of immersion. As time passes, the absorption rate increases and becomes constant. Untreated fibres absorbed more than 300% of water after four days of immersion and that of rubber coated fibres is only around 70%. Fig.2 shows the water absorption curves for untreated and rubber coated fibres.

The moisture absorption capacity of banana fibres reduced when it is coated with water repellent rubber coating.

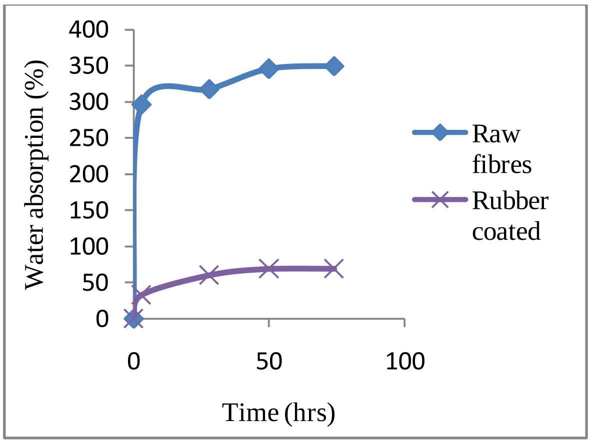

Fig 2. Water absorption curves for untreated and rubber coated fibres

Unconfined compression test

1) Unconfined Compressive Strength of untreated banana fibre of specific length reinforced soil:

The unconfined compressive strength of soil samples with different percentages of untreated banana fibres having specific length were calculated from the loads at failure and shown in Table V. The variation of UCS value of reinforced soil sample against fibre length and fibre content are plotted and shown in Fig.3 and Fig.4 respectively.

TABLE V. UNCONFINED COMPRESSIVE STRENGTH OF UNTREATED BANANA FIBRE REINFORCED SOIL

Mix particulars	Fibre length		
	1 cm	2 cm	3 cm
Soil+0% fibre	34.01	34.01	34.01
Soil+0.25% fibre	36.59	44.58	46.51
Soil+0.5% fibre	45.89	47.80	50.56
Soil+0.75% fibre	37.25	43.93	45.22
Soil+1% fibre	35.92	38.03	42.64

The Unconfined Compressive Strength value of banana fibre reinforced soil is highest at 0.5% fibre content. At this fibre content, UCS value increased by 1.3 times for 1 cm length, 1.4 times for 2 cm length and 1.5 times for 3 cm length. It is also observed that the UCS value of fibre reinforced soil increases with increase in fibre length. The increase in strength may be due to the shear transfer mechanism induced by the fibre inclusions.

2) Unconfined Compressive Strength of Untreated banana fibre reinforced soil:

The Unconfined Compressive Strength of soil samples with different percentages of untreated banana fibres of varying length were calculated from the loads at failure and shown in Table VI.

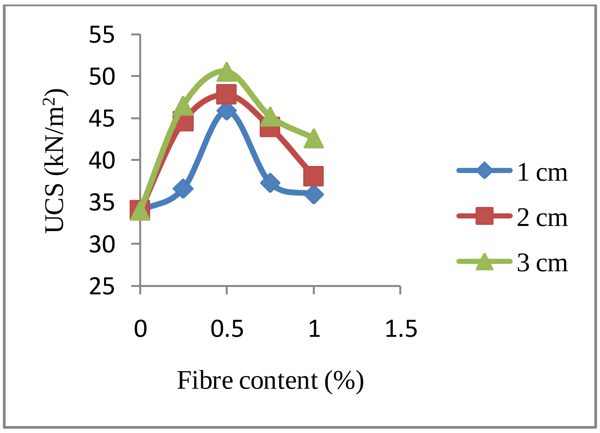

Fig. 3 Variation of UCS with fibre content

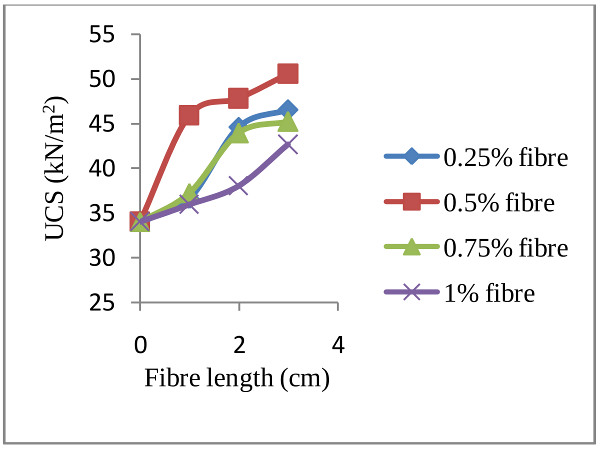

Fig. 4 Variation of UCS with fibre length

TABLE VI. UNCONFINED COMPRESSIVE STRENGTH OF UNTREATED BANANA FIBRE REINFORCED SOIL

Fibre content (%)	**0**	**0.25**	**0.5**	**0.75**	**1**
UCC(kN/m^2)	34.01	45.87	54.11	42.93	39.41
Improvement factor	-	1.35	1.59	1.40	1.16

3) Unconfined Compressive Strength of rubber coated banana fibre reinforced soil:

The Unconfined Compressive Strength of soil samples with different percentages of rubber coated banana fibres of varying length were calculated from the loads at failure and shown in Table VII.

TABLE VII. UNCONFINED COMPRESSIVE STRENGTH OF RUBBER COATED BANANA FIBRE REINFORCED SOIL

Fibre content (%)	**0**	**0.25**	**0.5**	**0.75**	**1**
UCS(kN/m^2)	34.01	52.32	63.29	57.91	51.68
Improvement factor	-	1.54	1.86	1.70	1.52

The unconfined compressive strength for samples reinforced with untreated and rubber coated fibres is observed to increase with increase in fibre content up to 0.5% after which it is seen to decrease with fibre content. At 0.5% fibre content, the unconfined compressive strength of rubber coated fibre reinforced soil sample shows an increased value by 17% compared with that of samples prepared with untreated fibres. Fig.5 shows the variation of improvement factor for untreated and rubber coated fibre reinforced samples at various fibre content.

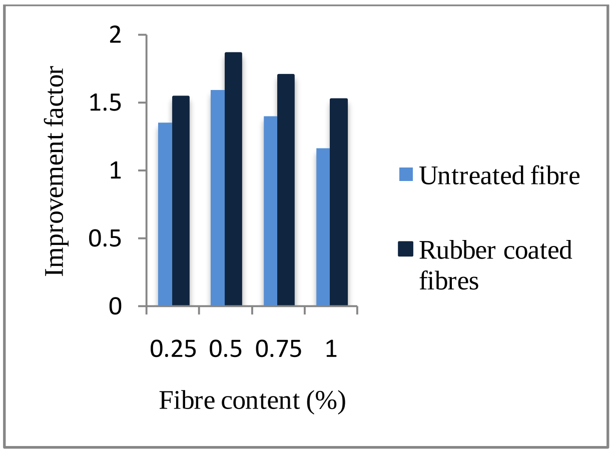

Fig.5 Variation of improvement factor with fibre content for untreated and rubber coated fibre reinforced samples

4) Unconfined Compressive Strength of Lime stabilized Soil:

The Unconfined Compressive Strength of soil samples with different percentages of lime were calculated from the loads at failure and shown in Table VIII.

TABLE VIII. UNCONFINED COMPRESSIVE STRENGTH OF LIME STABILIZED SOIL

Lime content (%)	**0**	**2**	**4**	**6**	**8**
UCC (kN/m^2)	34.01	66.46	77.63	87.04	79.98
Improve-ment factor	-	1.95	2.28	2.56	2.35

The unconfined compressive strength is observed to increase with increase in lime content up to 6% and then reduced for 8% lime content. At 6% lime, around two fold increase is observed in lime stabilized soil compared with that of unstabilized one. Therefore, 6% is taken as the optimum value of lime and this lime content is taken constant when soil is further reinforced with optimum percentage of untreated and bitumen coated fibre added in combination with lime.

5) Unconfined Compressive Strength of Lime stabilized Soil reinforced with optimum percentages of untreated and rubber coated fibres:

The Unconfined Compressive Strength of soil samples with optimum percentages of untreated and rubber coated fibres of random length added in combination with optimum lime (6%) were calculated from the loads at failure and shown in Table IX. Variation of improvement factor with untreated and rubber coated fibres in lime stabilized soil are shown in Fig. 6.

TABLE IX. UNCONFINED COMPRESSIVE STRENGTH OF FIBRE REINFORCED LIME STABILIZED SOIL

Results	**Untreated fibres**		**Rubber coated fibres**	
	Soil alone	**Soil+ lime**	**Soil alone**	**Soil+ lime**
UCC(kN/m^2)	54.11	89.62	63.29	122.79
Improvement factor	1.59	2.63	1.86	3.61

An increase of about 3.61 times improvement with respect to unreinforced soil is seen in the UCS of the reinforced soil when 0.5% of rubber coated fibres in combination with 6% lime are added to the soil. About 37% increase in strength is found in lime stabilized soil with rubber coated fibres compared to that with untreated fibres.

Durability test

1) Durability tests results of untreated banana fibres subjected to alternate wetting and drying:

The tensile strength and Unconfined compressive strength samples reinforced with 0.5% untreated banana fibres subjected to alternate wetting and drying in $Ca(OH)_2$ and water are shown in Table X.

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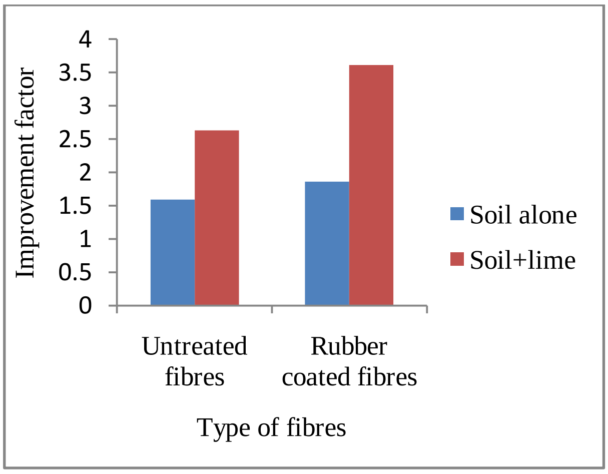

Fig.6 Variation of improvement factor with various treated fibres in lime stabilized soil

TABLE X. TENSILE STRENGTH AND UCS OF UNTREATED BANANA FIBRES SUBJECTED TO ALTERNATE WETTING AND DRYING

Fibre type	Untreated fibres	In $Ca(OH)_2$ solution	In water
Tensile strength (N/mm^2)	11	1.4	3.0
% decrease	-	87	73
UCC (kN/m^2)	54.11	30.82	36.26
% decrease	-	43	33

2) Durability tests results of rubber coated banana fibres subjected to alternate wetting and drying:
The tensile strength and Unconfined compressive strength samples reinforced with 0.5% rubber coated banana fibres subjected to alternate wetting and drying in $Ca(OH)_2$ and water are shown in Table XI.

TABLE XI. TENSILE STRENGTH AND UCS OF RUBBER COATED BANANA FIBRES SUBJECTED TO ALTERNATE WETTING AND DRYING

Fibre type	Rubber coated fibres	In $Ca(OH)_2$ solution	In water
Tensile strength (N/mm^2)	19.08	16.21	16.79
% decrease	-	15	12
UCC (kN/m^2)	63.29	58.22	59.49
% decrease	-	8	6

It can be observed from the table that the tensile strength of untreated fibre and rubber coated fibre decreases by 87% and 15% respectively when subjected to alternate wetting and drying in alkaline medium. This may be attributed to the chemical dissolution of lignin, especially in alkaline mediums, which acts as the binder for the cellulose and hemi-cellulose present in the fibre, and the alkaline water gets crystallized in the pores thereby making the fibre brittle. The above chemical dissolution is responsible for the loss in strength of the fibres and their efficiency as reinforcement.

The reduction in tensile strength of fibre when subjected to alternate wetting and drying in water may be due to microbiological action on banana fibres.

3) Durability tests results of untreated banana fibres subjected to continuous immersion in solutions:
The tensile strength and Unconfined compressive strength samples reinforced with 0.5% untreated banana fibres subjected to continuous immersion in $Ca(OH)_2$ and water are shown in Table XII.

TABLE XII. TENSILE STRENGTH AND UCS OF UNTREATED BANANA FIBRES SUBJECTED TO CONTINOUS IMMERSION IN SOLUTIONS

Fibre type	Untreated fibres	In $Ca(OH)_2$ solution	In water
Tensile strength (N/mm^2)	11	2.6	4.9
% decrease	-	76	55
UCC (kN/m^2)	54.11	36.60	43.26
% decrease	-	32	20

4) Durability tests results of rubber coated banana fibres subjected to continuous immersion in solutions:
The tensile strength and Unconfined compressive strength samples reinforced with 0.5% rubber coated banana fibres subjected to continuous immersion in $Ca(OH)_2$ and water are shown in Table XIII.

TABLE XIII. TENSILE STRENGTH AND UCS OF RUBBER COATED BANANA FIBRES SUBJECTED TO CONTINOUS IMMERSION IN SOLUTIONS

Fibre type	Rubber coated fibres	In $Ca(OH)_2$ solution	In water
Tensile strength (N/mm^2)	19.08	17.17	17.95
% decrease	-	10	6
UCC (kN/m^2)	63.29	60.75	61.70
% decrease	-	4	2.5

The effect of alkaline medium and water on banana fibres is more severe in alternate wetting and drying type exposure than continuous immersion type exposure because the main reasons is that the transport of OH^- ions or Ca^{2+} ions from the water or alkaline medium to the fibres occurs slowly when the environment is kept constant. When the fibres are subjected to alternating wet and dry conditioning, the capillary pore system would be alternately filled and emptied with alkaline pore water. This movement increases the transport of hydration products from the medium to the fibres.

III. CONCLUSIONS

- The unconfined compressive strength of soil reinforced with 0.5% rubber coated fibres of random length and 6 % lime shows an increase by 37% compared to that with untreated fibres.
- The optimum percentage of lime is obtained to be 6%.
- The unconfined compressive strength of soil reinforced with 0.5% untreated and rubber coated fibres of random length shows an increase of 1.59 and 1.86 times respectively with respect to that of unreinforced soil.
- Both untreated and rubber coated fibres are more severely attacked by alkaline medium and water when subjected to alternate wetting and drying type exposure than continuous immersion type exposure.

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