Effect of variation of strain rate on the tensile properties of Coconut leaf midrib - A sustainable material for ground improvement

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ABSTRACT

This paper aims at introducing a new natural fibers used as ground improvement material, which enables to improve the engineering properties of poor soil in an economical and sustainable manner. An investigation of extraction procedure of coconut leaf midrib has been undertaken. The study of tensile behavior of ground improvement material with different strain rate is very significant since, the small strain rate study simulates long term loading and large strain rate study simulates impact loading condition. The strain rate chosen for the present study were in terms of percentage of gauge length of specimen per minute. Moreover, the optimum strain rate and characteristic tensile strength of coconut leaf midrib was established by using Weibull parameters.

Keywords: Ground improvement, Coconut leaf midrib, Natural fibers, Weibull analysis

1 Introduction

Ground improvement is an artificial method to improve the engineering properties of bare soil. Because of fast growing urbanization and scarcity of appropriate land for construction, the ground improvement is inevitable. The aim of ground improvement is to increase the tensile as well as shear strength properties of soil. Presently, a plenty of reinforcing materials has been successfully using in ground in the form of sheet, strip and net. The petroleum by-product synthetic materials are being more popular in now a days, because of its light weight, non-biodegradability and high tensile properties. However, it should be noted that, the world wide capacity of plastic- composite has been rising from 0.36 million metric tons on 2007 to 3.45 million on 2020 (Shen et. al.). This leads to contamination of ground by leachate of chemicals to ground water table. Moreover, it may affect adversely to the entire environmental habitat.

Natural- fiber reinforced soil considered as eco-composite which can be successfully used for improved in soil subgrade road embankment, slope protection works of canal. Natural materials successfully which have been used in ground improvement industry are coir, Bamboo and jute. Coir is considered as the most popular ground improvement material for subgrade because of its easily availability, low cost and large durability compared to other fibers. Babu and Vasudavan (2008) conducted series of tri axial test and study reveals that, the inclusion of coir on clayey soil increases the clay composite stiffness and ductility. A parametric study of ground improvement using bamboo in planar form was conducted by Akhil et.al (2018). After a series of experimental analysis, they recommended numerous optimum values in terms of depth of reinforcement, number of reinforcement layers and effect of aperture size. Jute is one of the major non crop species used in soil reinforcement. Aggarwal et al. (2010) have conducted a detailed analysis on jute reinforced soils. The results indicate the efficiency in terms of *CBR* value, which increases in the range of 1.8 to 5.5. in addition to it, the thickness of the subgrade can decreased by 35%.

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The major focus of this paper has been intended for ground improvement of soil using Coconut leaf midrib (*CLM*) fibers. The extraction of *CLM* fibers from coconut leaf is represented in Figure.1 strength with the aid of Weibull statistical distribution.

Figure 1. Extraction of CLM from coconut leaf

2 Materials and Experimental programmes

The coconut leaf midribs (*CLM*) were sampled in the Vallikkunnu region (11^{o} 07” *N* and 7^{o} 51” *E*). The climate in this area is semiarid with a temperature variation of 24 ^{o}C to 27 ^{o}C. The major soil type is loamy soil. The sampling was conducted in November 2019. The *CLM* were extracted from ripe coconut leaf or fallen coconut leaf. The extracted long strip of *CLM* fibers were preserved in water for seven days.

Figure. 2 Tensile strength measurement arrangement

The *CLM* strips were tested in computer controlled Universal testing machine as shown in Figure. 2. The load – Displacement, Stress-Strain relations, were directly obtained from the display unit. The capacity of load cell is 10*kN* and an accuracy of 0.001. All the tests were conducted and analyzed from Biomechanics Laboratory, Department of Mechanical Engineering, National Institute of Technology, Calicut. The possible range of strain rate recorded was 0.001mm/min to 500mm/min. The tensile strength (T_s) of the *CLM* was evaluated by using Eqn. 1.

$$T_s = \frac{F_{max}}{A} \quad (1)$$

Where F_{max} is the maximum tensile force at failure and A is the cross sectional area. The thickness of the sample was found out by using Vernier calipers with an accuracy of 0.01mm.

In order to ensure the accuracy in strength measurement, the cross section area 10mm away from the break point was also evaluated. Moreover, the variation is more than 5%, the reduced cross sectional area at the breakage were included in the tensile strength calculations. The tests were carried out on specimen with different gauge lengths and strain rates. To ensure the repeatability of results, each combination of fiber were tested fifteen times. The samples broken at the grip or clamp and fracture or peeling visible on the samples before testing were removed.

3 Results and discussions

3.1 Weibull distribution and analysis

Unlike man-made fibers, the variability of tensile strength results of natural fibers among the same species is inevitable. Since, the properties of natural fibers mainly depends on surrounding climate, extraction methods, maturity, growing places etc. therefore a suitable method to obtain the mean value of tensile strength is very significant. In the case of natural fibers, the Weibull statistical distribution analysis is widely used to evaluate the characteristic tensile strength of natural fibers. The application of Weibull distribution was discussed by several past researchers (Chawla et al. 2005, Defoirdt et al. 2010, Tripathy et al . 2008.). The Weibull analysis was first proposed by W. Weibull and it is a measure for variability of fibers strength and a useful graphical plot of variable data (Weibull 1939).

$$f(\varphi) = 1 - e^{(\frac{\varphi}{\varphi_o})^{\beta}} \quad (2)$$

The function $f(\varphi)$ is the Weibull distribution function. Where, φ is the fibre strength for a given probability of survival, φ_o is the characteristic tensile strength and β is the shape factor or Weibull modulus. The function $f(\varphi_1)$ is the cumulative probability of survival corresponding to its strength. *N* is the total number of fiber sample tested. To lesion the variation of tensile strength in *CLM* fiber, 25 numbers of samples were tested in each combination.

$$f(\varphi_1) = 1 - \frac{i}{N+1} \quad (3)$$

Then a plot of $\ln\ln\frac{N+1}{N+1-1}$ and $\ln\varphi$ yields a straight line with slope of β.

$$\ln\ln\frac{N+1}{N+1-1} = \beta\ \ln\varphi + \beta\ln\varphi_o \quad (4)$$

The shape factor (β) is the indicator of variability of data. For man-made fibers the βvalues were usually in the range of 5 to 15. In the case of natural fibers, the values are in between 1 to 6 (Defoirdt et al. 2010). Higher $\beta\ value$ explains the less variation in the observed data. The minimum $\beta\ value$ indicates more consistent in the result data. The comparison of $\beta\ value$ with different natural fibres are represented in Table 1. The figure 3 represents the Weibull statistical plot for the determination of shape factor.

Table.1 Comparison of β and φ_o values of *CLM* with past literatures (150.0mm gauge length and 0.5$\%/min$ strain rate)

Parameters	Coir	Bamboo	Jute	CLM
β	5.8 -9.3	9.3	3.0	3.02
φ_o *(MPa)*	120-304	140-800	393-1000	211-300
	(Munder et al 2006)	(Ahmed et al. 2007)	(Varma et al. 2007)	(Present study)

From the above analysis it is clear that, the value of coefficient of variations is very less for the combination having 150mm gauge length and 0.5$\%/min$ strain rate. More over the characteristic tensile strength obtained is 211.00*MPa*.

3.2 The gauge length and strain rate effect

Consider a thread of length '*L*' which is divided into '*n*' number of links and assume the length of each link is '*l*'. The total length of tread is '*nl*'. The probability of failure of '*nl*' length is '*F*', and then the probability of survival of '*nl*' links is *1-F*. Since, the failure occurred in one of the links, it referred as failure of entire sample. Therefore, the probability of failure of '*nl*' links is same as that of total length '*l*'. Moreover, as the number of links increases, the chances of getting failure are also increases. Weibull introduced an expression for chances of breaking of samples during testing. i.e,

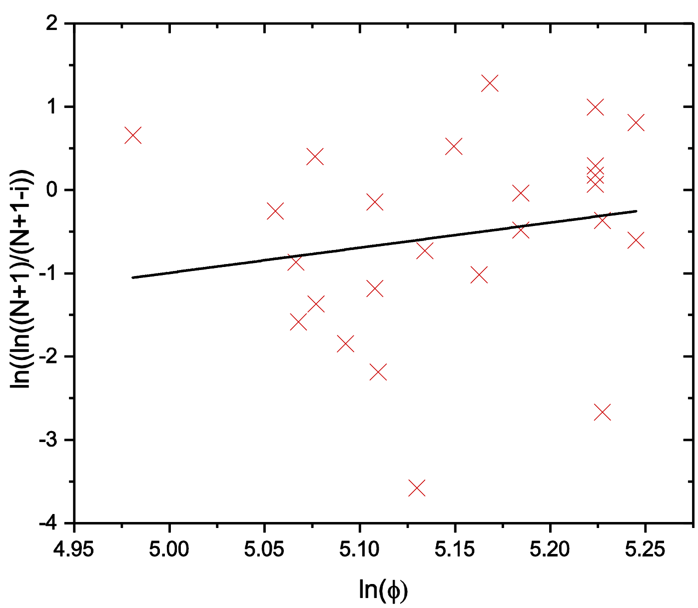

Figure. 3 Weibull statistical distribution of *CLM* fiber with 150.0mm gauge length and 0.5$\%/min$ strain rate.

$$f(\varphi) = 1 - (1 - F)N \quad (5)$$

But for very large samples, Weibull introduced a function $f(\varphi_1) = (\frac{\varphi}{\varphi_o})^\beta$

$$f(\varphi) = 1 - e^{Nf(\varphi_1)} \qquad (6)$$

From the results obtained it is inferred that, as the gauge length increases the tensile strength of the material decreases or the results may be inconsistent. The reason for this may be due to, the *CLM* strips consists of tremendous cellulose strands. Each strand is discontinuous up to a certain extend. Therefore, an optimum value of gauge length required to maintain the friction between the cellulose strands. Whenever, the mobilsed friction between the strands and equilibrium gauge length exceeds certain limits failure occurs. In this present study the optimum value observed from the analysis is 150.00mm gauge length. From the Weibull distribution analysis, the value of shape factor observed very less in the fiber having gauge length of 150.00mm, this implies that, consistency of the results is more when compared to other gauge length.

Since the material is a bio-degradable natural by product, it is highly recommended for the ground improvement for short term improvement of soil, such as ground improvement of subgrade road pavement, road embankment, slope protection work etc. For the ground improvement of above works the determination of properties in infinite length is more significant. The Young's modulus of infinitely long fibers is obtained from E- modulus Vs. 1/ Test length curve at extrapolation of 1/ test length equal to zero as shown in Figure. 4. The comparison of young's modulus of different natural fibers and *CLM* fibers are resented in Table. 2.

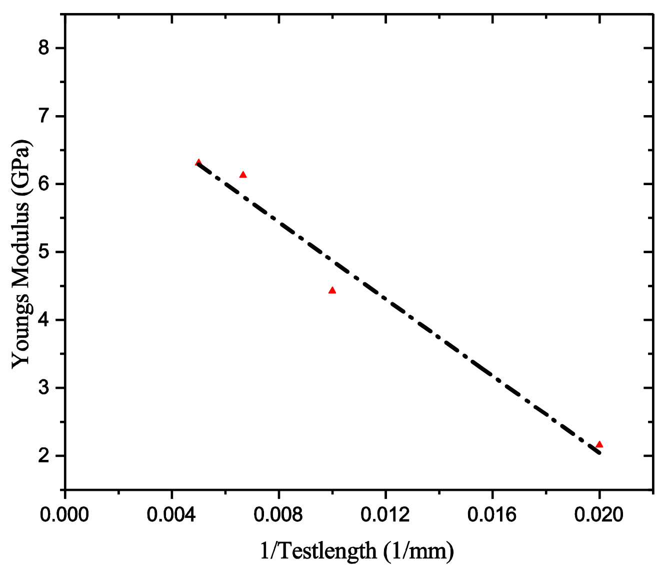

Figure. 4 Young's modulus of an infinitely long fiber (Strain rate= 0.5 $\%/min$)

Table. 2 Comparison of *E*- values of infinitely long natural fibers

Natural fibers	*E*- Value (*GPa*)	References
Coir	4-6	Silva et al. 2000
Bamboo	11-30	John et al. 2008
Jute	13-54	Munder et al. 2006
CLM	7-9	Present study

To characterize the tensile properties of natural fibers, the study of properties by varying strain rates are also inevitable. The materials parameters that appear in the sample can be easily identified from number of test performed at different constant strain rates. Figure 5 represent the stress- strain curve of *CLM* obtained from the sample having 150.00*mm* gauge length and 0.5%/min strain rate. The experiments were conducted with different strain rates, the consistent values were evaluated by Weibull statistical analysis. From the results it is inferred that, as the strain rate increase the value of tensile strength is eventually inconsistent. Moreover, the *E*-value increases as the strain rate increases.

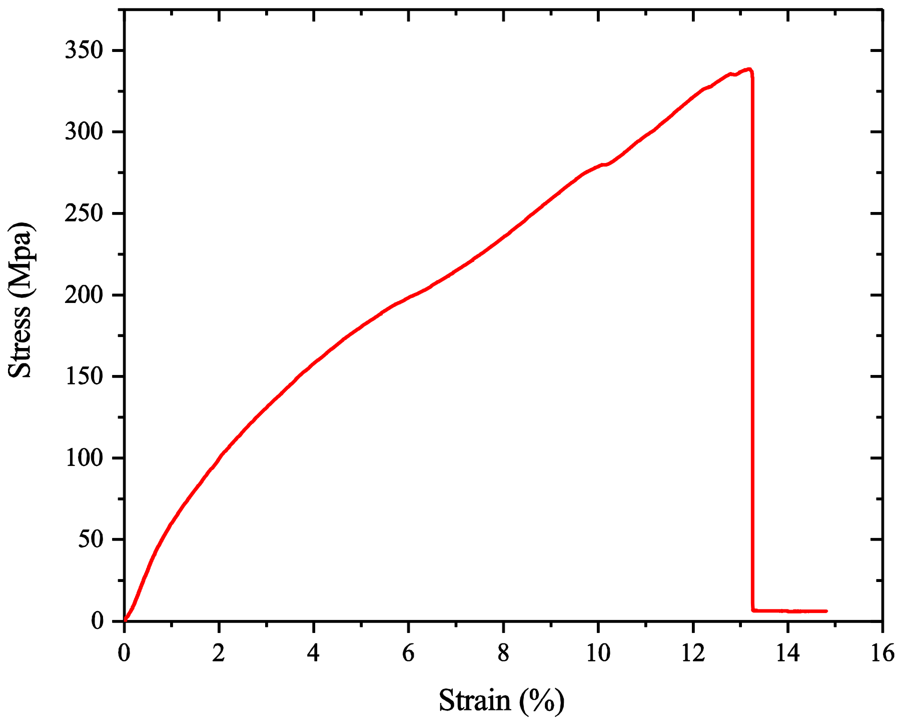

Figure. 5 Stress - Strain curve of *CLM* sample (Gauge length= 150.00*mm* and strain rate = 0.5*%/min*)

4 Summary

A series of tensile strength were conducted to carry out the parametric study of optimum strain rate and gauge length of *CLM* fibers. The results of the tests were compared with Weibull statistical analysis. Based on the experimental studies, the following conclusions were drawn.

1. The optimum gauge length and strain rate for the determination of characteristic tensile strength is 150.00*mm* and 0.5%/*min*.
2. The characteristics compressive strength obtained from Weibull statistical distribution analysis is in the range of 210-350*MPa*.
3. The Weibull parameters obtained from the analysis were found to be between 1 and 6, which has made good agreement with past literatures.

One of the major drawbacks of the natural material is, the biodegradation due to fungus or microorganisms. To increase the durability of these materials, different treatment methods were recommended by the past researchers (Ahmad et al. 2010, Aggarwal et al. 2010, Dutta et al. 2012 Pavani et al. 2016,). From this experimental study, it is evident that, tremendous new researches are yet to be explored in this area.

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