Appropriate software model for evaluating the effect of untreated and treated sisal fibre with different gauge length and strain rates for geotextile applications

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ABSTRACT – REZUMAT

Appropriate software model for evaluating the effect of untreated and treated sisal fibre with different gauge length and strain rates for geotextile applications

Geotextiles are commonly used as reinforcement in building, engineering and road laying applications. The sisal fibre is one of the natural fibres which is used to reinforce soil and prevent damage. This sisal fibre is specifically helpful to fill gaps between roads to improve soil structure, and prevent soil erosion but allows the water to drain off. This paper is concerned with the study of the effect of gauge length on the strength and elongation of sisal fibres in untreated and treated states with sodium hydroxide at different concentrations and duration of treatment. The reason for applying sodium hydroxide treatment on sisal fibre is to remove the impurities from it and to improve the inter fibre adhesion with resin for producing a composite. The effective reinforcement of composites with plant fibres depends on the moisture content and the fibre matrix interfacial adhesion. Treatment with alkali improves the performance of fibres when they are used as composites. Also, the effect of strain rate on the strength and elongation of sisal in untreated and treated states has been investigated. The Weibull modelling software model has been used in many studies to quantify the degree of variability in the fibres. This paper deals with the application of an appropriate software model such as the Weibull distribution model for quantifying the variability in strength and elongation at different gauge lengths varied from 10 mm to 100 mm and also varied the strain rate from 10 mm/min to 500 mm/min. In addition to the Weibull distribution model, air plasma treatment and SEM (Scanning Electron Microscope) analysis on sisal fibre were also carried out in this paper. The result shows that the sisal fibre is more suitable for geotextile applications.

Keywords: *air plasma treatment, composite, gauge length, SEM analysis, sisal fibre, strain rate, Weibull distribution model*

Model de software adecvat pentru evaluarea influenței lungimii de referință și alungirii fibrei de sisal netratate și a celei tratate pentru aplicații geotextile

Geotextilele sunt utilizate în mod frecvent ca armare în domeniul construcțiilor, ingineriei și amenajării drumurilor. Fibra de sisal este una dintre fibrele naturale utilizate pentru a întări solul și pentru a preveni deteriorarea. Această fibră de sisal este utilă, în mod special, pentru a umple golurile dintre drumuri, pentru a îmbunătăți structura solului, pentru a preveni eroziunea solului, permitând apei să se scurgă. Această lucrare se referă la studiul influenței lungimii de referință asupra rezistenței și alungirii fibrelor de sisal în stare netratată și în cea tratată cu hidroxid de sodiu, la diferite concentrații și durate de tratament. Motivul aplicării tratamentului cu hidroxid de sodiu pe fibra de sisal este de a îndepărta impuritățile din aceasta și de a îmbunătăți aderența dintre fibre cu rășină, pentru producerea unui compozit. Armarea eficientă a compozitelor cu fibre vegetale depinde de conținutul de umiditate și de aderența la interfața matrice-fibră. Tratamentul cu alcalii îmbunătățește performanța fibrelor, atunci când sunt utilizate sub formă de compozite. De asemenea, a fost investigată influența vitezei de deformare asupra rezistenței și alungirii sisalului în stare netratată și în cea tratată. Modelul software de modelare Weibull a fost folosit în multe studii pentru a cuantifica gradul de variabilitate a fibrelor. Această lucrare tratează aplicarea unui model software adecvat, cum ar fi modelul de distribuție Weibull, pentru cuantificarea variabilității rezistenței și alungirii la diferite lungimi de referință variate de la 10 mm la 100 mm și, de asemenea, a variat viteza de deformare de la 10 mm/min la 500 mm/min.

Pe lângă modelul de distribuție Weibull, în această lucrare au fost efectuate și tratarea cu plasmă de aer și analiza SEM (microscop electronic cu scanare) pe fibra de sisal. Rezultatul arată că fibra de sisal este mai potrivită pentru aplicații geotextile.

Cuvinte-cheie: *tratament cu plasmă de aer, compozit, lungime de referință, analiză SEM, fibră de sisal, viteză de deformare, model de distribuție Weibull*

INTRODUCTION

Although the effect of gauge length on the tensile properties of sisal fibres by Mukherjee and Satyanarayana [1] and Silva et al. [2] has been investigated, the data were not modelled using Weibull distribution. Also, the gauge lengths used by them were limited (10 mm to 50 mm), and in this study, they ranged between 10 mm and 100 mm and also varied the strain rate from 10 mm/min to 500 mm/min. Tenacity and elongation values for untreated and treated sisal fibres at each gauge length and strain rate are discussed together with their values of

Weibull modulus and characteristic values. The overall trend of tenacity and elongation and their Weibull modulus values as a function of gauge length and strain rate are also commented on better understand side size effects. The relationship between $\ln(\sigma_f)$ and $\ln(\ln(1/(1-Pf)))$ was determined least-squares method.

RELATED WORK

Andrade Silva et al. [2] have reported on the tensile behaviour of sisal fibres. Weibull modulus decreased from 4.6 to 3 as the gauge length increased from 10 to 40 mm respectively. Young's modulus of sisal fibres was found to be around 18 GPa. It was found that the modulus was unaffected and the elongation decreased from 5.2 to 2.6% when the gauge length was increased from 10 to 40 mm. Abir et al. [3] studied the relationship between tensile behaviour and gauge length for sisal fibre composites. With the increase in gauge length, the tensile strength decreased. In general, the strength was found to be between 255 to 377 MPa and the Weibull modulus was around 2.5. Kulkarni et al. [4] used Weibull statistics to analyse the strength of coir fibres. This parameter Weibull treatment has been used for statistical analysis. The increase in Weibull parameters resulted in more uniform flow distribution. This was found in agreement with fibre strength histograms plotted for various fibre diameters of 150 μm to 350 μm. Andrade Silva et al. [5] presented an experimental analysis of the mechanical performance of sisal fibre. Young's modulus was determined using the tensile test. The increase in gauge length resulted in a decrease in Weibull modulus. At a stress level of 320 MPa, sisal fibres showed maximum fatigue. To investigate the failure mode of the fibres, SEM analysis has been used. Fernandes et al. [6] have studied the mechanical properties and tensile failure prediction concerning fibre treatment. Cork polymer composite materials were produced using sisal fibre with and without polyethylene-graft – maleic anhydride.

Improved tensile and flexural properties of the composite were achieved using alkali-treated sisal fibres and polyethylene-graft – maleic anhydride. The tensile strength failure of the hybrid materials was predicted using Weibull statistics. Inacio et al. [7] have studied Weibull analysis of sisal fibre tensile strength led to arrive at a correlation with the fibre diameter. SEM analysis was used to observe the ruptured fibres. The result showed that the tensile strength decreased with the diameter of the fibre.

Realff et al. [8] have conducted experiments to study the effect of test gauge length on the mechanical properties of yarns and fabrics. A Weibull distribution with shape and scale parameters was determined from yarn strength data. The yarn failure mechanism was attributed to changes in gauge length. SEM analysis was also provided. Fabrics were produced with plain and twill weave from the yarns produced at different spinning systems and these fabrics were also tested for tensile properties. The effects were found to be the same as that of yarn tenacity as a function of the gauge length. Tensile strength and modulus of elasticity were determined using a single fibre tensile strength tester and microscopic tests were used to study the fibre cross-sectional area. The high degree of linearity of $R^2 = 0.942$ was observed for coir fibre and the Weibull modulus was 3.650 giving good variability in tensile strength [9].

Zhang et al. [10] have developed a conventional Weibull weakest link model by incorporating the within fibre diameter variation. They claimed that this modified Weibull model could predict the effect of gauge length more accurately than the conventional model. This new model incorporated the diameter variation among the fibres. The fibre strength of wool has been found to fit in this model successfully. Sia et al. have found that Oil Palm Fibre (OPF) extracted from empty fruit bunches was good raw material for bio-composites [11]. The strength of these fibres was estimated at different gauge lengths and subjected to the Weibull weakest link distribution model. For exact prediction of the effect of gauge length the modified Weibull distribution was utilized. The failure strength of OPF was not affected by gauge length, unlike in the case of coir fibres [12–16]. The air plasma treatment [17] and SEM analysis [18] of sisal fibre are also discussed.

EXPERIMENTAL

The following tables 1 to 6 show the sample data for tensile properties of untreated and treated sisal fibres.

Weibull Distribution Model

The software model like Weibull modelling has been used in many studies to quantify the degree of variability in the fibres. Thus, the appropriate software

Table 1

UNTREATED SISAL FIBRE BREAKING LOAD (GF) AT DIFFERENT GAUGE LENGTHS (STRAIN RATE: 100 mm/min)									
10 mm	20 mm	30 mm	40 mm	50 mm	60 mm	70 mm	80 mm	90 mm	100 mm
530.86	444.98	594.50	274.68	343.65	255.15	326.35	317.25	372.79	345.43
565.30	494.64	691.18	471.87	447.86	404.51	418.27	424.39	439.91	353.40
632.88	505.88	692.76	581.06	492.19	425.48	468.31	426.64	487.60	361.41
759.48	536.45	693.73	617.27	502.74	436.59	533.48	463.30	536.95	476.64
804.39	566.00	703.98	664.50	623.70	438.53	552.04	476.29	540.61	505.04

Table 2

UNTREATED SISAL FIBRE ELONGATION (%) AT DIFFERENT GAUGE LENGTHS (STRAIN RATE: 100 mm/min)

10 mm	20 mm	30 mm	40 mm	50 mm	60 mm	70 mm	80 mm	90 mm	100 mm
11.61	6.05	2.18	6.57	4.71	2.27	3.46	3.60	2.20	2.25
12.00	7.00	5.96	6.86	5.43	6.06	5.53	4.34	4.18	3.88
12.01	8.80	6.62	8.01	6.47	6.39	6.05	4.79	4.35	3.95
12.07	9.20	8.72	8.13	7.45	7.12	6.30	5.30	4.69	3.97
12.07	9.59	8.91	8.25	8.34	7.30	6.43	5.90	5.30	4.37

Table 3

5% NAOH TREATED SISAL FIBRE BREAKING LOAD (GF) AT DIFFERENT GAUGE LENGTHS (STRAIN RATE:100 mm/min)

10 mm	20 mm	30 mm	40 mm	50 mm	60 mm	70 mm	80 mm	90 mm	100 mm
230.8	349.2	277.7	204.0	207.3	221.9	218.7	184.0	204.2	200.5
261.0	360.1	280.7	223.1	265.0	247.3	275.3	216.8	253.5	220.7
270.6	389.0	308.9	243.9	272.5	264.0	291.5	280.9	268.9	223.0
289.2	394.4	364.5	249.0	274.4	279.6	296.3	283.3	273.4	225.1
305.6	396.3	394.5	277.9	279.3	281.0	300.7	285.9	292.0	225.2

Table 4

5% NAOH TREATED SISAL FIBRE ELONGATION(%) AT DIFFERENT GAUGE LENGTHS (STRAIN RATE: 100

10 mm	20 mm	30 mm	40 mm	50 mm	60 mm	70 mm	80 mm	90 mm	100 mm
7.1	4.9	4.7	3.8	4.7	1.9	3.8	4.3	2.6	3.6
10.7	5.7	4.9	5.1	5.4	3.6	4.9	4.7	4.3	4.7
12.0	6.2	5.2	5.3	5.9	4.1	5.3	4.7	4.6	4.8
12.1	6.3	5.7	5.7	5.9	4.6	5.4	5.1	5.0	4.8
12.6	7.1	6.5	6.2	5.9	5.3	5.6	5.3	5.1	5.0

Table 5

10% NAOH TREATED SISAL FIBRE BREAKING LOAD (GF) AT DIFFERENT GAUGE LENGTHS (STRAIN RATE: 100 mm/min)

10 mm	20 mm	30 mm	40 mm	50 mm	60 mm	70 mm	80 mm	90 mm	100 mm
265.8	257.7	237.7	297.3	232.1	241.3	237.5	160.8	235.3	208.8
323.1	288.2	288.7	347.9	277.2	291.7	323.5	277.4	246.6	222.5
347.7	293.1	317.2	350.5	294.6	303.2	325.4	280.6	277.5	228.6
408.7	368.8	321.1	360.4	314.3	304.3	327.6	305.9	299.7	233.6
424.7	380.2	331.8	361.2	322.1	332.5	331.6	306.8	314.4	240.6

Table 6

10% NAOH TREATED SISAL FIBRE ELONGATION(%) AT DIFFERENT GAUGE LENGTHS (STRAIN RATE: 100 mm/min)

10 mm	20 mm	30 mm	40 mm	50 mm	60 mm	70 mm	80 mm	90 mm	100 mm
6.8	3.2	5.2	5.0	6.0	2.6	3.4	2.9	2.8	2.7
7.3	5.7	5.5	5.3	6.1	3.2	4.6	4.1	5.2	3.6
7.7	6.2	5.8	5.3	6.2	3.7	4.6	5.2	5.9	5.0
7.7	6.9	5.9	6.5	6.4	4.1	5.8	5.6	6.3	5.3
7.8	7.0	6.5	6.6	6.7	4.9	5.9	5.7	6.5	5.3

model such as the Weibull distribution model was used to quantify the strength and elongation data of both untreated and treated sisal fibres at different gauge lengths. Weibull parameters were determined by Microsoft Excel. The mean rank is obtained from the following equations: $\hat{F}(t_{(i)}) = (i - 0.5)/n$ (called the median rank estimator). The following procedures were used for Weibull modelling.

Part A: Plotting

1. Reorder the data from the smallest to the largest so that $t_{(1)} \le t_{(2)} \le \ldots \le t_{(n)}$.
2. Compute $\hat{F}(t_{(i)})$ for $1 \le i \le n$.
3. Compute $y_i = \ln\{-\ln[1 - \hat{F}(t_{(i)})]\}$ for $1 \le i \le n$.
4. Compute $x_i = \ln(t_{(i)})$ for $1 \le i \le n$.
5. Plot y_i versus x_i for $1 \le i \le n$.

Part B: Estimation

6. Determine the best straight-line fit using regression or the least-squares method.
7. The slope of this line yields $\hat{\beta}$, the estimate of β which is the Weibull modulus.
8. Compute y_0, the y-intercept of the fitted line; $\hat{\alpha}$, the estimate of α, is given by $\hat{\alpha} = \exp(-y_0/\hat{\beta})$ which is the characteristic value.

Using the Weibull distribution, two parameters were estimated. These are the scale and shape. The shape parameter gives an idea of scattering of strength while the scale parameter gives the characteristic value which is an estimated one.

RESULTS AND DISCUSSION

Comparison of values of tenacity and elongation of sisal fibre with other workers

To know whether the values of tenacity and elongation of sisal fibre are correct, a comparison has been made with literature values and these are given in table 7. That the tenacity and elongation of sisal fibre compare favourably with values reported in the literature can be seen.

COMPARISON OF VALUES OF THE TENACITY OF SISAL FIBRE WITH OTHER WORKERS

Tenacity (MPa)	Elongation (%)	References
600 – 700	3.0 – 5.0	Nam et al. [19]
568 – 640	2.0 – 3.0	Mahjoub et al. [20]
764	5.0	Mukherjee et al. [1]
363 – 700	2.0 – 7.0	Yan et al. [21]
511	7.63	Indu and Senthilkumar [22]
637 – 893	**7.0 – 16.0**	**Present work**

The effect of gauge length and alkali concentrations on tensile properties of sisal fibre

Table 8 presents data on tensile properties of untreated and alkali-treated sisal fibres at different gauge lengths. 25 readings are available for each gauge length with a constant strain rate of 100 mm/min, but only 5 sample details are given in tables 1, 3 and 5. It is apparent that with an increase in gauge length, there is a decrease in tenacity obviously due to a greater number of weak places. This is in agreement with the findings of Bharani and Mahendra Gowda [12]. Alkali-treated fibres generally show a drop in strength, but an interesting observation is that at 10% concentration and with a treatment time of 10 minutes the retention of strength is higher. This is due to the variation in cellulose content and the removal of lignin and waxes from the surface.

Effect of strain rate and alkali concentrations on tensile properties of sisal fibre

Table 9 presents data on tensile properties of untreated and alkali-treated sisal fibres at different strain rates. 25 readings are available for each strain rate with a constant gauge length of 50 mm, but only 5 sample details are given in tables 2, 4 and 6. It is noticed that the tenacity increases both for untreated

TENACITY AND ELONGATION OF UNTREATED AND ALKALI-TREATED SISAL FIBRE AT DIFFERENT GAUGE LENGTHS (STRAIN RATE: 100 mm/minute) (EXPERIMENTAL VALUES)

Gauge length (mm)	Tenacity (MPa)						Elongation (%)					
	0% NaOH		5% NaOH		10% NaOH		0% NaOH		5% NaOH		10% NaOH	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
10	893.00	267.82	445.00	191.86	467.00	132.01	16.06	3.72	16.76	5.66	12.42	5.19
20	843.00	406.01	437.00	139.54	442.00	133.58	12.69	3.303	10.25	3.34	9.23	3.09
30	842.00	304.02	434.00	192.15	422.00	122.48	11.61	3.29	8.30	2.1	8.64	2.01
40	796.00	312.4	409.00	193.46	418.00	117.84	10.67	2.29	7.92	2.34	8.32	1.8
50	785.00	306.87	382.00	152.2	404.00	160.51	9.70	1.96	7.90	2.27	8.05	1.47
60	782.00	426.5	378.00	146.25	395.00	104.4	8.74	2.14	7.86	2.47	8.01	3.62
70	774.00	348.23	368.00	120.7	389.00	135.04	8.22	1.92	7.75	1.99	7.80	2.14
80	719.00	344.81	363.00	118.2	370.00	139.74	8.06	2.3	7.55	2.6	7.79	2.26
90	651.00	241.2	345.00	112.75	364.00	125.85	7.13	2.1	7.40	2.76	7.64	1.81
100	637.00	273.08	316.00	121.55	350.00	164.34	6.29	2.3	7.33	2.29	7.59	1.3

Strain rate (mm/min)	Tenacity (MPa)						Elongation (%)					
	0% NaOH		5% NaOH		10% NaOH		0% NaOH		5% NaOH		10% NaOH	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
10	303.00	158.43	338.00	101.44	392.00	121.97	5.75	2.59	8.86	2.57	8.87	2.61
50	309.00	170.23	369.00	123.36	409.00	139.76	6.14	2.49	8.45	2.5	8.69	3.21
150	327.00	147.72	411.00	124.48	419.00	113.18	6.77	1.91	8.39	1.73	8.28	2.62
250	338.00	140.16	457.00	143.9	428.00	154.9	6.95	2.31	8.63	1.83	7.85	2.45
500	504.00	283.59	510.00	162.32	559.00	176.59	5.92	2.22	10.75	3.75	11.86	2.67

TENACITY AND ELONGATION OF UNTREATED AND ALKALI-TREATED SISAL FIBRE AT DIFFERENT STRAIN RATES (GAUGE LENGTH: 50 mm) (EXPERIMENTAL VALUES)

and treated sisal fibres with the increase in strain rates. With theExcepted sisal fibre, elongation also increases following the same trend. As for treated fibres, elongation shows a higher value at 500 mm/min.

Effect of gauge length on tenacity and elongation

Table 10 presents data on Weibull modulus and characteristic value in respect of untreated and alkali-treated sisal fibres at different gauge lengths.

As far as the strength is concerned, values of the Weibull modulus do not show any specific trend. The difference in characteristic values of strength between 5% and 10% alkali is much less. Generally, the strength of treated sisal fibre is found to be lower than that of untreated. This is due to the removal of lignin, hemicelluloses and recrystallization. The same trend is noticed in elongation. The characteristic values of elongation of alkali-treated fibres are lower in comparison to untreated fibres except for 90 and 100mm gauge lengths. Gauge length has a significant effect on strength in that as the gauge length increases, there is a drop in strength. This is attributed to the weak places present in the fibre. These are

in substantial agreement with the findings of Bharani and Mahendra Gowda [13]. Values of Weibull modulus in respect of elongation of treated fibres are found to be low in comparison to untreated fibre. Also, it should be clear that the values of Weibull modulus for elongation are found to be lower compared to strength.

Effect of strain rate on tenacity and elongation

Table 11 presents data on Weibull modulus and characteristic values at different strain rates for untreated and alkali-treated sisal fibres. It is apparent that with an increase in strain rate the tenacity shows an increase in all the cases. This is in substantial agreement with the finding of research workers Bharani and Mahendra Gowda [14].

As regards elongation, there is a drop which is attributed to the stiffening of the material. Values of Weibull modulus of strength show an increase with the increase in a strain rate. With regard to elongation, it is noticed that at a 500 mm/min strain rate, there is a drop in Weibull modulus for the material in untreated and 5% alkali-treated states. This shows that the scatter in elongation is quite high. While at 500 mm/min a significant increase in Weibull modulus

VALUES OF WEIBULL MODULUS AND CHARACTERISTIC VALUE AT DIFFERENT GAUGE LENGTHS FOR UNTREATED AND ALKALI-TREATED SISAL FIBRES

Gauge length (mm)	Tenacity (MPa)						Elongation (%)					
	Concentration of alkali						Concentration of alkali					
	0%	5%	10%	0%	5%	10%	0%	5%	10%	0%	5%	10%
	WM	WM	WM	CV	CV	CV	WM	WM	WM	CV	CV	CV
10	4.25	2.98	4.43	977	500	512	4.70	3.49	2.83	17.59	18.65	14.00
20	2.67	4.30	4.09	951	484	488	4.39	3.53	3.24	13.95	11.38	10.34
30	3.82	4.48	3.50	935	476	469	2.61	4.40	4.84	13.47	9.09	9.42
40	3.05	2.74	4.60	895	460	458	5.30	4.02	5.13	11.57	8.71	9.04
50	3.13	3.25	3.48	889	428	449	4.77	3.87	6.34	10.63	8.70	8.64
60	2.17	3.46	4.68	880	420	432	3.28	2.72	2.40	9.92	8.92	9.05
70	2.90	4.15	3.90	868	406	431	4.42	4.18	3.93	9.03	8.53	8.62
80	2.66	3.83	3.43	812	401	412	3.73	3.53	3.62	8.94	8.39	8.66
90	3.59	4.10	3.81	731	381	404	3.33	3.32	4.06	7.98	8.27	8.48
100	3.09	3.26	2.85	712	355	394	3.07	3.73	3.28	7.05	8.12	8.49

Table 11

Gauge length (mm)	Tenacity (MPa)						Elongation (%)					
	Concentration of alkali (%)						Concentration of alkali (%)					
	0	5	10	0	5	10	0	5	10	0	5	10
	WM	WM	WM	CV	CV	CV	WM	WM	WM	CV	CV	CV
10	2.73	4.34	4.32	341	372	431	2.16	3.36	2.79	6.69	9.93	10.17
50	2.38	3.90	3.63	349	409	454	2.78	3.74	3.02	6.90	9.37	9.74
150	2.74	4.08	4.91	368	454	457	4.08	5.47	3.75	7.45	9.07	9.18
250	2.97	4.27	3.62	380	503	475	3.04	5.43	3.71	7.81	9.35	8.70
500	2.31	4.34	3.81	569	560	620	2.74	4.93	4.95	6.69	11.71	12.92

VALUES OF WEIBULL MODULUS AND CHARACTERISTIC VALUE AT DIFFERENT STRAIN RATES FOR UNTREATED ANDALKALI-TREATED SISAL FIBRE

was noticed in respect of 10% alkali-treated sisal, in untreated and 5% alkali-treated samples the values are low. An increase in Weibull modulus in respect of elongation is observed in a few cases. A decrease in strength is noticed during sisal following treatment with caustic soda at 5% concentration. This is principally due to the removal of lignin and de-crystallization. Also, the same phenomenon is noticed at 10% concentration with a treatment time of 10 minutes. At 10 mm gauge length, alkali-treated sisal fibre exhibits a progressive increase in Weibull modulus and at other gauge lengths, treatment with 10% caustic soda is found to be better. Characteristic values of elongation are found to increase in alkali-treated samples as the treatments were applied in the slack state. This has been found to agree substantially with the findings of other research workers Mwaikambo and Ansell [15] and Anjali Karolia and Bhoj [16].

Weibull modelling

Tenacity and elongation values for untreated and treated sisal fibres at each gauge length and strain rate are discussed together with their values of Weibull modulus and characteristics values. The overall trend of tenacity and elongation and their Weibull modulus values as a function of gauge length and strain rate are also commented on to better understand the size effects. The figures for the Weibull distribution relationship between $\ln(\sigma_f)$ and $\ln(\ln(1/(1-Pf)))$ were determined by the least-squares method and were drawn in respect of untreated and alkali-treated sisal fibres tested at various gauge length such as 10 mm, 20 mm, 30 mm, 40 mm, 50 mm, 60mm, 70 mm, 80 mm, 90 mm and 100 mm respectively. Only the sample figures 1, *a–c* and 2, *a–c* display data on Weibull distribution in respect of untreated and alkali-treated sisal fibres tested at 10 mm is shown. Table 12 summarizes the data as noticed in the Weibull distribution plots.

Weibull parameters for untreated and treated sisal fibre tested at 10 mm gauge length with a strain rate of 100 mm/min.
Table 12 presents data on Weibull modulus and characteristic values. It may be noted that the characteristic values are more reliable than those of experimental values as they are estimated ones. It is

Table 12

Details of sisal fibre samples	Weibull Modulus		Characteristic Value	
	Tenacity (MPa)	Elongation (%)	Tenacity (MPa)	Elongation (%)
Untreated	4.25	4.70	977	17.59
5% NaOH treated	2.98	3.49	500	18.65
10% NaOH treated	4.43	2.83	512	14.00

WEIBULL MODULUS AND CHARACTERISTIC VALUES – 10 mm GAUGE LENGTH

noticed from table 8 that in respect of the Weibull modulus for tenacity, an improvement is noticed at a 10% concentration of alkali. Characteristic values, although in general, are lower in comparison to untreated fibre, the tenacity obtained at a 10% concentration of caustic soda with a duration of 10 min is slightly higher than that of 5% treated fibre.
About elongation, there is a drop in Weibull modulus following treatment with caustic soda. The characteristic value for a 5% concentration of caustic soda is higher. Similarly, the Weibull plots for all gauge lengths from 20 mm to 100 mm were drawn.

Effect of treatments on sisal fibres tested at different gauge lengths keeping strain rate constant at 100 mm/min on the correlation coefficient
The correlation coefficient of untreated and alkali-treated sisal fibres obtained at various gauge lengths keeping strain rate constant at 100 mm/min were examined and are given in table 13. After the treatment with 10% for 10 minutes, values of correlation coefficient show an increase compared to untreated in 50% of the cases. Hence, it can be concluded that there is a very good relationship between the two parameters for which the linear regression analysis has been performed. The same trend is noticed in elongation also.

Weibull parameters for untreated and treated sisal fibre tested at a 10 mm/min strain rate with a gauge length of 50 mm
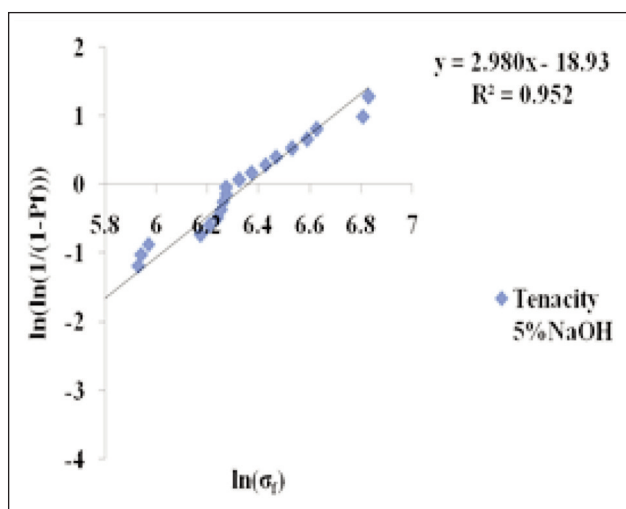There is an all-around improvement in tenacity and elongation for both untreated and treated sisal fibres
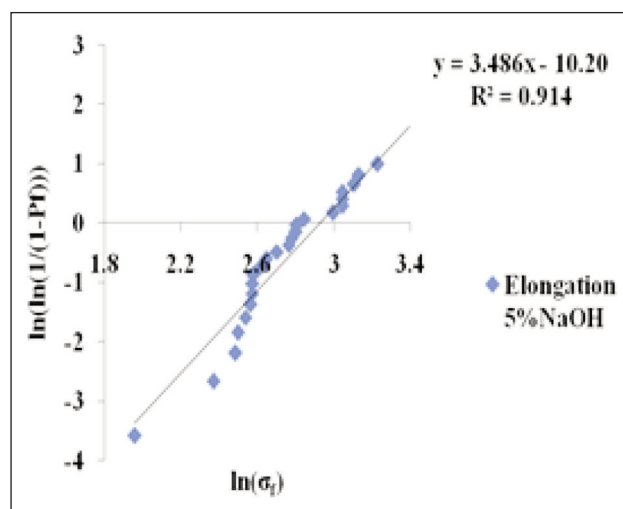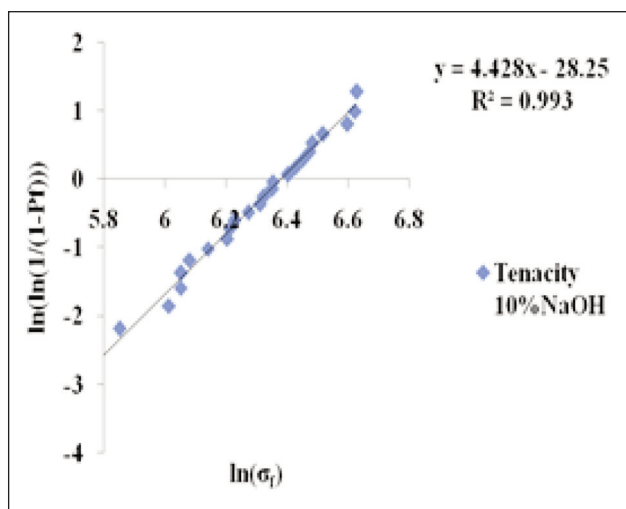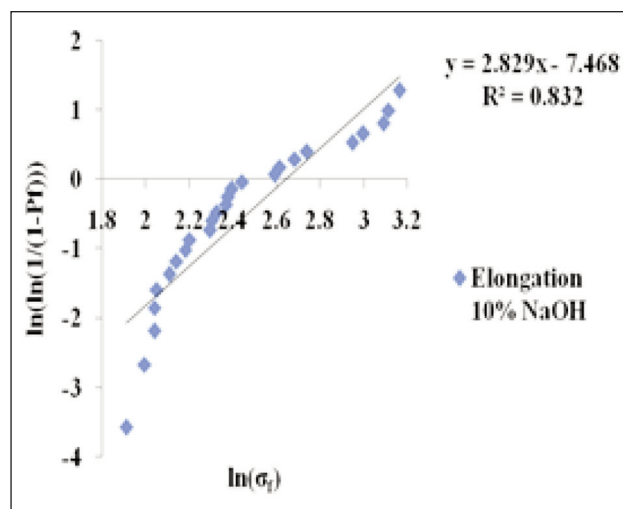
a

b
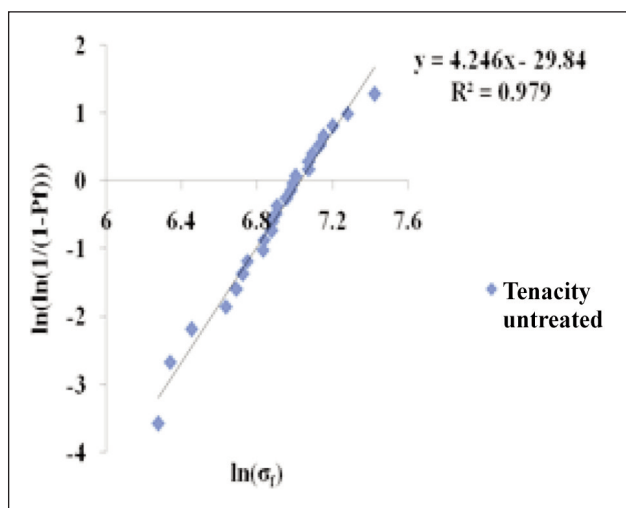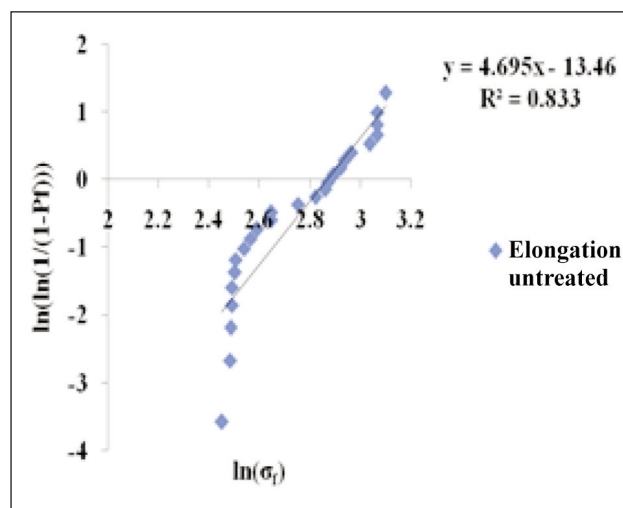
c

Fig. 1. Weibull plot for untreated and treated sisal fibre tenacity tested at 10 mm gauge length (Strain rate 100 mm/min): *a* – untreated; *b* – 5%NaOH treated; *c* – 10%NaOH treated

a

b

c

Fig. 2. Weibull plot for untreated and treated sisal fibre elongation tested at 10 mm gauge length (Strain rate 100 mm/min): *a* – untreated; *b* – 5%NaOH treated; *c* – 10%NaOH treated

tested at a 10 mm/min strain rate (table 14) and the Weibull plots are depicted in the figures 3, *a–c* and 4, *a–c*. Similarly, the Weibull plots for all strain rates 50 mm/min, 150 mm/min, 250 mm/mm and 500 mm/min were drawn.

Effect of alkali treatment and strain rates keeping gauge length constant at 50 mm of sisal fibre on the correlation coefficient

The correlations between the two parameters from which the two Weibull parameters have been

Table 13

	CORRELATION COEFFICIENT FOR UNTREATED AND ALKALI-TREATED SISAL FIBRES TESTED AT DIFFERENT GAUGE LENGTHS KEEPING STRAIN RATE CONSTANT AT 100 mm/min					
Gauge length (mm)	**Tensile Strength**			**Elongation (%)**		
	0%	**5%**	**10%**	**0%**	**5%**	**10%**
10	0.98	0.95	0.99	0.83	0.91	0.83
20	0.92	0.80	0.98	0.95	0.97	0.92
30	0.82	0.98	0.95	0.85	0.97	0.97
40	0.97	0.95	0.91	0.96	0.95	0.97
50	0.98	0.94	0.93	0.93	0.84	0.91
60	0.94	0.94	0.98	0.84	0.97	0.97
70	0.98	0.94	0.89	0.94	0.97	0.99
80	0.93	0.98	0.95	0.99	0.89	0.98
90	0.95	0.96	0.92	0.96	0.97	0.87
100	0.94	0.89	0.89	0.94	0.94	0.98

Table 14

	WEIBULL MODULUS AND CHARACTERISTIC VALUES – 10 mm/min STRAIN RATE			
Details of sisal fibre samples	**Weibull Modulus**		**Characteristic Value**	
	Tenacity (MPa)	**Elongation (%)**	**Tenacity (MPa)**	**Elongation (%)**
Untreated	2.73	2.16	341	6.69
5% NaOH treated	4.34	3.36	372	9.93
10% NaOH treated	4.32	2.79	431	10.17

obtained by linear regression analysis are given in table 15. There is an improvement in the correlation following the treatment at the strain rates employed for the treated materials both in tenacity. Such a trend is not noticed in elongation.

Table 15

|	CORRELATION COEFFICIENTS FOR UNTREATED AND ALKALI-TREATED SISAL FIBRES TESTED AT DIFFERENT STRAIN RATES KEEPING GAUGE LENGTH CONSTANT AT 50 mm					
Strain rate (mm/min)	**Tenacity (MPa)**			**Elongation (%)**		
	0%	**5%**	**10%**	**0%**	**5%**	**10%**
10	0.93	0.94	0.94	0.97	0.96	0.88
50	0.92	0.95	0.95	0.96	0.95	0.96
150	0.97	0.99	0.92	0.96	0.98	0.89
250	0.98	0.96	0.97	0.99	0.94	0.92
500	0.91	0.94	0.99	0.98	0.94	0.96

Air plasma treatment on sisal fibre

Air plasma treatment is used to modify the surface characteristics of sisal fibre [17]. The effects of air plasma treatment on interfacial bonding between untreated and treated sisal fibres are evaluated using
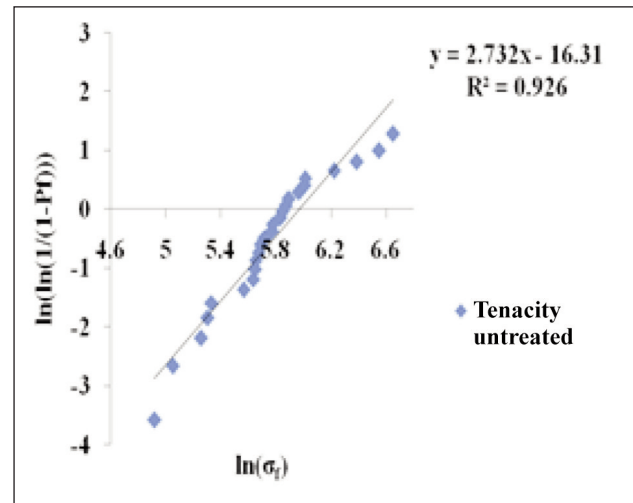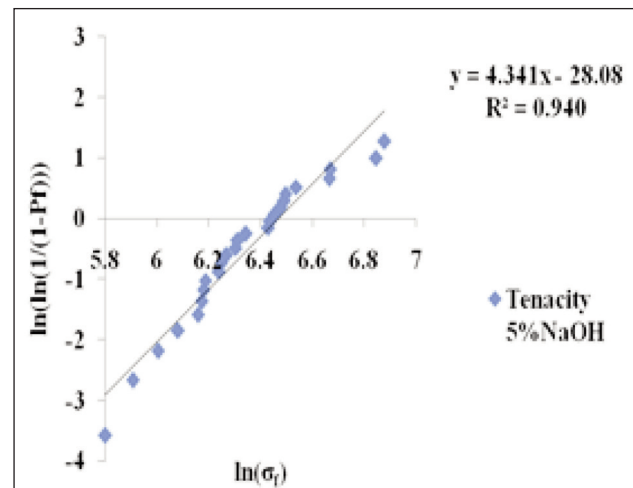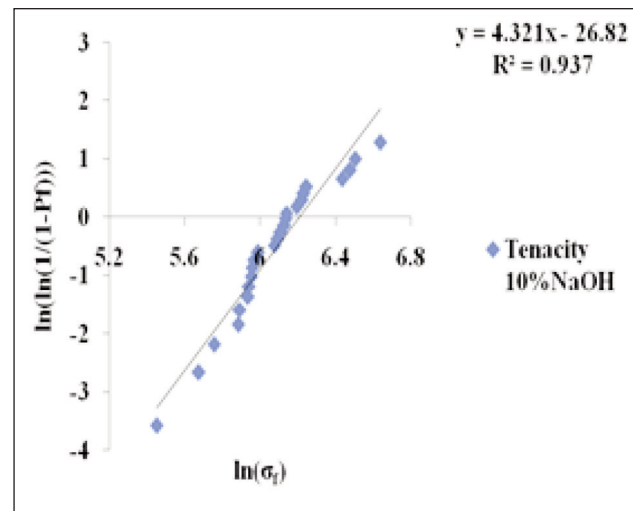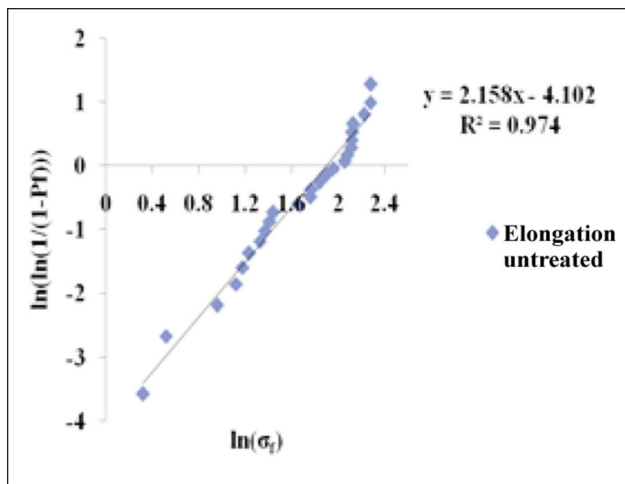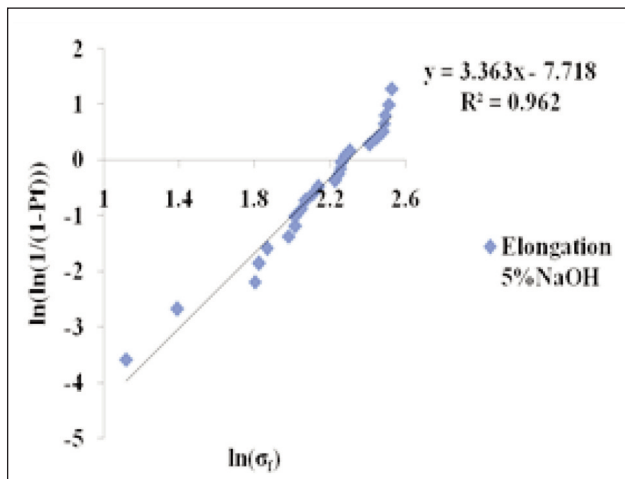
Fig. 3. Weibull plot for untreated and treated sisal fibre tenacity tested at 10 mm/min strain rate (Gauge length 50 mm): *a* – untreated; *b* – 5%NaOH treated; *c* – 10%NaOH treated
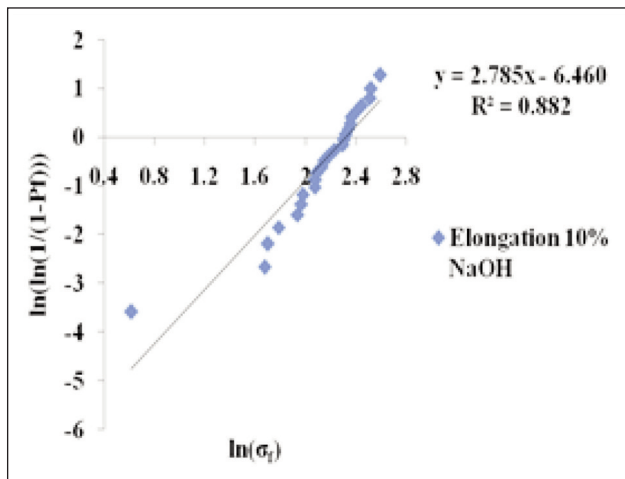
a single fibre pull-out test. In the present work, a single fibre pull-out test was used to measure the interfacial adhesion between an untreated and treated sisal fibre. All the pull-out tests were performed on the Instron testing machine using a special micro vise. The test results of untreated and air plasma-treated sisal fibres are given in table 16. The result

Fig. 4. Weibull plot for untreated and treated sisal fibre elongation tested at 10 mm/min strain rate (Gauge length 50 mm): *a* – untreated; *b* – 5%NaOH treated; *c* – 10%NaOH treated

shows that the tensile strength decreases almost proportionately with the increase in the treatment time. But elongation increases with the plasma treatment time.

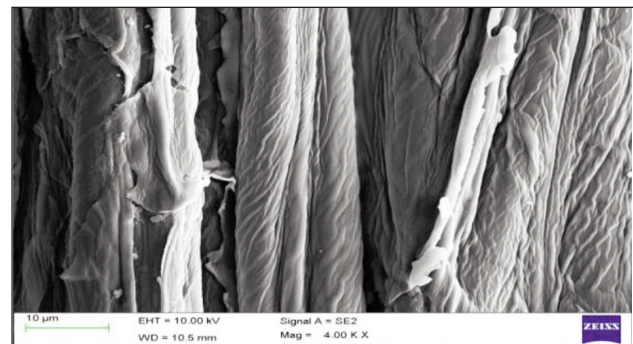## SEM analysis of untreated and NaOH-treated sisal fibres

Figures 5, *a–c* show scanning electron micrographs of untreated and treated sisal fibres with sodium hydroxide with different concentrations and duration
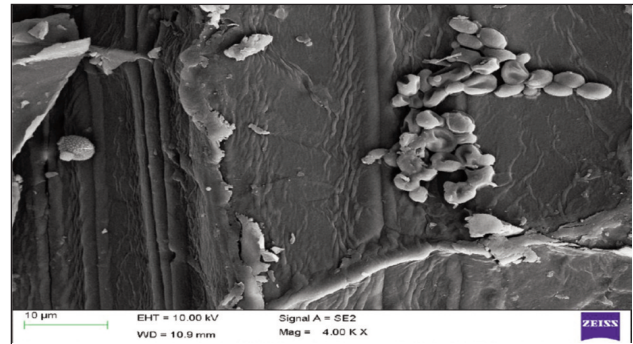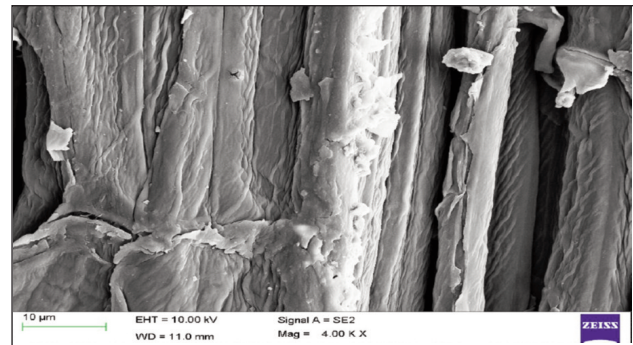
Fig. 5. SEM micrographs of untreated and treated sisal fibre at 4000 magnification (scale bar = 20 μm): *a* – Untreated sisal fibre; *b* – NaOH treated for 1 hour at room temperature; *c* – 10% NaOH treated for 10 min at room temperature

Table 16

Sample details	Testing conditions			Average fibre tensile strength (MPa)	Average fibre elongation (%)
	Time (s)	Power level (W)	Pressure (torr)		
Untreated sisal fibre	-	-	-	651	7.13
Plasma-treated sisal fibre	30	60	2	565	8.2
	60	60	2	512	9.7
	120	60	2	467	10.8

of treatment. In untreated sisal fibre, the presence of some impurities and waxes can be seen. The surfaces show a significant difference following alkali treatment.

CONCLUSION

With the appropriate Weibull distribution software model, the results show that gauge length affects the strength and elongation of untreated and alkali-treated sisal fibres in that with an increase in gauge length there is a decrease in strength and elongation. Strain rate significantly affects strength and elongation. While the former shows an increase, the latter shows a decrease. On basis of Weibull modulus values, treatment of fibre with 10% caustic soda at a treatment time of 10 minutes has provided better performance in comparison to treatment with 5% concentration for 1 hour. After the treatment with 10% for 10 minutes, values of correlation coefficient show an increase compared to untreated in 50% of the cases. Hence, it can be concluded that the treatment has improved the performance. The same trend is noticed in elongation also. Tensile strength shows an improvement following treatment with alkali. The correlation coefficients have improved showing a better relation compared to the gauge length effect, the strain rate for the treated materials shows an improvement. The scanning electron micrographs show the removal of impurities and the other substances following alkali treatment. The presence of fibrillar structure is noticed in alkali-treated sisal fibre. In addition to the Weibull distribution model, the air plasma treatment and SEM analysis also prove that the treated sisal fibre is more suitable for geotextile applications.

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