Saaidia, A., Bezazi, A., Belbah, A., Bouchelaghem, H., Scarpa, F., & Amirouche, S. (2017). Mechano-physical properties and statistical design of Jute Yarns. *Measurement*, *111*, 284-294. https://doi.org/10.1016/j.measurement.2017.07.054

Mechano-physical properties and statistical design of Jute Yarns

A. SAAIDIA[1], A. BEZAZI[1*], A. BELBAH[1], H. BOUCHELAGHEM[2,1], F. SCARPA[3], S. AMIROUCHE[4]

[1]Laboratoire de Mécanique Appliquée des Nouveaux Matériaux (LMANM), Université 8 Mai 1945 Guelma, B.P.401 Guelma 24000 Algérie.

E-mails: saidia_aziz@yahoo.fr ar_bezazi@yahoo.com ahmedbelbah@gmail.com

[2]Université des frères Mentouri, Constantine, Département de Génie Mécanique, route de Ain El Bey Constantine 25000, Algérie. E-mail: bouchelghem_h@yahoo.fr

[3]Department of Aerospace Engineering, University of Bristol, Queens Building, University, Walk BS8 1TR Bristol UK. E-mail: f.scarpa@bris.ac.uk

[4]Université de Tizi-Ouzou –Algeria E-mail: say.amirouche@yahoo.fr

Abstract:

The work describes the statistical characterization of the tensile properties of raw and treated jute yarn fibers. The yarns are treated with various alkaline sodium hydroxide concentrations (0.5, 2 and 5%) and different immersion times at room temperature (30 minutes, 2, 8 and 12 hours). Due to the scattering of the experimental results, statistical analysis was performed using both two- and three-parameters Weibull, and Anova variance methods. In terms of stress, failure strain, and Young modulus, the results obtained from uniaxial tensile yarns show a variation that depends essentially on the immersion time and the NaOH concentration. Optimum mechanical properties are obtained for a concentration of 2% of NaOH and an immersion time of 2 hours. The results are further discussed in view of an extensive Fourier Transform Infrared Spectroscopy (FTIR) analysis carried out on the different classes of yarns.

Key words:

Jute fiber, Material testing, Mechanical properties, Chemical treatment, Statistical analysis

* Corresponding author:

Prof. Abderrezak BEZAZI

Laboratoire de Mécanique Appliquée des Nouveaux Matériaux (LMANM), Université 8 Mai 1945 Guelma, B.P.401 Guelma 24000 Algérie.

E-mail : ar_bezazi@yahoo.com

1. Introduction

The demand for commercial products that are environmentally sustainable is becoming strong. Composite materials based on natural fibers can be considered as an ideal class of solids for sustainability applications. Different types of plant fibers such as jute [1- 3], sisal [4, 5], flax [6, 7], hemp [8], alfa [9] and other natural fibers [10-14] are used as reinforcement in composite materials. Natural fibers may be considered as an interesting alternative to synthetic fibers like glass, particularly in terms of equivalent stiffness. The short coming of using natural fibers resides however in the non-uniformity in their mechanical and physical characteristics (non-constant diameter of the fiber, variable length, micro-fibril angle fiber and its cellulose ratio). This lack of uniformity leads to the dispersion and scattering of their mechanical properties [15, 16].

Natural fibers have been the subject of various studies, starting from the production of the crop, its spinning, the choice of the micro-fibril angle, the weaving mode and the fiber treatment. As far as the fiber treatment is concerned, many investigations have been carried out to improve the interface bonding between the fiber and the matrix by the application of a chemical treatment over the fiber surface [17]. To this end, two parameters are generally taken into consideration: (1) the sodium hydroxide concentration ratio, and (2) its effective processing time.

Numerous research studies have been focused on the characterization of natural fibers, but little has been focused on fiber yarns linked together, the most commonly used type of natural fiber reinforcement consists in ropes. Fibers are constituted by a multitude of components like cellulose, hemicellulose, pectin, lignin and wax [17, 18]. The optimization of the interface flax fiber-unsaturated polyester resin within composites has generated a series of procedures involving successive treatments of the flax fiber, either by using sodium hydroxide (10g/*l*), acetic anhydride or formic acid. These treatments result in the increase of the bonding

between the fiber and the polymer matrix, and the smoothing of the surface of the fibers by reducing its roughness [19].

A solution of NaOH with concentrations equal to 2% to 5% at an ambient temperature of 23°C was used for the treatment of date palm fibers [20]. These fibers were intended to be used as reinforcement in polymer composites and were consequently immersed in a sodium hydroxide solution for 2, 4, 6 and 24 hours. This treatment cleaned most of the impurities from fiber surface. Impurities may affect the absorption properties, with particular reference to the moisture, because the minimization of the hemicelluloses reduces the water absorption property of the fiber [20]. The impact of the NaOH treatment on the mechanical properties of date palm fruit branches for different immersion times has also been investigated [13]. The results showed a net improvement of the mechanical properties for these fibers, in particular for a NaOH concentration of 0.5% and an immersion time of 12 hours.

Studies have also been performed on the influence of the surface characteristics of jute fabrics, along with the characterization of the mechanical properties of jute/polyester composites [21]. Three surface treatments using alkali, silicone micro-emulsion (MS), and fluoro-carbon agents (FA) have been considered. The results obtained show the decrease of the fiber stiffness after each surface treatment, and the jute yarn tensile strength increasing by 10.8% after the jute alkali treatment [21]. Lyocell fibers have also been subjected to investigation [22]. In order to find out the impact of the alkali treatment on the absorption behavior of the cellulose II of the lyocell fibers, a continuous pre-treatment using NaOH with concentrations ranging from 0.00 to 7.15 mol/dm^3 and varying tension was applied to the woven fabric. The process was intended to condition the samples in a 65±4% relative humidity and at 20±2^{o}C temperature for 48 hours before the alkali treatment. The results show an increase of the absorption energy of the hydrolyzed reactive dyes onto cellulose II lyocell

fibers with higher NaOH concentrations (2.53mol/dm^{3}to3.33mol/dm^3), followed by a decrease of the same energy with further increase of NaOH beyond 3.33mol/dm^3.

The jute fiber is one of the cheapest natural fibers available, with its crop taking approximatively four months to reach maturity, with up to two tons per hectare of yield [23]. Jute is totally biodegradable and recyclable, and it is especially used in the manufacturing of bags used for storing agricultural products. Among the commonly used plant fibers, those obtained from the jute crops show quite interesting properties, and the present investigation focuses on further evaluation of the mechanical properties of the yarn jute fibers. In this work, different NaOH concentrations (0.5, 2 and 5%) are applied at room temperature for immersions lasting 30 minutes, 2, 8 and 12 hours. A two and three parameters Weibull statistical method and an Anova variance analysis have also been carried out to provide a robust statistical appraisal of the dispersion of the results. Furthermore, a Fourier transform infrared spectroscopy (FTIR) characterization has been carried out to identify the influence of the treatment on the fibers chemical composition, and its results are reported.

2. Experimental Approach

2.1. Material

Samples have been provided by a natural fiber ropes factory located in Bejaïa, Algeria. The length of the fibers varies between 1m to 4m, and their diameter from 17 μm to 20 μm. The jute yarns are composed of many jute fibers with an average diameter of 860 μm ± 125μm. They are produced with a twisted surface angle ranging between 11° and 13°, and a linear density of 267 Tex ± 4 Tex [16]. The average mechanical properties used have been reported in a previous work [24]. The samples are taken from a bidirectional fabric that possesses a surface density of 400 g/m^2. They are cut to a length of approximately 100 mm.

2.2. Alkali treatment of the jute yarns

To improve the interface fiber/matrix quality and consequently enhance the performance of the composite material, the external surfaces of the fibers may be modified chemically and/or physically by removing their natural and/or artificial impurities [25-27]. The jute yarns investigated in this work have been immersed, at room temperature and in open barrels, in a NaOH solution with different concentrations (0.5%, 2% and 5%) and immersion times (0.5, 2, 8 and 12 hours). The yarns were subsequently rinsed using tap water before being immersed in a 1%-concentrated sulfuric acid solution (H_2SO_4) for 5 minutes to neutralize the sodium ions present in the fibers during the alkali treatment. After being washed again and immersed in distilled water for 15 minutes to reach a neutral pH, the yarns were finally dried in an oven at a temperature of 70°C for 5 hours. The above-cited treatments have resulted in an approximately 20% decrease of the diameter of the treated yarn.

2.3. Measurement of the fiber diameter

The original yarns jute fibers had diameters varying between 600µm and 1200µm (**Fig. 1**). The measurements have been taken by using a Zeiss optical microscope equipped with a Moticam 2500 digital camera controlled by MoticImages plus V2.0 processing image program. The diameters of the yarns has been measured before and after the treatment. For every sample, the measurements have been taken at nine different stations along its length.

Figure 1

2.4. Scanning Electron Microscopy

The longitudinal and transversal surfaces of the treated and untreated yarns have also been examined using a scanning Electron Microscope type ESEM-XL30, and the results are presented in **Fig. 2**. The surfaces of the treated fibers are rough compared to those which have

not been treated. The removal of the surface impurities including non-cellulosic substances, inorganic substances and waxes leads to a cleaner and rougher external state of the fiber that agrees well with the findings of Hossain *et al.* [28].

Figure 2

2.5. Infrared spectrometry analysis

Infrared spectrometry has been performed using a Thermo Scientific Nicolet Spectrum iS10 FT-IR type spectrometer with proprietary analysis software. The spectra were measured performing sampling at intervals of 125 nm within the band width 500 cm^{-1}- 4000 cm^{-1}.

2.6. Test machine

Monotonic tensile tests on the jute yarns have been performed using a universal testing machine Zwick Z005 type with a 5kN capacity load at a speed of 2 mm/min at an ambient temperature of 23°C and an approximate humidity ratio of 55%. The Young's modulus of the jute yarns has been determined according to the ASTM D578 standard using a 50mm gage length. Due to the variability of natural fibers, 390 specimens divided in 13 series of 30 samples each have been tested in total.

3. Results and Discussion

3.1. Infrared Spectrometry

The FTIR spectra with the main IR bands corresponding to the whole untreated and treated fiber jute yarns for different concentrations of NaOH and diverse immersion times, and their different groups' vibrations are shown in **Fig. 3**. The wave forms of the spectra are plotted as Transmittance (T) versus the wave number (1/cm). The FTIR spectrum analysis of the untreated jute fiber shows a large band at 3330cm^{-1} mainly due to the OH groupings existing in the jute fiber structure, which originate from the α-cellulose present in all types of yarns. The results are in good agreement with those obtained by Shaha *et al.* [29].

Figure 3

The peak of 2917 cm^{-1} corresponds to the vibrations of the CH aliphatic chains, while the ones corresponding to 1732 cm^{-1}, 1638 cm^{-1}, 1314 cm^{-1}, 1243 cm^{-1} and 1022 cm^{-1} indicate the existence of the C═O stretching mode of the carboxylic acid, the CH3 asymmetric stretch, the CH symmetric stretching and aromatic and C─O simple connections, respectively. The NaOH treatment resulted in a structural alteration of the treated jute fiber surface where the peaks 1732 cm^{-1} and 1250 cm^{-1} (corresponding to the C=O stretching of the hemicelluloses and the CH stretching of the aromatic skeleton ring vibration of the lignin) vanished. The FTIR analysis shows that the NaOH treatment has affected the intensity of the spectra of the fibers, as well as the peaks of the absorption bands (see **Fig. 3** and **Table 1**), with consequent effects on the chemical composition, the hemicelluloses and the lignin [15, 30]. The results obtained are presented in **Table1,** and compared to those obtained in the literature for several classes of fibers, like jute [28, 29], kenaf [30, 31] and sisal [32].

Table 1

3.2. Tensile strength of jute yarn

Of the total 390 jute yarn specimens assembled into 13 groups of 30 samples each that underwent static tensile tests, 360 were subjected to diverse alkali treatments using NaOH. The rest remained untreated.

Fig. 4(a) shows the results of the tensile tests from the 30 untreated jute yarns. A significant dispersion of the results can be noticed, which is a phenomenon characteristic of most natural fibers, and shows the need of performing a robust statistical analysis. **Fig. 4(b)** shows a representative stress/strain curve of the thirty untreated samples presented in **Fig. 4(a)**. The stress varies first linearly and then quasi-linearly, with the increase of the strain until it reaches its maximum value, followed by a sudden drop in stress without total rupture

of the sample. This behavior is due to the topology of the jute yarns created by the fibres twisted into a spiral. This configuration creates voids and spaces between the fibres. **Fig. 4(c)** shows a comparison of the treated and untreated fibers, with representative curves of thirteen group specimens (thirty tests by group). The results of **Fig. 4(c)** show that the representative curve of the treated yarns with 2% NaOH and 2 hours immersion time has higher tensile strength and Young's modulus than the case related to the untreated fiber, with an equivalent strain at failure. However, the typical curve of the specimen treated with 2% NaOH for an immersion time of 12 hours has a tensile strength, Young's modulus and strain at failure lower than the untreated one (see **Fig. 4(d)**).

Figure 4

For a better understanding, all the results obtained are regrouped in **Table 2** and plotted in Fig. 5 with the average values of the stress, strain and the Young's modulus for the NaOH concentrations of 0.5%, 2% and 5% using different immersion times. The treated jute yarns by different NaOH concentrations at different immersion times show an increase of 5% to 34% of the tensile strength, and 5% to 25% of the Young's modulus compared to the untreated fibers case. The strain at failure however decreased with the increase of the treatment time. The best case is obtained for a 2% NaOH concentration and 2 hours of immersion time and the average ultimate values at failure are found to be 178.4 MPa for the stress, 26.4 GPa for the Young's modulus and 4.17% for the strain. Concerning the untreated fibers, the same properties have been measured at 117.7 MPa, 19.78 GPa and 4.39 %. An increase of 34% and 25% for the stress and Young's modulus respectively and a decrease of 16% for the strain, due to the treatment is noticed. **Table 2** summarizes the variation of the average values of the mechanical properties with regard to the various NaOH concentrations and immersion times used. These values are then analysed using the Coefficient of Variation (CoV %), which is described as the ratio between the standard deviation and the average one

[34]. A low value of the CoV indicates a little variation in the results. In the present case, the results of the CoV obtained are compared to those reported in the literature (see **Table 2**).

Figure 5

Table 2

4. Statistical Study

4.1. Two-and three-parameter Weibull distribution

The experimental characterization of jute yarns carried out and presented above shows a large dispersion of the stress and strain at failure, and also of the Young's modulus. An effective engineering use of these results needs a statistical analysis carried out through the application of both two- and three-parameters Weibull approach, using the software Minitab16 in this particular work.

The three mechanical properties under investigation represented by the stress, the strain and the Young's modulus may be described by using the two-parameter Weibull distribution law [35, 36]:

$$P(\chi) = 1 - \exp\left[-\left(\frac{\chi}{\chi_0}\right)^m\right], \qquad \chi>0, \quad \chi_0>0, \quad m>0 \qquad (1)$$

Where m is a dimension less shape factor related directly to the dispersion of the data, χ_0 a local parameter representing an average value of χ, and $P(\chi)$ the fiber failure probability function related to the parameter χ.

When the ultimate parameter (χ_u) is integrated into the distribution theory, the three-parameter Weibull distribution law is then expressed as [32]:

$$P(\chi) = 1 - \exp\left[-\left(\frac{\chi-\chi_u}{\chi_0}\right)^m\right], \qquad \chi>\chi_u>\chi_0> 0, \quad m>0 \qquad (2)$$

The value of $P(\chi)$ is computed by a metric estimator represented as an average value rank [37] as:

$$P(\chi_i) = \frac{i-0.3}{n+0.4} \quad (3)$$

Where 'i' represents the i^{th} data point and n the number of points, and the parameters m and χ_0 are obtained from a straight line Weibull model approach. Linear transformation of equations (2) and (3) as function of ln (χ) leads to:

$$\ln[-\ln(1-P)] = m\ln\chi - m\ln\chi_0 \quad (4)$$

$$\ln[-\ln(1-P)] = m\ln(\chi - \chi_\mu) - m\ln\chi_0 \quad (5)$$

Fig.6 illustrates the two- and three-parameters Weibull distributions of the mechanical properties obtained from the experiments carried out at various NaOH concentrations during a 2 hours period. It may be observed that the experimental results are close to the Weibull line, the correlation factor varying from 0.947 to 0.996 thus indicating a good agreement between the linear regression of the fiber mechanical properties and the experimental results.

Figure 6

The two-parameter Weibull distribution enables the estimation of the stress and the Young's modulus as σ_0 = 193.27 MPa and E_0 = 27.73 GPa, corresponding to the Weibull shape factors of m_σ = 3.89 and m_E = 2.62. These results are close to the measured ones (σ = 178.39 MPa and E = 26.4 GPa). The three-parameter Weibull distribution does not provide quite a satisfactory estimation as the two-parameter one, with σ_0 = 144.97 MPa and E_0 = 19.14 GPa and Weibull shape factors m_σ = 2.56 and m_E = 1.44. These values are significantly lower than the experimental ones.

It may be therefore stated that, while the two-parameter Weibull approach slightly overestimates the experimentally measured mechanical properties represented by the tensile

strength and the Young's modulus, the three-parameter Weibull distribution however largely deviates from and underestimates the actual experimental results (**see table 3**).

Table 3

4.2. ANOVA analysis

Applying the one-parameter Anova variance approach to all experimental results of the stress, strain and Young's modulus measured on untreated and treated yarn fibers with different NaOH concentrations (0.5%, 2% and 5% at 30 min, 2 hours, 8 hours and 12 hours immersion times) lead to different values of *p*, which is different than the significance level (*p* = 0.05, or 95% confidence level). **Table 4** shows the degrees of freedom (DF), sum of squares (SS), mean square (MS), Fisher modulus (F) and probability (P). The mean square (MS) is the ratio between the sum of the squares (SS) and the degrees of freedom (DF). The F-value represents the ratio between the mean square and the experimental error mean square. In a robust design, the F-value can be used as a qualitative understanding of the relative factor effects. If the F-values are greater than a critical value (F critical) the effects will be considered to be significant. Conversely, if the F-value is less than F critical, then the effects would be considered insignificant. The independent variable in the analysis is represented by the concentration of the NaOH groups and the untreated one (four groups), while the dependent variables are the stresses at failure (30 samples for each group) for an immersion time. The same procedure is followed for the strain and Young's modulus. For example, for the yarns treated with 2% NaOH for an immersion time of 2 hours (which represents the best case featuring the highest mechanical properties- see Table 2), the Fisher modulus of the stress F = 8.90 and strain F = 4.23 are superior to their critical value F_{cr} = 2.60 (see Table 4). In this case, the null hypothesis is dropped. However, the Fisher modulus of the Young's modulus (F = 0.62) is lower than the critical value, which means that there are non-significant

differences of the Young's modulus between treatments. Moreover, the individual charts (**Fig. 7)** present the average values of the ultimate stresses (**Fig. 7a)**, strains (**Fig. 7b)** and Young's modulus (**Fig. 7c),** for all the experimental results, differ for different NaOH concentrations at various immersion times. The yarns treated with 2% NaOH concentration for 2 hours immersion time shows the highest values on stress and Young's modulus equal to σ = 178.39 MPa, and E = 26.40 GPa respectively and an equivalent strain, leading to a good agreement with the untreated one of 117.70 MPa, 19.78 GPa and 4.39%.

Table 4

Figure 7

The residual values curves are represented in **Fig. 8**, and they are intended for the control of the statistical hypotheses. The Non-uniformity diagram (**Fig.8(a)**) shows a nearly straight line (known as the Henry straight line) meaning that the residuals values are uniformly distributed. **Fig.8(b)** plots the residual values against the adjusted ones, and shows a random distribution around zero. The histogram of **Fig.8(c)** represents the residuals and identifies multiple peaks along with aberrant normal values and non-uniformity. The residual values when expressed as a function of the observation order leads to identifying their chronological dependence, presenting the random structure illustrated in **Fig.8(d)**. The residual graphs show no contradiction with the statistical hypotheses, and the Anova one-factor model is thus found to be a good fit to the experimental data.

Figure 8

5. Conclusions

An experimental investigation is undertaken to show the influence of NaOH alkali treatment on the mechanical properties of the yarn jute fibers. Three hundred and sixty specimens were treated differently in terms of sodium hydroxide concentration and immersion times, and compared to 30 untreated samples. The study included processing using a scanning optical microscope, and further examined using the FTIR technique.

In view of the dispersion of the experimental results obtained, statistical analyses were carried out through the application of both two- and three-parameters Weibull, and Anova variance approaches. The comparison between results of this study leads to the following conclusions:

1. The current research is better than the previous ones found in the literature because almost of the authors have considered the treatment of the jute fibers with a high concentration of NaOH (5%, 10% and 25%). However, in the present investigation it has been demonstrated that for the jute yarns the best results leading to an enchantment of the mechanical properties are obtained at low concentration of NaOH (2%) and low immersion times (2h) which is more environmental friendly. In other words, the NaOH treatment improves the mechanical properties of the jute yarns, and provides an increase of 5% to 34% of the tensile strength, and 5% to 25% for the Young's modulus and equivalent strain compared to the untreated fibers, using low concentrations (0.5% and 2%). Optimum results are obtained for a 2% NaOH concentration along with a 2 hours immersion time with 178.4 MPa for the stress, 26.4 GPa for the Young's modulus and 4.17% for the strain.
2. The experimental results obtained are characterized by their high dispersion, leading to the need for a statistical analysis to achieve a true estimation of the mechanical properties.
3. The two-parameter Weibull distribution analysis leads to better results compared to its three-parameter counterpart in terms of estimation of the experimental results obtained.

4. The Anova approach was also applied to the experimental results, with a 95% of confidence level. By using this statistical method one can conclude that the treatment affects the mechanical properties of jute yarns. For the best case obtained with a 2% NaOH treatment for an immersion time of 2 hours, the Fisher factors of the ultimate stress and strain are valued at F = 8.90 and F = 4.23. These values are greater than their critical threshold (F_{cr} = 2.60). This means that there are significant differences in stress and strain between treatments. However, the Young's modulus of F = 0.62 is less than the critical value, which means there are non-significant differences of the Young's modulus between treatments.

5. The analysis of the spectra obtained by the FTIR technique shows that the peaks at 1732 cm^{-1} and 1250 cm^{-1} vanish for the treated jute fiber. This corresponds to the C=O stretching bands of hemicelluloses and CH stretching of aromatic skeleton ring vibration of lignin.

Acknowledgements

The authors would like to thank Mr. Mahmoud Saidia for correcting the English language.

References

[1] A. Roy, S. Chakraborty, S.P. Kundu, R.K Basak, S.B. Majumder, B. Adhikari, Improvement in mechanical properties of jute fibers through mild alkali treatment as demonstrated by utilisation of the Weibull distribution model, Bio-res. Tech. 107 (2012) 222-228.

[2] A. Memon, A. Nakai, Mechanical properties of Jute spun yarn/PLA tubular braided composite by pultrusion molding, Energy Proc. 34 (2013) 818 – 829.

[3] A.MIR, R. Zitoune, F. Collombet, B. Bezzazi, Study of mechanical and thermo mechanical properties of jute/epoxy composite laminate, Reinf. Plas. Comp. 29 (2010) 1669-1680.

[4] A. Belaadi, A. Bezazi, M. Bourchak, F. Scarpa, Tensile static and fatigue behavior of sisal fiber, Mater. Des. 46 (2013) 76–83.

[5] F.de Andrade Silva, N. Chawla, R. D. de Toledo Filho, Tensile behavior of high performance natural (sisal) fibers, Comp. Sci. Tech. 68 (2008) 3438-3443.

[6] C. Baley, Analysis of the flax fibers tensile behavior and analysis of the tensile stiffness increase, Appl. Sci. Man. 33 (2002) 939-948.

[7] A.A. Abdul Nasir, A.I. Azmi, A.N.M. Khalil, Measurement and optimisation of residual tensile strength and delamination damage of drilled flax fibre reinforced composites, Measurement.75 (2015) 298–307.

[8] G.W. Beckermann, K.L. Pickering, Engineering and evaluation of hemp fiber reinforced polypropylene composites: Micro-mechanics and strength prediction modeling, Appl. Sci. Man.40 (2009) 210-217.

[9] A. Benyahia, A. Merrouche, Effect of chemical surface modifications on the properties of alfa fiber-polyester composites, Polym. Plas. Tech. Eng.53 (2014) 403-410.

[10] A. Elsaid, M. Dawood, R. Seracino, C. Bobko, Mechanical properties of kenaf fiber reinforced concrete, Const. Buil. Mater. 25 (2011) 1991-2001.

[11] A.N. Benítez, M.D. Monzón, I. Angulo, Z. Ortega, P.M. Hernández, M.D. Marrero, Treatment of banana fiber for use in the reinforcement of polymeric matrices, Measurement. 46 (2013) 1065-1073.

[12] R. Chollakup, W. Smitthipong, W. Kongtud, R. Tantatherdtam, Polyethylene green composites reinforced with cellulose fibers (coir and palm fibers): effect of fiber surface treatment and fiber content, Adh. Sci. Tech. J. 27 (2013) 1290-1300.

[13] S. Amroune, A. Bezazi, A. Belaadi, C. Zhu, F. Scarpa, S. Rahatekar, A. Imad, Tensile mechanical properties and surface chemical sensitivity of technical fibers from date palm fruit branches (Phoenix dactylifera L.), Appl. Sci. Man. 71 (2015) 95-106.

[14] D. Rosa, I. M. Kenny, J. M. D Puglia, C. Santulli, F. Sarasini, Morphological, thermal and mechanical characterization of okra (Abel moschusesculentus) fibers as potential reinforcement in polymer composites,Comp. Sci. Tech. 70(2010) 116-122.

[15] J. Lin, L. Yu, F. Tian, N. Zhao, X. Li, F. Bian, J. Wang, Cellulose nanofibrils aerogels generated from jute fibers, Carb. Polym. 109 (2014) 35-43.

[16] R. Codispoti, D.V. Oliveira, R.S. Olivito, P.B. Lourenço, R. Fangueiro, Mechanical performance of natural fiber-reinforced composites for the strengthening of masonry. Comp. Part B: Eng. 77 (2015) 74-83.

[17] M. Rokbi, H. Osmani, l'effet des traitements de surface des fibres sur les propriétés mécaniques de composites polyester- fibres alfa, 20eme Congrès Français de Mécanique ; Aout 29-Septembre 2 ; Besançon, France.

[18] A. Alawar, A. M. Hamed, K. Al-Kaabi, Characterization of treated date palm tree fiber as composite reinforcement, Comp. Part B: Eng. 40 (2009) 601-606.

[19] E. Balnois, F. Busnel, C. Baley, Y. Grohens, An AFM study of the effect of chemical treatments on the surface microstructure and adhesion properties of flax fibers, Comp. Interfaces 14 (2007) 715-731.

[20] I. Taha, L. Steuernagel, G. Ziegmann, Optimization of the alkali treatment process of date palm fibers for polymeric composites. Comp. Interfaces 14 (2007) 669-684.

[21] K. Sever, M. Sarikanat, Y. Seki, G. Erkan, Ü.H. Erdoğan, S. Erden, Surface treatments of jute fabric: the influence of surface characteristics on jute fabrics and mechanical properties of jute/polyester composites, Indust. crops Prod. 35 (2012) 22-30.

[22] J. Siroky, R.S. Blackburna, T. Bechtold, J. Taylor, P. White, Alkali treatment of cellulose II fibers and effect on dye sorption, Carbo. Polymers 84 (2011) 299–307.

[23] A. Lewington, Plants for People: Eden Project Books/Transworld Publisher: London 2003.

[24] A. Saaidia, A. Bezazi, A. Belbah, S. Amroune, F. Scarpa. Evaluation of Mechanical Properties of Jute yarns by two and three parameters Weibull Method, Structural integrity and life 15 (2015) 157–167.

[25] D. Ray, B.K. Sarkar, Characterization of alkali-treated jute fibers for physical and mechanical properties, Appl. Polym. Sci. J. 80 (2001) 1013-1020.

[26] H. Hamada, N. Ikuta, N. Nishida, Z. Maekawa, Effect of interfacial silane network structure on interfacial strength in glass fiber composites, Composites 25 (1994) 512-515.

[27] V. Anggraini, A. Asadi, B.B.K. Huat, H. Nahazanan, Effects of coir fibers on tensile and compressive strength of lime treated soft soil, Measurement 59 (2015) 372-381.

[28] M.K. Hossain, M.W. Dewan, M. Hosur, S. Jeelani, Mechanical performances of surface modified jute fiber reinforced biopolnanophased green composites, Comp. Part B: Eng. 42(2011) 1701-1707.

[29] S. K. Shaha, S. Dyuti, Q. Ahsan, M. Hasan, Effect of Alkali Treatment on Surface Morphology and Properties of Jute Yarns, Adv. Mat. Res. Vols 264-265 (2011) 1922-1927.

[30] N. I. Mbada1, O. Aponbiede, T. Ause, A. Alabi, Effects of Mercerization Treatment on Kenaf Fibre (Hibiscus cannabinus L.), Int. J. Mat. Eng., 6 (2016) 8-14.

[31] H. Onggo, S. Pujiastuti, Effect of Weathering on Functional Group and Mechanical Properties of Polypropylene-Kenaf Composites, Jurnal Sains Materi Indonesia, 11(2010) 1-6.

[32] A. Belaadi, A. Bezazi, M. Bourchak, F. Scarpa, C. Zhu, Thermo-chemical and statistical mechanical properties of natural sisal fibers, Comp. Part B: Eng. 67 (2014) 481-489.

[33] A. Bezazi, S. Amroune, F. Scarpa, Statistical analysis and effect of chemical treatment on the physico-mechanical behavior of fibres from date-palm fruit branches, Rev. Sci. Technol., Syn. 31(2015)108 -120.

[34] A.S. Virk, W. Hall, J. Summerscales, Failure strain as the key design criterion for fracture of natural fibre composites, Comp. Sci. Tech. 70(2010) 995-999.

[35] J.M. Park, S.T. Quang, B.S. Hwang, K.L. De Vries, Interfacial evaluation of modified Jute and Hemp fibers/polypropylene (PP)–maleic anhydride polypropylene copolymers (PP–MAPP) composites using micromechanical technique and nondestructive acoustic emission,Comp. Sci. Tech. 66(2006) 2686 - 2699.

[36] L. Peponi, J. Biagiotti, J.M. Kenny, I. Mondragon, Statistical analysis of the mechanical properties of natural fibers and their composite materials, II. Composite materials: Poly. Comp. 29 (2008) 321-325.

[37] M. Guo, T. H. Zhang, B. W. Chen, L. Cheng, Tensile strength analysis of palm leaf sheath fiber with Weibull distribution, Appl. Sci. Man. 62 (2014) 45-51.

Figure captions

Fig. 1. (a) Bundle of 30 yarn jute fibers, (b) Measurement of the diameter using optical microscope.

Fig.2. Scanning electron microscopy (SEM) image of untreated (a,b) and treated (c,d) yarn jute fibers

Fig. 3. Spectra of jute fibers untreated and treated by different concentrations of NaOH for diverse immersion times.

Fig. 4. Tensile strength representation:

(a) Stress/Strain curves of thirty tests on untreated yarn jute fibers;

(b) Representative stress/strain curve of the thirty tests on untreated yarn jute fibers;

(c) Comparison of representative stress/strain curves of thirteen group's treated and untreated yarn jute fibers;

(d) Comparison of representative stress/strain curves of treated and untreated yarn jute fibers.

Fig.5. Mechanical properties of untreated yarn jute fibers and treated by different NaOH concentrations for diverse immersion times.

Fig.6. Two-and Three-parameter Weibull statistical analysis results of untreated yarn jute fibers and treated by various NaOH concentrations during 2 hours immersion time.

Fig.7. Individual value diagrams of the mechanical properties of untreated yarn jute fibers and treated by different NaOH concentrations for diverse immersion times.

Fig.8. Representation of the residual stress values

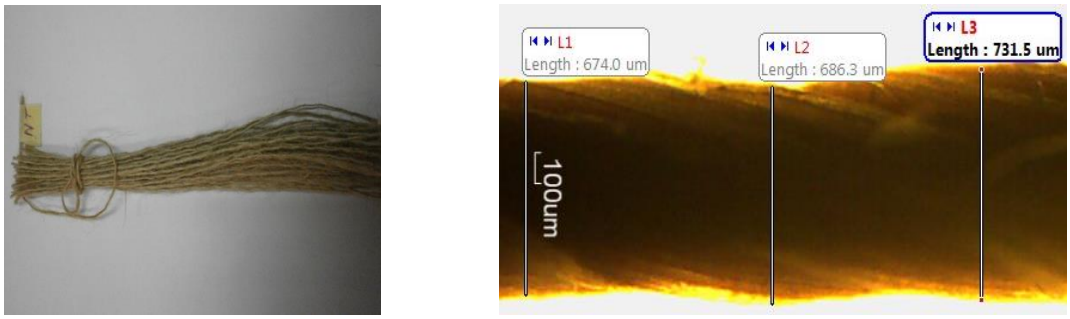
Table captions

Table 1. Peaks' attribution with their intensities observed in FTIR spectra of jute fibers untreated and treated by different concentrations of NaOH for diverse immersion times.

Table 2. Average values of the mechanical properties of untreated yarn jute fibers and treated by different concentrations of NaOH for diverse immersion times.

Table 3. Average values of 2 and 3 parameters Weibull yarns jute fibers untreated and treated by NaOH for different concentrations during 30 min, 2h, 8h and 12h immersions time.

Table4. Variance analysis of tensile strength (MPa), Young's modulus (GPa) and strain (%) versus NaOH concentration ratio at 95% level of significance.



-a- -b-

Fig. 1. (a) Bundle of 30 yarn jute fibers, (b) Measurement of the diameter using an optical microscope.

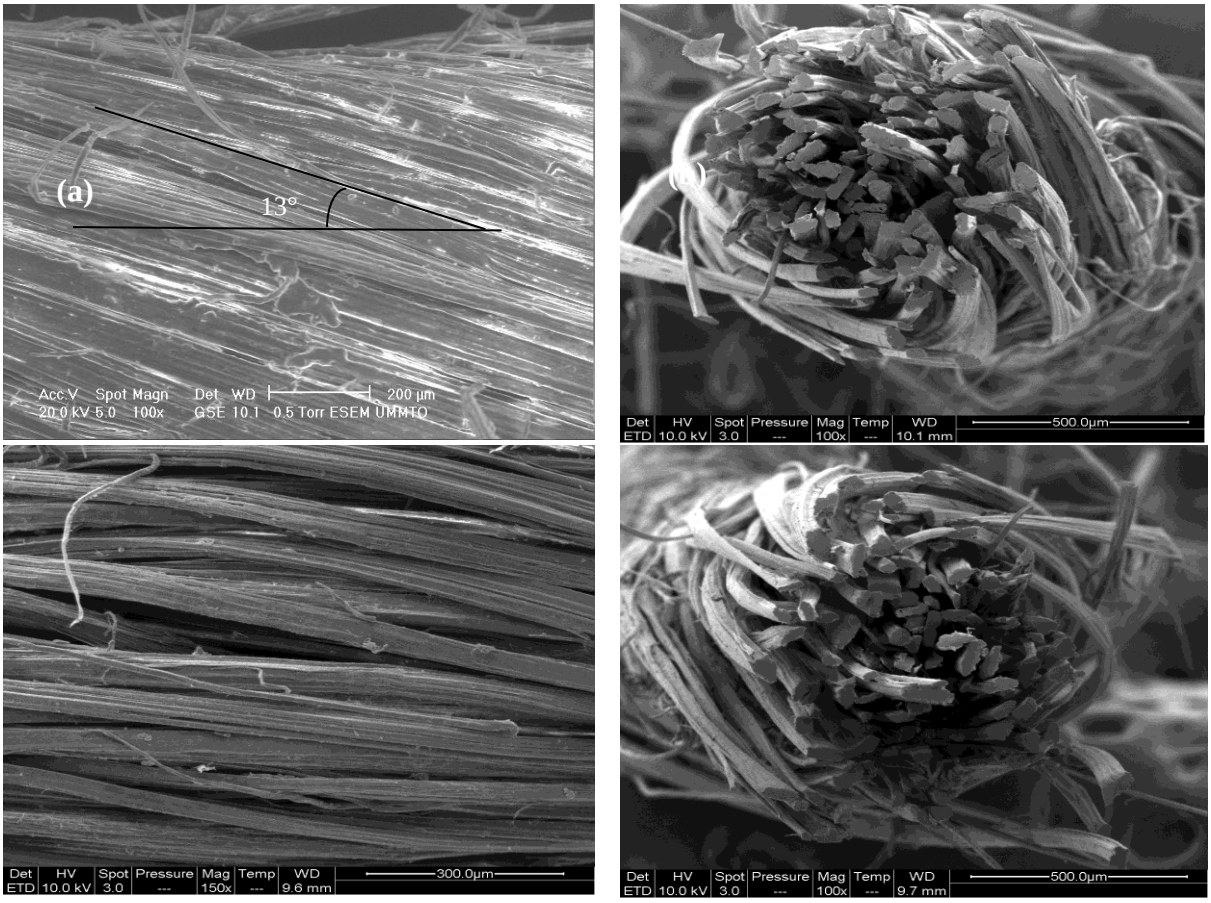


Fig. 2. Scanning electron microscopy (SEM) image of untreated (a,b) and treated (c,d) yarn jute fibers.

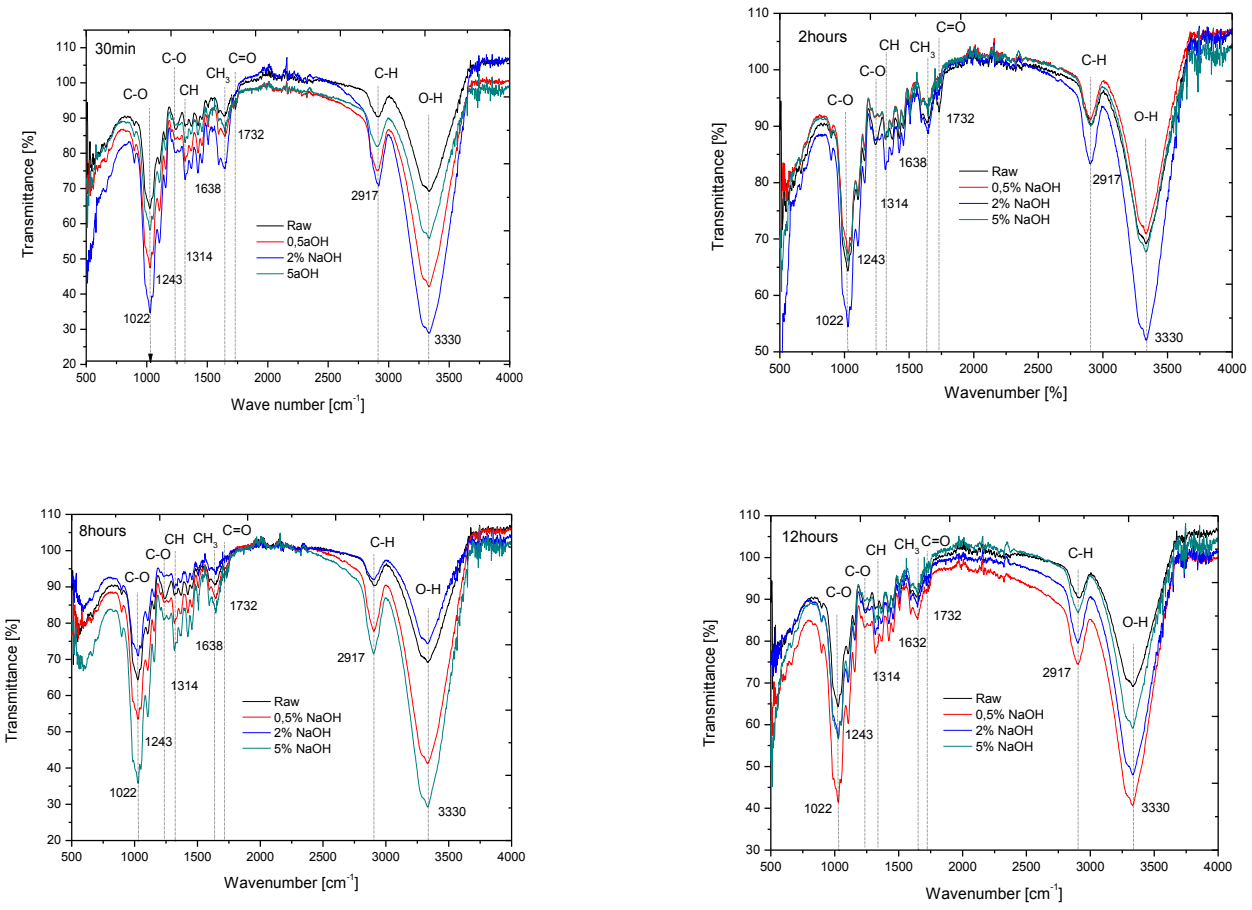


Fig. 3. FTIR spectra of jute fibers untreated and treated by different concentrations of NaOH for diverse immersion times.

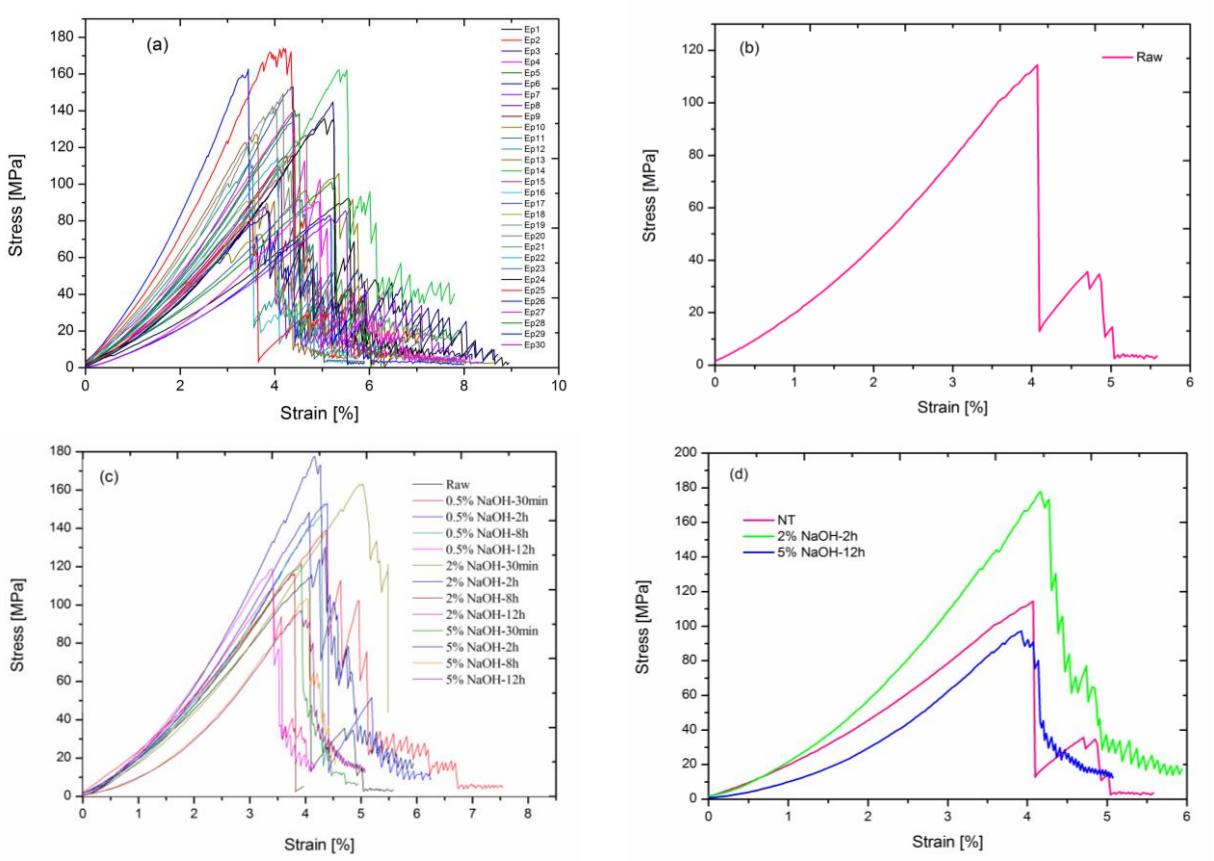


Fig. 4. Tensile strength representation: (a) Stress/Strain curves of thirty tests on yarn jute fibers; (b) Representative stress/strain curve; (c) Comparison of representative stress/strain curves of thirteen group's treated and untreated yarn jute fibers; (d) Comparison of representative stress/strain curves of treated and untreated yarn jute fibers.

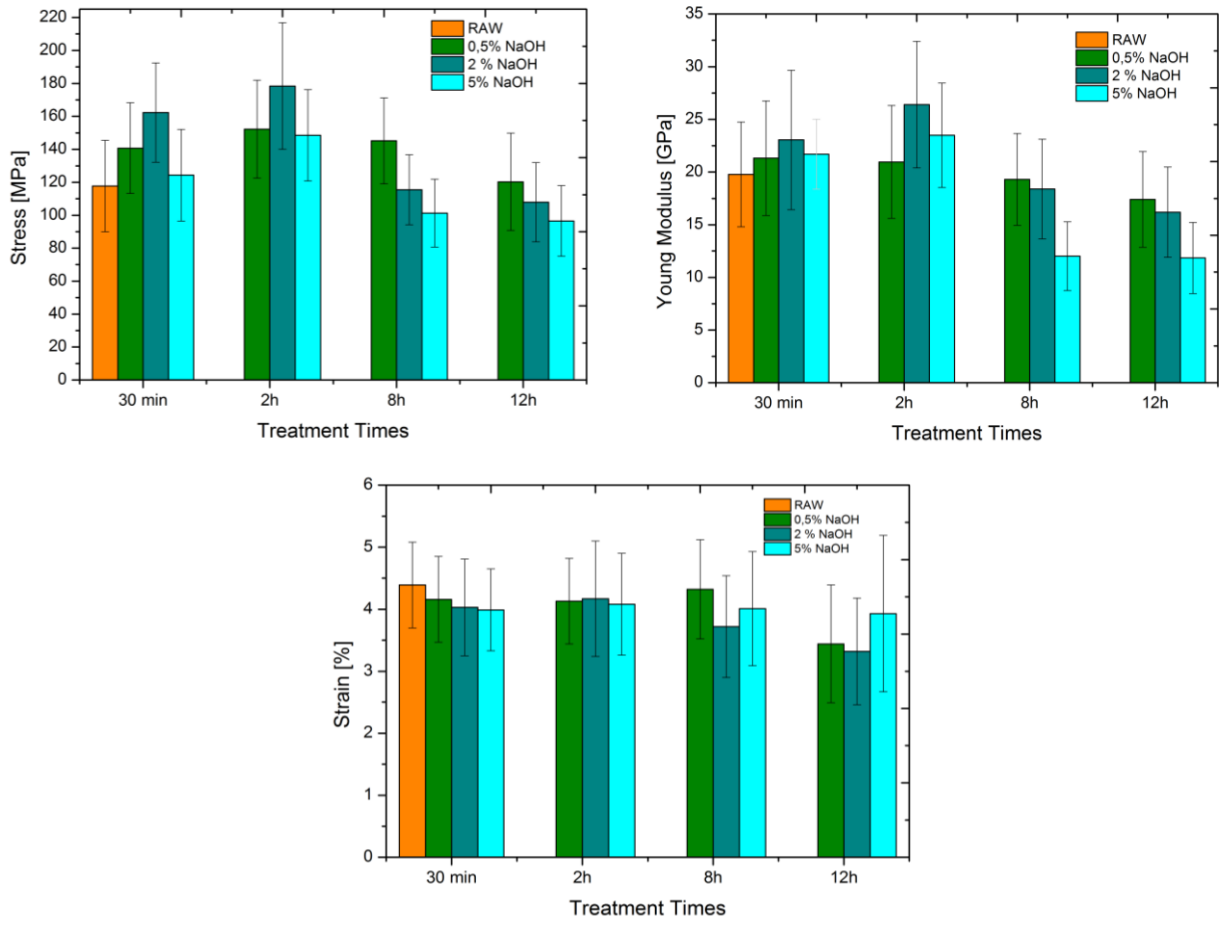


Fig. 5. Mechanical properties of untreated yarn jute fibers and treated by different NaOH concentrations for diverse immersion times.

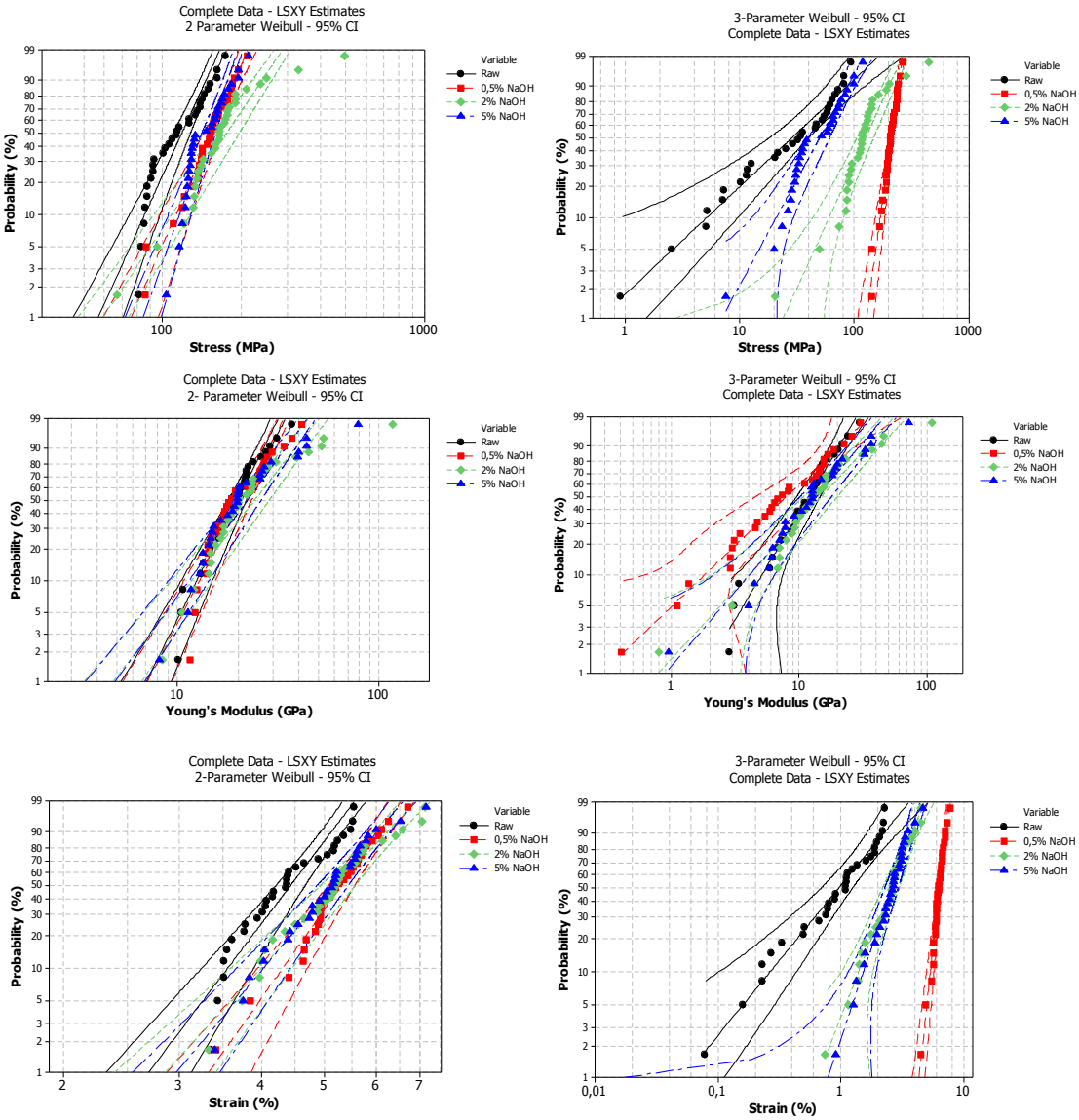
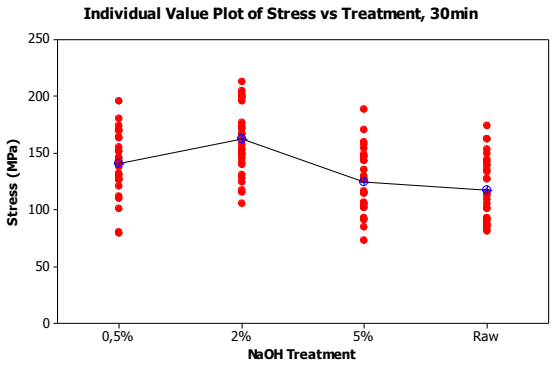
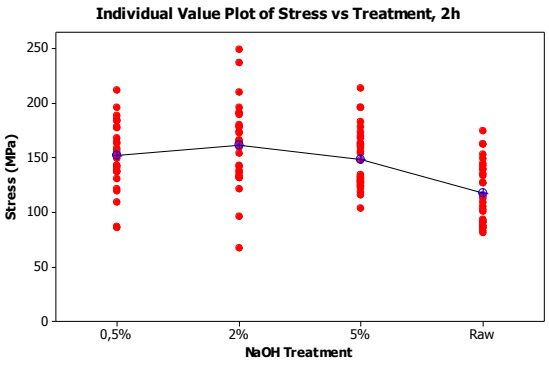
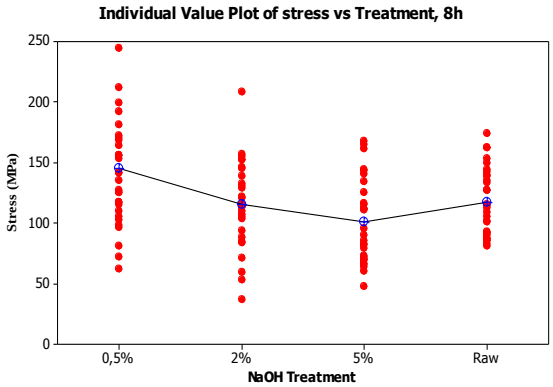


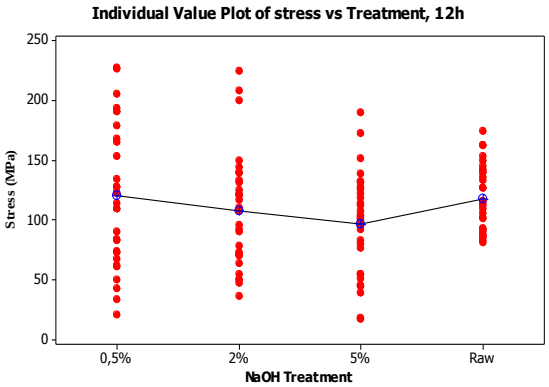
Fig. 6. Two-and Three-parameter Weibull statistical analysis results of untreated yarn jute fibers and treated by various NaOH concentrations during 2 hours immersion time

(a)

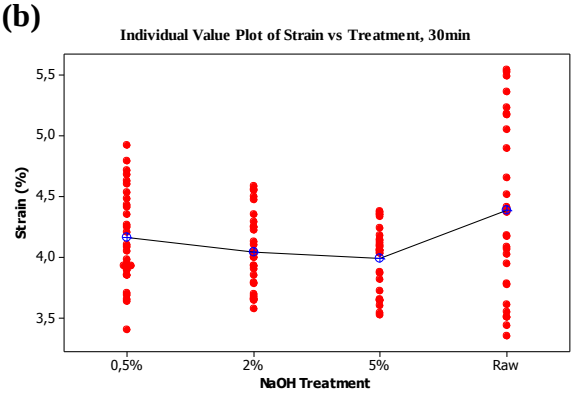

Individual Value Plot of Stress vs Treatment, 30min
Stress (MPa)
250
200
150
100
50
0
0,5%
2%
5%
Raw
NaOH Treatment

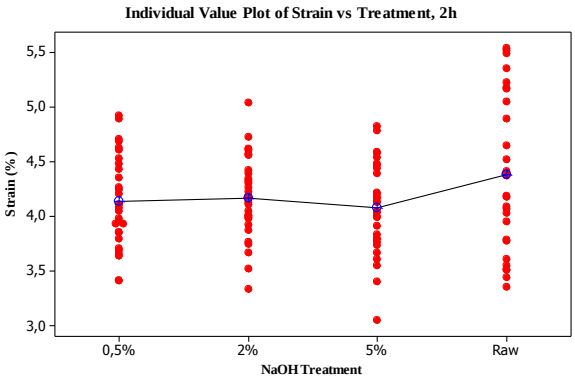

Individual Value Plot of Stress vs Treatment, 2h
Stress (MPa)
250
200
150
100
50
0
0,5%
2%
5%
Raw
NaOH Treatment

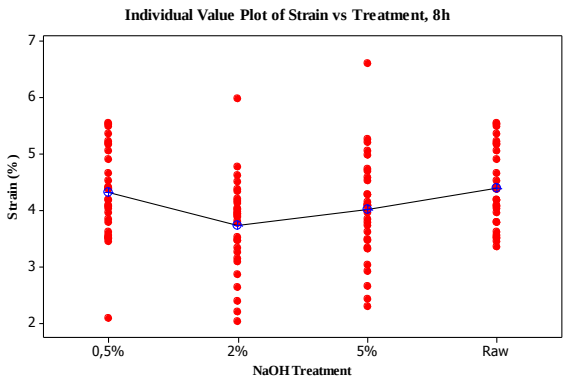

Individual Value Plot of stress vs Treatment, 8h
Stress (MPa)
250
200
150
100
50
0
0,5%
2%
5%
Raw
NaOH Treatment

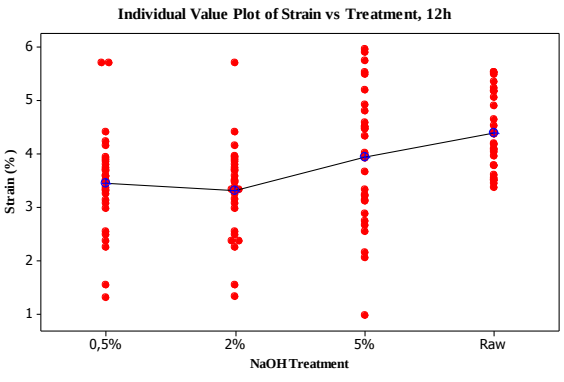

Individual Value Plot of stress vs Treatment, 12h
Stress (MPa)
250
200
150
100
50
0
0,5%
2%
5%
Raw
NaOH Treatment

(b)


Individual Value Plot of Strain vs Treatment, 30min
Strain (%)
5,5
5,0
4,5
4,0
3,5
0,5%
2%
5%
Raw
NaOH Treatment


Individual Value Plot of Strain vs Treatment, 2h
Strain (%)
5,5
5,0
4,5
4,0
3,5
3,0
0,5%
2%
5%
Raw
NaOH Treatment


Individual Value Plot of Strain vs Treatment, 8h
Strain (%)
7
6
5
4
3
2
0,5%
2%
5%
Raw
NaOH Treatment


Individual Value Plot of Strain vs Treatment, 12h
Strain (%)
6
5
4
3
2
1
0,5%
2%
5%
Raw
NaOH Treatment

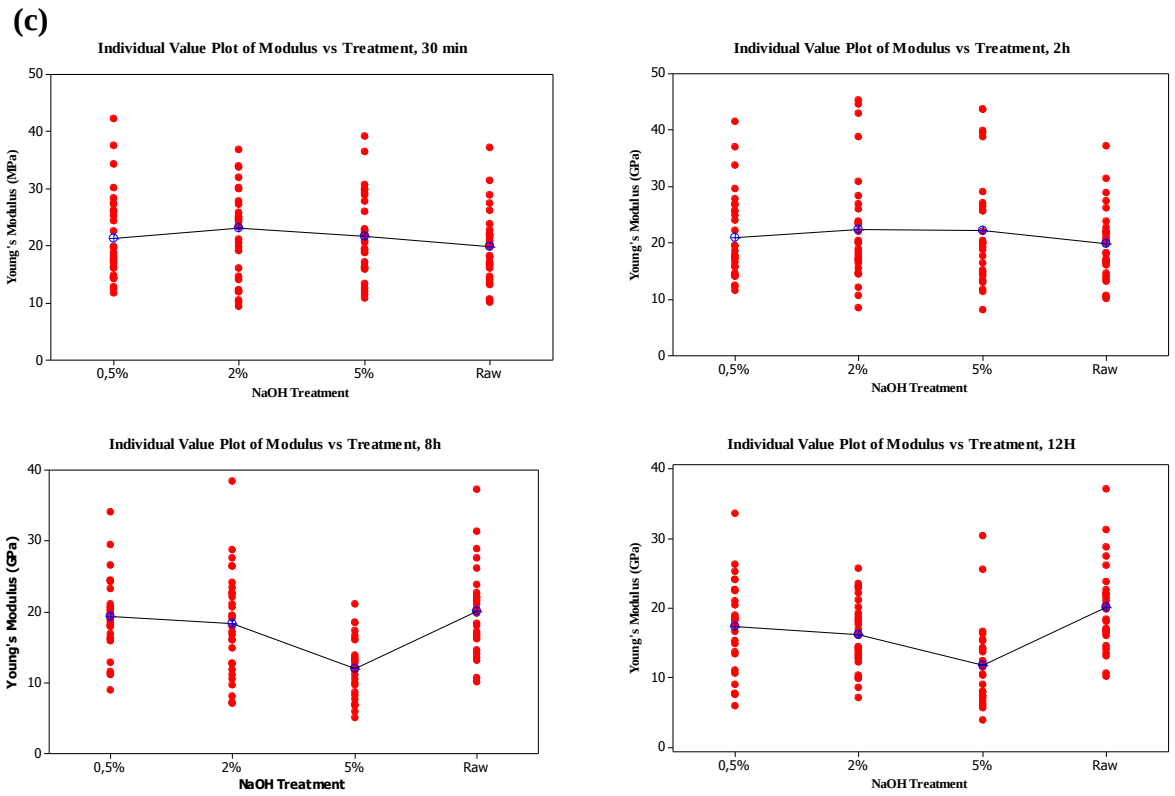


Fig. 7. Individual value diagrams of the mechanical properties of untreated yarn jute fibers and treated by different NaOH concentrations for diverse immersion times.

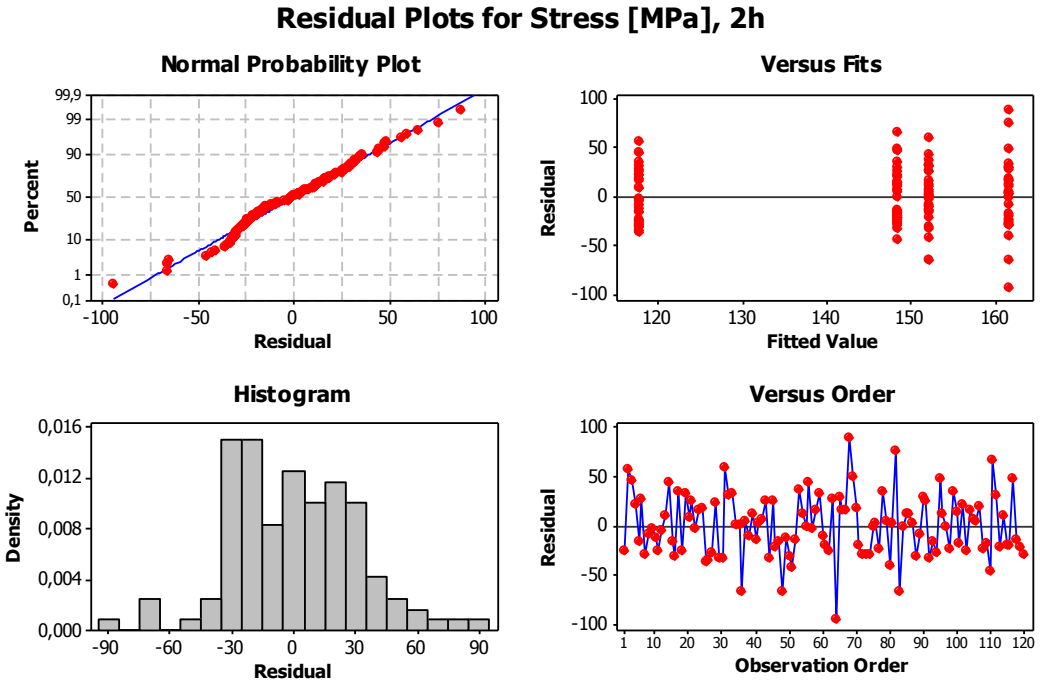


Fig. 8. Representation of the residual stress values

Table 1. Peaks' attribution with their intensities observed in FTIR spectra of jute fibers untreated and treated by different concentrations of NaOH for diverse immersion times.

Fiber	*Treatment* (NaOH)		1	2	3	4	5	6	7	Ref.
		Peak	C-O Stretching vibration	C-O stretching vibration of the acetyl group in lignin	CH symmetric stretching and aromatic	CH_3 Asymmetric stretching	C=O Stretching vibration of carboxylic acid	C-H Stretching of cellulose	O-H Hydrogen bonded of OH stretching in cellulose	
		Position	1022	1243	1314	1638	1732	2917	3330	
Jute	*Raw*	*Height*	64.42	86.71	88.47	90.58	92.85	90.58	69.26	This work
	0.5% -30min	*Height*	64.14		86.89	89.78	-	91.60	84.46	
	2% -30min	*Height*	34.57	-	72.99	74.84	-	70.88	29.18	
	5% -30min	*Height*	58.12	-	83.31	86.04	-	82.10	55.71	
	0.5%-2h	*Height*	67.45	-	88.18	90.28	-	91.17	70.95	
	2%-2h	*Height*	54.80	-	82.50	85.58	-	83.26	51.71	
	5%-2h	*Height*	66.02	-	87.80	89.98	-	90.33	67.84	
	0.5%-8h	*Height*	53.63	-	80.17	83.14	-	77.90	41.63	
	2%-8h	*Height*	71.15	-	89.77	91.88	-	91.95	74.62	
	5%-8h	*Height*	36.16	-	72.66	83.30	-	71.78	28.96	
	0.5%-12h	*Height*	41.44	-	77.27	80.42	-	74.30	41.00	
	2%-12h	*Height*	57.39	-	81.28	84.28	-	79.45	48.13	
	5%-12h	*Height*	56.77	-	84.32	87.05	-	86.89	58.94	
Kenaf	*Raw*	*Position*	897 1045	1251	- 1420	1575 -	1737	2923	3440 3812	[30]
		Height	12.88 10.29	11.68	- 8.37	6.15 -	11.87	17.17	6.45 12.19	
	1%	*Position*	802 1043	-	- 1420	1576 -	-	2932	3419 -	
		Height	15.42 13.13	-	- 11.96	10.05 -	-	14.93	10.03 -	
Jute	*Raw*	*Position*	830 1030	1240	1370 1455	1625	1755	2900	3350	[29]
Jute	*5% -2h*	*Position*	-	-	- 1464	-	1730	2950	3400	[28]
kenaf	*Raw*	*Position*	899 1053	-	- 1505	1595 1640	1740	2900	3400	[31]
Sisal	*Raw*	*Position*	1027	1236	1371 1426	1604	1736	2918	3331	[32]

Table 2. Average values of the mechanical properties of untreated yarn jute fibers and treated by different concentrations of NaOH for diverse immersion times.

Experimental results												
Fiber	*GL mm*	*Concentration* [NaOH]	*Stress σ* [MPa]	*SD*	*CoV %*	*Young's Modulus E* [GPa]	*SD*	*CoV %*	*Strain ε* [%]	*SD*	*CoV %*	*Ref.*
Yarn Jute	*50*	*Raw*	*117.70*	*27.77*	*23.59*	*19.78*	*4.98*	*25.18*	*4.39*	*0.69*	*15.72*	*This work*
		0.5%-30min	*140.74*	*27.50*	*19.54*	*21.32*	*5.44*	*25.51*	*4.16*	*0.69*	*15.00*	
		2%-30min	*162.30*	*30.09*	*18.54*	*23.05*	*6.61*	*28.68*	*4.03*	*0.78*	*15.35*	
		5%-30min	*124.31*	*27.74*	*22.31*	*21.7*	*3.32*	*15.30*	*3.99*	*0.66*	*16.54*	
		0.5%-2h	*152.22*	*29.74*	*19.54*	*20.96*	*5.35*	*25.52*	*4.13*	*0.69*	*16.70*	
		2%-2h	*178.39*	*38.42*	*21.54*	*26.4*	*6.01*	*22.76*	*4.17*	*0.93*	*22.45*	
		5%-2h	*148.54*	*27.72*	*18.66*	*23.5*	*4.95*	*21.06*	*4.08*	*0.82*	*20.09*	
		0.5%-8h	*145.13*	*26.09*	*17.98*	*19.3*	*4.35*	*22.54*	*4.32*	*0.80*	*18.52*	
		2%-8h	*115.43*	*21.25*	*18.41*	*18.39*	*4.73*	*25.72*	*3.72*	*0.82*	*22.04*	
		5%-8h	*101.24*	*20.61*	*20.36*	*12.02*	*3.26*	*27.12*	*4.01*	*0.92*	*22.94*	
		0.5%-12h	*120.32*	*29.54*	*24.55*	*17.4*	*4.55*	*26.15*	*3.44*	*0.95*	*27.62*	
		2%-12h	*107.88*	*24.00*	*22.25*	*16.2*	*4.29*	*26.48*	*3.32*	*0.86*	*25.90*	
		5%-12h	*96.56*	*21.46*	*22.22*	*11.85*	*3.38*	*28.52*	*3.93*	*1.26*	*32.06*	
Jute	50	Raw	*81.42*	*10*	-	*1.92*	*0.45*	-	*3.83*	*0.62*	-	[28]
		5%-2h	*92.54*	*11*	-	*2.25*	*0.34*	-	*3.21*	*0.68*	-	
FPD	50	Raw	*125.97*	*33*	*26*	*4.52*	*1.58*	*0.35*	*3.44*	*0.8*	*0.23*	[33]
		2%-48h	*291.9*	*11*	*28*	*8.96*	*3.14*	*0.35*	*4.10*	*0.6*	*0.15*	
Yarn Jute	-	Raw	*74.8*	-	*20*	*27. 69*	-	*24*	*0.03*	-	*15*	[16]
Flax	-	Raw	*198.1*	-	*14*	*59.13*	-	*18*	*3.22*	-	*7*	[16]
Hemp	-	Raw	*124.1*	-	*19*	*42.37*	-	*16*	*2.94*	-	*12*	[16]
Sisal	20	Raw	*424*	*125*	-	*9.69*	*3.02*	-	*6.03*	*2.16*	-	[32]

SD:Standard Deviation and CoV: Covariance

Table 3. Average values of two- and three-parameter statistical Weibull untreated yarns jute fibers and treated by different concentrations of NaOH during diverse immersion times.

Concentration	*Two-parameter Weibull*				*Three-parameter Weibull*							
	m	σ_0	*m*	E_0	*m*	ε_0	*m*	σ_0	*m*	E_0	*m*	ε_0
Raw	*5.74*	*126.51*	*4.08*	*21.67*	*8.48*	*4.63*	*1.09*	*39.95*	*2.22*	*14.03*	*1.23*	*1.45*
0.5%-30min	*5.95*	*151.65*	*3.94*	*23.21*	*10.13*	*5.42*	*8.46*	*204.30*	*1.27*	*10.73*	*11.04*	*6.56*
2%-30min	*6.71*	*173.59*	*3.03*	*25.55*	*8.34*	*5.32*	*2.56*	*82.83*	*1.40*	*16.32*	*2.33*	*1.94*
5%-30min	*5.67*	*134.09*	*3.8*	*23.82*	*9.40*	*5.25*	*2.64*	*74.74*	*1.64*	*13.71*	*4.22*	*2.68*
0.5%-2h	*5.95*	*164.03*	*3.94*	*22.82*	*10.24*	*5.39*	*8.46*	*220.97*	*1.27*	*10.55*	*11.04*	*6.56*
2%-2h	*3.89*	*193.27*	*2.62*	*27.73*	*6.98*	*5.51*	*2.56*	*144.97*	*1.44*	*19.14*	*3.08*	*2.88*
5%-2h	*7.34*	*157.88*	*2.81*	*25.32*	*7.72*	*5.39*	*2.14*	*59.17*	*1.55*	*17.26*	*3.55*	*2.87*
0.5%-8h	*3.65*	*159.76*	*4.34*	*21.13*	*6.39*	*4.63*	*2.11*	*110.36*	*3.04*	*16.31*	*12.54*	*8.32*
2%-8h	*3.55*	*128.27*	*2.98*	*20.49*	*5.39*	*4.03*	*4.66*	*156.12*	*2.05*	*16.12*	*4.33*	*3.39*
5%-8h	*3.85*	*110.93*	*3.51*	*13.30*	*5.40*	*4.34*	*1.83*	*66.18*	*2.07*	*9.39*	*3.07*	*2.82*
0.5%-12h	*2.11*	*135.96*	*2.98*	*19.45*	*4.11*	*3.78*	*1.99*	*131.91*	*2.48*	*17.27*	*5.14*	*4.47*

2%-12h	*2.77*	*119.91*	*3.98*	*17.85*	*4.34*	*3.63*	*1.65*	*88.19*	*2.76*	*13.81*	*6.11*	*4.73*
5%-12h	*2.15*	*109.77*	*2.90*	*13.07*	*3.27*	*4.39*	*3.35*	*143.54*	*1.84*	*9.84*	*5.30*	*6.22*

Table 4. Variance analysis of tensile strength (MPa), Young's modulus (GPa) and strain (%) versus NaOH concentration ratio at 95% level of significance.

Variations Source	Squares sum	Degree of freedom	Squares mean	F	Probability	F_{cr}
ANOVA test for ultimate tensile stress data (120 samples)						
Between groups	55613	3	18538	8.90	0.000	2.60
Within groups	241556	116	2082			
Total	297168	119				
ANOVA test for Young's modulus (120 samples)						
Between groups	135.2	3	45.1	0.62	0.604	2.60
Within groups	8451.9	116	72.9			
Total	8587.2	119				
ANOVA test for strain at failure data (120 samples)						
Between groups	8.353	3	2.784	4.23	0.000	2.60
Within groups	76.373	116	0.658			
Total	84.725	119				

Research Highlights

- Influence of NaOH alkali treatment on the mechanical properties of yarns jute fibers.
- Micro structural analysis of untreated and treated jute fiber.
- Statistical mechanics and properties of jute yarns