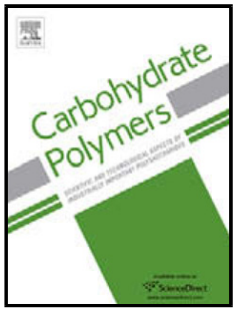

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Characterization of alkali treated and untreated new cellulosic fiber from Saharan aloe vera cactus leaves

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Highlights

- Novel natural Saharan Aloe Vera Cactus Leaves fibers were characterized in this work.
- Effects of alkali treatment on the fibers were studied.
- Chemical composition was determinate by using standard test methods.
- Mechanical properties were investigated by single fiber test.
- Thermal behavior was investigated by Thermogravimetric Analysis.
- Characterized fiber has the potentiality to replace the harmful artificial fiber.

ABSTRACT

The aim of this study is to examine the use of new natural fibers, which are extracted from the Saharan aloe vera cactus plant leaves as reinforcement in polymer composites. The

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physicochemical, mechanical and thermal properties of the Saharan Aloe Vera Cactus Leaves (SACL) fibers are investigated, through the effect of alkali treatment. The contents of α-cellulose, hemicellulose, wax and moisture present in SACL fibers were characterized by standard test methods. The mechanical properties of SACL fibers were measured through single fiber tensile test. The interfacial strength between the fiber and matrix was estimated by the fiber pull-out test. These results ensure that the chemical and mechanical properties of the fibers are improved after the alkali treatment. FT-IR spectroscopic analysis confirms that the alkali treatment process has removed certain amount of amorphous materials from the fibers. XRD analysis results show that the alkali treatment has enhanced the Crystallinity Index and Crystalline Size of the fibers. Thermal behavior of the fibers was analyzed by using TGA. The thermal stability and the thermal degradation temperature increases after the alkali treatment of fibers. The morphologies of fibers were analyzed by SEM and prove that the fiber surfaces become rough after alkali treatment.

Keywords: Physicochemical properties, Mechanical properties, FT-IR, XRD, TGA analysis, Kinetic analysis.

1. Introduction

The recent growing environmental awareness has triggered the research attitude of the researchers towards developing the bio-degradable products (Iyer, & Torkelson, 2015). Because of increasing ecological consciousness, the use and end-of-life removal of synthetic composite structures, usually made of glass, carbon etc., are becoming more important, Hence, natural fiber based composite materials are used in many static and dynamic applications like automobiles,

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sports equipment's, constructions, electronic and food packing industries. The natural fibers are eco-friendly and little energy is needed for the production of fibers. The fibers possess low-density, low-cost and lower level hazards in the manufacturing process compared to the synthetic fibers (Jayaramudu, Guduri, & VaradaRajulu, 2009;Yoldas Seki et al., 2013;Sarikanatet al., 2014). Nowadays, the level of production of cellulosic fibers does not fulfill the growing industrial demands. That is why the researchers have incorporated new natural fibers such as Napier Grass Fiber Strands (Kommula et al., 2015), Thespesia (Reddy et al., 2013), Ferula (Suryanto et al., 2014), ProsopisJuliflora Bark (Saravanakumar et al., 2013), Red coconut empty fruit bunch fiber (Nagarajan et al., 2016), Kusha grass (Balaji et al., 2016) Indian mallow stem fiber (Vignesh et al., 2016) as reinforcement materials for thermoset and thermoplastic composites. The mechanical and thermal properties of the specific natural fibers extremely depend on whether the fibers are taken from plant bark, seeds, fruits or leaves along with the age of the plant, extraction process (retting) and the locations of the plant (Mohanty, Misra, & Drzal, 2001). The amount of α-cellulose, hemi (β+ γ)-cellulose, and lignin, present in lignocellulosic systems depends on the age of the plant (Mohanty, Misra, & Drzal, 2001). The natural fibers contain extremely renewable raw material of Cellulose fibrils, which contains a linear chain of several hundred β (1- 4) linked D-glucose units and lot of hydrogen bonds (hydroxyl groups) present in cellulose gives hydrophilic nature to the natural fiber. The hydroxyl groups absorb moisture from the atmosphere, when they come into contact with the fiber. The main drawback of using hydrophilic fibers as the reinforcement of hydrophobic polymeric matrices (like ethylene, polypropylene, etc.) is the poor interfacing between the fibers and the matrix (Sgriccia , Hawley , & Misra,2008;Alvarez, Ruscekaite, & Vazquez, 2003). Hemi (β+ γ)-cellulose or Pentosan is strongly bound to cellulose fibrils presumably by hydrogen bonds. Hemicellulosic

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polymers (amorphous material), have significantly lower molecular weight than the hydroxyl groups of cellulose. However, the hemicellulose is partly soluble in water (Xue, Li et al., 2007). Lignin is non-cellulosic biochemical and aromatic polymers. It is associated with hydroxyl and methoxyl groups and functions as a protecting device for carbohydrate from chemical & physical damages and stiffening of cell walls (Iyer, & Torkelson, 2015; Mohanty, Misra, & Drzal, 2001). The natural fibers have some drawbacks such as lower mechanical properties and thermal stability in addition to incompatibility with several polymer matrices compared to synthetic fibers (Obi Reddy et al., 2013). The natural fibers have higher moisture absorption due to the presence of hydroxyl and other polar groups and they lead to poor interface between the fibers and the resins (Obi Reddy et al., 2012). Various fiber surface treatments like alkali treatment (mercerization), acetylation treatment, silane treatment, peroxide treatment, isocyanate treatment, acrylation and permanganate treatment have been carried out and they result in improving composite properties (Obi Reddy et at., 2012). Alkali treatment is one of the most used chemical treatments leading to the reduction of moisture gain, as well as changes in the fiber surface. It leads to the improvement of mechanical and thermal properties (Kabir, Wang, Lau, & Cardona, 2012). The optimum alkali (5% NaOH) treatment of natural fiber is the low-cost method which produces very effective surface modification by removing certain amount of non-cellulosic chemical polymers and it increases the moisture resistance property and crystalline size of the fibers (Saravanan et al., 2014). The following reaction proceeds as a result of alkali treatment (Bogoeva-Gaceva et al., 2007):

$$\text{Cell-OH} + \text{NaOH} \longrightarrow \text{Cell-O}^{-}\text{Na}^{+} + \text{H}_2\text{O} + \text{surface impurities.}$$

Integration of new natural cellulosic fiber is available in abundance and with adequate properties, it can contribute to increase the production rate and meet a part of worldwide demand. In this

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way, a new kind of natural cellulosic fibers is extracted from the leaves of Saharan Aloe Vera Cactus (SAC) plant, which is a member of the Agavoideae family. The SAC plant grows to a height of 1-2 meter as shown in Fig. 1(a). It is abundantly available in Morocco country, which is part of the Sahara desert in the western tropical region of Africa. In this country, people use these plant fibers for weaving clothes, tablemats, window curtains etc. The world famous super fine Sabra silk sarees are manufactured in Morocco using these fibers. In this paper, the chemical, physical, surface morphology, mechanical and thermal properties of the alkali treated and untreated SACL fibers are extensively investigated. The experiments were carried out by the techniques of chemical analysis, Fourier Transform InfraRed Spectroscopy (FT-IR), X -Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), single filament tensile tests and ThermoGravimetric Analysis (TGA).The mechanical properties and the diameter of the samples were analyzed by using Weibull distribution in Minitab17 software.

2. Materials and methods

2.1 Materials

Natural fibers are extracted from the plant by various techniques like mechanical retting, chemical retting and water retting process (Kommula et al., 2013). The SACL fibers are extracted by water retting process where long spiky leaves from SAC plant are crushed and soaked in distilled water for two weeks to separate the fiber and the filament. The extracted fibers are washed with distilled water thoroughly for more than seven times to remove any pulp adhering to them. The fibers are dried in sunlight for about 10-12 hours to remove the residual moisture. The extracted SACL fibers are shown in Fig. 1(b). For the present investigation, the

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SACL fibers were purchased from Chandra Prakash, &Co., Jaipur, Rajasthan, India. Sodium hydroxide (analytical grade) pellets were purchased from Sigma–Aldrich, Bangaluru, Karnataka, India. The diglycidyl ether of bisphenol-A (DGEBA) with density1.6g/mL at 25°C and an epoxide equivalent weight of 172-176 g eq-1 were purchased from Sigma–Aldrich, Bangaluru, Karnataka, India. Epoxidized Soybean Oil (density @ 25°C =0.985g/cm^3) was purchased from Suvidhi industries, Vapi, Gujarat, India. Curing Agent: methylhexahydrophthalic anhydride and Catalyst: 2-methylimidazole obtained from Vasavibala Resins (P) Ltd., Chennai, Tamil Nadu, India.

2.2 Alkali treatment

The SACL fibers were treated with 5% of sodium hydroxide (NaOH) solution (by weight) at room temperature (27 °C) for 60 min at atmospheric pressure. Then, the fibers were washed with distilled water for several times until a range of pH value 7-7.2was reached. The optimized pH value was ensured due to the removal of NaOH contents in the fibers by using red litmus paper. The washed fibers were dried in a hot air oven at 102°C for a period of 24 hours to remove the excess moisture.

2.3 Physicochemical properties

The chemical compositions of the treated and untreated SACL fibers in terms of α-cellulose, hemicellulose, and lignin content were determined using standard test Methods (Doree, 1950; Pearl, 1967). The moisture content of the SACL fiber was identified using Sartorius MA45 moisture analyzer (Yoldas Seki, & Mehmet Sarikanat, 2013). The density of the fibers was determined by using the Mettler Toledo XSZ05 balance method (Sathishkumar,

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Navaneethakrishnan, & Shankar, 2012). The percentage of the ash content of the fibers was analyzed as per the ASTM E1755-01 standard and the wax content was quantified by the Conrad method (Contrad, 1944). The diameters of twenty SACL fibers were determined using air wedge micrometer (±0.001 mm) for both treated and untreated conditions (Nagarajan, & Balaji, 2016). The diameter of each fiber was measured at three different random locations and the average value was considered for Weibull distribution analysis.

2.4 Mechanical properties

2.4.1 Single fiber tensile test

In accordance with ASTM D 3822, the mechanical properties such as maximum tensile strength, young's modulus, and elongation at break were determined with an Instron 5500R universal testing machine. The analysis was carried out for a fiber gauge length of 70 mm at the crosshead speed of 5 mm/min. Twenty single SACL fibers were tested and the results were analyzed statistically using two parameters Weibull distribution for alkali treated and untreated conditions (Fiore et al., 2014). The microfibril angle (α) was calculated by using equation (1) (Charlet et al., 2009; Indran, & Edwin Raj, 2014):

$$\varepsilon = \ln\left(1 + \frac{Lf - Lo}{Lo}\right) = -\ln(\cos\alpha) \qquad (1)$$

Where ε is the beginning of the final linear part of the stress-strain curve, Lf is the length of a microfibril, which initially forms an angle α with the fiber axis, and Lo is the gauge length.

2.4.2 Fiber Pull-out test

By using single fiber pull-out test, the adhesion between the fiber and the matrix was characterized by the interfacial shear strength. The Epoxy and Epoxidized Soybean Oil bio-based

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blends were prepared at the ratio of 80:20 (Wt. %). Subsequently, 0.86 wt. % of curing agent and 0.90 wt. % of catalyst added to the resin blends and continuously stirred to get a homogeneous mixture. The fiber was embedded in the homogeneous mixture. The fiber pull-out test was performed after embedding of the fiber in the matrix for 2 hours at 150 °C. The embedded length (Le) of fiber in the Matrix was 10 mm and the gauge length was about 15 mm (Fiore, Scalici, Nicoletti, Vitale, Prestipino, & Valenza, 2016). The test was carried out at a crosshead speed of 1 mm/min. Six specimens were tested and the average value and the standard deviation values of the interfacial shear strength were reported for alkali treated and untreated condition. The interfacial shear strength (τ) of (Saravanakumar, Kumaravel, Nagarajan, Sudhakar, & Baskaran, 2013) the SACL fibers was calculated using equation (2)

$$\tau = \frac{F_{max}}{\Pi d L_e} \qquad (2)$$

Where F_{max} is the debonding force, d is the diameter of SACL fibers, and Le is the length of the fiber in the Matrix.

2.5 XRD analysis

The Crystalline Size (CS) and the Crystallinity Index (CI) of treated and untreated SACL fibers were examined by using XRD technique compatible with the computerized data acquisition facility and analytical tools, with the Cu-Kα radiation wavelength of 0.154 nm. All the samples were scanned in 2θ range between 10°and 81° at the rate of 1° /min in order to obtain an acceptable diffraction pattern. The CI (Segal, Creely, Martin, & Conrad, 1959; Kufre Edet Okon et al., 2017) of the fibers was calculated using equation (3):

$$CI = \frac{I_C - I_{am}}{I_C} X\ 100 \qquad (3)$$

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Where I_{am} represents the low-intensity peak (110) which contributes the amorphous fraction and the high-intensity peak (002) I_c, contributes the crystalline fraction.

The CS of the SACL fibers was calculated for treated and untreated conditions for the crystallographic plane (0 0 2) by using Scherer's formula expressed in equation (4) (Nishiyama, Kuga, & Okano, 2000; D'Almeida, Aquino, & Monteiro, 2006).

$$CS=K\lambda/\beta COS\theta \qquad (4)$$

Where K is the Scherrer constant (0.84), λ is the X-ray wavelength (0.154 nm), θ is the Bragg angle and β is the peak's full-width at half-maximum.

2.6 FT-IR analysis

The powdered samples of the alkali treated and untreated SACL fibers were mixed with potassium bromide (KBr) pellets with a scan rate of 32 scans per minute at a resolution of 4 cm-1 in the wave number region of 4000–500 cm-1 at the atmospheric condition. It was analyzed by using Smart iTR ATR Nicolet iS10 FTIR spectrometer. The transmittance curve of FT-IR was used to examine the functional group present in the samples.

2.7ThermoGravimetric Analysis

The thermal stability and the degradation behavior of alkali treated and untreated SACL fibers were analyzed by TGA of Jupiter thermal analyzer (Model STA 449 F3, NETZSCH, Germany). The nitrogen was kept at a flow rate of 20 ml/min for preventing oxidation effects. The measurement was examined using alumina crucible in the temperature range of 27°C-720°C.

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2.8Non-isothermal degradation kinetics analysis

The data that were interpreted from the non-isothermal TGA curves were subjected to mathematical analysis for the determination of kinetic activation energy (E_b) of both untreated and treated SACL fibers. The kinetic activation energy (E_b) (Broido, 1969) of the fibers was calculated by using broido's first-order kinetics equation. (5):

$$\ln\left[\ln\left(\frac{1}{Y}\right)\right] = -\left(\frac{E_b}{R}\right)\left[\left(\frac{1}{T}\right) + K\right] \qquad (5)$$

Where Y is the normalized weight $\frac{w_t}{w_o}$, w_t denotes the weight of the sample at any time t, w_o indicates the initial weight, R is the gas constant (8.32 J/molK), T is the temperature in Kelvin, K is the rate of constant, and T is the maximum peak temperature.

2.9Scanning Electron Microscopy (SEM)

The morphology of alkali treated and untreated SACL fibers were examined by using CARL ZEISS model V18 scanning electron microscope. Before the analysis, each fiber was cut to a height of 10 mm and coated with gold to make it conductive. Further, it was rubbed upon a 25 mm diameter aluminum disc.

3. Results and Discussion

3.1 Physicochemical and mechanical properties

The physicochemical and mechanical properties of alkali treated and untreated SACL fibers are summarized in Table 1. After the alkali treatment, hemicellulose and wax contents are reduced from 14.2 % to 8.2 % and 1.5% to 0.24 % respectively. This proves that NaOH treatment diminishes the intermolecular binding possibilities, which in turn leads to an increase

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of solubility of hemicellulose and wax content. The lignin content of the fiber does not vary after the alkali treatment of the fibers and it is shown in Table 1. The high content of hydrophobic lignin protects against the biological attack and it potentially contributes to the fiber properties and morphology (Saravanakumar, Kumaravel, Nagarajan, & Ganesh Moorthy, 2014). After the alkali treatment, holocellulose and α-cellulose contents of the SACL fibers are increased from 74.4% to 75.6 % and 60.2% to 67.4 %. It may provide better mechanical properties, due to the increase in solid cellulose, which formed a microcrystalline structure with high order crystalline regions and low order amorphous regions (SusheelKalia, Kaith, & InderjeetKaur 2011).These characteristics have been proved in the following section of XRD analysis. After the alkali treatment, the moisture content of the fibers is decreased from 7.6 % to 5.8 %. Due to this, the moisture resistance property of the fibers increases and reduces the Hydrophilic hydroxyl groups. The ash content of treated and untreated fibers is found to be 4.1% and3.4 %.The density is found to be increased from 1325.1 Kg/m^3 for untreated fibers to 1623.1 Kg/m^3 for treated fibers. After the alkali treatment, the increase in density occurs due to the removal of low denser regions (hemicellulose) and thus resulting in the increase of α-cellulose content in Wt. % of the composition (Vishnu Vardhini, K. J. et al., 2016).Among the twenty samples, the Stress-Strain curves of three treated and untreated samples are shown in Fig. 2(a). Fig. 2 (b) explains the linear and nonlinear portions of the stress-strain curve for untreated sample: The portion (A) represents that the deformation varies linearly of about 0.25%. It could be associated with the global loading of the SACL fiber of each cell wall. In the second portion (B), nonlinearity is observed from 0.25% to 1.6 % of deformation. It could be interpreted as an elasto-visco-plastic deformation of the SACL fiber. In the final portion (C), linearity is observed from 1.6% to the final rupture of the SACL fiber. It corresponds to the elastic response of the aligned microfibrils

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to the applied tensile strain (Charlet et al., 2009). Based on the stress-strain curve, the results of the tensile tests on single lignocellulosic fiber are difficult to analyze, since a high scatter is observed. This observation can be mainly related to several factors such as source, age of the plant, the processes of fiber extraction and the presence of defects (Liu, Han, Huang, & Zhang, 2009; Fiore et al., 2014). For these reasons, a statistical approach is required to evaluate the mechanical and physical properties of natural fibers using two parameters Weibull distribution (Andersons et al., 2005; De Rosa, 2010; Fiore et al., 2014; Weibull, 1939). The Weibull shape parameter signifies the characteristic value of the distribution and the reliability of the experimental data. If the parameter is 3, the curve approximates a normal curve and it is between 2 and 4. It is still normal. Moreover, the higher shape parameter is equivalent to a lower coefficient of variation in parameters in a normal distribution (Fiore et al., 2016). The diameter and elongation at break (%) of fibers are reduced after the alkali treatment and it is shown in Figs. 3(a) and 3(b). The Young's modulus (GPa) and Tensile Strength (MPa) of fibers increase after the alkali treatment as evidenced in Figs. 3(c) and 3(d). The mechanical properties are improved, due to partial removal of hemicellulose and formation of new hydrogen bonds between the cellulose fibrils along with the formation of closed packed structure in the fiber (Wang, Koo, & Kim, 2003). Comparisons of the physicochemical and mechanical properties of SACL fibers with that of other classical natural fibers are presented in table 1. After the alkali treatment, the interfacial strength between the fiber and the matrix increases from 2.95 ± 0.1Mpa to 3.2± 0.05 MPa because of strong adhesion between the fiber and the matrix and it results in better mechanical interlocking (Xue , Tabil, & Panigrahi, 2007). The microfibril angle of alkali treated and untreated SACL fibers computed from equation (1) is 10.3 ° and 11.1 °. This is attributed to the partial removal of hemicellulose, wax and non-crystalline contents. The smaller

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microfibril angle of alkali treated SACL fibers may provide higher tensile strength, Young's modulus and stiffness to fibers. This value is closely related to other natural fibers such as Prosopis juliflora (10.64°), Sisal (10° -22°) and Banana (11° -12°) (Belouadah,Ati,& Rokbi 2015).

3.2 XRD analysis

The X-ray diffractogram of the alkali treated and untreated SACL fibers are shown in Fig.4. The low-intensity peak (110), which contributes amorphous fraction (Iam), occurs at 2θ closer to 17.8°. It indicates the presence of amorphous materials in the fibers. The high-intensity peak (0 0 2), which contributes crystalline fraction (Ic), occurs at around 2θ=22.59° and it indicates the content of α-cellulose in fibers. Fig.4 shows that the intensities of (0 0 2) and (1 1 0) crystallographic plane are increased significantly, due to the alkali treatment of SACL fibers. The CI of alkali treated fibers is found to be 56.5 %, which is higher than the untreated (52.6%) fibers and it calculated by using equation (3). This can be attributed to the partial removal of amorphous hemicelluloses, wax and non-crystalline contents from the fibers (Obi Reddy et al., 2013). This is also supported by the chemical analysis of interpreting data and FT-IR analysis, as shown in Fig. (5). The calculated CI values of alkali treated and untreated SACL fibers are higher than that of Prosopis juliflora bark (46%), Ferula (48%),Thespesia(48%) and smaller than Napier grass fiber strands (62.43%), Jute (65.8 %), Cotton(68%), Flax (70%), Hemp (80%) (Suryanto et al., 2014; Reddy et al., 2014; Fiore et al., 2014;Kommulaet al., 2015; Reddy et al., 2013).

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The Crystalline Size (CS) of treated and untreated SACL fibers is found to be 5.72 nm and 5.6 nm, respectively and it computed from equation (4). Due to the higher crystalline size, the structure tends to reduce the moisture absorption capacity and chemical reactivity of the fibers and it enhances the mechanical properties of the fibers (Saravanakumar et al., 2014).

3.3 FT-IR analysis

The peaks with wave numbers from 4000 to 500 cm^{-1} for treated and untreated SACL fibers are presented in Fig 5. α-cellulose, hemicelluloses and lignin contents are the unique features of the SACL fibers spectrum. The strong and broad peak at 3340 cm^{-1} is associated with the hydrogen bonded O-H (Alcohol Group) stretching vibration of the hydroxyl groups in cellulose molecules. The peaks at wave numbers 1750 cm^{-1} and 1250 cm^{-1}refer to C=O stretching vibration of aldehyde functional groups (hemicelluloses). The peak at 1663 cm^{-1} can be attributed to the presence of alkene carboxyl group of C=C stretching, which shows the presence of hemicelluloses. The peak at 1600 cm^{-1} refers to the presence of absorbed water confirming the hydrophilic nature of the fibers (Karbowiak, Ferret, Debeaufort, Voilley, & Cayot, 2011). The C=C band of SACL fiber represents the aromatic vibration at 1525 cm^{-1} from methoxyl groups of lignin. A small peak at 890 cm^{-1} is attributed to the presence of β-glycosidic linkages between the monosaccharides (Fiore et al., 2014). After the alkali treatment, the intensity peaks at wave numbers 3340 cm^{-1}, 1750cm^{-1}, 1250 cm^{-1}, 1663 cm^{-1}, and 1600 $cm^{-1}$are significantly reduced. It clearly indicates the less percentage content of hemicelluloses and hydroxyl groups, which are advantageous, because higher contents will affect the mechanical properties of the fibers.

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3.*4Thermogravimetric analysis*

Thermal stability of the alkali treated and untreated SACL fibers were investigated by TGA. Fig. 6(a) and Fig. 6(b) show the TGA and DTG curves of alkali treated and untreated SACL fibers. The minor weight loss has been observed between room temperature and 100°C, due to the evaporation of moisture content from SACL fibers. At this stage, the minor mass loss was found to be 6.8% and 4.31% for untreated and alkali treated fibers, respectively. The initial degradation temperature is higher for the alkali treated fibers. Thermal stability of the SACL fibers gradually decrease and the thermal degradation eventually takes place in the next two stages. The first stage of the degradation progress occurs from the temperature region of 238°C- 272°C and 243°C- 284°C for untreated and alkali treated fibers, respectively. This happens due to the reason of thermal depolymerization of hemicellulose, lignin and the glycosidic linkages of cellulose with mass loss of 20% for untreated fiber and 17% for treated fibers. The second stage of weight loss occurs between 272°C- 350°C and 284°C- 355°C for untreated fibers and alkali treated fibers respectively. At this stage, it shows a major mass loss of about 55 % -60 %, due to the degradation of α-cellulose. After alkali treatment, the thermal stability of SACL fibers increases from 225 °C to 231°C and the degradation temperature rises from 350 °C to 355°C. From the DTG curve, it clearly observed that the thermal stability and degradation temperature are increased. These results clearly show that the alkali treated SACL fibers can be preferably used as reinforcements in thermoplastic and polymers whose processing temperature is below 220°C. At 720°C, the residual char content, however, increases from 10% to 13% after alkali treatment.

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3.5 Non-isothermal degradation kinetics analysis

Another important parameter in the evaluation of the thermal stability of SACL fibers is the activation energy. The activation energy was calculated to know the kinetic parameter of alkali treated and untreated SACL fibers by using equation (5). To activate atoms or molecules of the SACL fibers in order to transform from one stage to another stage, 60.2 KJ/mol activation energy is required whereas after the alkali treatment, the activation energy increases to 74.35 KJ/mol, which is interpolated from the broido's plot shown in Fig.7. The increase in kinetic activation energy is because of the removal of hemicellulose and wax content. If the calculated E_b is positive, it indicates that no phase transition (solid phase to solid phase) has taken place in the selected temperature span (Sundaram Ramukutty, & Esakki Ramachandran, 2014). This value is closer to those obtained from the kinetic analysis of other natural fibers such as Prosopis juliflora bark (76.72KJ/mol), Cissusquadrangularis (74.18KJ/mol) (Belouadah, Ati, & Rokbi, 2015).

3.6 SEM analysis

The SEM image analysis of the alkali treated and untreated SACL fiber surface as shown in Fig. 8. In Fig. 8(a), the filaments of the untreated fibers are joined together and due to the presence of hemicellulose, wax, lignin and oils and very smooth surfaces are observed. After the application of alkali treatment, the fibers are separated and roughness is increased around the fiber surfaces, due to the removal of wax and hemicelluloses as shown in Fig. 8(b).

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Conclusion

In this work, the chemical, mechanical and thermal properties of SACL fibers investigated for alkali treated and untreated conditions. The properties of alkali treated SACL fibers provide new hope for natural fiber research. The investigation concludes, after the alkali treatment, there is an increase in the cellulose content and decrease in hemicellulose, moisture and wax contents through standard chemical methods. These results ensure that the hydrophilic nature of the fibers is reduced and provide good interfacing between the fiber and the matrix. The results obtained from FTIR analysis confirm that the amorphous materials and moisture contents are reduced due to the effect of alkali treatment. XRD analysis results show that the crystalline size and crystallinity index of the SACL fibers are improved by following the alkali treatment. The alkali treatment leads to increase the mechanical properties of SACL fibers due to improved fiber crystalline structure. The TGA analysis has revealed an increase in the thermal stability and degradation temperature of the SACL fibers on alkali treatment. The non-isothermal analysis confirms that the thermal stability of the fibers is improved by the effect of alkali treatment. The SEM measurement exposes rough outer surface of the fibers, due to the removal of hemicellulose and wax contents on alkali treatment. The experimental results of the alkali treated SACL fibers are compared with those of other common natural fibers. The comparison results confirm that these fibers represent as valid alternative to those ones as reinforcement in polymer composites. Further, the study can extended to develop the bio-based epoxy composite reinforced with alkali treated SACL fibers and its mechanical properties, and dynamic & thermal behaviors can be evaluated.

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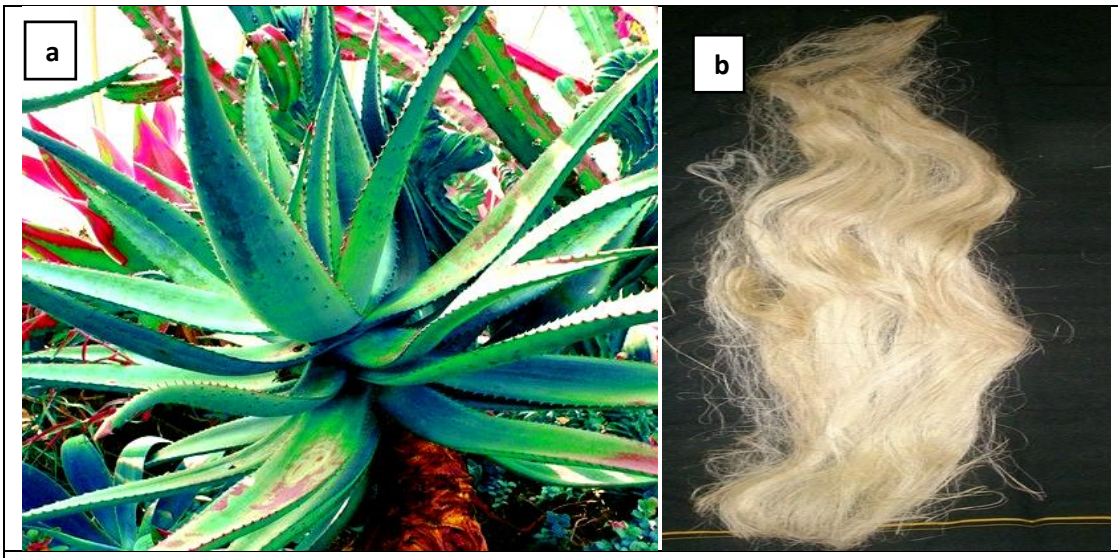

Fig. 1.(a) Aloe vera cactus plant (b) Extracted SACL fibers

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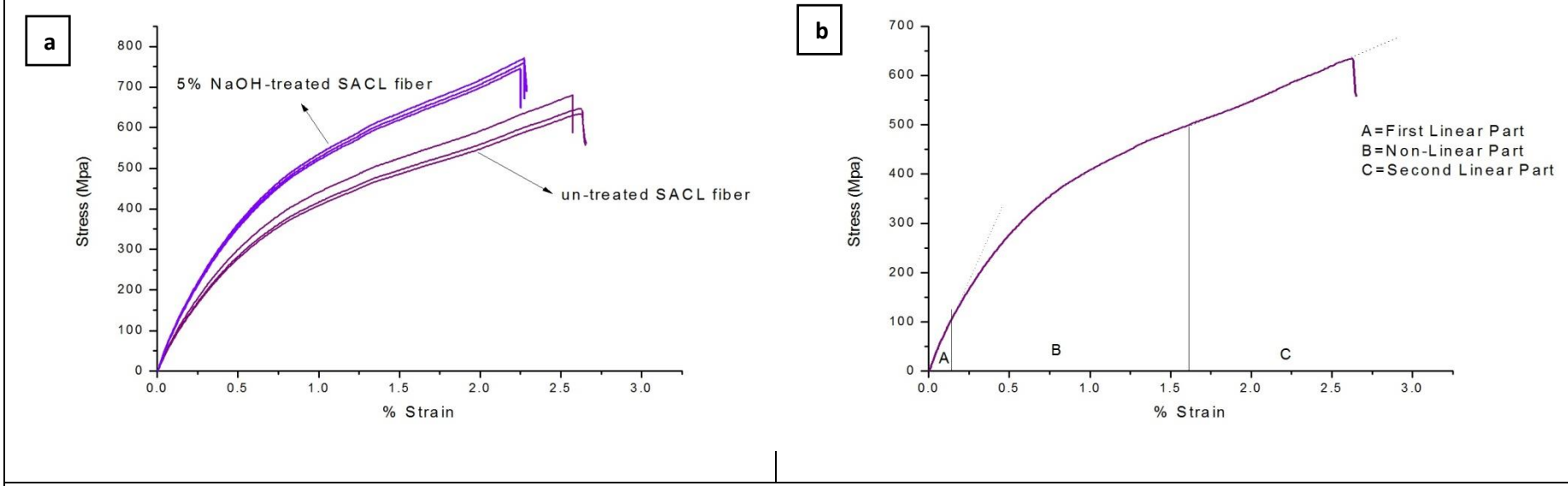

Fig. 2. Stress-Strain curve **(b)**Sample of SACL fiber tensile curves, showing the strain at which deformation becomes linear again.

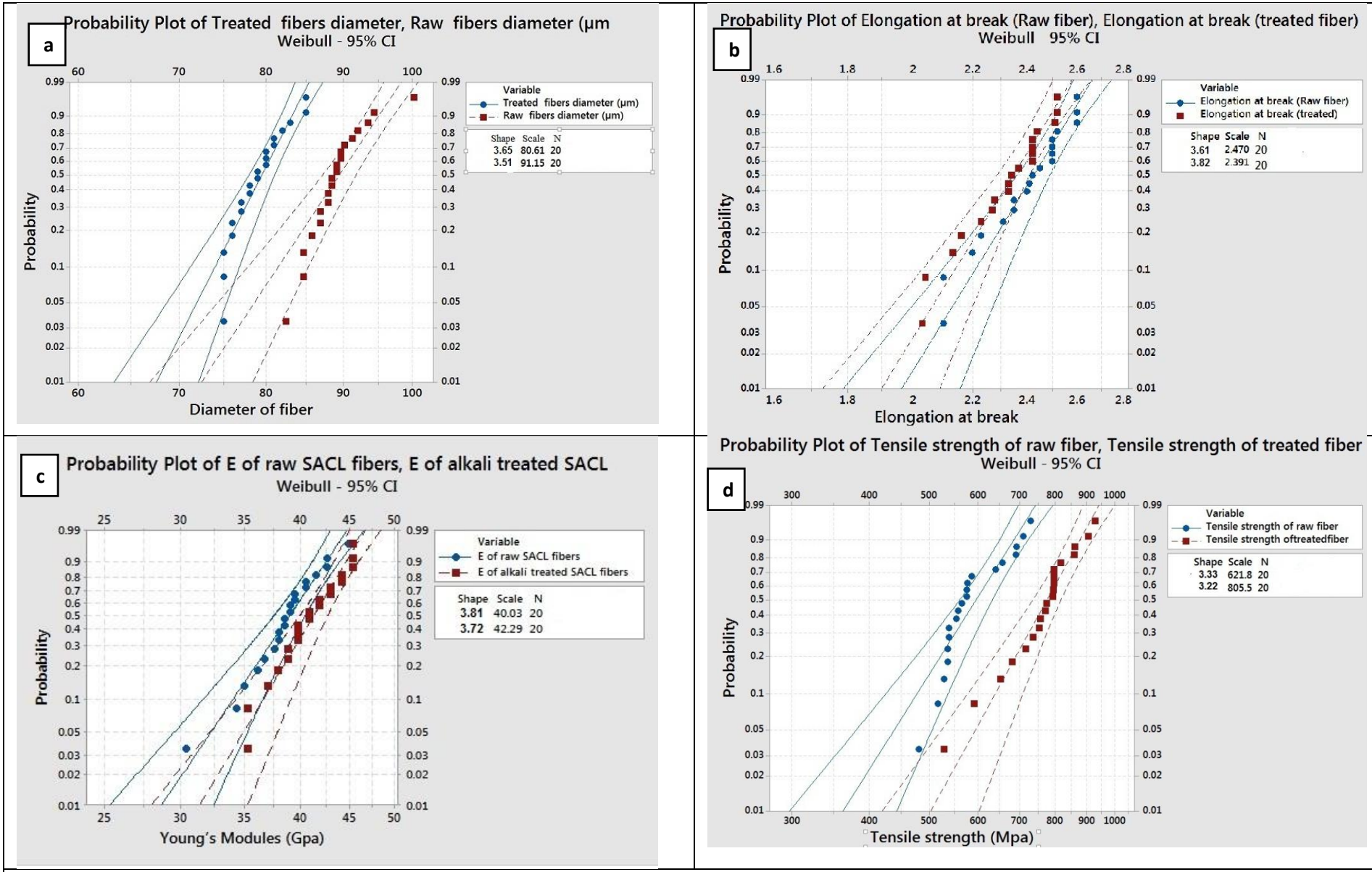

Fig. 3. Weibull distribution plot for (a) Diameter (b) Elongation at break (c) Young's modulus(d) Tensile Strength.

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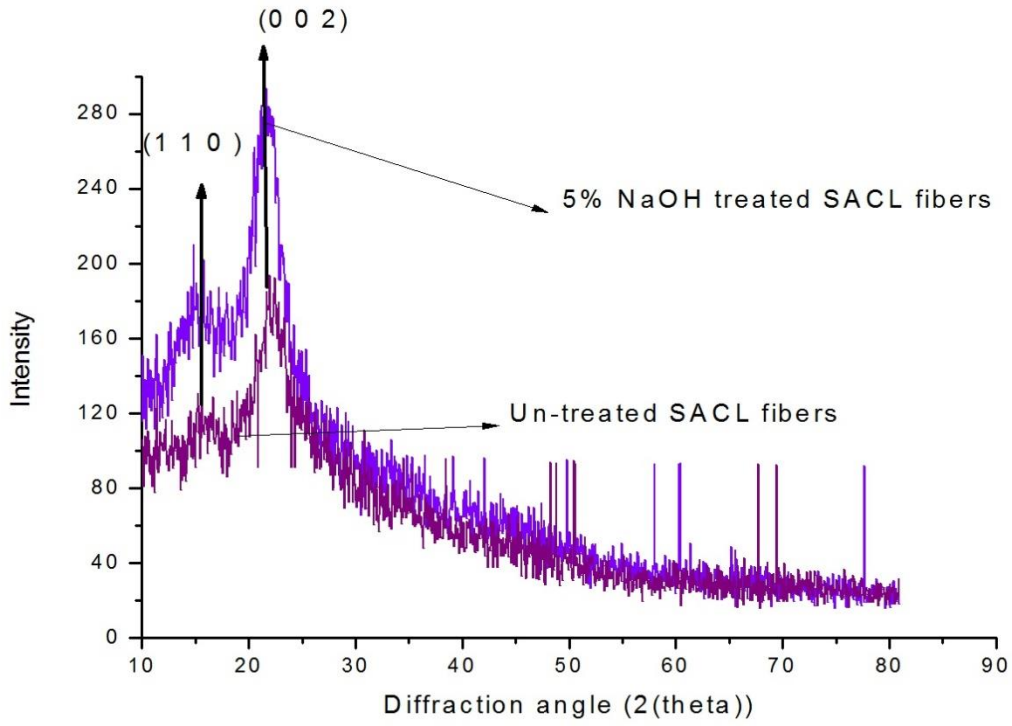

Fig.4. X-ray diffractogram.

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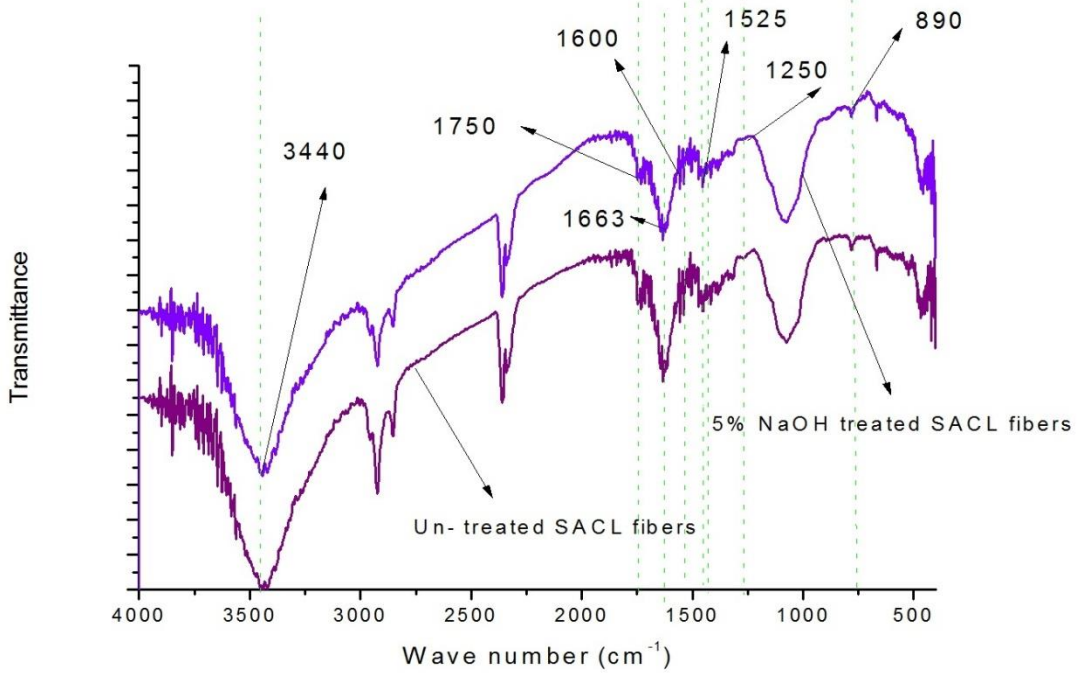

Fig.5. FT-IR Spectrum

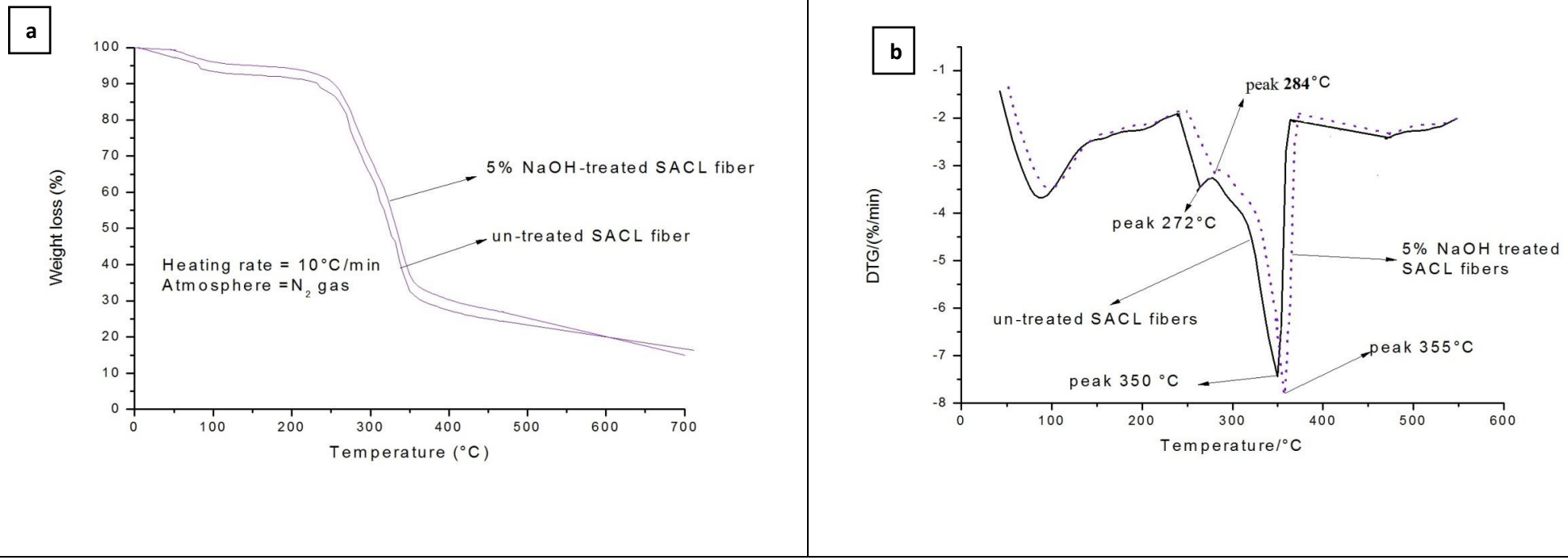

Fig.6.TGA and DTG thermogram.

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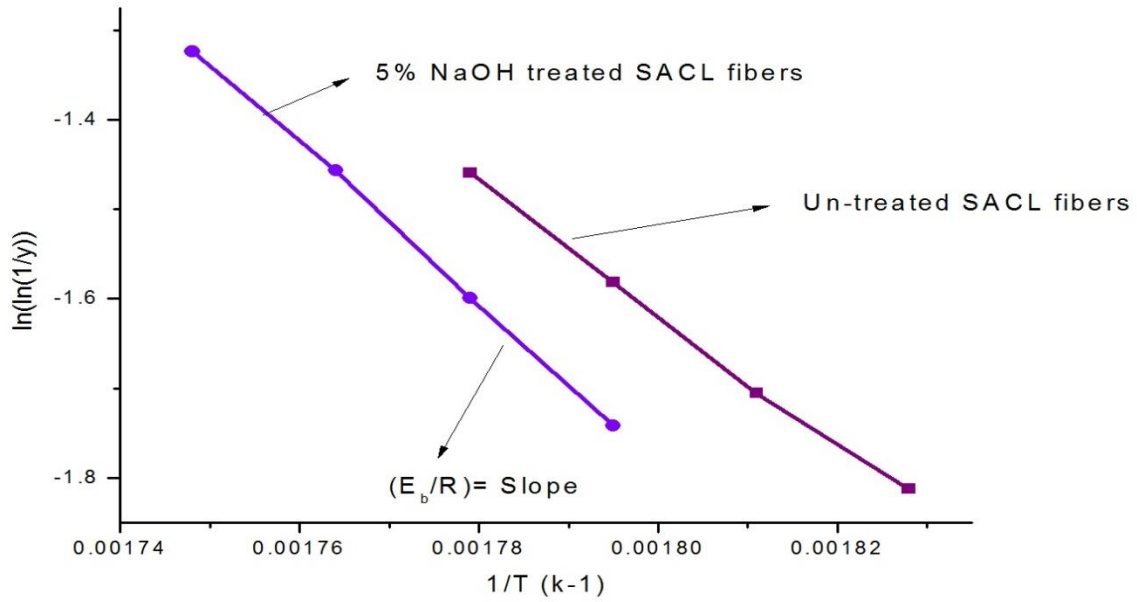

Fig.7. Broido's plot .

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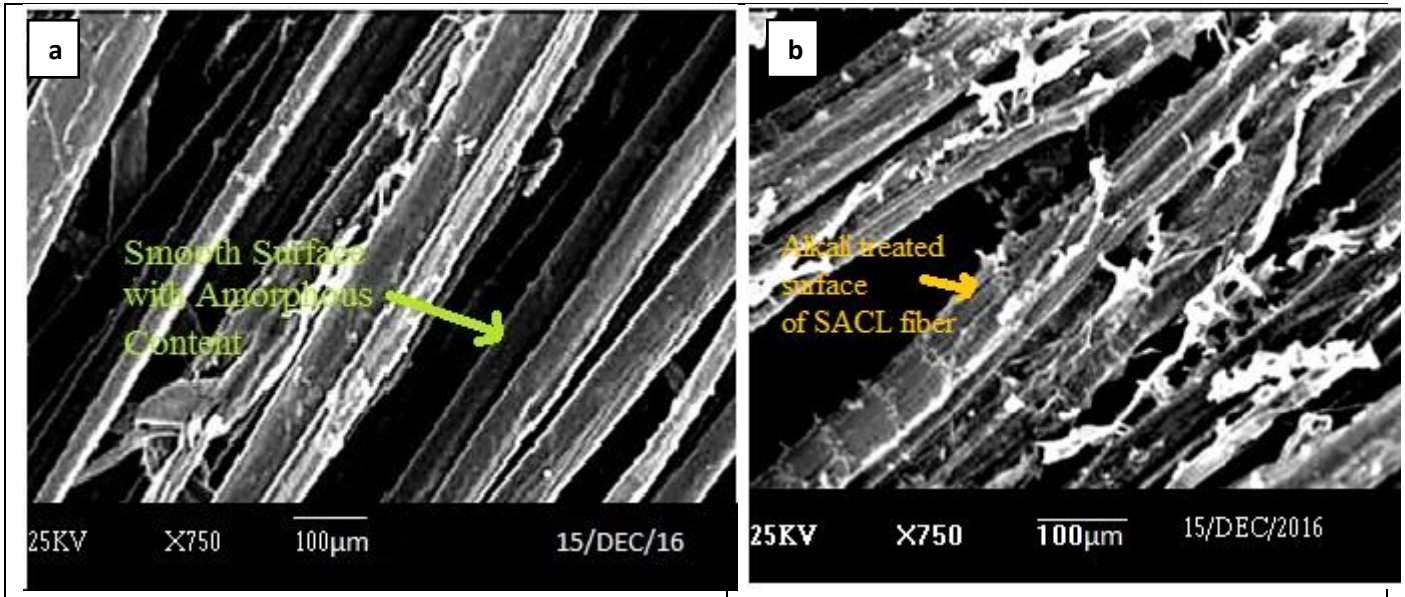

Fig.8. SEM images.

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Table 1: Comparison of the Physicochemical and mechanical properties of SACL fibers with other common natural fibers.

Natural fiber	Chemical properties					Physical properties			Mechanical properties			
	α-Cellulose (Wt. %)	Hemicellulose (Wt. %)	Lignin (Wt. %)	Wax (Wt. %)	Moisture (Wt. %)	Diameter (μm)	CI (%)	Crystall-inesize (nm)	Young's modulus (GPa)	Tensile Strength (MPa)	Elongation at break (%)	Reference
5% NaOH treated SACL fibers	**67.4**	**8.2**	**13.7**	**0.24**	**5.8**	**80.61**	**56.5**	**5.72**	**42.29**	**805.5**	**2.39**	**Present work**
Raw SACL fibers	**60.2**	**14.2**	**13.7**	**1.5**	**7.6**	**91.15**	**52.6**	**5.6**	**40.03**	**621.8**	**2.47**	
Coir	43	0.3	45	-----	-----	-----	-----	-----	4-6	175	30	Fiore et al.,(2014); Suryanto et al., (2014); Reddy et al., (2014);Kommula et al.,(2015).
ProsopisJuliflora Bark	61.65	16.14	17.11	0.61	9.48	-----	46	15	----	558	1.77	Saravanakumar et al., (2015).
Bamboo	26–43	30	21-31	-----	-----	-----	-----	-----	11 - 17	140 - 230	-----	Fiore et al., (2014).
Flax	85	9	4	1.7	10	-----	70	5.4	61.4–128	400–938	3.6–3.8	Suryantoetal., (2014);Reddy et al.,(2014);
Ferula	53.3	8.5	1.4	-----	-----	-----	48	1.6	52.7	475.6	4.2	Suryanto et al.,(2014).
Hemp	58.7	14.2	6	0.8	9	-----	80	4.5	70	690	2.0–	Suryanto et al.,

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											4.0	(2014);Reddy et al., (2014).
Jute	58–63	20–24	12–15	0.5	12.6	40-350	65.8	29.25	10–30	400–773	1.5–1.8	Suryanto et al.(2014); Reddy et al.(2014)
Sisal	78	19	8	2	11	50-300	55	16.99	9.4–22	511–635	2.0–2.5	Suryanto et al. (2014); Reddy et al., (2014).
Cotton	85–90	1–3	0.7–1.6	-----	1.0	-----	68	5–7	5.5–12.6	287–597	---	Reddy et al., (2014).
Ramie	76	15	1	-----	-----	-----	-----	-----	24.5	560	2.5	Fiore et al., (2014).
Napier Grass Fiber Strands	47.12	31.27	21.63	-----	-----	-----	62.43	2.83	13.15	88.40	0.99	Kommula et al., (2015).
Thespesia	60.63	26.64	12.70	-----	-----	-----	48	-----	61.2	573	0.79	Reddy et al.,(2013).