



Ingeniería e Investigación

ISSN: 0120-5609

revii\_bog@unal.edu.co

Universidad Nacional de Colombia  
Colombia

Mejía Osorio, Julio César; Rodríguez Baracaldo, Rodolfo; Olaya Florez, Jhon Jairo  
The influence of alkali treatment on banana fibre's mechanical properties  
Ingeniería e Investigación, vol. 32, núm. 1, abril, 2012, pp. 83-87  
Universidad Nacional de Colombia  
Bogotá, Colombia

Available in: <http://www.redalyc.org/articulo.oa?id=64323227015>

- How to cite
- Complete issue
- More information about this article
- Journal's homepage in redalyc.org

redalyc.org

Scientific Information System  
Network of Scientific Journals from Latin America, the Caribbean, Spain and Portugal  
Non-profit academic project, developed under the open access initiative

# The influence of alkali treatment on banana fibre's mechanical properties

## Influencia del tratamiento alcalino sobre las propiedades mecánicas de la fibra de plátano

Julio César Mejía Osorio<sup>1</sup>, Rodolfo Rodríguez Baracaldo<sup>2</sup>, Jhon Jairo Olaya Florez<sup>3</sup>

### RESUMEN

Este trabajo estudia el efecto del tratamiento alcalino sobre las propiedades mecánicas de la fibra de plátano (*Musa paradisiaca*). Las fibras fueron extraídas del pseudotallo del plátano empleando una maquina desfibradora. Seguidamente fueron mercerizadas y modificadas mediante tratamiento alcalino con NaOH al 5% (m/v). El análisis morfológico evidenció que la rugosidad de la superficie es mayor en las fibras tratadas que en las no tratadas. La caracterización mecánica reveló que el módulo de Young, la resistencia máxima a la tracción y la deformación disminuyen con el aumento del diámetro de la fibra, tanto para las fibras tratadas como para las no tratadas.

**Palabras clave:** Fibra de plátano, Tratamiento alcalino, Propiedades mecánicas.

### ABSTRACT

This work analyses the effect of alkali treatment on the mechanical properties of banana fibre (*Musa Paradisiaca*). Fibres were extracted from the pseudostem by a defibring machine; they were mercerised and modified by 5% NaOH (w/v) alkali treatment. Morphological characterisation showed that treated fibres' surface was rougher than that of untreated fibres. Mechanical characterisation indicated that Young's modulus, ultimate tensile strength and strain became decreased by increasing both treated and untreated fibres' diameter.

**Keywords:** Banana fibre, alkali treatment, mechanical property.

Received: December 20th 2010

Accepted: January 10th 2012

### Introduction

Natural fibres have appeared to be the materials which will become a feasible replacement for non-renewable, abrasive and expensive synthetic fibres during recent years, mainly due to their availability in large quantities, biodegradability, low cost, low density, recyclability and ease of manufacturing them (Oladele *et al.*, 2010; Rout *et al.*, 2001; Saheb and Jog, 1999). It is well known that natural fibres (i.e. banana fibres) have become an important reinforcement material over the last few decades because of their advantages over conventional materials. They supply to composite high specific stiffness, strength and biodegradability (Charlet *et al.*, 2009; Herrera-Franco and Valadez-González, 2004; Ibrahim *et al.*, 2010).

Banana fibre's lignocellulose nature means that it consists of several cells; such cells consist of cellulose, hemicellulose, lignin,

pectin, wax and water-soluble components (Barreto *et al.*, 2010; Bledzki and Gassan, 1999). The crystalline matrix consists of cellulose fibrils spirally wound in an amorphous matrix composed by hemicellulose, lignin and, in some cases, pectin (Zuluaga *et al.*, 2009). The microstructure is extremely complex due to its hierarchical organisation and these materials' variable proportions in layers. They are distributed in two cell walls; the outer cell wall is made up of a single layer whilst the second one consists of three layers arranged as concentric cylinders with a small channel in the centre, called the lumen. The first wall is deposited during cell growth, thereby encircling the secondary wall which is a compound of three layers (Jayaraman 2003; Maya and Rajesh, 2008).

Fibre properties are determined by the physical, mechanical and chemical properties of its morphological constituents and their interfaces. Several studies have stated that fibre's mechanical properties are determined by the secondary wall's middle layer. Mechanical behaviour depends on factors such as the fibrils' spiral angle, the degree of cellulose polymerisation, porosity content and the size of the lumen (Baley 2002). Agricultural variables, age, specie, plant variety and fibre processing parameters also influence mechanical behaviour (Kulkarny *et al.*, 1982).

Chemical reactions in cell walls generate biodegradability, thermostability and dimensional instability regarding moisture due to their lignocellulose-associated hygroscopic nature (Rowell *et al.*, 1993). This lignocellulose contains strongly-polarised hydroxyl groups causing water affinity; such hydrophilic nature makes it incompatible with a hydrophobic matrix (Alix *et al.*, 2009; Cuellar

<sup>1</sup> Industrial Engineer, Universidad Nacional de Colombia, Sede Manizales. Colombia. E-mail: jcmejiao@unal.edu.co

<sup>2</sup> PhD. in Material Engineer, Universitat Politècnica de Catalunya, España. Associated Professor, Departamento de Ingeniería Mecánica y Mecatrónica, Universidad Nacional de Colombia, Sede Bogotá, Colombia. E-mail: rodriguez-ba@unal.edu.co

<sup>3</sup> PhD. in Engineering, Universidad Nacional Autónoma de México. Associated Professor, Departamento de Ingeniería Mecánica y Mecatrónica, Universidad Nacional de Colombia, Sede Bogotá. Colombia. E-mail: jjolayaf@unal.edu.co

and Muñoz, 2010). These shortcomings have been resolved by suitable physical, chemical or enzyme treatment. The treatment used can reduce moisture absorption, clean the surface and enhance fibre roughness, mainly reducing hydrophilic behaviour (Mohd *et al.*, 2007; Wang *et al.*, 2003). The structural changes occurring on the fibre surface and cell wall structure after treatment influence mechanical properties (Rong *et al.*, 2001). Lignocellulose fibre surface modification has been reported, involving alkali treatment, silane treatment, acetylation treatment and benzylation treatment; these have been discussed by Li *et al.*, (2007). The simplest chemical modification is alkali treatment of fibres which has been used to treat almost all natural fibres with successful results (Bisanda, 2000; Valadez-Gonzalez *et al.*, 1999).

Alkali treatment's main purpose is to disrupt hydrogen bonding in the network structure and remove some hemicellulose, lignin, wax and oils, thereby increasing surface roughness and reducing its hydrophilic nature. This treatment influences fibre's mechanical behaviour, especially regarding strength and stiffness (Li *et al.*, 2007).

The effect of alkali treatment on treated and untreated banana fibres' mechanical properties is analysed in this paper to identify composite behaviour by understanding the properties of reinforcement before becoming combined into the matrix. Treatment parameters such as fibre immersion time and NaOH concentration were selected from references. Structural changes regarding treated and untreated banana fibres' morphology and mechanical properties were evaluated by a tensile test and scanning electron microscopy (SEM).

## Materials and methods

The stems from banana plants (*Musa paradisiaca*) were selected from an 11-month-old plantation. The plantation is located 1,050 meters above sea level, has 22.5°C average temperature, 76% relative humidity, 2,100 mm annual rainfall, 6.1 PH and 2,010 hours annual sunshine (Aristizábal *et al.*, 2008).

The banana fibres were drawn from the banana plants' pseudostems (helically surrounding the stem). The pseudostems were first air-dried at 18°C average temperature for 72 hours (i.e. natural drying). Banana fibres were extracted from the pseudostems by a defibring machine; this consists of a framework and a paddle wheel. The stems were fed to the paddle wheel; the pulp was separated from the stem and the fibres extracted. Bundles of fibres were then placed in water for 12 hours at room temperature to remove impurities and facilitate their separation before being left at room temperature for 6 hours.

The following experimental procedure was based on the work of Wang *et al.*, (2003) and Jafferjee *et al.*, (2003). The treated fibres were first washed with 2% detergent-water prior to alkali treatment and dried at 70°C for 24h to remove external wax. They were then mercerised to remove fibre surface impurities, causing changes in the crystalline cellulose, and preparing the fibre for the effects of chemical treatment. Sequential extraction was used for mercerisation with 1:2 mixture of ethanol and benzene for 6h, followed by washing with distilled water and air drying to eliminate water-soluble polymers and waxes. The fibres were then chemically-treated to remove lignin and hemicellulose to improve fibre surface roughness and compatibility when composite material was formed. Alkali treatment induced such modification where fibres were immersed in 5% NaOH aqueous solution (w/v) for 1h at

room temperature (1:15 fibre-to-solution weight ratio). The treated fibre was then washed thoroughly with distilled water to remove excess NaOH from the surface and oven dried at 110°C.

As suggested by Hu *et al.*, (2010), fibres were carefully manually separated from the bundles. Single banana fibres were randomly chosen; fibres having apparent defects were discarded and those having greater uniform length were selected for the tensile test. It is well-known that natural fibres' cross-section is not perfectly round and that diameter size varies along a fibre's length (Mukhopadhyay *et al.*, 2008). All fibres' diameters were measured at different locations along their length to overcome such problem, using an optical microscopy before tensile test (average value being taken as parameter).

A universal testing machine was used for assessing treated and untreated fibres' mechanical behaviour; 50 mm gauge and constant 4 mm/min crosshead speed were used for all tests. A paper frame with a window was designed, constructed and used with the testing machine's fixtures to hold the fibre during the tensile test. The fibres were carefully positioned on the paper frame to prevent slippage and misalignment looking for axial forces during the test. SEM was used for characterising the morphology of the structural changes occurring on the surface of treated and untreated banana fibres and also the tested specimens' fracture surface.

## Results and Discussion

Fibre surface morphology analysis is important to ascertain the structural changes occurring in a fibre upon alkali treatment. This knowledge offers fundamental information regarding interfacial adhesion between a fibre and the matrix when developing the composite.

Figure 1(a) shows the untreated fibre; it has an irregular surface having variable roughness where the microfibrils appear to be parallel to the fibre's axis. The fibre has some impurities on its surface. Figure 1(b) shows treated fibre having a rougher surface produced by lignin and hemicellulose removal. It may also be noticed that most impurities have been removed from the fibre's surface. This cleaner and rougher surface would increase the number of possible interaction sites, thereby improving mechanical fibre-matrix adhesion.

Each fibre's mechanical properties were analysed. Banana fibres were chosen at random from the bundle fibre, ensuring a wide diameter range. The banana fibres were classified into 4 classes based on a 0.035 mm class interval, considering lower and higher diameters between treated and untreated fibres. The fibre selected for tensile test was the most representative of each interval (i.e. closest to the class mark) to facilitate analysis of the information and its subsequent comparison with other fibres.

Figure 2(a) and 2(b) shows stress-strain curves for untreated and treated fibres, respectively. The stress-strain curve for 0.175 mm-0.210 mm diameter treated fibres was not displayed due to lack of fibres in this interval. Treated and untreated banana fibres had brittle behaviour, characterised by a lineal relationship between deformation and stress until failure, without noticeable plastic deformation. The fibre's Young's modulus was evaluated by the slope of the curve in the linear region. The stress-strain curve had fluctuation activity in specific sections; this phenomenon may have been associated with constant rearrangement of microfibrils in the direction of the fibre axis. Mukhopadhyay *et al.*, (2008) also ob-

served this behaviour in banana fibre. Table 1 shows the results of the tensile test for untreated banana fibres and Table 2 shows that for treated banana fibres.

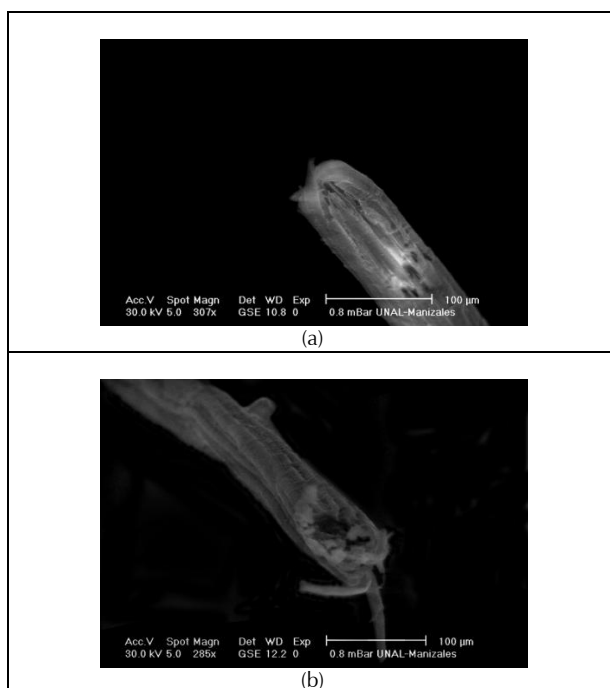


Figure 1. SEM micrograph of (a) an untreated banana fiber and (b) a treated banana fiber

Young's modulus experimental value for untreated fibres was 6.6 to 25.6 GPa, ultimate tensile strength was 222.3 to 780.3 MPa and strain was 1.79% to 3.27%. The resulting values for untreated banana fibre mechanical behaviour agreed with data presented in the literature (Guimarães *et al.*, 2009; Lilholt and Lawter, 2000; Mahji *et al.*, 2010). Value variation amongst authors can be explained by three factors: defects such as cross-marks, kink bands or dislocations that become stress concentrators (Baley *et al.*, 2006), the fibre's internal structure causing a non-constant cross-section along fibre length and variability in fibre composition. Table 1 shows that Young's modulus, ultimate tensile strength and strain decreased with increased fibre diameter in the range being investigated. This may have been due to the presence of a hollow fibril in the centre of each fibre cell modifying the real cross-section and therefore the mechanical properties. Baley (2002) has reported similar results for flax fibre. These results motivated a deeper study of the effect of the real cross-section on mechanical properties.

Diameter range (mm)	Diameter (mm)	Young's modulus (Gpa)	Ultimate strength (Mpa)	Strain (%)
0,07-0,105	0,0874	25,6	780,3	2,68
0,105-0,140	0,1328	13,7	300	1,93
0,140-0,175	0,1563	11,3	198,9	1,79
0,175-0,210	0,1925	6,6	222,3	3,27

Young's modulus experimental value for treated fibres was 9.73 to 21.6 GPa, ultimate tensile strength was 148.1 to 536.2 MPa and

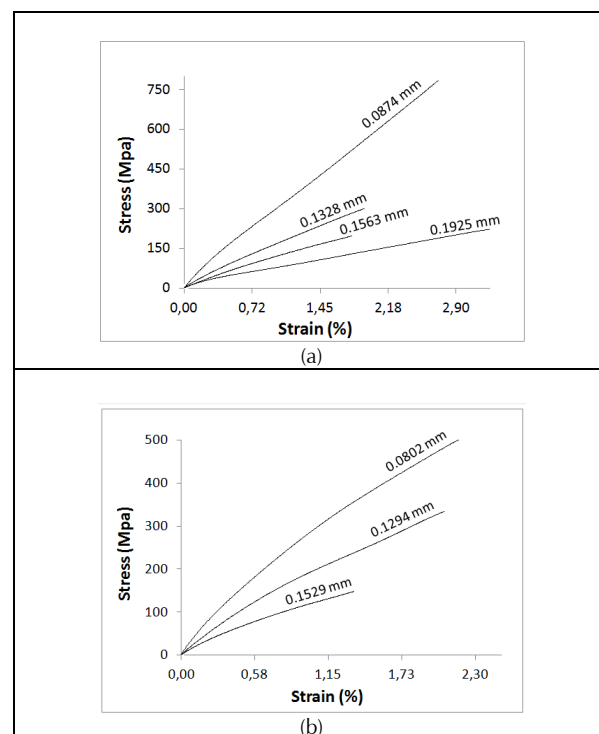


Figure 2. Stress-strain curves for (a) untreated banana fiber and (b) treated banana fiber

strain was 1.38% to 2.57%. Young's modulus and tensile strength decreased with increasing fibre diameter in the range investigated due to cross-section variation explained above for untreated fibres. Comparing untreated fibres' Young's modulus, ultimate tensile strength and strain values to those for treated ones showed that all decreased in the ranges investigated here. This may have been due to cellulose delignification and degradation during alkali treatment thereby disrupting bonding and leading to morphological changes, like increased surface roughness. Similar findings have been reported by Arifuzzaman *et al.*, (2009) in okra fibre. Such increased roughness acts as stress concentrator for decreasing fibre's mechanical behaviour.

Table 2. Different diameter treated banana fibres' mechanical properties

Diameter range (mm)	Diameter (mm)	Young's modulus (Gpa)	Ultimate Strength (Mpa)	Strain (%)
0.07-0.105	0.0802	21.6	536.2	2.37
0.105-0.140	0.1294	17.2	337.3	2.1
0.140-0.175	0.1529	9.73	148.1	1.38

Fracture surface analysis studied internal structure behaviour regarding axial forces. It also provided better understanding of brittle fracture by analysing each fibril's behaviour. Figure 3 (a) shows that many fibre cross-sections had channels negatively influencing mechanical properties. Figure 3 (b) shows that cell wall thickness appeared to decrease due to loss of material compared to that of untreated fibres. Such loss of material changed the shape and size of the holes, making them highly variable. The microfibrils shared the load during tension test, causing a gradual brittle fracture.

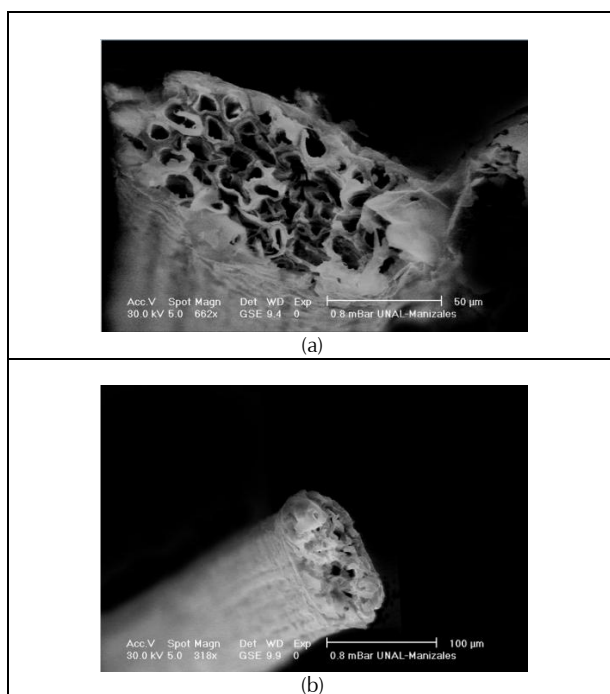


Figure 3. Angular view of surface fractured of (a) untreated banana fiber and (b) treated banana fiber.

## Conclusions

Two types of behaviour were observed and analysed regarding applying loads to alkali-treated banana fibres before becoming a composite material. Young's modulus and ultimate tensile strength decreased as fibre diameter increased in treated and untreated banana fibres due to the presence of a hollow fibril in the centre of each fibre cell thereby modifying the fibre's real cross-section. The treated fibres showed decreased mechanical properties. It is thus suggested that such variations were related to the removal of lignin and hemicellulose from the surface of the fibres, possibly causing weakening in the fibre's outer wall. Studying banana fibres' behaviour before becoming combined into the matrix has led to understanding reinforcement's real contribution to the composite material.

## References

- Alix, S., Philippe, E., Bessadok, A., Lebrun, L., Morvan, C., Marais, S., Effect of chemical treatments on water sorption and mechanical properties of flax fibres., *Bioresource Technology*, Vol. 100, 2009, pp. 4742–4749.
- Arifuzzaman, K. G. M., Shaheruzzaman, Md., Rahman, M. H., Abdur, R. S., Sakinul, I. Md., Shamsul, A. Md., Surface Modification of Okra Bast Fiber and Its Physico-chemical Characteristics., *Fibers and Polymers*, Vol. 10, 2009, pp. 65–70.
- Arístizábal, L. M., Cardona, P. L. F., Osorio, U. C. A., Efectos del ácido giberélico y el desmane sobre las características del racimo en plátano Dominicó Hartón., *Revista Acta Agronómica*, Vol. 57, No. 4, 2008, pp. 253–257.
- Barreto, A. C. H., Costa, M. M., Sombra, A. S. B., Rosa, D. S., Nascimento, R. F., Mazzetto, S. E., Fachine, P. B. A., Chemically Modified Banana Fiber: Structure, Dielectrical Properties and Biodegradability., *Journal of Polymer and environment*, Vol. 18, 2010, pp. 523–531.
- Baley, C., Analysis of the flax fibres tensile behaviour and analysis of the tensile stiffness increase., *Composites: Part A*, Vol. 33, 2002, pp. 939–948.
- Baley, C., Busnel, F., Grohens, Y., Sire, O., Influence of chemical treatments on surface properties and adhesion of flax fibre–polyester resin, *Composites: Part A*, Vol. 37, 2006, pp. 1626–1637.
- Bisanda, E. T. N., The Effect of Alkali Treatment on the Adhesion Characteristics of Sisal Fibres., *Applied composite Materials*, Vol. 7, 2000, pp. 331–339.
- Bledzki, A.K., Gassan, J., Composites reinforced with cellulose based fibres, *Progress in polymer science*, Vol. 24, 1999, pp. 221–274.
- Charlet, K., Eve, S., Jernot, J. P., Gomina, M., Breard, J., Tensile deformation of a flax fiber., *Procedia Engineering*, Vol. 1, 2009, pp. 233–236.
- Cuellar, A., Muñoz, I., Fibra de guadua como refuerzo de matrices poliméricas., *Revista Dyna*, Vol. 162, 2010, pp. 137–142.
- Guimarães, J. L., Frollini, E., da Silva, C. G., Wypych, F., Satyanarayana, K. G., Characterization of banana, sugarcane bagasse and sponge gourd fibers of Brazil., *Industrial Crops and Products*, Vol. 30, 2009, pp. 407–415.
- Herrera-Franco, P. J., Valadez-González, A., Mechanical properties of continuous natural fibre-reinforced polymer composites., *Composites: Part A*, Vol. 35, 2004, pp. 339–345.
- Hu, W., Ton-That, M. T., Perrin-Sarazin, F., Denault, J., An improved method of single fiber tensile test of natural fibers., *Polymer Engineering and Science*, Vol. 50, 2010, pp. 819–825.
- Ibrahim, M. M., Dufresne, A., El-Zawawy, W. K., Agblevor, F. A., Banana fibers and microfibrils as lignocellulosic reinforcements in polymer composites., *Carbohydrate Polymers*, Vol. 81, 2010, pp. 811–819.
- Idicula, M., Malhotra, S. K., Joseph, K., Thomas, S., Dynamic mechanical analysis of randomly oriented intimately mixed short banana/sisal hybrid fibre reinforced polyester composites., *Composites Science and Technology*, Vol. 65, 2005, pp. 1077–1087.
- Jafferjee, M., Piyasena, I., Tambyrajah, D., Composite applications using coir fibres in Sri Lanka., *Common Fund for Commodities Fast Track Project*, 2003.
- Jayaraman, K., Manufacturing sisal–polypropylene composites with minimum fibre degradation., *Composites Science and Technology*, Vol. 63, 2003, pp. 367–374.
- Kulkarni, A. G., Satyanarayana, K. G., Rohatgi, P. K., Vijayan, K., Mechanical properties of banana fibres (*Musa sepientum*)., *Journal of Materials Science*, Vol. 18, 1983, pp. 2290–2296.
- Li, X., Tabil, L. G., Panigrahi, S., Chemical Treatments of Natural Fiber for Use in Natural Fiber-Reinforced Composites: A Review., *Journal of Polymers and Environment*, Vol. 15, 2007, pp. 25–33.
- Lilholt, H., Lawther, J. M., Natural Organic Fibers., *Comprehensive Composite Materials*, Vol. 1, 2000, pp. 303 – 325.
- Mahji, S. K., Nayak, S. K., Mohanty, S., Unnikrishnan, L., Mechanical and fracture behavior of banana fiber reinforced Polylactic acid biocomposites., *International Journal of Plastics Technology*, 2010, DOI 10.1007/s12588-010-0010.
- Maya, J. J., Rajesh, D. A., Recent Developments in Chemical Modification and Characterization of Natural Fiber-Reinforced Composites., *Polymer Composites*, Vol. 29, 2008, pp. 187–207.
- Mohd, E. A. M., Akil, H., Zainal, A. M. I., Chemical modification of kenaf fibers., *Materials Letters*, Vol. 6, 2007, pp. 2023–2025.

- Mukhopadhyay, S., Figueiro, R., Arpaç, Y., Şentürk, U., Banana Fibers – Variability and Fracture Behaviour., *Journal of Engineered Fibers and Fabrics*, Vol. 3, 2008, pp. 39-45.
- Oladele, I. O., Omotoyinbo, J. A., Adewara, J. O. T., Investigating the Effect of Chemical Treatment on the Constituents and Tensile Properties of Sisal Fibre., *Journal of Minerals & Materials Characterization & Engineering*, Vol. 9, 2010, pp. 569-582.
- Rong, M. Z., Zhang, M. Q., Liu, Y., Yang, G. C., Zeng, H. M., The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy composites., *Composites Science and Technology*, Vol. 61, 2001, pp. 1437-1447.
- Rout, J., Misra, M., Tripathy, S. S., Nayak, S. K., Mohanty, A. K., The influence of fibre treatment on the performance of coir- polyester composites., *Composites Science and Technology*, Vol. 61, 2001, pp. 1303-1310.
- Rowell, R. M., Cleary, B. A., Rowell, J. S., Clemons, C., Young, R. A., Chemical modification of lignocellulosic fibers for use in composites., *Proceedings of 1st Wood fiber-plastic composite conference*, Madison, USA, 1993, pp. 121-127.
- Saheb, N. D., Jog, J. P., Natural fiber polymer composites: a review., *Advances in Polymer Technology*, Vol. 18, No. 4, 1999, pp. 351-363,.
- Valadez-Gonzalez, A., Cervantes-Uc, J. M., Olayo, R., Herrera-Franco, P. J., Effect of fiber surface treatment on the fiber-matrix bond strength of natural fiber reinforced composites., *Composites: Part B*, Vol. 30, 1999, pp. 309-320.
- Wang, B., Panigrahi, S., Tabil, L., Crerar, W., Sokansanj, S., Braun, L., Modification of flax fibers by chemical treatment, *Proceeding CSAE/SCGR Meeting*, July 6-9, Montreal, QC, Canada, 2003, Paper No. 03-337.
- Zuluaga, R., Putaux, J. L., Cruz, J., Vélez, J., Mondragón, I., Gañan, P., Cellulose microfibrils from banana rachis: Effect of alkaline treatments on structural and morphological features, *Carbohydrate Polymers*, Vol. 76, 2009, pp. 51-59.