RESEARCH ARTICLE OPEN ACCESS

Effect of degumming conditions on the deformation behavior of banana *(Musa accuminata)* pseudo-stem fibers

David N Githinji*, Dennis O Bichang'a, John T Githaiga and Diana S Madara
Department of manufacturing, Industrial & Textile Engineering, Moi University, Eldoret
dng@davidnjuguna.net

ABSTRACT
The current work investigates the effects of degumming conditions on the deformation behavior of banana (*Musa accuminata*) pseudo-stem fiber. The sodium hydroxide (NaOH) concentration was varied from 0.75M to 1.5M, treatment temperature from 80°C to 110°C and treatment time from 60 to 180 minutes. The fibers exhibited a continuous strain hardening on loading, the rate of which decreased with increasing NaOH concentration, treatment time and treatment temperature. An increase in NaOH concentration at constant treatment time and temperature had a degrading effect on the fiber's breaking tenacity and breaking extension. Similarly, an increase in treatment time at a constant NaOH concentration and treatment temperature, reduced fiber's breaking tenacity and breaking extension. Degumming of banana fibers at a NaOH concentration of 1M at 90°C for 90 minutes gave a good compromise between breaking tenacity and breaking extension.
Keywords - Banana fiber, Delignification, Degumming, Mechanical properties, Hydrolysis

I. INTRODUCTION

Banana pseudo-stem fibers are classified as bast fibers and serve to strengthen the stem of the banana plant. The fibers are integrated with natural gum in the plant structure and are located in the outer periphery of each sheath. The inner part of the banana sheath is non-fibrous and consist of large air canals separated by narrow parenchyma, and is thus easily detached from the outer fibrous region [1].

Banana fibers being lignocellulose in nature consists of cellulose, hemicellulose, lignin, pectin, wax, ash and water-soluble components [2, 3, 4]. This lignocellulose contains strongly-polarized hydroxyl groups which impact hydrophilicity in the fibers. The fiber morphology consists of crystalline matrix of cellulose fibrils spirally wound in an amorphous matrix of mainly hemicelluloses and lignin [5]. The main factor that influences the mechanical behavior of these fibers include the fibrils' spiral angle, the degree of cellulose polymerization, porosity content and the size of the lumen [6]. Several methods exist for extracting banana fibers from the pseudo-stem such as mechanical extraction, chemical extraction and bioextraction process. Each extraction method has the its own limitation, e.g. in the mechanical process the detachment of vegetable matter from the fibers is incomplete [7] while in the chemical process, strong alkali treatment have an adverse affects on fiber properties [8]. Bioconversion method such as conventional retting process has been shown to have significant effect on the fiber quality [9]. Upon extraction of banana pseudo-stem fibers, a degumming process which entails treatment with an alkali follows. The process separates the lignin fraction of lignocelluloses from the cellulose, making fibers soft. The absorption of alkali by the fibers disrupts hydrogen bonding in the structure [10, 11] which may affects the fiber's mechanical properties, especially strength and stiffness.

The effect of the degumming conditions on the mechanical properties of the banana fibers has not been explored exhaustively in the literature. Several studies [12, 13, 14] on the effect of alkali treatment on the mechanical properties of banana fiber are mainly based on room temperature tests and on those fibers extracted mechanically using machine. Since the mechanical and the letting extraction methods, have advanced effects on mechanical properties of the lingo-cellulose fiber, the current study is based on banana fibers extracted manually. The current paper explores the effects of degumming conditions on the deformation behavior of manually extracted banana fibers. The main conditions investigated in the study included; alkali concentration, treatment time and treatment temperature.

II. MATERIALS AND METHODS

II.1 Materials

Banana pseudo-stems were obtained from farmers in Eldoret region of Kenya. The stems were cut into half a meter lengths. Beginning from the outer sheath, the concentric sheaths were separated and hand-stripped by scraping away the plant tissue using a blunt blade till fibers were fully separated (Fig. 1).

The fibers were then air dried in the sun to a moisture content of about 10%.

Fig. 1: Extracted banana pseudo-stem fibers.

II.2 Alkali treatment of banana fibers

The extracted banana pseudo-stem fibers were treated with four sodium hydroxide (NaOH) solutions of 0.75M, 1M, 1.25M and 1.5M. For each solution, 20 grams of banana fibers were treated at 100°C for 120 minutes maintaining a liquor ratio of 1:25. After alkali treatment, the fibers were first rinsed with hot water followed by cold rinsing after which they were left to dry. To study the effect of treatment time, an alkali concentration of 1M and treatment temperature of 100°C were selected while the treatment time was increased from 60 to 180 minutes at 30 minutes increment. To study the effect of treatment temperature, an alkali concentration of 1M and treatment time of 120 minutes were selected while the treatment temperature was raised from 80°C to 110°C at 10°C increments.

II.3 Tensile testing of treated banana fibers

Tensile tests were conducted on a Universal Tensile Tester machine (rycobel TH2730) in accordance with ASTM D-5035 standard. The tests were performed in displacement controlled mode at a constant rate of 200mm/min crosshead speed using a gauge length of 100mm. The load and the extension (difference between final and initial lengths) at the point of fiber rupture were recorded as the breaking load and breaking extension, respectively. The tenacity was computed by dividing the breaking load with the linear density of the unstrained fiber which was about 79tex. The tests were conducted at 65%RH and 21°C.

III. RESULTS AND DISCUSSION

III.1 Effect of sodium hydroxide concentration on banana fiber deformation behavior

Fig. 2 shows the load versus extension curves for banana fibers treated with various concentrations of sodium hydroxide solutions. The curves indicate a continuous strain hardening of fibers irrespective of the alkali concentration. This observation is consistent with previous studies [12, 13] and may be attributed to constant rearrangement of microfibrils in the direction of the fiber axis. The decrease in strain hardening rate as the alkali concentration increases, may be due to increased cellulose delignification and hydrolysis thereby decreasing their molecular lengths and hence the extent of their extensibility.

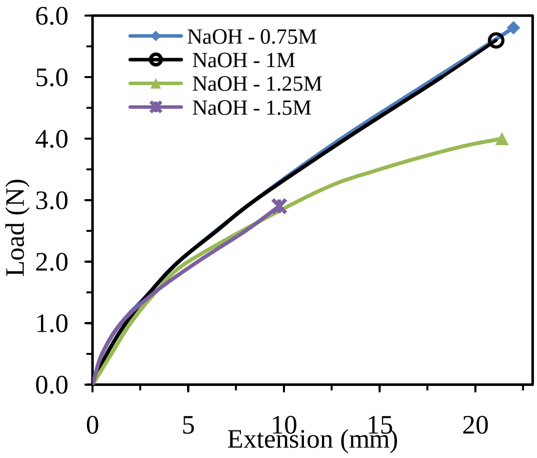

Fig. 2. Load versus extension curves for banana fibers treated with different concentration of NaOH solutions at 100°C for 120minutes.

The variation of the banana fiber breaking tenacity and breaking extension with different concentrations of sodium hydroxide solutions obtained at 100°C for 120minutes is illustrated in Fig. 3 (a) and Fig. 3 (b), respectively. A rapid decrease in fiber tenacity is observed for alkali concentration above 1M, which can be attributed to rapid hydrolysis of the cellulosic thus lowering their load carrying capacity. The relatively large extensibility of the banana fiber may be due to rearrangement and realignment of microfibrils within their structure, which may allow relatively large displacement between them. Consequently, as the concentration of alkali increases the effect of fibers hydrolysis on fiber extensibility may be less pronounced (see Fig. 3b). However, at relatively high alkali concentrations, the cellulose delignification and disintegration may occur owing to advanced hydrolysis, leading to a reduction in fiber extensibility. Apparently, degumming of banana fibers at an alkali concentration of 1M at 100°C for 120 minutes gives the best compromise between the fiber's breaking tenacity and the breaking extensions.

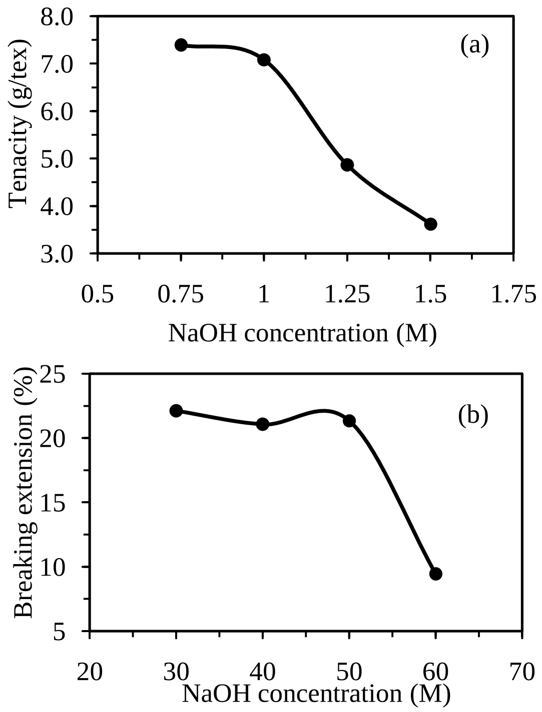

Fig. 3. Variation of sodium hydroxide solution concentration with banana fiber: (a) breaking tenacity, (b) breaking extension.

III.2 Effect of treatment time on banana fiber deformation behavior

The variation of the banana fiber breaking tenacity and breaking extension as a function of treatment times for constant NaOH concentration of 1M at 100°C is shown in Fig. 4(a) and Fig. 4(b), respectively. The corresponding load versus extension curves are shown in Fig. 5 and indicates a reduction in strain hardening rates with increasing treatment time. The fiber breaking tenacity decreases rapidly for treatment time above 90 minutes which may indicate an increase in hydrolysis of cellulose molecules thus a decrease in their load carrying capacity. Since fiber hydrolysis is a chemical reaction, an increase in treatment time at constant alkali concentration, would allow increased interaction between the cellulosic molecules and alkali protons leading to tendering of the fibers owing to delignification and depolymerization.

Apparently, as treatment time increases at constant alkali concentration and temperature, the fiber extensibility increases up to a maximum value after which it falls rapidly (see Fig. 4b). The initial increase in extension can be attributed to change in fibril and molecular structure of the fiber owing to formation of alkali-cellulose which causes fiber swelling. The change enhances the movement of fiber molecules which translate to increased fiber extension. Similar increment for banana fibers treated at room temperature with increasing alkali concentration of up to 18% has been reported previously [14]. The observed reduction in fiber's breaking extension at relatively high treatment time may be attributed to hydrolysis of the fiber molecules, which limit their lengths and thus the extent to which they can elongate. Apparently, degumming of banana fibers at an alkali concentration of 1M at 100°C for 90 minutes gives the best compromise between the fiber's breaking tenacity and the breaking extensions.

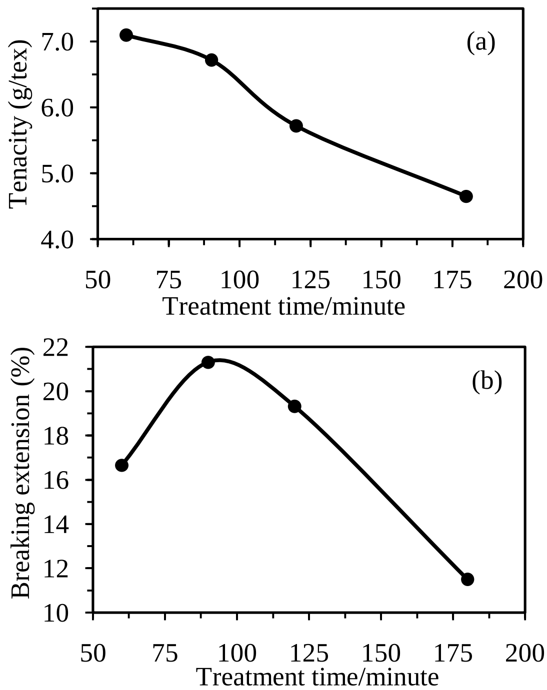

Fig. 4. Variation of banana fiber treatment time with: (a) breaking tenacity, (b) breaking extension.

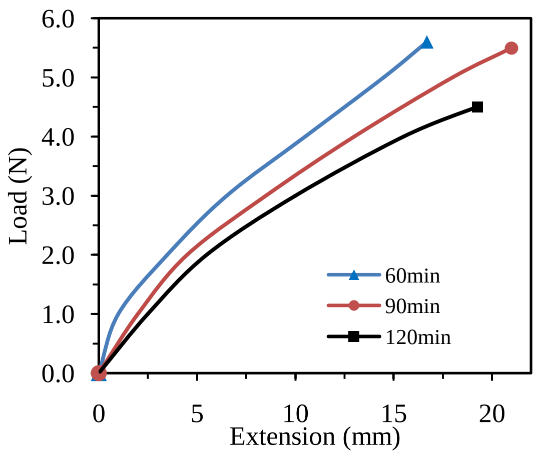

Fig. 5. Load versus extension curves for banana fibers treated at 100°C with 1M NaOH solution for 60 to 120minutes.

III.3 Effect of treatment temperatures on banana fibers deformation behavior

The variation of the banana fiber breaking tenacity and breaking extension as a function of treatment temperature at constant NaOH concentration of 1M for 120 minutes is shown in Fig. 6(a) and Fig. 6(b), respectively. The corresponding load versus extension curves are shown in Fig. 7 and indicates a reduction in strain hardening rates with increasing treatment temperature. The breaking tenacity and extensions increases to a maximum value before falling rapidly. This behavior can be explained in terms of the internal structure of the banana fibers. An increase in temperature may partially remove the non-cellulosic materials making inter-fibrillar region less dense and rigid, allowing easy rearrangement of the fibrils in the fiber direction. These rearrangements may results in better load sharing between fibrils and hence an increase in fiber breaking tenacity. Further temperature increase may cause hydrolysis of cellulosic molecules in addition to removal of non-cellulosic materials. This may thus explain the reduction in breaking tenacity and extension as the treatment temperature goes beyond 90°C. Apparently, degumming of banana fibers at an alkali concentration of 1M at 90°C for 120 minutes gives the optimal fiber's breaking tenacity and the breaking extensions.

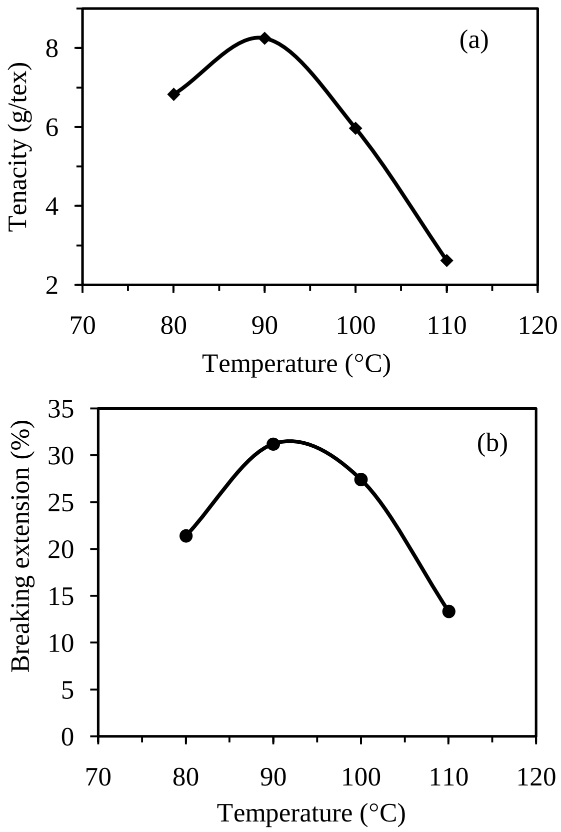

Fig. 6. Variation of banana fiber treatment temperature with: (a) breaking tenacity, (b) breaking extension.

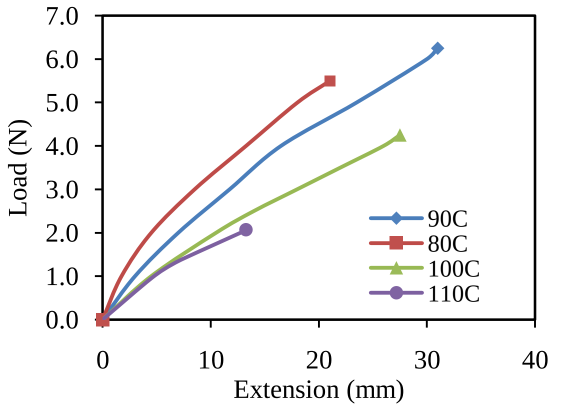

Fig. 7. Load versus extension curves for banana fibers treated with 1M NaOH solution for 120minutes at 90°C to 110°C.

IV. CONCLUSION

The effects of degumming conditions on the deformation behavior of banana pseudo-stem fiber were investigated in the current study and the following conclusions drawn:

(1) The load-extension curves of alkali treated banana fibers exhibit continuous strain hardening on loading, the rate of which, decreases with increasing alkali concentration, treatment time and treatment temperature. This is thought to arise from constant rearrangement of microfibrils in the direction of the fiber axis.
(2) The banana fiber breaking tenacity and breaking extensions diminishes with increasing alkali concentration at constant treatment temperature and time. This is attributed to delignification of the fiber and hydrolysis of cellulose molecules which adversely affects their load carrying capacity.
(3) Degumming of banana fibers at an alkali concentration of 1M at 90°C for 90 minutes gives the best compromise between the fiber's breaking tenacity and the breaking extensions.

V. ACKNOWLEDGEMENT

The author would like to thank Mr. HR Ayub, DA Kegesa and Mr. BN Osumu for their assistance in experimental work and VLIR-OUS for partially funding the research.

REFERENCES

[1] K. Li, S. Fu, H. Zhan, Y. Zhan and L. A. Lucia, Banana pseudostem chemistry, structure, *Bioresources, 5(2), 2010, 576-585.*
[2] A. C. H. C. M. M. Barreto, A. S. B. Sombra, D. S. Rosa, R. F. Nascimento, S. E. Mazzetto and

P. B. A. Fechine, Chemically Modified Banana Fiber: Structure, Dielectrical Properties and Bio-degradability,*Journal of Polymer and environment, 18, 2010, 523-531.*

[3] E. T. N. Bisanda, The Effect of Alkali Treatment on the Adhesion Characteristics of Sisal Fibers, *Applied composite Materials, 7, 2010, 331-339.*

[4] V. Manilal and J. Sony, Banana Pseudostem Characterization and Its Fiber Property Evaluation on Physical and Bioextraction, *Journal of Natural Fibers, 8, 2011, 1-12.*

[5] R. Zuluaga, J. L. Putaux, J. V. J. Cruz, I. Mondragón and P. Gañan, Cellulose microfibrils from banana rachis: Effect of alkaline treatments on structural and morphological features, *Carbohydrate Polymers, 76, 2009, 51-59.*

[6] C. Baley, F. Busnel, Y. Grohens and O. Sire, Influence of chemical treatments on surface properties and adhesion of flax fiber-polyester resin, *Composites: Part A, 33, 2002, 939-948.*

[7] A. G. Kulkarni, K. G. Satyanarayana and P. K. Rohatgi, Mechanical properties of banana fibers, *Journal of Material Science, 18, 1983, 2290-2296.*

[8] L. A. Pothan, F. Simon, S. Spange and S. Thomas, XPS studies of chemically modified banana fibers, *Biomacromolecules, 7, 2006, 892-898.*

[9] P. Ganan, R. Zuluaga, J. M. Velez and I. Mondragon, Biological natural retting for determining the hierarchical structuration of banana fibers, *Macromolecular Bioscience, 4, 2004, 978-983.*

[10] S. Alix, E. Philippe, A. Bessadok, L. Lebrun, C. Morvan and S. Marais, Effect of chemical treatments on water sorption and mechanical properties of flax fibers, *Bioresource Technology, 100, 2009, 4742-4749.*

[11] A. Cuellar and I. Muñoz, Fibra de guadua como refuerzo de matrices poliméricas, *Revista Dyna, 162, 2010, 137-142.*

[12] C. Julio, R. R.B and J. Jhon, The influence of alkali treatment on banana fiber's mechanical properties, *Ingenieria e Investigacion, 32(2), 2012, 39-45.*

[13] M. Samrat, F. Raul, A. Yusuf and Ş. Ülkü, Banana Fibers – Variability and Fracture Behaviour, *Journal of Engineered Fibers and Fabrics, 3(2), 2008, 41-45.*

[14] T. Lin, C. Suying and B. Xiaoyun, The effects of alkali treatment to the properties of banana fibers, *Applied Mechanics and Materials, 268-270, 2013, 258-261.*

[15] K. Mohanty, M. Misra and L. T. Drzal, *Natural Fibers, Biopolymers and Biocomposites* (Florida, FL: CRC Press, 2005).