Effect of Fiber Surface Treatments on the Tensile Properties of Polycarbonate-Coated Napier Grass Fibers

Obi Reedy Kanchireddy, and Edison Muzenda

Abstract**—**In this work forestry waste natural Napier grass fibers were extracted from stems by water retting process. Polycarbonate coating of theses fibers was done by solvent casting method. Three surface treatment systems were used to improve the Napier grass fiber-polycarbonate interfacial bonding as follows: alkali, silane and a combination of alkaline and silane treatments. The effect of chemical treatments of fibers on tensile properties of the coated fibers was studied. The tensile properties of the coated fibers with surface modified fibers were found to be higher than those with unmodified and uncoated fibers. This is due to an improvement in the interfacial bonding between the surface modified Napier grass fiber and polycarbonate. The moisture absorption of the polycarbonate-coated fibers was lower than that of unmodified and uncoated fibers. Morphological analysis was carried out to observe interfacial bonding of the samples using scanning electron microscope.

Keywords**—**Fibers**,** Morphology, Napier grass, Polycarbonate, Tensile properties

I. Introduction

THE addition of natural fibers to polymer matrices to attain desirable material properties has led to the development of environmental friendly natural fiber composites [1]. Natural fibers are ligno-cellulosic in nature and are the most copious renewable biomaterial of photosynthesis on earth. These fibers have a low density and a high specific strength and modulus, lower abrasiveness to processing equipment, harmless, good thermal and insulating properties, surfaces that are easily modified and are also widely available [2]. There is a growing interest in natural fiber composites for various applications as a result of these advantages [3]. Many researchers have investigated the suitability of natural fibers as reinforcing components [4, 5].

However, the drawbacks of natural fibers such as degradation during processing, poor wettability, incompatibility with a few polymeric matrices and high moisture absorption make them unsuitable for composite applications [4]. Another problem encountered in their use is fiber–matrix adhesion arising due to the incompatibility between the hydrophilic natural fibers and the hydrophobic polymer matrix [4]. To improve the fiber properties it is necessary to improve the fiber–matrix adhesion and to reduce the moisture content of the fiber. This can be achieved by fiber surface modification through physical or chemical methods [2, 4, 5]. The use of different physical treatment methods (corona discharge, cold plasma and UV bombardment) and chemical treatment methods (alkalization, grafting, acrylation, acetylation, silane and peroxide) lead to reduction in moisture gain, as well as changes in the fiber surface [2]. The conditions of modification influence fiber properties such as morphology and thermal stability.

Alkali treatment is an inexpensive and effective method to modify the fiber surface resulting in enhanced interfacial adhesion between the natural fiber and the polymeric matrix [4]. There is a considerable difference between primary treatment such as alkali and secondary treatment for example silane application [4, 5]. While the earlier are mostly devoted to the removal of nonstructural matter from the fibers, the second appear capable of providing protective coating to the fibers, furthermore improving their adhesion to the polymer matrix. Alkali combined with silanes modified fibers were used to improve the mechanical properties of polymer composites in various studies [5-7]. Various natural fibers were coated with organo-soluble polymers like polycarbonate, polystyrene and polymethyl methacrylate which enhanced mechanical properties after coating [6, 8-10]. This method is inexpensive and effective in modifying the fiber surface for enhanced interfacial adhesion between the natural fiber and the polymeric matrix.

Napier grass (*Pennisetum purpureum*), also called elephant grass, belongs to the Poaceae family. Napier grass is a rapid-growing, internodal, fibrous, perennial grass available in abundance and has huge economic potential. The authors have already reported preliminary studies on properties of Napier grass fibers in particular their suitability as a reinforcement [11]. Polycarbonate is an important engineering-toughened material, a good insulator, and a polar polymer that is resistant to water and many organic compounds [6]. In the present work, Napier grass fibers were coated with polycarbonate and their tensile properties were determined. The effect of alkali and silane treatment on the tensile properties of the fibers was also investigated. The morphology of these fibers under

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different conditions was studied using a scanning electron microscope.

II. Materials And Methods

A. Materials

Extracted Napier grass fibers, Polycarbonate (Rare & Research Chemicals), sodium hydroxide (SD Fine Chem.), acetic acid, 3-aminopropyltriethoxy silane and toluene (Merck) were used.

B. Fibre Extraction

The Napier grass fibers were extracted from the grass internodes by the usual retting process. The separated fibers were washed thoroughly using distilled water and then sun dried for one week to ensure maximum moisture removal.

C. Alkali Treatment

Extracted Napier grass fibers were treated with 5% aqueous sodium hydroxide (aq. NaOH) solution at room temperature for 30 min, maintaining a liquor ratio of 20:1 to remove the hemicellulose and other greasy materials. Finally, the fibers were washed with tap water and repeatedly with distilled water, and finally dried at 105 °C.

D. Silane Treatment

A solution of 1% 3-aminopropyltriethoxy silane was prepared in acetone. The pH of the solution was adjusted to 4 with acetic acid and stirred continuously for 5 min. Untreated fibers were then immersed in the solution for 1 h. After treatment, fibers were removed from the solution and dried in oven at 60 ^{o}C for 12 h. Similar silane treatment procedures were also employed for fibers that were previously alkali treated.

E. Polycarbonate Coating

A solution of 10% w/v polycarbonate was prepared using dichloromethane as solvent, and then the untreated, alkali treated, silane and alkali with silane treated fibers were coated with the polymer solution. The coated fibers were vertically hung on a wooden frame, allowed to dry at room temperature for 24 h, and dried in a hot air oven at 60 ^{o}C for 2 h.

F. Tensile Properties

The tensile properties (Young's modulus, maximum stress, and elongation at break) of the fibers were determined using an Instron 3369 Universal Testing Machine. All the fibers tested were conditioned for 24 h in a standard testing atmosphere of 21 ^{o}C and 65% relative humidity. Tensile testing of the fibers was carried out at a crosshead speed of 5mm/min, maintaining a gauge length of 50mm using a 10 kN-load cell. A total of 10 fibers were tested for each condition and the average values reported.

G. Scanning Electron Microscopy Analysis (SEM)

In this study, uncoated and polystyrene-coated Napier grass fiber surface morphology was studied using a JEOL JSM 820 scanning electron microscope operating at a voltage of 5 kV. Samples were sputter coated with gold to make them conductive prior to SEM observation.

H. Water Absorption

To study the water absorption of the uncoated and coated Napier grass fibers, tests were carried out as per the ASTM D 543-87 standard. The pre-weighed specimens were dipped in the distilled water for 24 h, removed, dried by pressing them between filter paper and reweighed. The % water absorption was determined using (1).

$$\%Water\ absorption = \left[\frac{FW - IW}{IW}\right] X100 \quad ------ \ 1$$

where FW and IW are the final and initial weights respectively.

III. Results And Discussion

The primary work relating to the extraction of the fibers from Napier grass stem internodes particularly the chemical composition and the influence of alkali treatment on the properties of the fibers was reported in literature [11]. Our preceding study on untreated Napier grass fibers indicated that they have an average α-cellulose, hemicellulose, and lignin content of 45.66%, 33.67%, and 20.6%, respectively. After alkali treatment, the fibers had α-cellulose, hemicellulose, and lignin of 55.99%, 20.01% and 24.0% respectively. Usually, natural fibers are treated with alkali to remove weak amorphous components so that the fiber retains crystalline components enhancing the strength of the fiber. Also our previous SEM analysis studies of alkali treated fibers showed the roughness of the fibers after alkali treatment suggesting the removal of impurities and facilitation of good interaction between fibers and matrices.

This work focused on the extraction of fibers from Napier grass, studying the tensile properties and morphology, and investigating the influence of chemical (alkali and silane) treatment and polycarbonate coating on the fibers. The average fiber length was found to be 142 mm. The average diameters of untreated, 5% alkali treated, silane treated and alkali combined with silane treated fibers were found to be 0.225, 0.158, 0.213 and 0.147 mm respectively. After polycarbonate coating, the average diameter of untreated, alkali-treated, and alkali and silane-treated fibers was found to be 0.375, 0.357, 0.361 and 0.348 mm respectively. No appreciable change in fiber diameter was observed after polycarbonate coating.

The SEM micrographs of the uncoated (untreated, alkali, silane and alkali combined with silane treated) fibers are shown in Fig. 1. The micrographs of untreated fiber surface is shown in Fig. 1(a), it can be observed that non-cellulosic layer was composed of materials such as hemicellulose, lignin, pectin, wax, and other impurities and localized on fiber surface. After alkali treatment, Fig. 1(b), the fiber surface became clearer and rougher. This indicates the maximum removal of the outer non-cellulosic layer and other impurities in the fiber [2, 6]. The micrograph of silane treated fiber surface is shown in Fig. 1(c) from which the partial removal of

nonpolar polymer matrices. However, the respective increases in tensile strength, modulus, and elongation at break of chemically modified fibers over the untreated fibers were: alkali treated (81.3, 54.4 and 14.2%), silane treated (2.6, 4.4 and 3.5%), and alkali combined with silane treated (85.3, 60.3 and 21.4%).

From Fig. 3, it is also evident that the tensile properties of the polycarbonate-coated Napier grass fibers were higher than those of the uncoated fibers. Also it is evident that the chemical modification of the fibers by alkali and silane treatment with polymer coating fibers enhanced the tensile properties. When the Napier grass fibers were treated with an alkali, the fiber surface became rough. The roughening of the surface leads to an increase in the contact area and lowering of the contact angle of the polymer on the fiber leading to an improvement in the interfacial bonding [5]. When silane is used, additional chemical sites were created on the fiber surface [6], that lead to better bonding between the fibers and the polymer, and improved the tensile properties. The respective increases in tensile strength, modulus, and elongation at break of chemically modified with coated fibers over the untreated with coated fibers were: alkali treated (77.5, 56.1 and 10 %), silane treated (6.2, 6.8 and 23.3%), and alkali combined with silane treated (88.7, 68.5 and 30 %).

The water absorption (%) of the uncoated and polycarbonate-coated and with untreated and chemically (alkali, silane and alkali combined with silane) modified Napier grass fibers were found to be 1.73, 1.22, 1.18, and 1.03%, respectively. These observations clearly indicate that water absorption by the alkali combined with silane treated polycarbonate coated fibers under study showed good water resistance. This is due to the good bonding between fiber and the polymer resulting in resistance to water penetration.

IV. Conclusion

In this work, the tensile properties of the polycarbonate-coated Napier grass fibers were studied. The effect of alkali and silane treatments on the tensile properties, morphology, and water absorption of uncoated and polycarbonate-coated fibers was studied. Obvious changes such as surface roughening and scratch formation were observed for alkali combined with silane treated uncoated fibers. For polycarbonate-coated fibers, the surface was found to be uniformly covered by the polymer. Surface treatment and polymer coating were found to improve the tensile properties. The water absorption of the polycarbonate-coated fibers was lower than that of the uncoated fibers. Our results indicated that the fiber treatment and polymer coating procedures can be chosen according to the target applications and the hydrophilic character of the polymer with which it will be compounded. Napier grass fiber is a promising raw material as a reinforcing agent in the production of biocomposites.

Acknowledgment

The authors acknowledge the Faculty of Engineering and the Built Environment, and University Research Committees, University of Johannesburg for supporting the postdoctoral appointment as well as conference attendance.

References

[1] V. K. Thakur, A.S. Singha, and I. K. Mehta, "Renewable resource-based green polymercomposites: Analysis and characterization," Int J Polym Anal Charact., Vol. 15, pp. 137-146, 2010. http://dx.doi.org/10.1080/10236660903582233

[2] K. O. Reddy, M. Shukla, C. U. Maheswari, J. I. Song and A. V. Rajulu, "Tensile and structural characterization of alkali treated Borassus fruit fine fibers," Comp Part B., Vol. 44, pp. 433-438, 2013. http://dx.doi.org/10.1016/j.compositesb.2012.04.075

[3] K. Pandey, S. H. Ahn, C. S. Lee, A. K. Mohanty and M. Misra, "Recent advances in the application of natural fiber based composites," Macr Mater Eng., Vol. 295, pp. 975-989, 2010. http://dx.doi.org/10.1002/mame.201000095

[4] M. J. John and R. D. Anandjiwala, "Recent developments in chemical modification and characterization of natural fiber-reinforced composites," Polym Compos., Vol. 29, pp.187-207, 2008. http://dx.doi.org/10.1002/pc.20461

[5] K. O. Reddy, C. U. Maheswari, M. Shukla, and A. V. Rajulu, "Evaluation of mechanical behavior of chemically modified Borassus fruit short fiber/ unsaturated polyester composites", J Compos Mater., Vol 46, pp. 2987-2998, 2012. http://dx.doi.org/10.1177/0021998312454032

[6] C. U. Maheswari, K. O. Reddy, E. Muzenda and A. V. Rajulu, "Tensile and thermal properties of polycarbonate-coated Tamarind fruit fibers," Int J Polym Anal Charact., Vol. 17, pp. 578-589, 2012. http://dx.doi.org/10.1080/1023666X.2012.718527

[7] Y. Xie , C. A. S. Hill, Z. Xiao, H. Militz, and C. Mai, "Silane coupling agents used for natural fiber/polymer composites: A review," Compos Part A., 41, pp.806- 819, 2010. http://dx.doi.org/10.1016/j.compositesa.2010.03.005

[8] C. U. Maheswari, K. O. Reddy, and E. Muzenda, "Tensile properties of polystyrene-coated tamarind fruit fiber", International Conference on Chemical and Environmental Engineering (ICCEE'2013) April 15-16, 2013 Johannesburg (South Africa).

[9] A. V. Rajulu, G. B. Rao, R. L. N. Reddy, and R. Sanjeevi, "Chemical resistance and tensile properties of epoxy/polycarbonate blend coated bamboo fibers", J Rein Plast Compos, Vol 20, pp 335-340, 2001. http://dx.doi.org/10.1177/073168401772678788

[10] V. Rajulu, X. H. Li, L. G. Devi, G. B. Rao, and Y. Z. Meng, "Tensile properties of ligno-cellulose fabrics coated with styrenated polyester resin", Cellulose, Vol 10, 179-183, 2003. http://dx.doi.org/10.1023/A:1024090511262

[11] K. O. Reddy, C. U. Maheswari, M. Shukla, and A.V. Rajulu, "Chemical composition and structural characterization of Napier grass fibers", Mater Lett., Vol 67, pp 35-38, 2012. http://dx.doi.org/10.1016/j.matlet.2011.09.027