Functionality Enhancement of Paperboard Using Okra Fiber: A Novel Resource for Fiber Reinforcement

Md Anwar Hossain[a,]*, Md. Nasir Uddin[a], Md. Asaduzzaman[a], Md. Shohel Rana[a]

[a]*Department of Textile Engineering, Uttara University, Dhaka-1230, Bangladesh*

Abstract

Paperboard is now being used to create a variety of functional products, including handicrafts that are easy to make and cost-effective. In this study, the effects of three types of fibers (Cotton, Polyester, and Okra) were used as reinforcement, and analyzed the mechanical properties such as tensile strength, ductility, and toughness of paperboard. The results showed that paperboard with Okra fiber reinforcement exhibited superior mechanical properties, including higher tensile strength, ductility, and toughness, compared to paperboard made with Cotton and Polyester fibers. This study revealed that Okra fiber could be a productive source of reinforcing fiber with superior mechanical qualities for the use of paperboard manufacturing.

Keywords: Paperboard; Okra fiber; Fiber Reinforcement

1. Introduction

Due to concerns about renewable resources and the environment, the creation of high-performance engineered goods created from natural resources is expanding globally [1]. Advanced material preparation techniques are used to combine material components with various qualities to create composite materials, which are multiphase solid materials [2][3]. Due to their high strength, great durability, and low weight, fiber-based composite materials have garnered a lot of attention. Fibers-based composite materials can both keep their original qualities and enhance or overcome the shortcomings of any single material by functionally altering the fiber components [2][4]. Since natural fiber-reinforced polymer composite materials are renewable, low-cost, fully or partially recyclable, and biodegradable, they are expanding quickly in both industrial applications and fundamental research [5]. The main issue with natural fibers is their incompatibility with hydrophilic thermoplastic matrices during incorporation, which results in unfavorable qualities of the composites produced [5][6]. Due to their characteristics and ease of availability, flax, hemp, jute, kenaf, and sisal are the most significant natural fiber types used in composite materials. The main issue with natural fibers is their incompatibility with hydrophilic thermoplastic matrices during incorporation, which results in unfavorable qualities of the composites produced [1][7][8]. High strength and stiffness are provided by synthetic fiber-reinforced composites, which are widely employed in aerospace and automotive applications. Consumer-friendly synthetic fibers are waterproof, stretchable, and stain-resistant. Bast fibers have a conventional cell structure made up of a thick wall and a lumen [8]. Swelling caused by water absorption can cause composites to micro-cracks and lose their mechanical characteristics. Three distinct processes allow moisture to enter composite materials. The diffusion of water molecules into the microscopic spaces between polymer chains makes up the primary process. The additional methods include transport through microscopic fissures in the matrix, which occur during compounding, and capillary transport through gaps and defects at the interfaces between fibers and polymer due to insufficient wettability and impregnation. Water molecules enter into the contact between the fibers and the matrix as part of the capillary process. When the interfacial adhesion is poor and the de-bonding of the fibers and matrix has begun, it is very important. Water flow and storage in the pores, micro-cracks, and microscopic channels of the composite structure are also included in the definition of transport by micro-cracks. These flaws may have developed during the material's production or as a result of environmental and service factors. The diffusion coefficient is the most crucial factor in determining how much water is absorbed since it indicates how easily solvent molecules may enter a composite structure [9][10]. For design purposes, accurate estimates of paperboard strength under complex stress states are

* Corresponding author. Tel.: +8802893234
E-mail address: hossainanwar@uttarauniversity.edu.bd
http://dx.doi.org/10.1016/j.cviu.2017.00.000.

necessary. For the majority of facilities, controlled testing of paper under biaxial normal and shear pressures is currently challenging. Uniaxial tests are simpler to do, but they do not physically demonstrate a material's strength under more complicated loadings. Both technological advancement and practical purposes must have mathematical failure criteria that can precisely forecast the strength of paperboard [11]. Paperboard companies are currently experimenting with the reinforcing of their products with different natural fibers. Industrial researchers have become interested in natural fiber-reinforced composites because of their accessibility, light weight, biodegradability, and recyclable nature. Simple water retting along with physical labor was used to remove natural fibers from the plants [12]. Lamination with easily available, inexpensive plastic materials has dominated the surface treatment of paperboard to increase functionality over the past few decades. Functional packaging should also have minimal production costs and use less energy by not requiring the product to be refrigerated or frozen. Paperboard provides flexibility and mechanical strength for the creation of packages, but because it lacks barrier qualities, it must be surface-treated to increase functionality [13].

In this study, we try to improve the mechanical characteristics such as tensile strength, ductility, and toughness of paperboard by adding cotton, polyester and okra fibers as a fiber reinforcement.

2. Materials and Method

2.1 Materials

Wastepaper was collected from households in the local area. Scissors, a domestic kitchen blender, an electric balance, mesh fabric, and fiber were obtained from the wet processing laboratory of Uttara University's Department of Textile Engineering. Table 1 represents the different fiber properties.

Table 1: Properties of fiber

Properties	Cotton	Polyester	Okra
Length (mm)	28.58	38	40
Strength (g/tex)	33.3	40.8	94.75
Fineness (dtex)	1.71	1.34	0.304
Elongation (%)	3.5	25	1.3

2.2 Experimental Design

The paperboard was prepared by tearing the waste paper into small pieces using scissors. The paper was then turned into pulp using a domestic kitchen blender at a paper-to-water ratio of 1:10. The resulting pulp was divided into four equal parts and transferred to four different cookers. In three of the cookers, 5 grams of fibers (cotton, polyester, and Okra) were added, while the fourth cooker contained only pulp as a control. The pulp and fiber mixture was thoroughly mixed by hand for 15 minutes to ensure that the fibers were evenly dispersed throughout the pulp. A fixed amount of the pulp mixture was then separated using a mesh fabric, and the excess water was drained using a sponge. The pulp mixture was then placed on a cotton fabric and pressed under a 25 kg load to form a fiber-reinforced paperboard (FRPB). The resulting coagulated pulp was allowed to dry for six hours in the sun. The paperboard samples were then tested for their mechanical properties, including tensile strength, ductility, and toughness. The results were analyzed and compared to determine the effects of the different types of fibers on the mechanical properties of the paperboard.

Fig. 1. Paperboard manufacturing process

3. Result and Discussion

Tensile strength is the maximum stress a material can withstand when stretched or pulled before breaking.it represents the ability of a material to resist being pulled apart or stretched when a force is applied along its length [14]. In this study, tensile strength, elongation% and, toughness properties of paperboard were evaluated with cotton, polyester, and Okra fibers reinforcement.

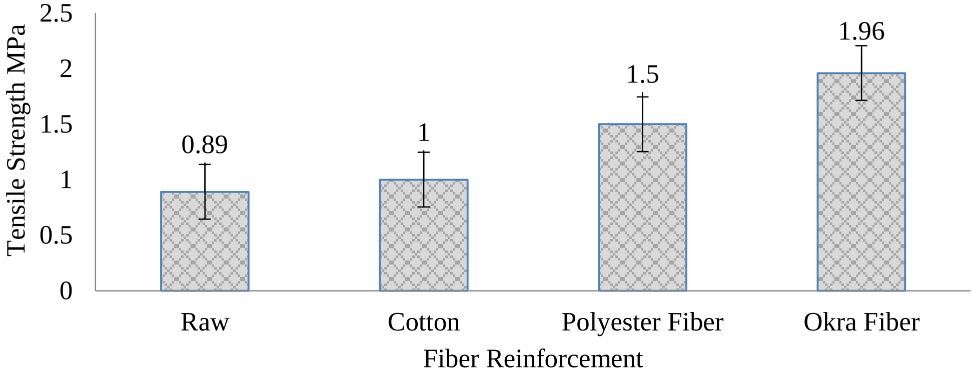

Fig. 2. Tensile strength of different fibers reinforcement in paperboard making

Figure 2 represents that, Okra fiber exhibited the highest tensile strength, with an average value of 1.96 MPa. This result can be attributed to the inherent strength of Okra fiber itself. The addition of Okra fiber to the paperboard resulted in a significant improvement in its tensile strength (Figure 5), compared to cotton fiber and polyester fiber reinforcement.

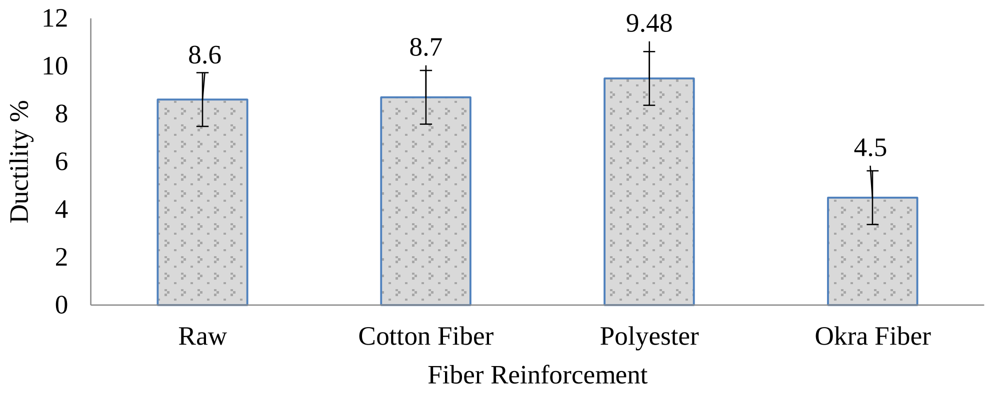

Fig. 3. Ductility of different fibers reinforcement in paperboard making

Ductility is the ability of a material to undergo significant deformation before fracturing when subjected to tensile stress, such as stretching or elongation [15]. However, the ductility properties of the paperboard made with Okra fiber reinforcement were found to be lower which is mentioned in Figure 3 compared to those made with cotton and polyester fiber reinforcement. This can be attributed to the high tensile strength of Okra fiber, which makes it less flexible and more brittle. Toughness is a measure of the ability of a material to absorb energy and deform plastically before fracturing. It combines both strength and ductility, indicating how much energy a material can absorb before failure [16]. Moreover, in Figure 4 it was observed that the toughness of the paperboard made with Okra fiber was found to be higher compared to those made with cotton and polyester fibers. This indicates that the paperboard made with Okra fiber is more resistant to tearing and breaking.

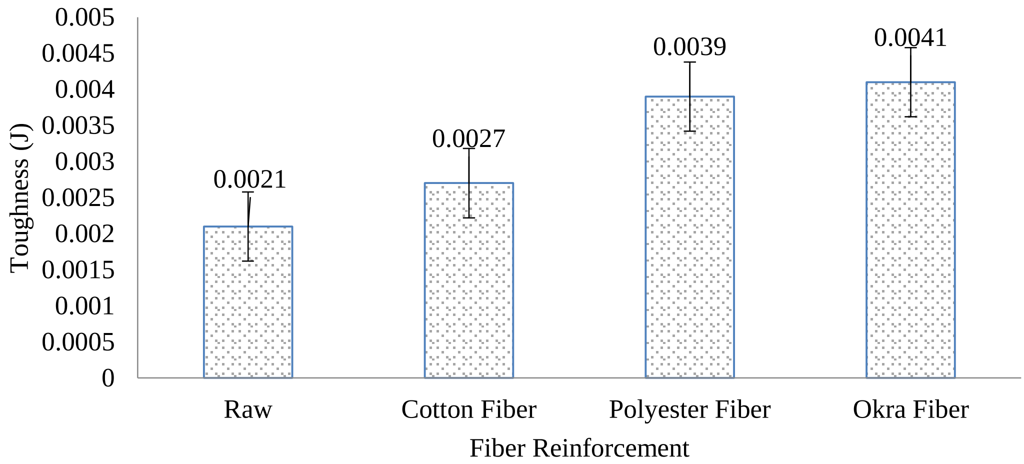

Fig. 4. Toughness of different fibers reinforcement in paperboard making

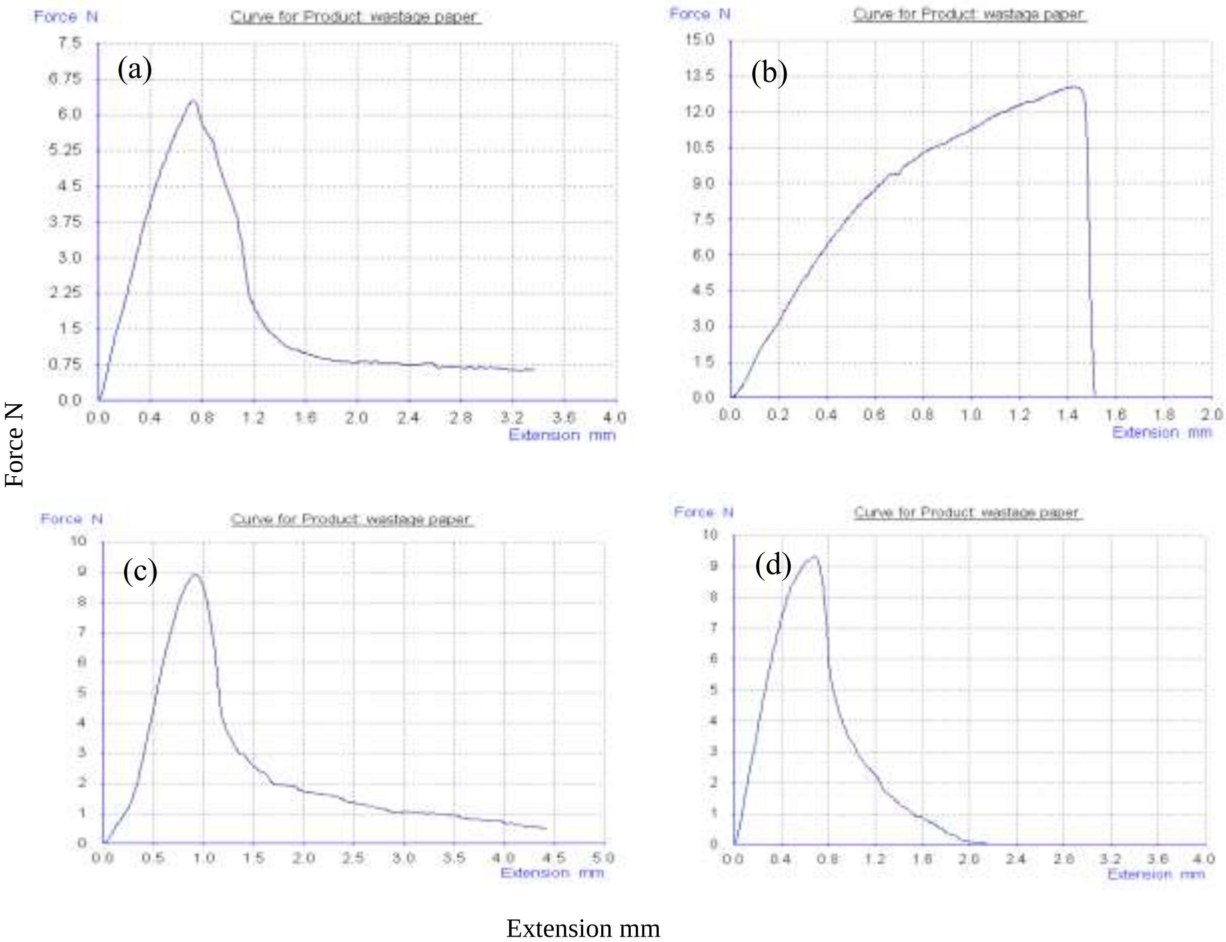

Fig. 5. S-S curve of different fibers reinforcement. (a) raw paper, (b) cotton fiber reinforcement, (c) polyester fiber reinforcement, and (d) okra fiber reinforcement

Overall, these results suggest that Okra fiber is a promising material for use as a reinforcing fiber in the production of paperboard, particularly for applications that require high tensile strength and tear resistance. However, further research is needed to optimize the fiber content and processing parameters to achieve optimal mechanical properties of the paperboard.

4. Conclusion

The results of this study showed that paperboard made with Okra fiber exhibited the highest tensile strength with lower ductility compared to cotton and polyester fibers. The higher toughness of the paperboard with Okra fiber reinforcement suggests that it is more resistant to tearing and breaking, which may make it suitable for certain applications where durability is required. Overall, this study provides valuable insights into the potential use of natural fibers as a reinforcement in paperboard for packaging applications.

Acknowledgment

The authors would like to express their sincere gratitude to Uttara University, Department of Textile Engineering, for their invaluable laboratory support. Their assistance has been instrumental in the successful execution of this research project.

References

[1] H. M. Akil, M. F. Omar, A. A. M. Mazuki, S. Safiee, Z. A. M. Ishak, and A. Abu Bakar, "Kenaf fiber reinforced composites: A review," *Mater. Des.*, vol. 32, no. 8–9, pp. 4107–4121, 2011, doi: 10.1016/j.matdes.2011.04.008.

[2] G. Yang, M. Park, and S. J. Park, "Recent progresses of fabrication and characterization of fibers-reinforced composites: A review," *Compos. Commun.*, vol. 14, no. May, pp. 34–42, 2019, doi: 10.1016/j.coco.2019.05.004.

[3] S. Garoushi, E. Säilynoja, P. K. Vallittu, and L. Lassila, "Physical properties and depth of cure of a new short fiber reinforced composite," *Dent. Mater.*, vol. 29, no. 8, pp. 835–841, 2013, doi: 10.1016/j.dental.2013.04.016.

[4] G. D. Goh, Y. L. Yap, S. Agarwala, and W. Y. Yeong, "Recent Progress in Additive Manufacturing of Fiber Reinforced Polymer Composite," *Adv. Mater. Technol.*, vol. 4, no. 1, pp. 1–22, 2019, doi: 10.1002/admt.201800271.

[5] K. Rohit and S. Dixit, "A review - future aspect of natural fiber reinforced composite," *Polym. from Renew. Resour.*, vol. 7, no. 2, pp. 43–60, 2016, doi: 10.1177/204124791600700202.

[6] S. V. Joshi, L. T. Drzal, A. K. Mohanty, and S. Arora, "Are natural fiber composites environmentally superior to glass fiber reinforced composites?," *Compos. Part A Appl. Sci. Manuf.*, vol. 35, no. 3, pp. 371–376, 2004, doi: 10.1016/j.compositesa.2003.09.016.

[7] J. A. Delicano, "A review on abaca fiber reinforced composites," *Compos. Interfaces*, vol. 25, no. 12, pp. 1039–1066, 2018, doi: 10.1080/09276440.2018.1464856.

[8] M. Muneer Ahmed, H. N. Dhakal, Z. Y. Zhang, A. Barouni, and R. Zahari, "Enhancement of impact toughness and damage behaviour of natural fibre reinforced composites and their hybrids through novel improvement techniques: A critical review," *Compos. Struct.*, vol. 259, no. December 2020, p. 113496, 2021, doi: 10.1016/j.compstruct.2020.113496.

[9] M. D. H. Beg and K. L. Pickering, "Mechanical performance of Kraft fibre reinforced polypropylene composites: Influence of fibre length, fibre beating and hygrothermal ageing," *Compos. Part A Appl. Sci. Manuf.*, vol. 39, no. 11, pp. 1748–1755, 2008, doi: 10.1016/j.compositesa.2008.08.003.

[10] D. Verma, K. L. Goh, and V. Vimal, "Interfacial Studies of Natural Fiber-Reinforced Particulate Thermoplastic Composites and Their Mechanical Properties," *J. Nat. Fibers*, vol. 19, no. 6, pp. 2299–2326, 2022, doi: 10.1080/15440478.2020.1808147.

[11] J. C. Suhling, R. E. Rowlands, M. W. Johnson, and D. E. Gunderson, "Tensorial strength analysis of paperboard," *Exp. Mech.*, vol. 25, no. 1, pp. 75–84, 1985, doi: 10.1007/BF02329129.

[12] N. Venkatachalam, P. Navaneethakrishnan, and T. P. Sathishkumar, "Characterization of novel Passiflora foetida natural fibers for paper board industry," *J. Ind. Text.*, vol. 2016, pp. 1–24, 2016, doi: 10.1177/1528083716682923.

[13] C. Andersson, "New ways to enhance the functionality of paperboard by surface treatment - A review," *Packag. Technol. Sci.*, vol. 21, no. 6, pp. 339–373, 2008, doi: 10.1002/pts.823.

[14] J. C. Pang, S. X. Li, Z. G. Wang, and Z. F. Zhang, "General relation between tensile strength and fatigue strength of metallic materials," *Mater. Sci. Eng. A*, vol. 564, pp. 331–341, 2013, doi: 10.1016/j.msea.2012.11.103.

[15] Y. T. Zhu and X. L. Wu, "Ductility and plasticity of nanostructured metals: differences and issues," *Mater. Today Nano*, vol. 2, pp. 15–20, 2018, doi: 10.1016/j.mtnano.2018.09.004.

[16] G. Li *et al.*, "Fracture toughness of thermoelectric materials," *Mater. Sci. Eng. R Reports*, vol. 144, no. December 2020, pp. 1–12, 2021, doi: 10.1016/j.mser.2021.100607.