Effects of Fiber Size on Moisture Resistance and Microstructure: Analysis of Maize Straw Vegetable Protein Adhesive Composites

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***Abstract* — The aim of this paper is to evaluate the effect of fiber size on the performance of moisture resistance and microstructure of corn stalk with vegetable protein adhesive composites. Various straw composites were prepared containing wood plastic and ones with varying vegetable protein adhesive and different fiber size straws. The three composites were prepared with vegetable protein adhesive and corn stalks, with the fiber sizes were 0.1mm, 1mm, 10mm. Water absorption, moisture absorption and contact angle tests were used to evaluate the moisture resistance. TGA test was utilized to analyze thermal stability, and section microstructures were examined with an ordinary microscope.**

Keywords - fiber size; maize straw; vegetable protein adhesive; natural composites; moisture resistance; microstructure analysis

I. INTRODUCTION

Straw has received much attention in recent years due to its high rich resource, specific strength, and biodegradable properties, which offer important economic benefits [1]. Straw is a natural polymer obtained mainly from agricultural residues. It has many possible uses in the packaging, composite floor, furniture, etc. and has also been investigated as a potential engineering material. Preparing natural composites from agricultural waste can reduce reliance on raw materials, as well as reducing cost and waste straw pollution. However, it has been found to be too weak under water and force to be used commercially. One way to toughen polymers is to mix plastic into straw powder or fine fibers and there has been extensive research regarding straw modification and mixture of composites. For example, Peyvandi A et al. [2] showed that surface treatment of polymer microfibrillar structures could improved surface wettability and adhesion. He Chunxia et al . [3] prepared composites with wheat straw and PP by adding varying amounts of zinc borate, and analyzed water absorption. Although the effect of the moisture barrier agent on the mechanical properties, moisture resistance and microstructure of straw composites was demonstrated more than ten years ago, little attention has been paid to the selection of an appropriate fiber size [4-5]. The present paper presents a set of criteria for selecting such content.

II. MATERIALS AND METHODS

A. Materials

Maize straw was provided by plots of Anhui science and technology, (Fengyang, Anhui). It was oven-dried at 80±5°C, crushed, ground and sieved to a fiber size of 0.1mm, 1mm, and 10mm, respectively. Vegetable protein adhesive, expressed as white and fine powder, was purchased from Pingqiao district, (Xinyang, Henan). Glycerol, presented as a colorless oily liquid and AR, was provided by Shiyi Chemicals Co., Ltd., (Shanghai, China). $NaHCO_3$, as a white powder, was purchased from founder reagent plant, (Beichen, Tianjin).

B. Maize straw and pretreatment

The three maize straw samples were pretreated by NaOH (5 wt%) solution for 24 hours. The treated maize straw fiber was then washed many times to make PH value be equal to seven and dried in the oven at 80±5°C temperature. The samples were filled to three moisture-proof bags and then sealed tightly to prevent contamination.

C. Maize straw natural composites preparation

Maize straw and vegetable protein adhesive were mixed (mass ratio of 5: 1), which glycerol and $NaHCO_3$ content in the mixtures was 1.2% and 3.3%, respectively. The mixture was stirred vigorously by mixer for 15 min at room temperature and pressed subsequently into rectangular composite plate with a molding machine (XLB-D400×400×2-Z, Qicai Hydraulic Machinery Co., Ltd. Shanghai) in a 100×120mm^2 special steel mold at 160°C, 2.2 MPa for 6 min. Three samples of composites with vegetable protein adhesive and maize straw, varying size is 0.1mm，1mm,and 10mm, were prepared by molding method, which cut to the desired size samples after cooling molding material and later stored in the desiccator for characterization and resistance experiment.

D. Characterization

(1)Mechanical Performance Test

The GB/T9341-2008 standard was followed for mechanical strength testing [6]. For tensile strength evaluation, modulus of rupture (MOR) and modulus of elasticity (MOE) were obtained from three-point bending tests. Tests were made on a computer-controlled electronic universal testing machine (SANS CMT6104, China). The

DOI 10.5013/ IJSSST.a.17.29.31

ISSN: 1473-804x online, 1473-8031 print

GB/T1451-2005 standard was followed for Impact strength testing. Tests were made on a charpy impact test machine, (XJJ-5,China). Maize straw/ vegetable protein adhesive composites samples was all cut into cuboids of 100mm×10mm×H mm(H is thickness, which range is 4.5-5.5 mm).

(2) Measurement of contact angle

Maize straw/vegetable protein adhesive composites samples were cut into cuboids measuring 20mm×10mm×H mm (H is thickness, which range is 4.5-5.5 mm). The sample was placed measurement platform, put a drop of distilled water on the surface, and measured contact angle of size after ten seconds by the five-point fitting of software. For contact angle evaluation, the results were obtained from three-time tests. Tests were made on an optical contact angle measuring instrument (JC2000D1, China) [7].

(3) Water resistance

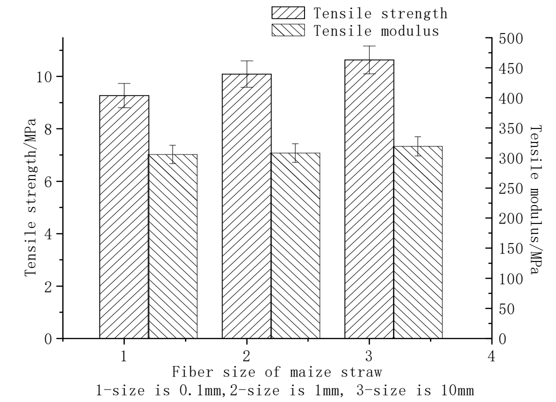
The GB/T21723-2008 standard was followed for water absorption tests and the GB/T20312-2006 standard was followed for hygroscopic tests[8-9]. Maize straw/ vegetable protein adhesive composites samples was cut into cuboids measuring 20mm×10mm×H mm (H is thickness, which range is 4.5-5.5 mm). Three samples of each treatment were soaked in tap water for 2 h. Weight, thickness and length were measured before and after soaking. Weight gain, thickness swell and linear expansion are calculated in the formula: $T=\frac{h_2-h_1}{h_1}\times 100\%$. T stands for two hours sample thickness swelling, h_1 for sample thickness before soaking, and h_2 for sample thickness after soaking two hours. All samples were preconditioned at 65% relative humidity, 23.8°C for 48 h. The absorption rate is usually counted by formula: $Q=\frac{m_2-m_1}{m_1}\times 100\%$. Q stands for moisture absorption rate at a time, m_1 for the sample quality after being dried, and m_2 for the sample quality after moisture absorption.

(4) Morphology analysis

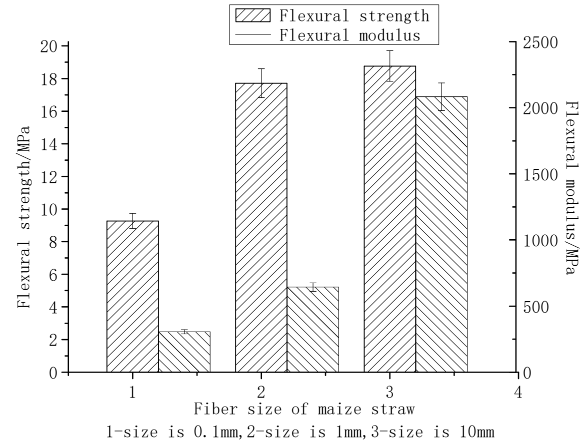
The morphology of sample curved section was observed and analyzed with a stereomicroscope (SMZ1000, Japan) [10].

III. RESULTS AND DISCUSSION

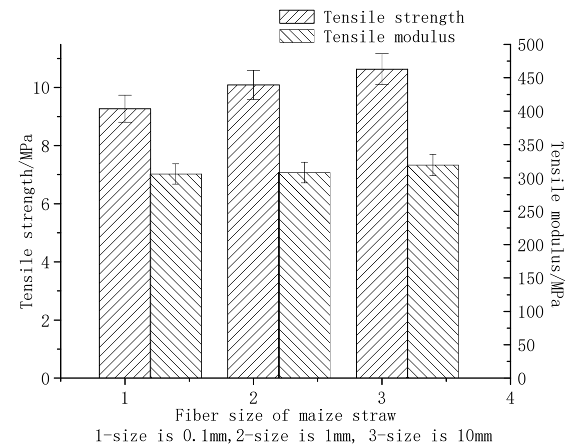
A. Mechanical Properties



(a) Tensile strength and modulus.



(b) Flexural strength and modulus.



(c) Toughness.

Figure 1. Effects of fiber size on mechanical properties of maize straw/vegetable protein adhesive composites

DOI 10.5013/ IJSSST.a.17.29.31 ISSN: 1473-804x online, 1473-8031 print

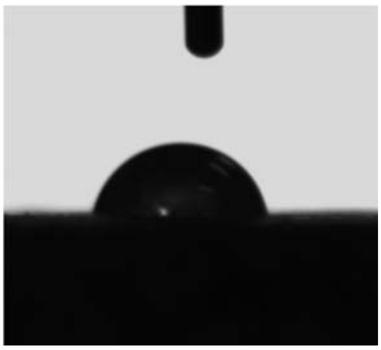
The Fig.1 showed that tensile strength and modulus, flexural strength and modulus, and toughness were all significantly improved with maize straw fiber size values of 0.1mm, 1mm, 10mm. The maximum values of tensile strength, flexural strength, and toughness were 10.63MPa, 18.76MPa, and 7.02 KJ/m2, respectively. Possible reasons are that maize fiber has higher mechanical properties and larger bonding surface areas, which would cause stronger chemical bonding between vegetable protein adhesives and the maize straw fiber surface.

B. Wettability

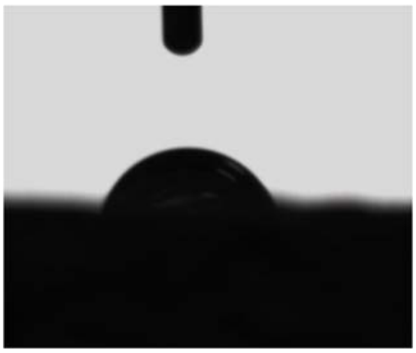
The contact angle was generally small and reduced with fiber size increasing (Table 1&Fig. 2). The minimum value was 71.17° C when the fiber size was 10mm. One reason might be that maize straw contained -OH, -COOH and other active groups, and reacted with vegetable protein adhesives. Thereby, the wettability of maize straw/vegetable protein adhesive natural composites was improved. The other reason probably was that cohesiveness between vegetable protein adhesives and matrix increased with fiber size, which increased the force between the inner component composites and effectively hindered the water molecules into the interior of the composite material.

TABLE 1. CONTACT ANGLE OF DIFFERENT FIBER SIZE OF MAIZE STRAW/VEGETABLE PROTEIN ADHESIVE COMPOSITES

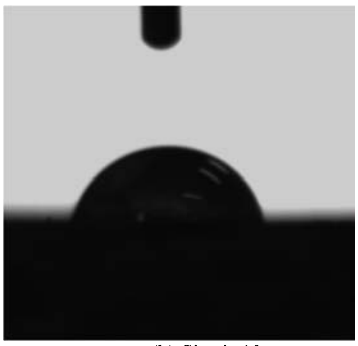
	1	2	3
Contact angle θ/°	74.76	72.51	71.17



(a) Size is 0.1mm



(b) Size is 1mm



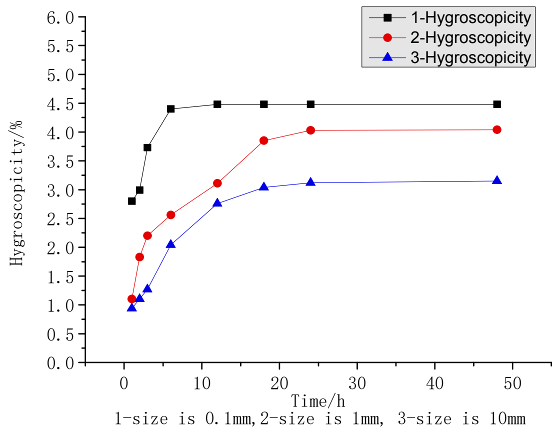
(b) Size is 10mm.
(c)

Figure 2. Effects of fiber size on wettability of maize straw/vegetable protein adhesive composites.

C. Water and moisture absorption

For water resistance, thickness swell was significantly reduced with the fiber size of maize straw (Fig. 3(a)). The minimum value of thickness swell was 24.3%, which increased 22% compared with fiber size of 0.1mm composite. The hygroscopicity increased faster within the first 15 hours with the time and tended to balance after 20

(a) Two hours Thickness swelling



(b) Hygroscopicity

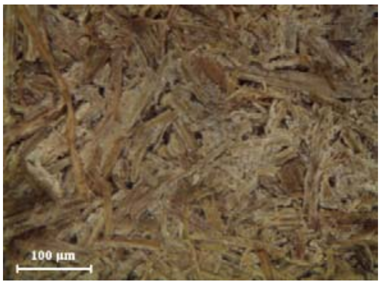
Figure 3. Effects of fiber size on water and moisture absorption of maize straw/vegetable protein adhesive composites

DOI 10.5013/ IJSSST.a.17.29.31 ISSN: 1473-804x online, 1473-8031 print

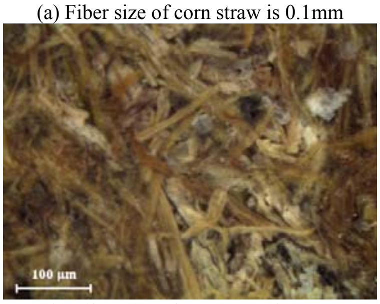
hours (Fig. 3(b)). When the fiber size of maize straw was 0.1mm, the changing trend was the slowest, equilibrium moisture was the minimum, and the value is lower than 3.15%. Probably because bonding strength was improved by the combination of more bonded area and less porosity with larger fiber size. Therefore, the moisture resistance improved significantly.

D. Microstructural analysis

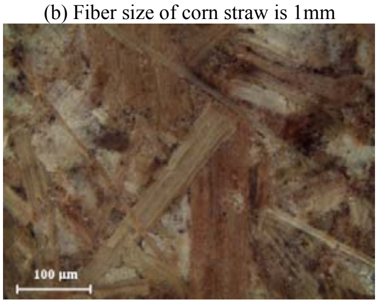
Fig. 4 showed a cross-sectional microstructure of three fiber size composites. Maize straw fiber size of 0.1mm is smaller and there are more and larger holes (Fig. (a)). Fig. 4(b) indicates that the fiber size is larger and has larger holes scattered distribution. This clearly demonstrates that maize straw and vegetable protein adhesive binds more closely, as shown in Fig. 4(c). Fig. 4(c) also reveals less exposed surface of the fiber and better moisture resistance.



(a) Fiber size of corn straw is 0.1mm



(b) Fiber size of corn straw is 1mm



(c) Fiber size of corn straw is 10mm

Figure 4. Effects of fiber size on microstructure of corn straw/vegetable protein adhesive composites

IV. CONCLUSION

This study investigated the effects of fiber size on moisture resistance and microstructure analysis of maize straw/ vegetable protein adhesive composites. The preferable water absorption capability was obtained after two hours at room temperature with three fiber sizes composites. The size was the most influential factor for mechanical properties, moisture resistance and microstructure. Compared with the size of 0.1mm composite, the ones of 1mm and 10mm increased significantly, while the pores of fracture surface decreased. The composite made from fiber size of 10mm showed excellent moisture resistance due to larger contact area and closer integration, providing a higher bond strength. Therefore, maize straw shows promise as a raw material for producing natural composites and a friendly green product from agricultural wastes.

ACKNOWLEDGMENTS

The authors wished to thank Key Laboratory of Intelligence Agriculture Equipment, Jiangsu, China This work is supported by The Natural Fund General Project of University of Science Technology of Anhui(ZRC2016492), The Key Construction Disciplines of University of Science Technology of Anhui (AKZDXK2015C03),The Key Youth Foundation of An ’ hui Educational Committee (2013SQRL062ZD).

REFERENCES

[1] Koshy RR, Mary SK, Thomas S, Pothan LA., “Environment friendly green composites based on soy protein isolate ‐ A review,” Food Hydrocolloids, vol. 50, pp. 174-192, 2015.

[2] Peyvandi A, Abideen SU, Huang Y, Lee I, Soroushian P, Lu J, “Surface treatment of polymer microfibrillar structures for improved surface wettability and adhesion,” Applied Surface Science, vol. 289, pp. 586-591, 2014.

[3] Yu Min, He Chunxia, Liu Junjun, et al, “Effects of different surface treatment for wheat straw on performances of woodplastic composites ,” Agricultural Engineering, vol. 28, pp. 171-177, 2012.

[4] Hou Renluan, He Chunxia, Yu Min, “Preparation and Properties of Rice Straw/Cornstarch Adhesive Composite,” Aging and Application of Synthetic material, vol. 41, pp. 1-5, 2012.

[5] Buddi T, Muttil N, Rao BN, Singh SK, “Development of a Soya Based Adhesive in Plywood Manufacturing,” Materials Today: Proceedings, vol. 2, pp. 3027-3031, 2015.

[6] Li X, Li Y, Zhong Z, Wang D, Ratto JA, Sheng K, et al, “Mechanical and water soaking properties of medium density fiberboard with wood fiber and soybean protein adhesive,” Bioresource technology, vol. 100, pp. 3556-3562, 2009.

[7] Ciannamea EM, Stefani PM, Ruseckaite RA, “Medium-density particleboards from modified rice husks and soybean protein concentrate-based adhesives,” Bioresource technology, vol. 101, pp. 818-825, 2010.

[8] Girard M, Gaillard Y, Burr A, Darque-Ceretti E, Felder E, “Nanoindentation of bio-sourced adhesive 75% rosin/25% beeswax: Experimental results and modelisation,” Mechanics of Materials, vol. 69, pp. 185-194, 2014.

[9] Ghaffar SH, Fan M, “Revealing the morphology and chemical distribution of nodes in wheat straw,” Biomass and Bioenergy, vol. 77, pp.123-134, 2015.

[10] Liu Z, Liu Xe, Fei B, Jiang Z, Cai Z, Yu Y, “The properties of pellets from mixing bamboo and rice straw,” Renewable Energy, vol. 55, pp.1-5, 2013.