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# Rice Straw and Cornstarch Biodegradable Composites

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**Abstract**

The main goal of this work was to use rice straw (RS) in the production of environmentally sound composites using corn based adhesives (CA). Treatments of RS with NaOH and hot-water were undertaken to evaluate the effect of such treatments on the performance of produced composites. The influence of composite density and starch content on properties of composites was also investigated. The microstructure of fractured surfaces was further observed. Results showed that cornstarch based composites had higher flexural strength. Composites made from hot-water treated straw and cornstarch had better interface and higher flexural strength, and flexural strength reached peak values at starch content of 10% and composite density of 0.7 g/cm$^3$. Composites made from non-treated straw and cornstarch had lower moisture absorption. Moisture absorption was increasing with starch content increasing and density decreasing. The composites developed from this work may have potential application for ceiling panels and bulletin boards.



*Keywords:* Rice straw, Cornstarch, Biodegradable, Flexural strength, Moisture absorption, Composites

## 1. Introduction

Straw is rich in resources, with low density, renewable nature and lustration[1], starch is biodegradable, renewable, with large sources and low price [2]. Crop straw and starch composites are provided with lightweight, cheap price, renewable and biodegradable characteristic, etc, and other composite materials can

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not match [3-8].

Using straw and other agricultural residues for preparation of composite materials has become the focus of world. But the crushed materials (e.g. straw powder, rice husk powder, husk powder or extracted straw fiber) of agricultural residues are the main materials of the composites [9-11], and using discarded tires, formaldehyde resins, polymers as matrix for preparation of composite [12-13]. Such composite materials have better water resistance and acoustic insulation properties, higher internal bond strength and flexibility and flexural strength, bigger fracture coefficient. But smashing agricultural residues and extracting fiber from straw waste lots of energy, and the matrix of the composites is difficult to degrade.

Energy saving and environmental protection are the world's urgent request. This research used rice straw and corn starch to prepare biodegradable composite materials, and focused on the influence of composite density and starch content on flexural strength and effect of straw treatments on moisture absorption. The microstructure of fractured surfaces was further observed.

## 2. Material and Methods

### *2.1. Materials and equipments*

Corn starch was food grade starch, Shandong Jincheng Food Co., Ltd. products. Rice straw was from Liuhe, Nanjing, previous year products. NaOH, AR (Analytical reagent); $Na_2S_2O_3$, AR; borax, AR; 30%$H_2O_2$, AR; $FeSO_4{\cdot}7H_2O$, AR, the reagents above mentioned were Nanjing Chemistry reagent Ltd. products.

Pressing equipment was XLB-DC magnetic plate vulcanizing machine, Rubber Machinery Co., Ltd. Huzhou Shunli products. Performance testing machine was TMS-Pro, FTC products, US. Moisture absorption testing instrument was HPX-16085 constant temperature and moisture case, Shanghai Xinmiao Medical Treatment Ltd. products. Stereomicroscope was SMZ1000, Nikon Japan products.

### *2.2. Sample preparation*

RS was extensively washed with distilled water in order to remove impurities (mainly dust). This operation was performed several times at room temperature and under vigorous stirring. After successive washings, RS was dried in an air-circulated oven at 103℃. This material was stored in hermetic plastic containers in order to prevent microbial attack (i.e. fungi) before using it in followed treatments. Washed RS without any further treatments was used as control and was labeled CRS.

Some components of cellulose fibres represent a hydrophobic blockage for fibre wetting and they must be efficiently removed [14-15]. RS is rich in silica and waxes, deteriorating the properties and making RS unsuitable for textile applications[15]. In order to improve the RS wettability and performance, different treatments were applied. CRS was soaked in 2% NaOH solution, for 2 h at room temperature with occasional shaking followed by washing with distilled water for several times to leach out the absorbed NaOH until neutral was reached subsequently oven dried. The NaOH-treated CRS was labeled as NRS.

CRS was soaked in hot-water, for 2 h at 100℃ followed by oven dried. The hot-water-treated CRS was labeled as HRS.

Cornstarch adhesives was prepared by the dispersion of the cornstarch (CS) powder in distilled water at a CS-to-water ratio 1:10 under stirring at room temperature for 2 h with 1.2wt% sodium thiosulfate ($Na_2S_2O_3.5H_2O$) on dry basis of CS for preventing deterioration. The resultant adhesives were then ready to be mixed with RS.

The composites were prepared using a hot compression molding process. Treated and untreated CRS (1~2 cm length) were blended with starch adhesives in a high-speed mixer for 10 min at room temperature. The equilibrated mixtures were subsequently hot-pressed into composites in a 10 cm×10 cm steel mould equipped with stops to achieve the same thickness (4.4 mm) at certain manufacturing parameters. Fig.1 was composites picture.

Fig.1 sample picture

### *2.3. Testing method*

Flexural strength and flexural modulus were studied in accordance with the GB/T 21723-2008 "Wheat/rice-straw particleboard", loading speed was 10 mm/min. Rectangular sample: 100 mm×15 mm×4.4 mm. Five replications were used to calculate mean value.

Moisture absorption ratio of the composites was determined with equation:

$$\omega = \frac{m_t - m_0}{m_0} \times 100\% \tag{1}$$

where: $m_0$ -mass before moisture absorption (g), $m_t$ - mass after moisture absorptio

## 3. Results and discussion

### *3.1. Comparison of flexural properties of composites*

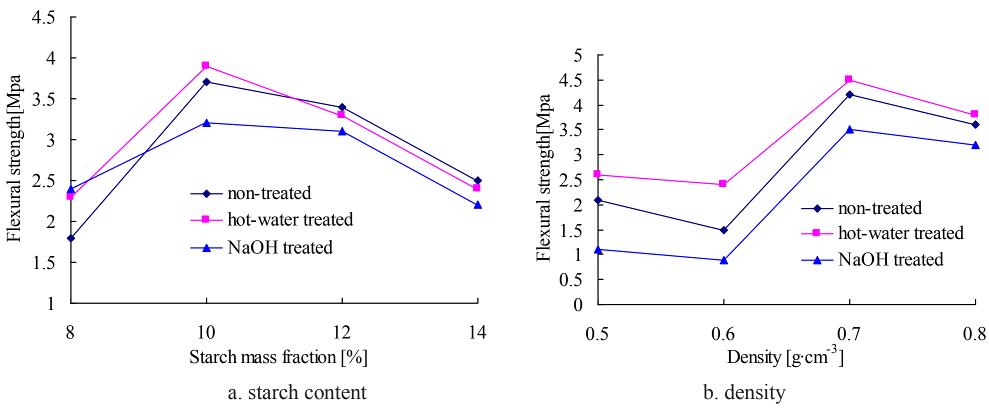



Fig. 2 Relationship between starch content (density) and flexural strength of composites.

Fig. 2 showed the relationship between starch content (density) and flexural strength of cornstarch based composites. From fig. 2a, flexural strength increased and then decreased with increasing of starch content, and reached the peak value at starch mass fraction of 10%. The flexural strength decreased with increasing of starch mass fraction above 10%. This could be accounted for that the relative starch dosage was less, adhesive had weakened solidification and could not glue the rice straw completely, so the flexural strength was lower at starch mass fraction below 10%. Interfacial area of straw was definite, and maximum utilized quantity of starch mantled straw existed. Excrescent starch adhesive made the composite internal structure looser at starch mass fraction above 10%, and the flexural strength decreased.

From fig. 2b, flexural strength increased with increasing of composite density, increased significantly with increasing of density at 0.6~0.7 g/cm$^3$, decreased slightly with increasing of density above 0.7 g/cm$^3$. This could be accounted for looser internal structure, more moisture content of composites and weakened adhesive solidification, and the flexural properties were lower at density below 0.7 g/cm$^3$. When density was 0.7 g/cm$^3$, moisture content was appropriate, starch adhesive diffuses uniformly and could glue the rice straw completely, flexural strength and flexural elastic modulus reached the peak value. The flexural properties decreased with increasing of density above 0.7 g/cm$^3$, this was due to more compact internal structure and more difficult starch adhesive diffusion.

From fig. 2, flexural strength of cornstarch based composites from hot-water treated straw was higher, and flexural strength of cornstarch based composites of NaOH treated straw was worst. This may be due to higher $SiO_2$ content of straw themselves, and $SiO_2$ forms a non-polar surface structure in fiber, weakening adhesive adsorption. Meanwhile, there was a wax layer on straw surface, making less friction between straw and more difficult for starch adhesive to permeate through straw, it was difficult to form "gel nails" in bonding process. All above mentioned had negative impact on composites manufacture, and decreased flexural properties of composites. Hot-water treatments could reduce $SiO_2$ and wax content of straw effectively, making better cementation of straw and starch adhesive, and also preserving straw fibers, so composites from hot-water treated had higher flexural properties. However, NaOH treatments could hydrolyze straw cellulose, making straw looser and softer, lower polymerization of straw cellulose and lower flexural properties of composites from NaOH treated straw.

### *3.2. Comparison of moisture absorption of composites*

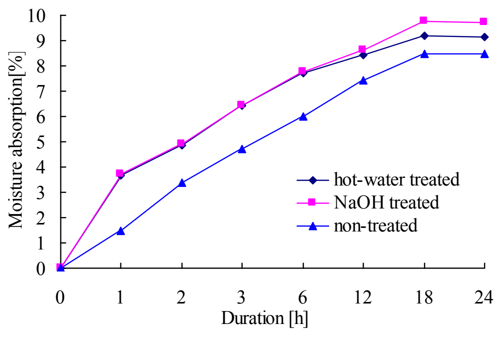
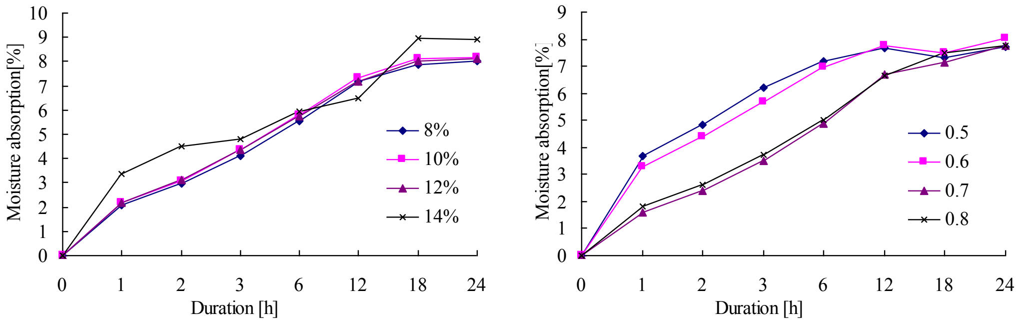



Fig. 3 Comparison of moisture absorption of composites at RH 95% and 23.8℃.

Fig. 3 showed moisture absorption of cornstarch based composites. From fig. 3, moisture absorption rate of non-treated straw based composites increased slower and was smaller. This could be accounted for the existence of $SiO_2$ and wax on straw surface, preventing water-soluble reagent penetrating through straw effectively, so non-treated straw based composites showed better water resistance.



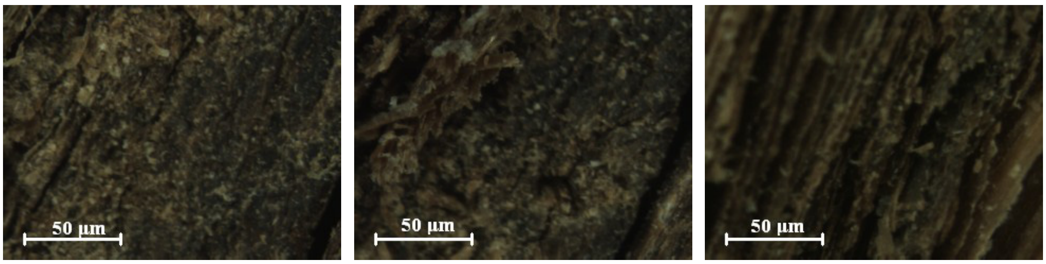

a. different cornstarch content composites b. different density of cornstarch composites

Fig. 4 Comparison of moisture absorption of composites at RH 95% and 23.8℃.

Fig. 4a showed moisture absorption of different cornstarch content composites. From fig. 4a, composites had faster increasing in prophase and higher moisture absorption rate at cornstarch mass fraction of 14%, and the other three kinds composites had similar moisture absorption curves. This could be accounted for more existence of hydrophile starch on surface and in interior of composites at starch mass fraction of 14%, leading to more starch content higher moisture absorption ratio and faster increasing in prophase.

Fig. 4b showed moisture absorption of different density cornstarch based composites at starch mass fraction of 10%. From fig.4b, moisture absorption rate of lower density (0.5、0.6 g/cm$^3$) composites increased faster than others. This could be accounted for lower density less tightness of composites, leading to more moisture absorption ratio at same phase. Moreover, composites had similar equilibrium moisture absorption rate due to same weight of straw and starch.

### *3.3. Fractured surfaces microstructure of composites*




a. hot-water treated b. NaOH treated c. non-treated

Fig. 5 Microstructure surface of composites.

Fig. 5(a, b, c) showed fractured surfaces microstructure of composites from straw with different treatments. From the figure, hot water and NaOH treatments could reduce $SiO_2$ and wax content of straw effectively, improving the interphase boundary of matrix and reinforcement, and composites from hot water and NaOH treated straw had less stratification and crack. NaOH treatments could hydrolyze straw cellulose, making straw looser and softer and composite from NaOH treated had lower flexural properties.

## 4. Conclusions

Composites from hot-water treated straw and cornstarch had better interface and higher flexural properties, and flexural strength reached peak values at starch mass fraction of 10% and density of 0.7 g/cm$^3$.

Composites from non-treated straw and cornstarch had lesser moisture absorption ratio, and equilibrium moisture absorption rate was 8.48%. Moisture absorption ratio increased with starch content increasing and density of composites decreasing.

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