Effect of fiber size of straw on properties of straw board

Li-guang Xiao¹,a and Yan-bo Ding²,b

¹School of Materials Science and Engineering, Jilin Jianzhu University, Changchun 130118)
²Corresponding authors’s e-mail: xlg627@163.com @jlju.edu.cn

Abstract: The fiber and powdered reed straw fibers of different sizes were pretreated with 2% NaOH solution at 180°C and 6MPa for 8min. The straw board without adhesive was prepared by hot pressing. The surface morphology, energy spectrum analysis, thermal stability and mechanical properties of the straw board were studied. The experimental results showed that the surface Si content of straw was significantly increased by alkali activation pretreatment, and the mechanical properties of straw board were significantly improved. The static bending strength (MOR), elastic modulus (MOE) and internal bonding strength (IB) were significantly increased, while the water absorption and expansion rate (TS) were significantly decreased. Compared with fibrous straw board, the fiber bond of straw board made from powdered straw is more compact, its mechanical properties are improved greatly, and its water absorption and expansion rate are reduced obviously.

1. Introduction
In recent years, with the development of infrastructure in various countries, people need a lot of wood and its products. As the main source of wood products, the number of trees has changed greatly. On July 21, 2020, the Food and Agriculture Organization of the United Nations released the Global Forest Resources Assessment 2020, which shows [1] that the total forest area of the world is only 4.06 billion hectares, accounting for 31% of the land area. And the world's forests continue to shrink. In most developing countries, deforestation and overfishing lead to insufficient forest resources [2]. In the context of decreasing wood resources and environmental protection, the use of agricultural and forestry wastes, such as corn straw [3], cotton straw [4] and other resources to replace wood resources, and the research on the preparation of environmentally friendly straw boards with excellent performance has become a hot research issue. As for the selection of raw materials, there are few reports on the preparation of glueless straw board from reed straw. The composition of reed straw is the same as that of wood, but the proportion is different. The main components are cellulose, hemicellulose, lignin and so on. Reed straw can replace wood to produce straw board with good performance. In this experiment, the alkali activation pretreatment method was used to treat the reed straw, and the straw fiber was self-cementing without any adhesive. After alkali solution pretreatment, the straw fibers expand and the surface becomes rough, removing the impurities on the straw surface and improving the interfacial properties of the straw [5]. It is conducive to the bonding of fibers. By using two different sizes of reed straw fiber to prepare straw board, the influence of straw fiber size on the performance of straw board was explored.
2. Materials and test methods

2.1. Materials and Instruments
Reed straw: common annual reed straw in Jilin Province, after drying and dusting, it is crushed by jaw crusher. One part is screened by a sieve with aperture of 1.18mm for reserve use, and the other part is crushed by a sieve with aperture of 0.6mm for powder reserve use. Sodium hydroxide: solid particles, analytical pure, Tianjin Jindong Tianzheng Fine Chemical Reagent Factory; The water used in this experiment: the water with sodium hydroxide solution is deionized water, and the other water is from laboratory tap water. ML-203 Electronic Analytical Balance (Metler Tolidor Instrument Co., Ltd., China), WGL-65 Electric Hot Blow Drying Oiler (Tianjin Tester Instrument Co., Ltd., China), DM-4L Jaw Crusher ((DM-4L, Nanjing Daran Technology Co., Ltd., Nanjing, China), TM3030 Scanning Electron Microscopic ((MIRA 3 LMH, TESCAN, USA), IRAffini-1 IR Spectrometer ((IrAffini-1, Shimadzu Manufacturing Institute, Japan), TGA-50 Thermogravimetric Analyzer (TGA-50, TA Instruments, Inc., Newcastle, USA), YAD-2000 Temperature Controlled Pressure Forming-System (Changchun Kexin Equipment Co., Ltd., China).

| Composition | Crude fiber content (%) | ash | other |
|-------------|-------------------------|-----|-------|
| Cellulose   | 42.7                    | 5.8 | 0.6   |
| Hemicellulose| 29.5                   |     |       |
| Lignin      | 14.3                    |     |       |
| Horn        | 7.1                     |     |       |

2.2. Preparation
Treat all ingredients at room temperature. NaOH solution with a mass fraction of 2% was prepared. Two kinds of reed straw fibers of different sizes were immersed in alkali solution for 40min. After the soaking, the two kinds of straw fibers of different sizes were washed with deionized water, respectively, until the pH value of the water was about 7. Put the cleaned straw into the oven and dry it until the moisture content is 30%. According to GB/T 27796-2011[6], the design density of the straw board is 0.8g/cm3, the size is 100mm×100mm×10mm, and the size of the molding mold is 100mm×100mm×80mm. The treated reed stalks are weighed and put into the mold. After manual prepressing, they are put into the hot press. The pressure set by the hot press is 6MPa, the temperature is 180℃, and the time is 8min. The hot-pressed reed straw sheet is shown in Figure 1. At the end of the experiment, the straw board prepared by two different sizes of reed straw fibers was placed at about 24℃ and relative humidity was about 60%. After stable for 24h, the test and analysis began.

![Figure 1](image)

(a) Fibrous straw (b) Powder straw.

2.3. Test
The profile microstructure of reed straw board and the energy spectrum analysis of reed straw before and after alkali treatment were tested and analyzed by MIRA 3 LMH scanning electron microscope and energy spectrum analyzer. Thermogravimetric analyzer was used to analyze the thermal stability of reed straw. The temperature was raised from the ambient temperature to 600℃, and the heating rate was...
15°C/min. IRAffinity-1 IR spectrometer. According to GB/T 17657-2013[7], the physical performance test is to test the static bending strength (MOR), elastic modulus (MOE), internal bonding strength (IB), water absorption thickness and expansion rate (TS). The straw board made of two different sizes of reed straw fibers was tested with 3 specimens respectively, and the average value was taken.

3. Test results and Analysis

3.1. Microscopic morphology analysis

Fig. 2 shows the micromorphology of straw board prepared by reed straw fibers of different sizes. In Fig. 2 (a), after the fibrous straw was hot-pressed at 180°C, the microscopic morphology of the straw board showed that irregular cracks and irregular cracks existed obviously in the observed area, and the straw fibers were not tightly bonded. At the same time, the irregular cracks mean that the fiber distribution in the straw board is not uniform during the hot pressing process, which may lead to poor mechanical properties of the straw board. In Fig. 2 (b), the microscopic morphology of the straw board after the hot pressing of the powdered straw at 180°C shows that the tissues are tightly bonded and seamless. This represents superior mechanical performance in the later stage. It can also be observed that there are no holes and thermal decomposition in the microscopic planing surface of the straw board after hot pressing, which indicates that the hot pressing temperature has no effect on the mechanical properties of the straw board in the later stage.

![Figure 2](a) Fibrous straw; (b) Powder straw.

3.2. Spectrum analysis

Fig. 3 shows the Si element distribution on the surface of straw before and after pretreatment and on the surface of straw board with different sizes of straw fibers after hot pressing. As shown in figure (a), (b), without pretreatment of straw surface can be found that there are a lot of Si elements per unit area, per unit area after alkali pretreatment of straw surface Si element within the mass fraction of greatly reduced, it shows that the pretreatment of straw using alkali solution can effectively remove the straw surface non-polar siliceous, improve the wettability on the surface of the reed straw, Also makes the polar fiber exposed, conducive to the bonding between the fibers. As shown in Fig. (c) and (d), there is little difference in the Si element content per unit area on the surface of straw board prepared with two different sizes of straw fibers, which indicates that different straw sizes have little influence on the Si element content on the surface of straw. In addition, the literature [8] also showed that sodium hydroxide solution treatment of straw can dissolve the non-polar organic wax on the surface of straw, expose the internal polar fiber, and further promote the bonding between corn straw fibers.
3.3. Thermal stability analysis

Fig. 4 shows the thermogravimetric analysis curve of reed straw. As can be seen from the figure, when the temperature is about 100°C, the weight of reed straw begins to decrease. The reason may be that the moisture in reed straw evaporates and diffuses into the air due to heating. After that, the weight does not change until the temperature rises to about 200°C and the weight begins to decrease. From 200°C to 450°C, the weight has been decreasing. Literature [9] reported that the thermal degradation sequence of plant macromolecules is hemicellulose (200-260°C), cellulose (240-350°C) and lignin (280-500°C). The thermal decomposition of hemicellulose may occur in the hot pressing of straw board at temperatures of 200°C and 230°C. At temperatures above 400 °C, the remaining lignin gradually degrades until about 14% of the ash content is left. It can be seen that the straw fiber has good stability and no decomposition trend in the process of hot pressing at 180°C.

![Figure 3 Si element distribution on the surface of straw before and after pretreatment and on the surface of straw board with different sizes of straw fibers after hot pressing. (a) Not processed; (b) NaOH treatment; (c) Fibrous straw; (d) Powder straw.](image1)

![Figure 4 weightlessness curve of reed straw.](image2)
3.4. FT-IR
Figure 5 shows the infrared spectra of reed straw fibers of different sizes after alkali treatment and hot pressing. The -C=O asymmetrical vibration absorption peak of reed straw in 1610 ~ 1640cm⁻¹ was obvious, which indicated that reed straw was modified with carboxyl group. 2900.2cm⁻¹ and 1372cm⁻¹ are respectively the expansion vibration absorption peak and bending vibration absorption peak of -CH;1636.0cm⁻¹ is the vibration absorption peak of adsorbed water.1130~1170cm⁻¹ is the C-O stretching vibration absorption peak of annular C-O-C [10]. The C-O vibration of cellulose and xylan is characterized by an absorption band with a wavelength of 1000-1200cm⁻¹ [11].After hot pressing, the C-O carbonyl absorption bands shift at the 1000-1100cm⁻¹ and 1739cm⁻¹ bases, indicating more hydrolysis of hemicellulose and the formation of aldehyde compounds [10].Studies have shown that lignin has the same characteristics as polymer, which can improve the bonding property of biological boards, and then improve the mechanical properties of biological boards [11]. After hot pressing, a relatively obvious change at 1162cm⁻¹ is considered to be the generation of new ether bonds, which is the reaction between the by-product of hemicellulose and lignin in the hot pressing process, i.e., lignin-carbohydrate complex (LCC)[12]. The enhancement at 900cm⁻¹ can be attributed to the polymerization of glycoside components in low-molecular compounds [13]. All these reactions can improve the bond strength of reed straw board.

![Figure 5 FT-IR images of reed straw of different sizes before and after alkali treatment and hot pressing](image)

3.5. Mechanical property analysis
Table 2 shows the static bending strength (MOR), elastic modulus (MOE), internal bonding strength (IB) and water absorption and expansion rate (TS) of straw board prepared with reed straw fibers of different sizes. Group A is the mechanical properties of the straw board prepared by fibrous straw, and group B is the mechanical properties of the straw board prepared by powder straw. It can be seen from Table 1 that the mechanical properties of straw board can be changed by improving the size of straw fiber. Compared with the fibrous straw board, the mechanical properties of the powdered straw board were improved, including the static bending strength (MOR) increased by 40.5%, the elastic modulus (MOE) increased by 7%, the internal bonding strength (IB) increased by 28.6%, and the water absorption and expansion rate decreased by 25.6%. The reasons for the improvement of mechanical properties of straw board prepared by powder straw may be as follows: Compared with the straw board prepared by fibrous straw, the hydrothermal action of powdered straw is more intense in the process of hot pressing, and the specific surface area of powdered straw is larger, in which more hemicellulose and cellulose hydrolyze, and more low-molecular weight furfural hydrolytic products that can react with lignin are...
generated. More phenolic-like adhesives were produced that acted as adhesives [14]. The infrared spectrum also confirmed the results.

Table 2 MOR, MOE, IB and TS values of different pretreatment artificial straw boards

| Code | MOR (MPa) | MOE (MPa) | IB (MPa) | TS (%) |
|------|-----------|-----------|----------|--------|
| A    | 17.3      | 2379      | 0.49     | 39     |
| B    | 24.3      | 2563.3    | 0.63     | 29     |

4. Conclusion
In summary, two kinds of straw boards with different fiber sizes were prepared by alkaline solution pretreatment and hot pressing. The microscopic morphology of straw board prepared by powdered straw showed that the fiber in the straw board was compact and uniform, and there were no holes and signs of thermal decomposition in the microscopic section of straw board, which indicated that the hot pressing temperature had no effect on the mechanical properties of straw board in the later stage. At the same time, alkali solution pretreatment can reduce the Si element content on the straw surface, improve the wettability of the straw surface and expose the polar fiber on the straw surface, so that the straw fibers are easy to glue. After alkali treatment and hot pressing, reed straw produced reactions and products that were beneficial to self-cementing. Compared with the straw board prepared by fibrous straw with large size, the mechanical properties of straw board prepared by powdered straw were significantly improved.

Acknowledgments
This work was financially supported by China's 13th five-year national key research and development plan (No.2018YFD1101001) and the Key project of science and technology development plan of jilin province, China (No.No.20180312018ZX).

Reference
[1] Global Forest Resources Assessment 2020, United Nations Food and Agriculture Organization, Rome, Italy: 2020(5).
[2] Azizi K, Tabarsa T, Ashori A. Performance characterizations of particleboards made with wheat straw and waste veneer splinters[J]. Composites Part B Engineering, 2011, 42(7):2085-2089.
[3] Wang D, Sun X S. Low density particleboard from wheat straw and corn pith[J]. Industrial Crops & Products, 2002, 15(1):43-50.
[4] A Z H , A H N C , A K T K , et al. Optimization and practical application of cottonseed meal-based wood adhesive formulations for small wood item bonding[J]. International Journal of Adhesion and Adhesives, 2019(95):1147-1152.
[5] LIU F H. Properties of composites made of pretreated-corn stalk fibers and high-density polyethylene[D]. Harbin: Northeast Forestry University, 2015.
[6] GB/T 27796-2011 Plant boards of straw for construction (2); Inspection and Quarantine of the People’s Republic of China/Standardization Administration of the People’s Republic of China: Beijing, China, 2013.
[7] GB/T 176577-2013 Test Methods of Evaluating the Properties of Wood-Based Panels and Surface Decorated Wood-Based Panels; Inspection and Quarantine of the People’s Republic of China/Standardization Administration of the People’s Republic of China: Beijing, China, 2013.
[8] F Zhang, L Zhang, QI Chu-Sheng, et al. Effects of pretreatment methods on properties of corn straw board[J]. Journal of Beijing Forestry University, 2017, 9(39):112-118.
[9] Macedo, J.S.; Otubo, L.; Ferreira, O.P.; de Fátima Gimenez, I.; Mazali, I.O.; Barreto, L.S. Biomorphic activated porous carbons with complex microstructures from lignocellulosic residues. Microporous Mesoporous Mat. 2008, 107, 276–285.
[10] CHEN J, YAN T, YAN S, et al. Experimental study on liquefied corn straw bonding powder coal [J]. Cellulose Science and Technology, 2019(3):8-14.
[11] YANG Z L, DU S R, MEI J Q, et al. Characterization of lignin content and distribution in corn straw treated with alkali by FTIR microscopic imaging [J]. Transactions of the CSAE, 2019, 035(008):280-286.

[12] Jiajun, Wang, Bo, et al. Effect of Hot-Pressing Temperature on Characteristics of Straw-Based Binderless Fiberboards with Pulping Effluent. [J]. Materials, 2019, 12(9):6-17.

[13] Dam J E G V, Oever M J A V D, Teunissen W, et al. Process for production of high density/high performance binderless boards from whole coconut husk: Part 1: Lignin as intrinsic thermosetting binder resin[J]. 2004, 19(3):207-216.

[14] Okuda N, Hori K, Sato M. Chemical changes of kenaf core binderless boards during hot pressing (I): influence of the pressing temperature condition[J]. Journal of Woodence, 2006, 52(3):244-248.