研究論文

Effect of Heating Temperature on Strength of Rice Straw Bio-board

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ABSTRACT

The main objective of this study was to investigate the possibility of making bio-board (biodegradable biomass board) using rice straw and the relationship between heating temperature and strength of bio-board. The making process included cutting, soaking, refining, forming and drying. Strength of the bio-board was measured by three-point bending test and tensile test. The result showed that making process of bio-board was appropriate. In addition, the maximum value of average rupture stress of bending test under the different experimental conditions was 18.50 MPa and the maximum value of average rupture stress of tensile test was 12.46 MPa, both of which appeared at temperature of 190°C. The result obtained that heating temperature affected the strength of bio-board. The rupture stress increased with the increase of heating temperature. Moreover, the strength of bio-board is suitable for the uses of agriculture, packaging materials and so on.

Keywords: bio-board, rice straw, biodegradable, heating temperature, rupture stress

1. Introduction

Biomass material is biological material derived from renewable raw materials, which is the product of plant photosynthesis with carbon dioxide. In modern history, petroleum and coal are indispensable materials for various industries. However, in the case of creating global environmental problems and increasing depletion, the fossil resources, petroleum and coal, must be replaced in the future. In addition, the supply of timber has been unable to catch up with the need of global economy. It is more and more necessary to develop environment-friendly material. Biomass material is refined as renewable organic material, which is the product of plant photosynthesis with carbon dioxide and after the use

it can be degraded into water and carbon dioxide by microbial action or reused as fertilizer through composting.

Crop straw is one kind of crop residues, which are defined as the nonedible plant parts and are left in the field after harvest. Every year, the amount of crop straw is tremendous; however, the availability is rare. The composition of crop straw contains cellulose and hemicellulose which makes straw products have certain physical strength, therefore, the products made of crop straw can replace some products made of wood, petroleum or coal. In addition, after use, it can be degraded into water and carbon dioxide by microbial action or reused as fertilizer through composting, which content the requirement of renewability. Hence, crop straw

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is considered as an environment-friendly biomass material.

Rice is one of the most important staple food for a large of people in the worldwide¹⁾. Every year, the yield of rice was the third-highest worldwide production, just after sugarcane and maize. Therefore, at the same time, there were a lot of rice straw are produced. However, as a kind of important biomass material, rice straw has not been effectively utilized. For China as an example, China was the biggest producer in the world, and the yield of rice straw was about 200 million tons²⁾. Moreover, 54.8 % of rice straws were burned as fuel, which caused a serious waste of rice straw resource^{3,4)}.

Therefore, producing bio-board using rice straw is able to not only replace some products made of wood petroleum or coal but also protect the atmospheric environment. Until the 1940s, the technology which produced the modern building panels made of rice straw appeared. The production technology was pioneered in Sweden in 1930. After World War II, the British made a further development and promotion. The bio-board is rice straw as raw material. After being combed, rice straw was made into board by hot pressing. And then, two pieces of cardboards were pasted on both sides of the board. Currently, there are more than 30 countries in the world to produce the rice straw board and the production capacity is more than 80 million m³ annually. The board has the disadvantage that: high wastage rate of raw material, poor water proofing property and the requirement of cardboards.

At the end of 1970s, the British invented rice straw particle board. In the 1980s, the rice straw particle board was begun to be produced. The production technology was named "Compark Technology" and the rice straw particle board was named "Compark Board". Currently, the production technology has been utilized by India, Pakistan, Sri Lanka, Indonesia, Philippines, Australia and other 10 countries. The production method was that: according to the different utilization requirements, different chemical adhesives were added to the rice

straw chips, and the mixtures were made into bio-board by hot pressing. The disadvantage of the bio-board was that: because of containing chemical adhesive, the bio-board was not biodegradable and renewable material.

In this study, rice straw that was raw material was used to make biodegradable bio-board. The making processes of bio-board adopt the physical method, which are cutting, soaking, refining, forming and drying. The bio-board made in this study contains no chemical adhesives or chemical compounds. For these reasons, it will not cause any pollution to the environment. In order to investigate material properties of bio-boards, the three-point bending test and tensile test were performed, and rupture stresses of bio-boards were measured.

2. Materials and experimental method

Dry rice straw was used as raw material in this study. The whole flowchart of making bio-board included cutting, soaking, refining, forming and drying was shown in Fig.1. First of all, dry rice straw was cut into chips about 15 mm. Then, the chips were soaked in water for 96 hours at room temperature. This process was very important to make bio-board successfully. During the process, the fiber of rice straw expanded in water, and some organic and inorganic substance dissolved in water. That is because, the microorganisms on rice straw began to ferment. Some chemical compositions which are disadvantageous to the strength of bio-board will be removed by the soaking process such as lignin, pectin, and so on. After soaking, the mixture of rice straw chips and water was refined into rice straw pulp by an electric beating refiner for 10 minutes,

Fig. 1 The process for making bio-board

so that the fibers of rice straw were separated into individual fibers using the electric beating refiner and the fiber whose length was under 5.6 mm was sieved from rice straw pulp for making bio-board. During this process, the macromolecular fibers were refined into microfibrils and more active hydroxyl groups were exposed, which were conducive to forming. The final making process was forming and drying. The schematic diagram of forming process was shown in Fig. 2. The dimension of the forming mold was 100 mm × 100 mm × 25 mm. In addition, some accessories were necessary for mold, which were two metal meshes, a copper block and an aluminum plate. In order to drain off water from rice straw pulp during this process, the forming mold, the copper block and the aluminum plate were drilled holes which were 2 mm in diameter with an interval of 7 mm × 7 mm. Pressure was applied gradually for 2 hours.

In this study, 5 bio-boards named A, B, C, D, E were made by the same maximum applied pressure 5 MPa and different temperature in the process of forming and drying. 5 levels of the heating temperatures 110°C, 130°C, 150°C, 170°C and 190°C were applied on bio-boards. Table 1 shows the experimental condition for making bio-board in this study.

3. Strength tests

In order to investigate the appliance scope of bio-board, strength experiments were carried out in this study. Each bio-board was cut into 2 specimens for three-point bending test^[5,6] and 3 specimens for tensile test^[7].

Fig. 2 The schematic diagram of forming process

Table 1 The experimental condition for making bio-board

Board Name	Fiber Length [mm]	Forming and Drying	
		Max. Pressure [MPa]	Temp. [°C]
A	0 ~ 5.6	5	110
B		5	130
C		5	150
D		5	170
E		5	190

The specimens for three-point bending test were rectangle with dimensions of 50 mm × 40 mm. In this study, a universal testing machine was used to measure load on specimens and deflection. At last, bending stress σ_b was obtained by the results of the bending test. The stress was calculated by Eq.(1).

$$\sigma_b = \frac{3Wl}{2bh^2} \quad (1)$$

Where, σ_b is bending stress; W is load applied; l is supported span, 34 mm; b is width of specimen; h is thickness of specimen.

The dimensions of specimens for tensile test were shown in Fig. 3. The universal testing machine was used for measuring load and elongation. Tensile stress σ_t was obtained by the results of the tensile test. The stress was calculated by Eq.(2).

$$\sigma_t = \frac{W}{bh} \quad (2)$$

Where, σ_t is tensile stress; W is load applied; b is width of experimental area; h is thickness of experimental area.

Fig. 3 The specimen size of tensile test

4. Results and discussion

4.1 Results of making bio-board

According to the above experimental process and experimental conditions, 5 pieces of bio-boards using rice straw were made successfully. Fig. 4 shows bio-board made under condition of heating temperature 110°C as an example.

As the basic physical properties of material, moisture content and density of bio-board were measured. In this study, moisture content was relative water content. Fig. 5 shows the values of moisture content and density of bio-board. The moisture content was in the range of 3.78% ~ 7.00%. The density was in the range of $0.83 \times 10^3 \text{ kg/m}^3 \sim 0.91 \times 10^3 \text{ kg/m}^3$.

4.2 Results of three-point bending test

2 specimens for bending test were cut from every bio-board respectively. The 2 specimens were named S1 and S2 from every bio-board made under different heating temperatures. The relationships

Fig. 4 Produced bio-board (110°C)

Fig. 5 Moisture content and density of bio-board

between stress and deflection of 5 bio-boards are shown in from Fig. 6 to Fig. 10. With Fig. 6 for example, according to the curve of stress-deflection, for the 2 specimens, the stress increased with the increase of deflection until the stress reached maximum value. At the time, specimens fractured. And then, the stress decreased to zero gradually. The maximum value of stress was named as rupture stress. Rupture stresses of the 2 specimens were 13.57 MPa and 14.77 MPa.

The stress-deflection curves of specimens cut from the other 4 bio-boards were similar to the bio-board A, which were shown in from Fig. 7 ~ Fig. 10. The relationship of stress-deflection for every specimen from one bio-board was similar while the

Fig. 6 The stress-deflection curve of bio-board A

Fig. 7 The stress-deflection curve of bio-board B

Fig. 8 The stress-deflection curve of bio-board C

Fig. 9 The stress-deflection curve of bio-board D

Fig. 10 The stress-deflection curve of bio-board E

rupture stresses were different from each other.

Rupture stress comparison is showed in Fig. 11. The rupture stresses were in the range of 13.35 MPa ~ 19.62 MPa, and the average values of 5 bio-boards are 14.17 MPa, 14.27 MPa, 15.06 MPa, 16.68 MPa, 18.50 MPa respectively. At heating temperature of 190°C, the average value of rupture stress is maximum, which is 18.50 MPa.

4.3 Results of tensile test

In tensile test, 3 specimens for tensile test were cut from every bio-board respectively. The 3 specimens were named S1, S2 and S3 from every bio-board made under different heating temperatures. Tensile test was carried out. The result of bio-board A is showed in Fig. 12. Based on the curve of Fig. 12, the stress increased with the increase of elongation. When the specimen was fractured, the stress reached a maximum value also named as rupture stress. Subsequently, the stress was back to zero rapidly.

The stress-elongation relationships of other 4 bio-boards were similar to the bio-board A. The relationship of stress-elongation for every specimen from one bio-board was similar. However, the rupture stress of every bio-board were different from each other, which were showed in from Fig. 13 ~ Fig. 16.

Rupture stress comparison is showed in Fig. 17. The rupture stresses of tensile test were in the

Fig. 11 The average rupture stress of bio-board

Fig. 12 The stress-elongation curve of bio-board A

Fig. 15 The stress-elongation curve of bio-board D

Fig. 13 The stress-elongation curve of bio-board B

Fig. 16 The stress-elongation curve of bio-board E

Fig. 14 The stress-elongation curve of bio-board C

Fig. 17 The average rupture stress of bio-board

range of 3.00 MPa ~ 17.22 MPa and the average values of 5 bio-boards are 5.25 MPa, 6.86 MPa, 9.71 MPa, 10.62 MPa, 12.46 MPa. At heating temperature of 190°C, the average value of rupture stress is maximum, which is 12.46 MPa.

4.4 Discussion

According to the results of three-point test and tensile test, it was showed that the stresses of specimens were different from each other from the same bio-board. Because the bio-board was made of natural cellulose, the cellulose direction was non-homogeneous. Therefore, the stresses of specimens were different from each other from one bio-board, which is different with metal materials.

In addition, according to the curves of Fig.11 and Fig.17, the rupture stress increased with the increase of heating temperature, which indicated that heating temperature affected the strength of bio-board.

5. Conclusions

The main objective of this study was to investigate the possibility of making biodegradable bio-board using rice straw and the relationship between heating temperature and strength of it. 5 pieces of bio-boards were made by the processes of cutting, soaking, refining, forming and drying with the experimental condition of the maximum applied pressure 5 MPa, temperatures 110°C, 130°C, 150°C, 170°C and 190°C. Strength of the bio-boards were investigated by three-point bending test and tensile test. It can be concluded as follows:

- 1) According to the result of this study, the rice straw bio-board was made successfully using the proposal method. The making process including cutting, soaking, refining, forming and drying was appropriate. In addition, no chemical adhesives or chemical compounds were added in whole making process of bio-board. The bio-board made in this study is biodegradable, and is an environment-friendly material.
- 2) In the three-point bending test, it showed that the rupture stresses were in the range of

13.35 MPa ~ 19.62 MPa. The average of maximum rupture stress appears at heating temperature of 190°C which is 18.50 MPa. And in the tensile test, the result showed that the rupture stresses were in the range of 3.00 MPa ~ 17.22 MPa. The average of maximum rupture stress was 12.46 MPa at heating temperature 190°C. The results indicated that heating temperature affected the strength of bio-board. The rupture stress increased with the increase of heating temperature.

- 3) Because bio-board is biodegradable material, it can be considered to be mulch film, thus replacing the plastics mulch film. Furthermore, according to the results of bending test and tensile test, the average of maximum rupture stress appeared at heating temperature of 190°C. The stress indicated that biomass board is stronger than the ordinary wrapping paper board, polystyrene board and the low density polyethylene (LDPE).

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乾燥温度による稲ワラバイオボードの強度への影響

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要 旨

本研究では、稲ワラによる生分解可能なバイオボードの作製可能性と乾燥温度によるバイオボードの強度への影響を調べるために、作製プロセスとして細断、浸漬、リファイニング、成形、乾燥を考案し、バイオボードを作製した。また、作製したバイオボードに対し引張試験と曲げ試験を用いてその強度を求めた。その結果、本研究で考案した作製プロセスを用いて一定の強度を持つバイオボードを作製することができた。強度試験の結果より、いずれの性能試験においても乾燥温度が高いほどバイオボードが強くなった。乾燥温度 190℃ のときに曲げ破断応力が最大となり、その値は 18.50 MPa であって、引張試験においては、最大引張破断応力は 12.46 MPa であった。本研究で考案した方法で作製したバイオボードは、農業資材、包装材料として利用することが可能であり、作製プロセスにおいては接着剤や他の化学合成剤を使用せず、利用後廃棄しても環境に何ら負荷がかからない再生可能な材料である。

キーワード：バイオボード、稲ワラ、生分解可能、成型温度、破断応力