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Research paper

# Effects of pressures on the mechanical properties of corn straw bio-board

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ABSTRACT

An environment friendly biodegradable board called Bio-board using corn straws was introduced. Five main board making processes were proposed. To investigate the effect of pressure on the strength of Bio-board, five pressures were applied in forming process. Board making results showed that under all experimental conditions, it is successful in making board using corn straw. Density of five bio-boards is in the range of 0.87 g/cm$^3$–1.02 g/cm$^3$. The moisture contents of Bio-board showed a range of 3%–6% in wet base. Strength test resulted that remarkable variety of rupture stress under different pressures could not been observed. Under the condition of 8 MPa, bio-board has bending strength as high as 29.37 MPa. Meanwhile Bio-board has tensile strength as high as 10.89 MPa resulted in the pressure of 10 MPa.


## 1. Introduction

Biomass is the most common form of renewable resources widely used in the world. World production of biomass is estimated at 146 billion metric tons a year, mostly wild plant growth (Cuff and Young, 1980). It has great potential as a renewable energy source, both for the richer countries and for the developing world (Demirbas, 2001).

As one of the representative agricultural residues, straw from corn grain production are primarily considered to be obvious source of biomass (Graham et al., 2007). Corn (maize) straws account for 29% of the worldwide tonnage of fibrous raw materials from field crops (Rowell et al., 1997) according to the statistics of United States Department of Agriculture (USDA) (1987) and according to Zhong et al. (2011) approximately 0.8 billion tons of various crop residues are produced annually in China, of which corn straw are make up 216 million metric tons. In general, these corn straw are inefficiently utilized, which also causes environmental problems such as open-air burning, dumping or animal feeding (Bringezu et al., 2007). In this context, research into a new board substitute for fossil-derived using corn straw is under consideration in this study.

Referring to the Asian Biomass handbook (Yokoyama and Matsumura, 2008), composition board has many names and definitions. Several physical technologies that have been developed include milling, grinding and steam explosion for converting agro-residues into a variety of composite board as structural and decorative products. These boards are named kenaf particle board (Fujiwara et al., 2010) and kenaf core board (Saad and Kamal, 2012) both of which are manufactured with urea formaldehyde (UF), phenol formaldehyde (PF) and polymeric 4,4-methyl phenylmethane di-isocyanate (PMDI) resins. The addition of resins is essential to obtain composite board having satisfactory properties, however it is not completely biodegradable after abandoned. On the other hand, some research has focused on fiberboard without any kind of binder. For example, Jain and Handa (1982) using wheat straw to produce binderless board, Mobarak et al. (1982) who used bagasse and Laemsak and Okuma (2000) developed board made from oil palm front. These conversion technologies mainly devote to the pretreatment to improve the combine property, however for steam explosion process, a large-scale device and energy would be needed.

The present research is dealing with the manufacturing process for a green biomass board using corn straw (stem and leaves). Bio-board is a kind of new material, which is different from metal, plastic, composite material, properties of bio-board is still unknown. The purpose of this study is to explore the possibility of making a biodegradable board using corn straw with the process proposed. Bio-board could be considered to be applied as insolation

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materials, packaging materials, mulch film for agriculture. Thus, density, moisture content and basic mechanical properties were measured. The process of board making which is different from other fiberboard is that hydrogen bonding. The hydrogen bonding connection is considered as the basic board making principle (Sun et al., 2010). Finally, effect of the pressure applied in forming process on the strength of biomass board is also investigated and discussed.

## 2. Materials and methods

### 2.1. Board making

#### 2.1.1. Basic principle

As Hubbe (2006) says cellulose and hemicellulose, two of the main components of fibers, are covered with hydroxyl groups. The oxygen atoms in these groups are able to hydrogen bond to hydrogen atoms on adjacent fibers or water molecules. Drying of bio-board causes some fiber-to-fiber hydrogen bonds to take the place of fiber-to-water hydrogen bonds.

Hydrogen bonding principle applied in board making is originality. The pressure applied in process is to press out water from bio-board and the slight temperature is considered to evaporate water molecular between celluloses of bio-board (Wu et al., 2012).

#### 2.1.2. Board making process

Sweet corn (*Zea mays* L. *convar. mays*) straws were used in this work. Sowing date was on May 1st and harvested on August 10th (Liu et al., 2009) at the Mie University Bio-resource Department's experimental farm. After harvesting, grains were removed. Stem and leaves were left in a ventilated storage air-dried for two months. The five processes are cutting, soaking, grinding, compressing and drying showed in Fig. 1. Compressing and drying procedures are carried out together and called "the forming process".

During pretreatment, dry corn straws were cut into chips using an electric cutter, then soaked in water at 22 °C for 168 h for softening the straw fiber. In soaking process, corn straw fiber bundles absorbed moisture from water condition. It is easier to soften fiber bundles in a wet condition than destroy the structure of lignocelluloses fibers in a dry state. Soaking process is a preparation to the fiberization of corn straws.

Soaked straw was then fiberized (pulped) by using an atmospheric refiner with conical blades in Fig. 2a (Model A Beatfiner. Satomi. Corp.). The motor capacity is 11kw × 4p-200, 60 Hz, rotational speed is 1750 r.p.m (60 Hz). The maximum flux control is 0.05–0.1 $m^3$/min. Air pressure is 0.6 MPa required. Grinding part is an assembling conical cutters with blades. Dimension of cutter is 2.5 mm × 3.0 mm × 8°(blade width × slot width × blade angle).

Fiberization of corn straws at atmospheric pressure was carried out by passing the damp cut straw along with running water through the refiner' rotating blades. During grinding process, fiber bundles would be fiberized by milling. Accordingly, milled-corn straw was sieved to possess particle size using a screen with 2 mm × 2 mm hole size. The ground straws were fractionated into a fine fraction which possessed particle size of 0.5 mm~2 mm. Grinding process was done with water. Therefore, corn straw pulp shown in Fig. 2b was prepared before compressing.

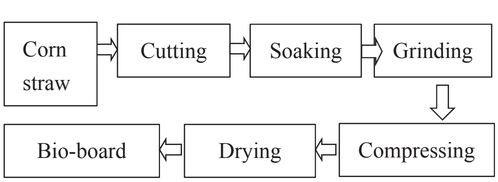


**Fig. 1.** Flow chart of Bio-board making process.

A closed stainless steel die with some accessories including metal block, meshes, were designed which enabled obtaining one square board, 100 mm long, 100 mm width and 40 mm depth. The calculated amount of ground corn straw was carefully filled in the die, and prepressed by for pressing excess water out from the die. Holes were drilled in the bottom of die, metal block and plate 2 mm in diameter, in a 7 mm × 7 mm grid allowing water to escape in the forming process.

The desired pressure was applied at the maximum temperature of 110 °C. 110 °C was chosen as a proper board making experimental condition for higher temperature may break the structure of lignocellulose and lower temperature does not evaporate water in bio-board (Saiki and Fujiwara, 1985). It took 8–10 min until the die containing the samples reach the maximum temperature. Forming experimental conditions are displayed in Table 1. As Pan (2009) described during forming process hydrogen bonds hold the chains firmly together side-by-side and forming micro fibrils with high tensile strength and water inside of bio-board could be also evaporated by high temperature and pressure.

Ten Bio-boards were made to demonstrate the five experimental conditions. For each of the experimental conditions, two Bio-boards were made. The number 1 for bio-board was applied in bending test and the number 2 for bio-board which was applied in tensile test. They are named A1, A2, ~, E1, E2.

Thickness of bio-board is measured as below. On one board three horizontal lines and three perpendicular lines were drawn then the area of bio-board was divided into sixteen square blocks. The area of each block was 25 mm × 25 mm. For thickness measurement, eight points at the outer side of four blocks in the center of board were chosen. Thus, densities of bio-board were determined as follows:

$$\text{Density} = \text{hot presser dry weight (g)} \Big/ \text{sample volume} \left(\text{cm}^3\right)$$

Moisture content analyze were done after strength tests: Numbered specimens were cut into chips and weighted, oven dried at 100 °C till constant weight, and moisture percentage was calculated according to JSPP (2007).

### 2.2. Strength tests

The mechanical property investigations applied on metal is referred to bio-board. Bending and tensile strength is a usual method to investigate the basic mechanical properties of material (JIS, 2011). Therefore, bending tests and tensile strength tests were conducted.

In the Three-Point Bending Test, five Bio-boards named A1, B1,

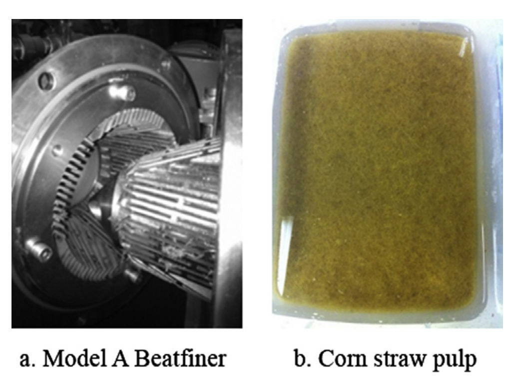


**Fig. 2.** Grinding machine and ground material.