Testing the Bending Strength of Solid Bamboo and Hollow Bamboo Particleboard

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Abstract. The aim of this study is to test experimentally and determine the bending strength of a particleboard made from hollow and solid bamboo chip composition with urea formaldehyde. The particle board is manufactured at Ethiopian Chip Wood And Furniture Share Company in Addis Ababa. The ratio of solid bamboo to hollow bamboo is 75/25, 25/75, and 50/50 respectively with urea formaldehyde. The bending strength of 75% hollow bamboo (HB) and 25% solid bamboo (SB) is 32.13 MPa and eucalyptus particleboard (EPB) bending strength is 30.63 MPa. The bending strength of 75/25 SB/HB is 159 MPa. The bending strength of 50/50 HB/SB is 30.80 MPa and the bending strength of eucalyptus particleboard is 30.63 MPa. The test results show that the bending strength of bamboo particle board is greater than the bending strength of eucalyptus particle board, and these boards can be used instead of eucalyptus particleboards. Based on the result of the study, bamboo can be recommended as a raw material.

Keywords: Solid bamboo · Hollow bamboo · Bending strength · Particle board · Eucalyptus · Urea formaldehyde

1 Introduction

The chip composition products are very important for different types of household service, construction purpose like partition board, ceiling, tables, bed etc. From those chip composition products particle board is the basic product which is manufactured in Ethiopia.

Composite materials are composed of two or more different materials, with the properties of the resultant material being superior to the properties of the individual materials which makes the composite. "Composite materials consist of one or more discontinuous phase embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous. Properties of composites are strongly dependent on the properties of their constituent materials, their distribution, and the interaction among them. The shape of the discontinuous phase (which may be spherical, cylindrical, or rectangular cross-sectioned prisms or platelets), the size and size distribution (which controls the texture of the material) and volume fraction determine the interfacial area, which plays an important role in determining the extent of the interaction between the reinforcement and the matrix. It can be either of random orientation or preferred orientation" [1].

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The raw material that used to manufacture different type of board is eucalyptus tree in Ethiopia. The reason to use it is, its availability in cheap cost. But lowland bamboo particleboard is not studied early in Ethiopia. Lowland bamboo particleboard can use for particleboard purpose. The particleboard made from lowland bamboo (Oxytenanthera Abyssinica) is stronger than eucalyptus tree particle board. As the study result shows, the bending strength of lowland bamboo particleboard in both dry and wet condition is stronger than eucalyptus tree particleboard [2].

The total Ethiopian natural bamboo forest is estimated to cover around 1 million hectare, which is about 7% of the total of the world and 67% of the African bamboo population. The lowland species (Oxytenanthera Abyssinica) covers 85% of the total population bamboo in Ethiopia. The species of the bamboo, which is the lowland bamboo, farmed in Benishagul Gumuz region [3].

It is known that the solid bamboo coverage is more than the hollow bamboo coverage in Ethiopia. This research needs to use the mixed of solid and hollow bamboo particleboard. The reason to use the mixed of sold and hollow bamboo chips is to balance the resource utilization in fifty percent and to keep the advantage of lowland and highland area farmers by supplying the raw materials.

The lack of skill and technological inputs into the production chain, resulting in poor quality products that do not command the attention of potential purchasers, a complete lack of marketing infrastructure to enable products to reach out and find new markets [4].

Urea formaldehyde (UF) resin at solid content can be used as an adhesive. According to the researcher, test result shows that the effect of temperature on the modulus of rupture (MOR) has an inverse relationship and density has a direct relationship with MOR. This test result shows that the screw holding strength becomes low when temperature value was increased in each specific density level [5].

The bamboo age difference has an effect on the bending strength of particleboard. Considering the age of the bamboo is important to determine the strength of the board. The bending strength of one-year-old bamboo fiberboard was the same as that of tallow wood fiberboard and has higher internal bond (IB) strength than tallow wood at 8% resin content [6].

Bamboo waste with urea formaldehyde can use for particleboard. To prepare the board the researcher used urea formaldehyde glue as a binder. Generally, the thickness swelling property and water absorption property are increasing when the time is increased in both planer waste and hammer milled chips [7].

The press temperature has an effect on properties of medium density fiberboard produced from Eucalyptus camaldulensis fibers. The target of the study was to investigate the possibility of MDF production from Eucalyptus camaldulensis wood. The study result show, longer steaming time produced higher MOR but lower modulus of elasticity (MOE) except for press temperature of 190 °C. It can be anticipated that longer steaming time initiated the thermo-hydrolysis of the wood substances especially hemicelluloses and weakens the structure of the wood itself [8].

The particleboard is produced from fonio husk with gum Arabic resin adhesive as a binder. The mechanical tests which a flexural strength tests standards are determined. The study standard was according to ASTM, D-1037. Three samples were tested for each replacement percent level and the average value was determined. After reviewing the above literature it is found that the research work on bending properties of solid and hollow bamboo mixture particleboard was not carried out. This research focuses on studying the bending properties of bamboo particleboard and replacing the eucalyptus particleboard by bamboo particleboard [9].

In the research observation, all chip wood factories are using eucalyptus tree as the raw material for particleboard in Ethiopia. For example Ethiopian Chip wood and Furniture Share Company in Addis Ababa, Maichew particleboard factory in Maichew, Debre Birehan particleboard factory in Debre Birehan and Hawassa chip wood factory in Hawassa are used eucalyptus tree as their raw materials. Till now they use it due to different reasons. As they mention some of the reasons to use eucalyptus are; its availability with less cost, its strength for the product and there is no any other raw material for which, mechanical properties are studied.

Due to the demand, the high land area wide planting of eucalyptus tree has its own negative side effect. From those negative impact, it reduces the crop productivity. The growth of the crop, which germinates near the tree is very less and its productivity is also low [12].

The objective of this research work is to test experimentally and determine the bending strength of a particleboard made from hollow and solid bamboo chip composition with urea formaldehyde and to compare its bending strength with eucalyptus particleboard. Before this time mixing of the solid and hollow bamboo for particleboard is not studied in Ethiopia. So to recommend solid and hollow bamboo plants as the raw materials and to substitute eucalyptus the bending strength of bamboo particleboard should be greater than or equal to the bending strength of eucalyptus particleboard since particleboard application areas are mostly subjected for bending load condition.

2 Methodology and Materials

2.1 Methodology

The processes that are used to manufacture the board are based on the factories manufacturing method to fulfill their manufacturing standard. Tasks in the factory were making boards in different ratios. The ratio of the board was 75/25 for solid bamboo (Oxytenanthera Abyssinica) with hollow bamboo (Yushania Alpina) respectively and the second proportion was reversing the ratio to 25/75 and made respectively to justify which species is more strong. The third proportion was also made the board in one to one (50/50) ratio. The reason to use these mixing ratio is to obtain the optimized result. Generally, there are three types of boards in different ratio. To prepare the board there is an additive which UF and it is used to give strength by making bonds between the smaller particles of chips. Then preparing a specimen for the test from the sample boards.

2.2 Materials

In this work materials such as solid bamboo chips, hollow bamboo chips, and urea formaldehyde as a resin are utilized directly for the board preparation and to carry out the particleboard.

Formaldehyde-Based Binders. The factory uses urea formaldehyde for their product as adhesive material, and also this research carried outs eucalyptus particleboard (EPB) with bamboo particleboard (BPB) by using similar manufacturing method with ECAFCO. The liquid Urea formaldehyde (UF) is shown in Fig. 1.

Fig. 1. Urea formaldehyde

Bamboo. Both the solid and hollow type of bamboo is grown either naturally grown or farmed in a farmyard north-west of the countryside of Ethiopia in Awi Zone. In the highland part of the area especially at Enjibara town area, the hollow bamboo or Highland bamboo (Yushania Alpina) species are grown widely. In the lowland part of the area especially at Jawi Woreda, the solid bamboo or lowland bamboo (Oxytenanthera Abyssinica) species are grown.

2.3 Bamboo Board Manufacturing Process and Specimen Preparation

The manufacturing process of the sample board was carried out at Ethiopian Chip wood And Furniture Share Company (ECAFCO). The basic raw materials were lowland bamboo (Oxytenanthera Abyssinica) chips, hollow bamboo (Yushania Alpina) chips, and urea formaldehyde as an adhesive material.

The additive content was 12% urea formaldehyde [10] (UF) in mass and the remaining is bamboo chips. The ratio proportion was the same with ECAFCO eucalyptus particleboard manufacturing ratio.

The particleboard preparation is randomly oriented discontinuous fiber lamina [11]. The three boards were prepared in different size and different proportions. The applied pressing pressure and the temperature was 220 kp/cm^2 and 181 °C respectively and the pressing time was 5 min for 8 mm thickness (Figs. 2, 3 and 4).

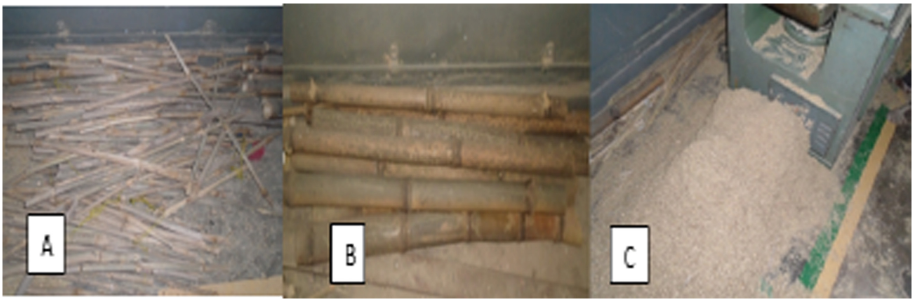

Fig. 2. The shaved chips of hollow and solid bamboo (A) The solid bamboo prepared for shaving (B) hollow bamboo prepared for shaving (C) bamboo chips after shaving at the exit of shaver machine

2.4 Randomly Oriented Discontinuous Fiber Lamina

A thin lamina containing randomly oriented discontinuous fibers in Fig. 3A exhibits planar isotropic behavior. The properties are ideally the same in all directions in the plane of the lamina [11] (Fig. 3).

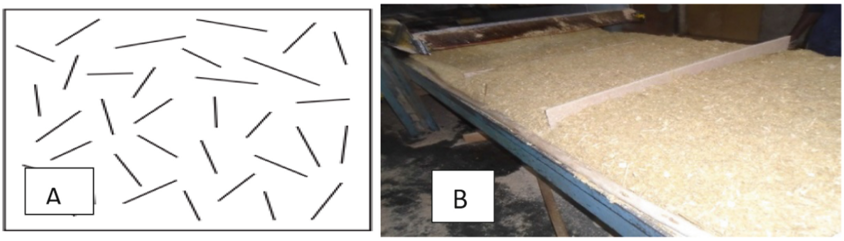

Fig. 3. (A) Randomly oriented discontinuous fiber lamina © [11] (B) Bamboo chips in the mould

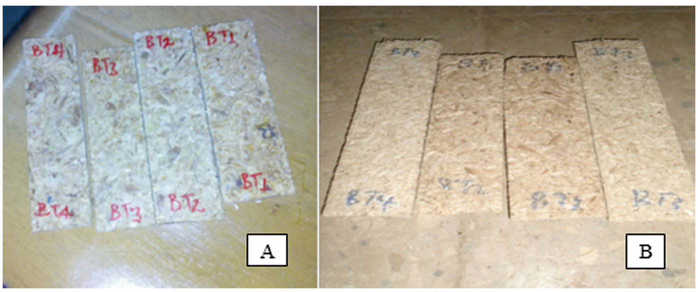

Fig. 4. (A) Specimen of bamboo particleboard, (B) Specimen of eucalyptus particleboard

Bending Strength Test. The flexural specimen is prepared as per the JIS A 5908 standards with a load rate of 10 mm/min and Samples dimension of the flexural test was 200 × 50 × 13 mm of length, width and thickness respectively [2]. Bamboo particle board was at a density of 0.6 g/cm^3 which obtained in measurement of mass per volume of the particleboard. But eucalyptus particleboard has a density of 0.596 g/cm^3 which measured in the same way of density measurement with bamboo particleboard to compare the two types of particleboards. That means density is mass per volume and the standard was JIS A 5908.

The three-point flexural test is the most common flexural test for composite materials. Specimen deflection was measured by the crosshead position [9].

The maximum fiber stress at a failure on the tension side of a flexural specimen is considered the flexural strength of the material. Thus using a homogeneous beam theory, the flexural strength in a three-point flexural test and the bending load resistance obtained during the test was related to the result of the highest flexural strength (uf) of three point bending calculated values [11].

$$\sigma_{UF} = \frac{3P_{max}L}{2bh^2} \tag{1}$$

Where, P_{max} = maximum load failure, b = specimen width, h = specimen thickness, L = specimen length between the two support points (Fig. 5).

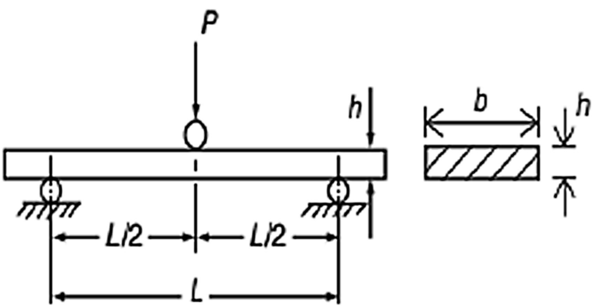

Fig. 5. Flexural test arrangements in three-point bending © [11]

Bending Strength Test Procedure. The test was carried out at Bahir Dar Institute of Technology (BIT) by using YF Zhejiang Tugong PN 0206000031 WAW-1000B Microcomputer controlled universal testing machine. The composition of the board was made from bamboo chips and urea formaldehyde. The bending load setup and failure is shown in Fig. 6.

As shown in Fig. 6B & C, the beam failure is happened due to the applied bending load in the specimen. In the Fig. 6B shown, the lower part is responsible for tensile stress and the upper side is subjected to compressive stress. At the edge of the object on the inside of the bend (concave face), the stress will be at its maximum compressive stress value. At the outside of the bend (convex face), the stress will be at its maximum

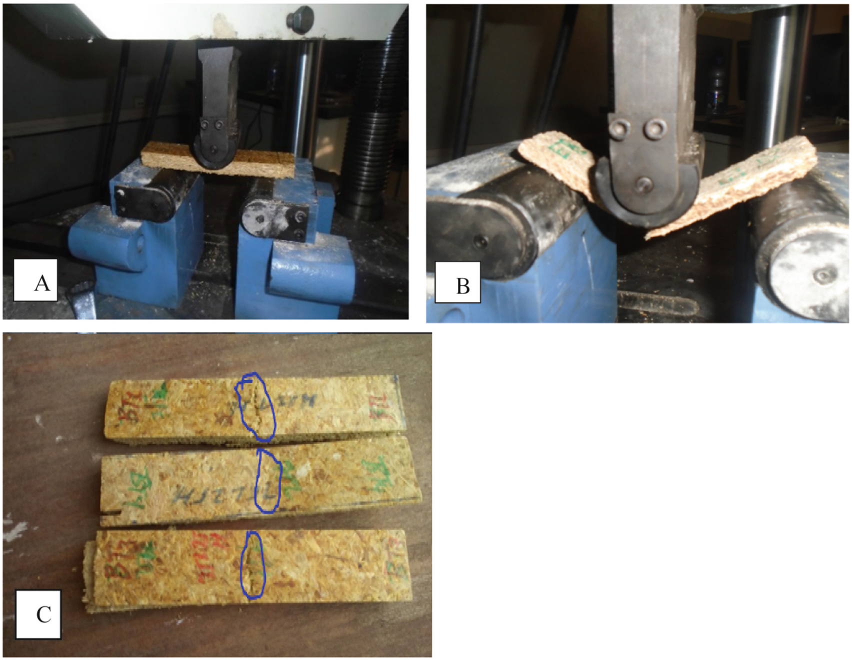

Fig. 6. (A) Three-point loading bending test setup (B) Failure of sample board for bending load C) Failure of sample board 1due to bending load

tensile stress value. Then the outsides maximum tensile stress value that can be sustained before the beam fails is its flexural strength. When a material is bent only the extreme fibers are the largest stress so, if those fibers are free from defects, the flexural strength will be controlled by the strength of those intact fibers.

3 Results and Discussions

3.1 Bending Strength Test Results of 75% SB and 25% HB Particleboard

In case of 75%, solid bamboo chips with 25% hollow bamboo chips particle board which has the dimension of 200 mm × 50 mm × 15 mm length, width and thickness, the average flexural strength were 159 MPa. But here the adhesive addition is the constant rate which was 12% in the liquid form of urea formaldehyde. Bamboo particle board which made from 75% solid bamboo chips with 25% hollow bamboo chips is stronger than any other particleboard. The reason to become strong in its bending load resistance is its intimacy between the chips was high.

The eucalyptus particleboard with a dimension of (200 × 50 × 13) mm length, width, and thickness respectively has a bending strength of 51.33 MPa in lengthwise at the dry condition [2] (Tables 1, 2 and 3).

Table 1. Bending strength test applied load on 75% SB and 25% HB

Type of materials	Applied load (kN)			
	Specimen 1	Specimen 2	Specimen 3	Average
Bamboo	12.71	13.13	9.94	11.93
Eucalyptus	0.7	0.65	0.61	0.65

Table 2. Bending strength test results of 75% SB and 25% HB

Type of materials	Specimens strength in MPa				Standard deviation
	Specimen 1	Specimen 2	Specimen 3	Average	
Bamboo	169.45	175	132.56	159	18.84
Eucalyptus	32.82	30.30	28.78	30.63	1.67

Table 3. Deformation of 75% SB and 25% HB due to a bending load

Type of materials	Maximum deformation (mm)				Standard deviation
	Specimen 1	Specimen 2	Specimen 3	Average	
Bamboo	19.026	19.828	16.11	18.32	1.60
Eucalyptus	16.502	13.186	7.474	12.38	3.73

3.2 Bending Strength Test Results of 50% SB and 50% HB

The bending strength test result of 50/50 solid and hollow bamboo chips with UF particleboard (PB) shows that better result obtained than eucalyptus particle board (EPB) bending load resistance. The mode of the graph profile becomes an irregular shape. The reason is in practice, fiber strength is not a unique value, and instead, it follows a statistical distribution. Therefore, it is expected that a few fibers will break at low-stress levels. Although the remaining fibers will carry higher stress, the may not fail simultaneously. The following Tables 4, 5 and 6 show the bending strength of 50% SB and 50% HB.

Table 4. Bending strength test load result of 50% SB and 50% HB

Type of materials	Applied load (kN)			
	Specimen 1	Specimen 2	Specimen 3	Average
Bamboo	0.67	0.64	0.67	0.66

Table 5. Bending strength test results of 50% HB and 50% SB

Type of materials	Specimens strength in MPa				Standard deviation
	Specimen 1	Specimen 2	Specimen 3	Average	
Bamboo	31.31	29.79	31.31	30.80	0.72
Eucalyptus	32.82	30.30	28.78	30.63	1.67

Table 6. Deformation of 50% HB and 50% SB due to a bending load

Type of materials	Maximum deformation (mm)				Standard deviation
	Specimen 1	Specimen 2	Specimen 3	Average	
Bamboo	14.136	16.046	13.928	14.70	0.95
Eucalyptus	16.502	13.186	7.474	12.38	3.73

3.3 Bending Strength Test Result of 75% HB and 25% SB

The bending strength test result of the 75% HB and 25% SB particleboard are shown in Tables 7, 8 and 9.

Table 7. Bending strength test result of 25% SB and 75% HB

Material	Applied load (kN)			
	Specimen 1	Specimen 2	Specimen 3	Average
Bamboo	0.57	0.66	0.83	0.69

Table 8. Bending strength test results of 75% HB and 25% SB

Types of materials	Specimens strength in MPa				Standard deviation
	Specimen 1	Specimen 2	Specimen 3	Average	
Bamboo	26.76	30.80	38.83	32.13	5.02
Eucalyptus	32.82	30.30	28.78	30.63	1.66

Table 9. Deformation of 75% HB and 25% SB due to bending load

Materials	Maximum deformation (mm)				Standard deviation
	Specimen 1	Specimen 2	Specimen 3	Average	
Bamboo	7.92	11.99	15.75	11.88	3.20

The deformation of each type of particleboard is proportional to the amount of load and the resulting stress.

The comparison between [2] test result and this research result, the bending strength of the two type of bamboo mixed particle board has higher strength in the lengthwise direction, and the study's test result was 69.6 MPa at a dry condition. The higher result is obtained in the condition of 75% SB & 25% HB particleboard. The researchers' test also carried out in the widthwise direction and the solid bamboo particleboard bending strength result (21.4 MPa) at dry condition is much lower than the mixed ratio 75/25 SB/HB of the two-species particleboard. That is mixing the two type of bamboo species for particleboard improves the bending strength of the particleboard. Due to this using both type of bamboo for particleboard can makes a profit since the resource is grown in both highland and lowland area in Ethiopia. That means the hollow bamboo is grown in the highland area and the solid bamboo grown in the lowland region. In this case, the farmers can also get benefit by supplying the resource.

The research result shows that the current eucalypts particleboard bending strength is about 30.63 MPa which is accepted in its strength in the market and bamboo particleboard bending strength is outshined (Fig. 7).

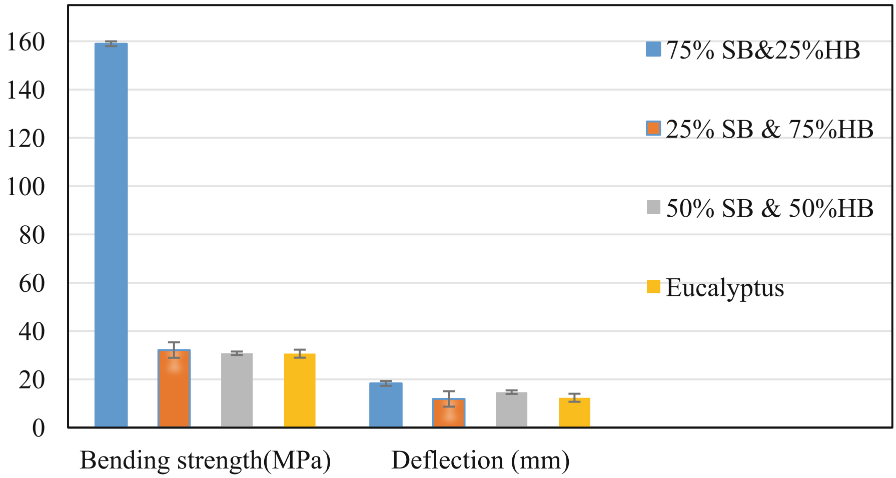

Fig. 7. Combined graph of each proportions deflection and bending strength results

The result which obtained from the bending strength test of solid and hollow bamboo particle board in different production ratio, the bending load resistance of the specimen was higher than the eucalyptus particle board bending load resistance. The deflection of the specimen illustrated in the above deflection Tables (3, 6 and 9) can be expressed in the following formula by considering the specimen as a beam from the center.

$$Dc = \frac{rxL^2}{6d} \tag{2}$$

Where, Dc = the maximum deflection at the center of the specimen in (mm), r = strain, d = depth of the specimen, L = span length between the support.

The reason to have high strength of 75% SB and 25% HB particle board is the natural intimacy of the chip each other was higher than the other chip particleboards and the board is manufactured in a medium density fiberboard mode.

4 Conclusions

In the research work, solid or lowland bamboo (Oxytenanthera Abyssinica) and hollow or highland bamboo (Yushania Alpina) chips are used to make particle board and the bending strengths have been examined. The bending strength of the bamboo particleboard is compared with that of eucalyptus particleboard and bamboo particle board has a greater strength. In addition this bamboo particle board has better smooth surface finish than eucalyptus particleboard in observation. But, the factory uses the machine to polish the surface of eucalyptus particleboard. Due to this, the factory expenses increase in machining, energy and operation cost. If the factory manufactures particleboard from bamboo, this expense will reduce totally, since the smoothness of bamboo particleboard was better than the polished eucalyptus particleboard. In general, if the manufacturing condition can be controlled well, the particleboard made from bamboo can substitute eucalyptus particle board and particleboard manufacturing companies can use bamboo plant. If the farmers teach about the advantage of bamboo and disadvantage of eucalyptus, they can plant bamboo instead of planting eucalyptus.

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