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Particle alignment and size influence properties in particleboards made from Ethiopian Highland Bamboo, *Yushania alpina*

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Abstract: The aim of this study was to evaluate the effects of particle alignment and particle sizes on mechanical properties and dimensional stabilities of oriented strand boards made from Ethiopian highland bamboo (*Yushania alpina)*. A total of 24 sample boards were prepared from 2 particle sizes (fine and coarse) and 4 particle alignment levels (90°, 0°,45° and random). The results revealed that parallely aligned boards from coarse particle sizes had 15% higher Modulus of rupture (MOR) than random boards. Similarly boards made from coarse particles had 22% higher Modulus of elasticity (MOE) values than random boards. The MOR and MOE of randomly arranged boards made from both particle sizes were higher than boards oriented at 45° and 90° but lower than parallel oriented boards. The internal bond strength (IB) of oriented boards was not affected by particle alignment but affected by particle sizes. Cross aligned boards made from fine particles had 35% greater IB strength than those made from coarse particles. Particle alignment and particle sizes had significant effects on surface and edge screw withdrawal strength. The screw withdrawal resistances of boards made from coarse particles were higher than those made from fine particles. Particle alignment did not show significant effect on thickness swelling and water absorption of oriented boards after 24h of water soaking test. Lower thickness swelling (TS) values were obtained from boards made with fine particles than with the coarse particles after 24h water soaking test.

Keywords: Particle alignment, particle size, strength, internal bond, screw withdrawal, thickness swelling

INTRODUCTION

In recent years, the use of oriented particleboards made by aligning the particles in desirable direction has become a common trend in various structural applications. The mechanical and electrostatic method of orientation used in the manufacture of particle-based structural composite can increases the use of low quality raw material to produce high quality engineered composite boards. Due to these achievements, particle-based structural composites like flake board, wafer board and oriented strand board (OSB) have continued to have wider applications compared to the traditional

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composite panels like plywood and glulams. The development of electrostatic orientation method has increased the use of short elements of low quality materials in the production of composite boards with equivalent or higher strength. Results of several studies have shown that when electrostatic method of alignment is applied, orientation can be achieved with particles regardless of dimension (Kawai, 1996).

Manufacturing bamboo particleboards by aligning the particles in the desirable direction can improve the strength properties and dimensional stably than traditional method of board manufacture. There are several processing variables that affect the mechanical and physical properties of particleboards. The alignment of particles is considered to be one of the major factors. Considerable amount of works had been reported on particle alignment of boards made from softwood species. For instance, bending strength of highly-oriented particleboard was found to be two times higher than that of random particleboard (Geimer, 1976; Suzuki and Sekino, 1982; Kawai *et al.,* 1990; McNatt *et al.*, 1992; Shupe *et al.,* 2001). Limited research has been reported on the use of hardwoods for manufacture of acceptable flake board products. For example, the stiffness of highly oriented particleboards made from hardwood species (Aspen and Red maple) had 18% and 3%, respectively as higher as that of random boards Kuklewski *et al*. (1985). However, there is lack of information on particle alignments of bamboo particleboards especially small particle sizes. Therefore, the objective of this study was to evaluate the effects of different levels of particle alignments and particle sizes on mechanical properties and dimensional stability of oriented boards made from *Yushania alpina*.

MATERIALS AND METHODS

Eighteen oriented boards were prepared from 1-2 mm and > 2 mm particle sizes with particles in the face and core oriented perpendicular to each other. All boards were prepared with equal proportions of face and core ratios. The orientation of particles was controlled with respect to the longitudinal axis of the boards. Three types of oriented boards with particle alignments perpendicular to the core or 90°, face particles aligned at 45° inclination to the core and face particle aligned parallel to the board length or 0° were prepared to evaluate the level of particle alignments. Then six identical three layered random boards were produced from both particle sizes for comparison purposes.

Board Manufacturing

Prior to board manufacture, particles were dried to below 5% moisture content. Ten percent of urea formaldehyde (UF) resin (based on the oven-dry weight of the particle) and 1% of liquid wax emulsion (based on the oven-dry weight of the particle) were used to bond the particles and to impart water repellency repeatedly. Blending was conducted using a laboratory rotary blender with air spray nozzle secured on the top of blender for uniform distribution of resins. The furnish moisture content throughout the thickness of the board was about 12%.

A square aluminium box of 400 mm by 400 mm size was used for board forming. The box had a frame consisting slots of 10 mm wide divided by thin aluminium plates between the slots which were located about 25-40 mm above the top of the mat. The furnish was passed between the slots manually. The space between the aluminium slots were ensured to fall in the same direction into the forming mat underneath. The distance between the bottom of the aluminium slot and the top of the mat was closely controlled by putting additional aluminium fame at the side of the frame so that the orientation of the particles remains the same.

The mats were then pre pressed at 3.5 MPa pressure for about 3 min. in a mat forming machine. The consolidated mat was finally hot pressed to a thickness of 15 mm and a target density of 750 kg/m^3. A 6 min. press cycle was used with 1 min. press closing time. The platen temperature was 170 ± 2ï C and the peak pressure applied was 4.0 MPa. Distance bars were used to control the final thickness of the board. All boards were conditioned at 20 ± 2°C room temperature with 65 ± 5% relative humidity for 5 days to allow sample boards to reach equilibrium with the surrounding atmosphere.

Evaluation of Orientation

Angle of the particle orientation were measured at ten points on the upper surface of each board using a method developed by Geimer (1976) to determine the degree of particle alignments. The average degree of particle alignment was measured in relation to the longitudinal axis of the board. All the measured angles were considered positive irrespective of whether the flake rotated clockwise or counter clockwise from the

Table 1. Calculated particle alignment used in the study

Sample board	Mesh size	True angle*	Alignment (%)
1	1-2	5.4	88.0
2	1-2	5.5	87.0
3	1-2	4.1	91.0
4	1-2	5.4	88.0
5	1-2	4.8	89.3
6	1-2	4.2	90.7
7	>2	5.8	87.0
8	>2	6.0	86.7
9	>2	7.7	82.9
10	>2	6.6	85.3
11	>2	4.5	90.0
12	>2	6.0	86.7
Average		5.5	88

* Deviation from the board cardinal axis

longitudinal axis. Based on the method introduced by Geimer, an alignment percent calculation that measures the average angle deviation from the reference angle 45° to the geometric axis of the specimen were evaluated as follows;

$$\text{Align \%} = \frac{45-\theta}{45}100 \qquad \text{Equation 1}$$

Where

Equation 2

Board Evaluation

Specimens were cut from oriented and random particleboards for static bending and dimensional stability tests. The modulus of elasticity (MOE), the modulus of rupture (MOR), internal bond (IB) strength, the thickness swelling and water absorption test were performed in accordance with ISO standards, (ISO/DIS 16978, 2003; ISO/DIS 16984, 2003 and ISO/DIS 16983, 2003). The Screw withdrawal test was conducted based on British Standard (BS 5669: Part 1,1989).

Experimental Design and Statistical Analysis

A factorial experiment was used to conduct this experiment by considering two factors (4 orientation levels and 2 particle sizes). Statistical analysis software (SAS) was used to analyse the data using analysis of variance (ANOVA). Least significant difference (LSD) was used for mean comparison.

RESULTS AND DISCUSSION

Bending and stiffness strength

The effects of four levels of particle alignments and two particle sizes were analyzed and the results showed that both significantly influence the MOR and MOE. As indicated in Figure 1, the MOR of parallel aligned boards made from coarse particles (>2 m) afforded an increase of only 6% than boards made from fine particles (1-2 mm). At 45° and 90° particle alignment, coarse particles produced significantly high strong boards 8% and 19%, respectively than fine particles. The MOR of randomly arranged boards made from both particle sizes were higher than boards oriented at 45° and 90° but lower than parallel oriented boards. In general, parallel aligned boards of both particle sizes had 15% higher strength value than random boards.

Totally different observation was seen in the stiffness values of the bamboo particleboard (Fig. 2) and the most obvious differences were in the effect of coarse

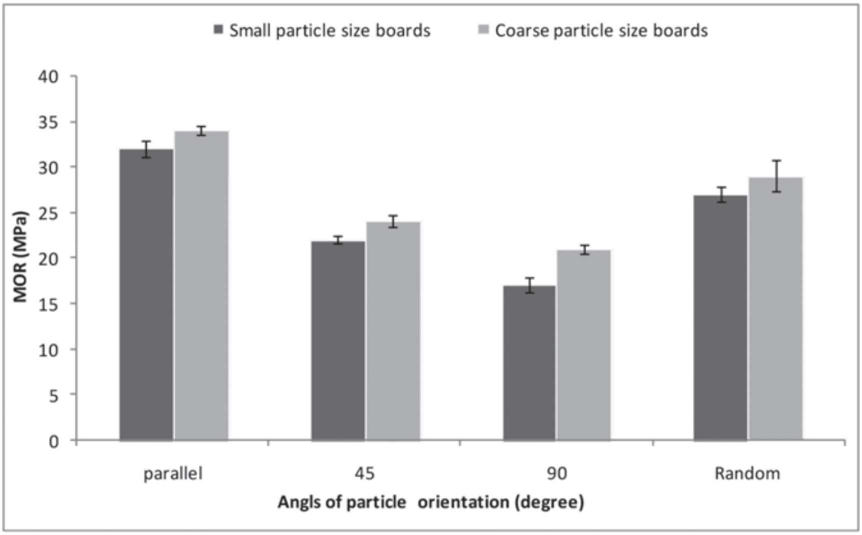

Figure 1. Effects of particle alignment and size on MOR

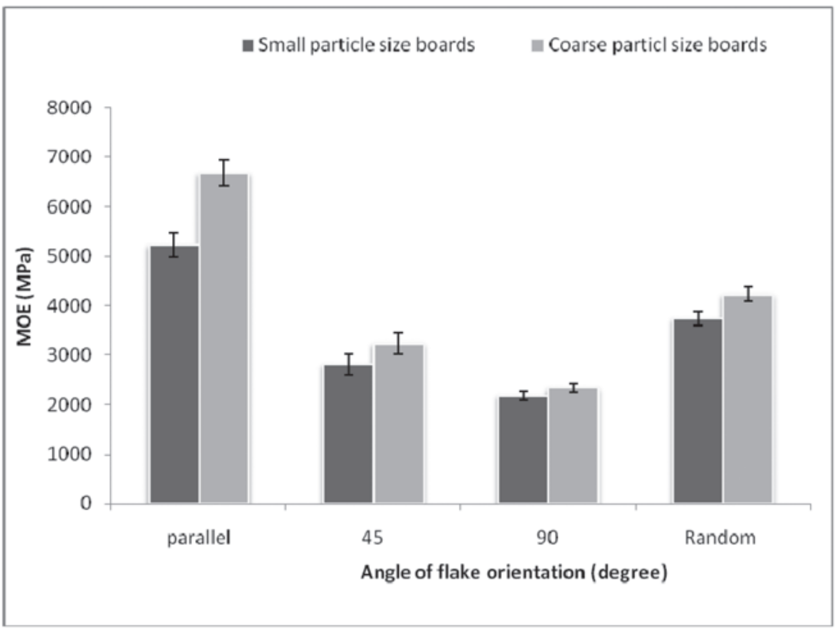

Figure 2. Effects of particle alignment and size on MOE

The effects of particle size on board stiffness for cross aligned at 45ï and random particleboards are slightly improved (10% and 11%, respectively) compared to that on the board strength. Use of coarse particles did not improve the stiffness at 90ï cross aligned boards (observed only 8%). The MOE values between oriented and random boards showed that stiffness of parallel aligned boards to the longitudinal axis was highly improved (28% and 37%, respectively for small and coarse particles) than those of random boards. On the other hand, random boards from both particle sizes had high strength and stiffness values than cross aligned boards at 45ï and 90ï. Therefore, it is clear that stiffness and strength properties of bamboo particleboards can be significantly increased by aligning the particles to the longitudinal axis of the board.

The results in this experiment indicated that particle alignment and size had more influence on MOE than MOR. The interaction effects of particle alignment and size on MOR and MOE suggested that changes in stiffness and strength properties was dependent on particle size. Analysis of results revealed that high strength and stiffness performances were observed in all boards made from coarse particles sizes. This implies that the size of coarse particles could be facilitated for the alignment of particles than small size particles .

Study on strand boards showed that an increase in strand length to a certain level increased the MOR and MOE. A wood particle should be sufficiently long to allow adequate overlap for transfer of applied stress from one particle to the next (Brumbaugh, 1960; Canadido et al. 1988; Barnes 2001). It is concluded that coarse particle size had high effects on strength and stiffness properties of oriented boards than fine particles. The dominant parameter controlling the strength and stiffness properties of oriented board in this experiment is particle alignment.

Comparison of Parallel oriented *Y.alpina* boards to the longitudinal axis oriented boards made from hardwood species showed that *Y.alpina* oriented boards had high MOR and MOE values (8% and 13%, respectively) than Maple (*Acer rubrum* L.)

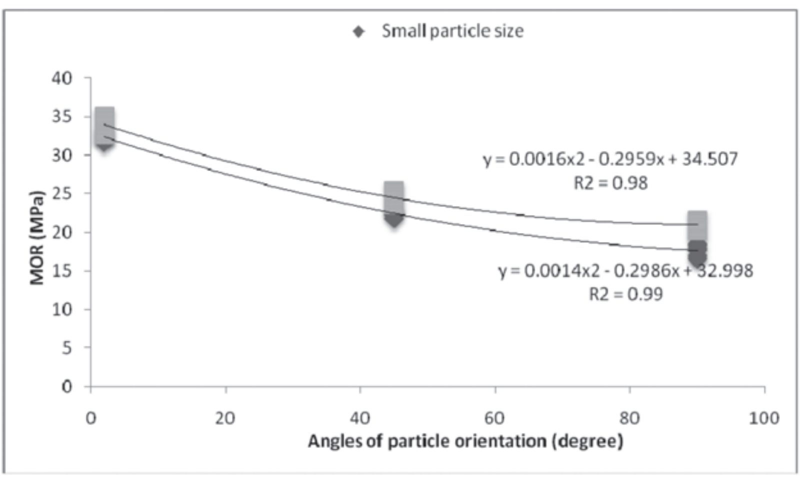

Figure 3. Relationship between MOR and particle alignment

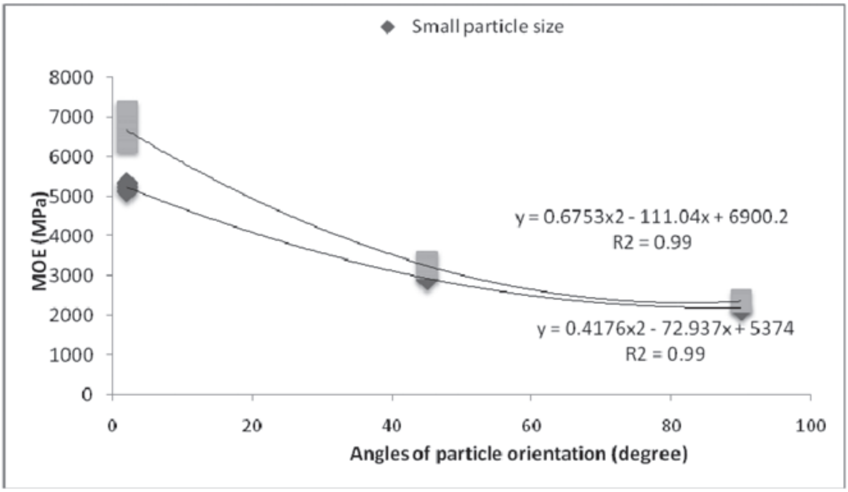

Figure 4. Relationship between MOE and particle alignment

and almost an equal MOR and MOE with Aspen, *Populous grandidentata* Michx) reported by Kuklewski *et al*. (1985).

Regression equation given in Figures 3 and 4 can be used to predict the bending and stiffness properties of oriented boards aligned from 0ï to 90ï. High r^2 values (R^2=0.99) indicated the strong relationship of particle alignment and strength properties of oriented boards. The MOR and MOE of oriented boards were drastically decreased with increases of particle alignment.

Internal bond, screw withdrawal and thickness swelling

The internal bond strength (IB) of oriented boards was not affected by particle alignment but affected by particle sizes. The result of this experiment revealed that cross aligned boards at 0° made from fine particles significantly gave higher IB strength than those made from coarse particles (Table 2).

As indicated in Table 2, cross aligned boards made from fine particles had 35% greater IB strength than those made from coarse particles. The higher IB strength in bamboo of fine particles could be attributed to the better ability of fine particles to act as gap filling during board pressing than those of coarse particles. In addition, fine particles are more flexible and compressible under hot press than coarse particle sizes. This improves inter-particle area thereby increasing the IB strength. As Brumbaugh (1960) stated that greater degrees of discontinuity of fine particles gave them higher strength as the possessed short discontinuous planes which probably reduced the tendency to develop area of failure.

Table 2. Mean comparisons of internal bond, screw withdrawal, thickness swelling and water absorption.

Measuring Variables	Particle alignment					
	Cross aligned		Parallel aligned		Random	
	Fine particles	Coarse particles	Fine particles	Coarse particles	Fine particles	Coarse particles
IB[1]	1.0a	0.648b	-	-	1.1a	6.52b
SWS[2]	773b	878a	793b	-	858a	-
SWE[3]	753b	831a	759b	-	824a	-
TS[4]	6.9b	7.8a	-	-	6.7b	-
WA[5]	30b	37a	-	-	30b	-

Note:1=internal bond, 2=screw withdrawal surface,3= screw withdrawal edge, 4=thickness swelling, 5=water absorption
Means having the same letter are not significantly different at P≥ 0.05

Particle alignment and particle sizes had significant effects on surface and edge screw withdrawal strengths as shown in Table 2. The screw withdrawal resistances of boards made from coarse particles were higher than those made from fine particles. The higher screw withdrawal capacity is probably due to thickness of the particles. Wong (1999) reported that large and less damaged wood elements provide high screw withdrawal ability than small wood elements. The reception of more resin per surface area by thick particles than thin particles probably increases the screw holding ability of coarse particles.
Random boards had superior screw withdrawal resistance compared to parallel aligned boards (Table 2). High internal bond strength's of random might increased the screw holding capacity. Suzuki and Sekino (1982) reported that when the aligned and the random mat are pressed to be on the same thickness, random flakes strongly pressed at bonded points to adjacent flakes and tend to develop a tight interconnecting structure.

Particle alignment did not show significant effect on thickness swelling and water absorption of oriented boards after 24 h water soaking test. Whereas, particle sizes had significant effects on both tests. As indicated in Table 2, lower thickness swelling (TS) values were obtained for boards made with fine particles than with the coarse particles after 24 h water soaking test. This could be related to the compression behavior of fine particles. Under hot press, small particle size could be pressed easily and fit together very closely, thereby reducing void spaces between them and this condition might create intimate inter-particle contact and increases the internal bond strengths (Brumbaugh, 1960; Kelly, 1977). Due to this condition, boards that have high internal bond strength have substantially lower thickness swelling.

Boards made from fine particle sizes absorbed 19% less water than those made from coarse particle sizes (Table 2). This might be due to better inter-particle bonding as shown by higher IB strength.

Conclusion

The results of this experiment revealed that particle alignment and particle sizes had significant effects on strength, stiffness, and surface and edge screw withdrawal properties. On the other hand, particle alignment did not affect internal bond strength, thickness swelling and water absorption properties. However, particle size had significant effects on these properties. Parallel aligned boards to the longitudinal axis from both particle sizes had significantly higher MOR (about 15%) and MOE (28%and 37%, respectively for small and coarse particles) than those of random boards. Boards made from fine particles showed 35% high IB strength values than those made from coarse particle. Superior screw withdrawal resistances were obtained from coarse particles size random and oriented boards compared with fine particle size boards. Boards made from small particles size absorbed less amount of water and had also less thickness swelling than boards made from coarse particles size due to it's high IB strength. In general, the dominant parameter controlling the strength and stiffness properties of oriented board is: particle alignment and particle sizes, screw withdrawal, thickness swelling and water absorption properties.

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