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Properties of Oriented Strand Board (OSB) Made from Mixing Bamboo

[1] Mulik Abaker Ibrahim, [2] Fauzi Febrianto
[1] Lecturer Department of Forestry Sciences
[2]Assoc.Prof. Department of Forest Product Technology
[1] malik_abaker@yahoo.com, [2] febrianto76@yahoo.com

ABSTRACT

Utilization of bamboo as wood substitute for bio-composite industry raw material is very important to support its sustainability due to the huge wood supply shortage for the industry. The objective of this research was to produce high quality of OSB made from mixing bamboo and to determine the effect of strand combination on the properties of OSB. In addition durability of OSB against termites attacks. This research was done of OSB with the core layer orientation perpendicular to the face and back layers. Nine strand combinations from three strand bamboo species Betung bamboo (B) (Dendrocalamus asper (Schult.f.) Backer ex Heyne) , Andong bamboo (A) Gigantochloa verticillata (Willd.) Munro)) and Tali bamboo (T) (Gigantochloa apus (JA. and JH. Schultes) Kurz)). Were manufactured, namely BBB, BAB, BTB, AAA, ABA, ATA ,TTT, TBT,and TAT. Bonded with 5% of Methylene Diphenyl Diisocyanate (MDI). The results of this research indicate that BAB, ABA, BBB board made from strand combination, produce the best OSB in terms of physical and mechanical properties, and fulfilled on JISA 5908: 2003 Standard. The results revealed that strand combination showed significant effect on board properties, density, MOR in parallel direction to the grain, screw holder power. The results of this study showed the feasibility of using of mixing bamboo species from planted forest for OSB manufacturing, it is important to qualify appropriate raw material supply for the board industry.

Keywords: *Bamboo, OSB, Isocyanides, Strand combination, Durability*

1. INTRODUCTION

Lignocelluloses materials such as bamboo can be used as raw material of Oriented Strand Board (OSB). The bamboo has been processed into an extended diversity of products ranging from domestic household products to industrial applications, especially as an alternative substitute for wood in producing pulp, paper and composite boards. There are many advantages of bamboo which includes fastest growing plant, availability for the housing, regenerates plant, bamboo is very composite product.

OSB is a structural composite products and one of the wooden panels that are designed to replace the plywood (Nishimura et al. 2004). Production trends in the forest product industry indicated less production of structural plywood and increased production of composite wood panels like OSB. OSB is a performance-rated structural panel engineered for uniformity, strength, versatility, and workability. It is utilized internationally in wide array of applications, including building construction, flooring, partitioning packing as and parts in furniture and automotive products (SBA 2004). OSB has a viable potential in time of curtailed timber supplies due to reducing forest, demand from conservation groups and public for saving the environment and more stringent logging regulations.

The performance of OSB is mainly affected by adhesive penetration in to strand, higher penetration can enhance its performance. Resin type and its content significantly influence the properties of wood based composites. The use of higher resin loading levels and more advanced resin systems, such as Methylene Diphenyl Diisocyanate (MDI) can directly improve strength and dimensional stability of the wood composites panels (Norita et al. 2008; Sumardi et al. 2008).

According to Saad (2008) that of face-core ratio of 50:50 with the levels of isocyanides adhesive glue 6% yield of Betung bamboo OSB with the best quality standard JIS A 5908-2003. Face-core ratio greater will increase the strength (MOE and MOR) in length parallel testing OSB will reduce the power otherwise the OSB wide parallel testing. A lot of bamboo species can be used as structural material in the Sudan, such as bamboo Betung, bamboo Andong and bamboo Tali, it's very promising to be used as material for OSB. With those considerations, the study about properties of oriented strand board from mixing bamboo is needed.

1.1 Objectives

The purpose of this research was to determine the properties of OSB made from mixing bamboo bonded with isocyanides resin, specific objective are:

- To evaluate the effect of strand combination on the physical properties, mechanical properties and durability of OSB against termites attack.
- To find out the best composition of OSB made from mixing bamboo.

1.2 Benefit of this Research

The result of this research are expected to be able to give information of exploiting of bamboo as one alternative of source of raw material to support accomplishment of industrial raw material of processing of wood and at the same time creates friendly product.

1.3 Research Hypothesis

Strand combination gives real influence on the physical, mechanical properties and durability of OSB against termites attack.

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2. LITERATURE REVIEW

2.1 Bamboo

Bamboo is one potential alternative raw material and very promising because of the abundant availability, rapid growth, and easily cultivated (Muin et al. 2006). Bamboo is a perennial grass and included in the subfamily Bambusoidae, family Graminiae with woody stems and beruas-sections. There are about 87 genera and more than 1500 kinds of bamboo in the world, and about 100 species of which have important economic value (Diver 2001). The data presented by Maoyi and Bay (2004) showed the increasing number of known species of bamboo, which are more than 1200 kinds of them found in Asia. Bamboo has many benefits, both ecological benefits as well as industrial raw materials. In ecological terms, bamboo is very beneficial for the environment because it produces a very high biomass. Bamboo forest biomass can produce seven times more than the trees. Therefore the role of bamboo forests as producers of oxygen (O_2) and absorbing carbon dioxide (CO_2) in the interest of the global ecosystem is very important, especially in tropical areas where natural forest has declined drastically. Other ecological functions are the ability to prevent erosion because it can strengthen the bonds holding soil particles and water runoff. Because of the diverse ecological functions, bamboo is a plant that can be used for the cultivation of marginal lands (PT Bamboo Nusantara).

Utilization of bamboo as an industrial raw material is often found on construction products, stairs, fences, container, furniture, and some handicraft products. In addition to the common use of bamboo, the bamboo is to use a more appropriate and more extensive, few studies about the characteristics and basic properties have been implemented. Dransfield and Widjaya (1995) wrote in her study of the anatomy of bamboo columns consisting of approximately 50% of parenchyma, 40%, 10% fiber and connective cells (vessels and save tubes). Parenchyma and connective cells are more common in the inside of the column, whereas more fibers found on the outside. While the joint arrangement connecting fibers between the book has a tendency to grow from the bottom up while parenchyma reduced. The results of the study (Londono et al. 2002) showed that species of bamboo Guadua angustifolia from Columbia consisting of 40% fiber, 51% parenchyma, and vascular tissue 9%. The research by Latif et al. (1990) on the type of Bambusa vulgaris, Bambusa bluemeana, and Gigantochloa scortechinii between the age of 1 - 3 years showed that the size of vascular bundle (the ratio of radial: tangential) and fiber length positively correlated to the MOE and the proportion of the voltage at the boundary. They explained that bamboo has a longer fiber will be more rigid if the size of vascular bundle was greater. The relationship between fiber lengths with sheer determination is negative. Fiber wall thickness correlated positively with the press and the MOE determination but negatively correlated with MOR.

Li et al. (2004) reported that the mechanical properties of bamboo increases with increasing age. Thiers research further suggested that increased concentrations of vascular bundle from the inside out (Li et al. 2007). in the same study also found that there was an increase of the significant weight of 1-year-old bamboo and 3 years due to the increased of number of cells in the vascular bundle and the secondary cell wall thickening. But despite holocellulose and lignin content klaxon also increased at the age of 3 years but its value is relatively small. So with extractive content also increased from age 1 year to 3 years of age.

The results of research on the chemical properties of bamboo and raised by Li et al. (2004) which stated that bamboo has a cellulose content ranged from 42.4% - 53.6%, lignin levels ranged between 19.8% - 26.6% while the levels of pentose 1.24% -3.77%, ash content of 1.24% - 3.77%, silica content 0,10% - 1.28%, extractive content (solubility in cold water) 4.5% - 9.9 %, extractive content (solubility in hot water) 5.3% - 11.8% and the extractive content (solubility of benzene in alcohol) 0.9% - 6.9%. Research conducted by Li et al. (2007). Showed that the bamboo Phyllostachys pubescent increased content of α-holocellulose and cellulose from the base to the tip of the rod, but the lignin content (klaxon) and ash levels are not significantly different. The outer layer has a degree holocellulose rod, α-cellulose, and lignin (klaxon) the highest compared to other parts and have the levels of extractive and ash levels are lowest. On the other hand, the silica content of the epidermis is three times higher than the deepest layers of bamboo.

Further research on the physical properties of bamboo proposed by Dransfield and Widjaja (1995) which stated that the bamboo water content increases from the bottom up from age 1 - 3 years, but then declined in bamboo older than 3 years. Increased water content in the wet season compared with the dry season. Further research by Hadjib and Karnasudirdja (1986) showed that some of the things that affect the physical and mechanical properties of bamboo are age, height position, diameter, thick bamboo meat, the position of the load (in a book or a segment), the radial position from the outside to the inside and levels bamboo water. Unlike the wood-dimensional change after water levels dropped below the fiber saturation point, and the diameter of the cell walls of bamboo experienced immediately after the bamboo shrinkage water loss. Bamboo with older age (3 years) has a stability dimension that is higher than younger bamboo (1 year) (Latif 1993). Results of research by Lee et al. (1994) showed that the shrinkage in the radial direction is much larger than the double dual tangential direction, while shrinking in the direction of relative longitudinal negligible.

Multifunctional bamboo panels are made by combining the product with bamboo stall round people using adhesive has been developed. Type bamboo panels can be used as a component of the walls, floors, beams, roof cover, and concrete printer. Noermalicha (2005) has

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developed a laminated arch design of bamboo as a phenomenon of technology-based design using Betung bamboo, bamboo ropes, and bamboo buggy. Utilization of bamboo as raw material of cement composite board has been done by Suhasman et al. (2008). In these studies found that the use of bamboo at different age classes (young bamboo, mature, and old) with conventional methods was to produce cement board with the same relative quality.

2.2 Overview of Betung Bamboo (Dendrocalamus asper (Schult.f.)

Bamboo has a Latin name Betung Dendrocalamus asper (Schult,) Backer ex Heyne. Betung Bamboo is also having a many local names for cultivars of green called Betung, Beto (Manggarai), Bheto (Bajawa), and Statues (Tetum), whereas for black cultivars called Bheto Laka (Bajawa). In the Lesser Sunda Islands, Betung bamboo scattered occurred everywhere, but grows best in places that are less juicy but lecil trunk diameter. This type of bamboo is habitat on alluvial soil in the humid tropical areas and wet, but bamboo is also grown in dry areas and high plains (Widjaya 2001).

Betung Bamboo is a cheap building materials and strong, but in its use of bamboo is very popular type of powder. This powder content closely related to the content of starch substance in Betung bamboo. To reduce the starch content of existing substances should be an effective treatment before the bamboo is used as building material (Prawirohatmojo 1979). Based on research Hadjib and Karnasudirdja (1986) Betung bamboo has physical and mechanical properties as shown in Table 1.

Table 1: Physical and Mechanical Properties of Betung Bamboo.

Value	Physical and Mechanical Properties	No.
342,47	MOR perpendicular (kg/cm^2)	1.
416,57	MOR parallel (kg/cm^2)	2.
53173,0	MOE (kg/cm^2)	3.
0,57	Specific gravity (g/cm^3)	4.

2.2.1 Taxonomy

Domain: Eukaryota
Kingdom: Plantae
Subkingdom: Viridaeplantae
Phylum: Tracheophyta
Subphylum: Euphyllophytina
Infraphylum: Radiatopses
Class: Liliopsida
Subclass: Commelinidae
Superorde: Poanae
Order: Poales
Family: Poaceae
Subfamily: Bambusoideae
Tribe: Bambuseae
Genus: Dendrocalamus
Specific epithet: asper
Botanical name: Dendrocalamus asper

2.3 Overview of Tali Bamboo (Gigantochoa Apus (J.A. and J.H. Schultes) Kurz)

Bamboo rope with a Latin name Gigantochoa apus (JA and JH Schultes) Kurz), has a strap Pring area, Pring apus (Java), awi rope (Sunda). Bamboo rope are scattered throughout Java, but also grows wild in National Park and Meru Alas Purwo Betiri. Original habitat of bamboo rope is a humid tropical region and dry. Bamboo rope is symposia, meetings, and upright (Widjaya 2001). Some physical and mechanical properties of bamboo rope Ginoga based on research (1987) included static bending strength, fortitude press parallel fibers, shear strength, tensile strength perpendicular to fibers, strength sides, density, water content, and stiffness. The complete value of physical and mechanical properties of bamboo learn presented in Table 2.

Table 2: Physical and Mechanical Properties of Tali Bamboo.

Value	Physical and Mechanical Properties	No
	Determination of static bending	1.
327	a. Proportion of tension in the limit (kg/cm^2)	
546	b. Voltage on a broken line (kg/cm^2)	
10100	c. Modulus of elasticity (kg/cm^2)	
504	Press parallel fibers (maximum stress, kg/cm^2)	2.
39,5	Shear strength (kg/cm^2)	3.
28,3	Perpendicular tensile tenacity fibers (kg/cm^2)	4.
58,2	Strength sides (kg/cm^2)	5.
	Weight type	6.
0,63	a. Specific gravity (g/cm^3)	
0,58	b. client dried (16.42%)	
	At determination	7.
45,1	a. On the inside (kg/cm^2)	
31,9	b. Tangential direction (kg/cm^2)	

2.3.1 Taxonomy

Domain: Eukaryota
Kingdom: Plantae
Subkingdom: Viridaeplantae
Phylum: Magnoliophyta
Subphylum: Euphyllophytina
Infraphylum: Radiatopses
Class: Liliopsida
Subclass: Commelinidae
Superorde: Poanae
Order: Poales
Family: Poaceae
Genus: Gigantochloa
Specific epithet: levis
Botanical name: Gigantochloa levis

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2.4 Overview of Andong Bamboo (Gigantochloa verticillata (Willd.) (Munro).

Bamboo has the name of the horse cart gombong Pring, Pring buggy, Pring letter (Java), awi buggy, and awi gombong (Sunda). Bamboo is spread across the island of Java with their habitat growing in lowland until height of 1500 mm and grows well in humid tropical areas with clumps symposia, upright and dense (Widjaya 2001). Hadjib and Karnasudirdja (1986) stated in their research, that the physical and mechanical properties of bamboo buggy is as follows: specific gravity of 0.55 g/cm^3 for a bamboo horse cart, press the parallel determination of 293.25 kg/cm^2, modulus of elasticity 23,775 kg/cm^2, and the maximum bending strength of 128.31 kg/cm^2.

2.4.1 Taxonomy

Domain: Eukaryota
Kingdom: Plantae
Subkingdom: Viridaeplantae
Phylum: Magnoliophyta
Subphylum: Euphyllophytina
Infraphylum: Radiatopses
Class: Liliopsida
Subclass: Commelinidae
Superorde: Poanae
Order: Poales
Family: Poaceae
Subfamily: Bambusoideae
Tribe: Bambuseae
Genus: Gigantochloa
Specific epithet: verticillata
Botanical name: Gigantochloa verticillata

2.5 Oriented Strand Board (OSB)

OSB are panel products made of aspen or poplar (as well as southern yellow pine in the US) strands or wafers bonded together under heat and pressure using a waterproof phenolic resin adhesive or equivalent waterproof binder. Oriented strand board (OSB) was developed in the late seventies. OSB is made of aspen-poplar strands, southern yellow pine or mixed hardwood species. However, the strands in the outer faces of OSB are normally oriented along the long axis of the panel thereby, like plywood, making it stronger along the long axis as compared to the narrow axis. The strands used in the manufacture of OSB are from 80 to 150 mm (3-1/8 to 6) long in the grain direction and less than 1 mm (1/32") in thickness. In Canada, OSB are manufactured to meet the requirements of the Canadian Standards Association (CSA) standard CAN/CSA O325.0, Construction Sheathing or the standard O437 Series on OSB. For engineered applications, OSB can also be certified to meet the requirements of CSA O452, Design Rated OSB. In the U.S., the requirements of PS 2, Performance Standard for Wood-Based Structural-Use Panels must be met. PS 2 is a voluntary product standard published by the National Institute of Standards and Technology of the US

Department of Commercial. OSB is efficient additions to the family of wood building materials because:

- They are made from abundant, fast growing, small diameter aspen poplar or pine to produce an economical structural panel.
- The manufacturing process can make use of crooked, deformed, small diameter trees which would otherwise have little commercial value, thereby maximizing forest utilization.
- Many strength-reducing defects are removed during manufacturing, and any remaining defects are evenly dispersed throughout the panel, resulting in consistent strength properties.
- The orientation of strands gives increased strength properties along the long panel dimension (strength axis) of OSB. For wafer board, random alignment of the wafers gives more consistent strength properties throughout the panel.
- Specific strength properties can be achieved by adjusting the orientation of strand or wafer layers.

2.5.1 Uses of OSB

Some specialty products are made for siding, rim boards, stair treads, concrete formwork, or treated or foil-faced sheathing. OSB is also used as the web material for most types of prefabricated wood I-joists, and as outer skins in structural insulated (foam-core) panels. The panels are cut and machined using regular carpentry tools. Tungsten carbide tipped blades are recommended.

2.5.2 Application of OSB

The physical and mechanical properties of OSB make it suitable for a wide range of structural and non-structural applications. OSB is widely employed in the U.S., Canada, and Japan, practically replacing plywood for many applications in residential construction and has also been gaining recognition in the commercial construction industry (Brochmann et al. 2004; Gu et al. 2005).

Oriented strand board is the most commonly used structural engineered wood panel in new residential housing construction in North America. OSB is aggressively-replacing plywood as the primary sheathing used in new construction in North America. Approximately 65% of the 43 billion square feet of construction sheathing used in 2005 consisted of OSB. While the remaining 35% consisted of plywood sheathing (Adair 2005). OSB and plywood share the same exposure durability classifications: Interior. Exposure 1 (95% of all structural panels). Exposure 2 and Exterior (SBA 2009). They share the same set of performance standards and span ratings. Both materials are installed on roofs, walls and floors using one set of recommendations. Installation requirements prescribing the use of all-clips on roofs, blocking on floors and allowance of single layer floor systems are identical**.**

2.5.3 Manufacture of OSB

The process described here is general and may vary in detail from one manufacturer to another but it is

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always comprised of log conditioning, stranding or wafer zing, drying, blending, forming, pressing, and final processing. Freshly cut logs are taken from the log storage yard and placed in hot water ponds. The soaking softens the wood to facilitate debarking and making of strands or wafers, thereby reducing the amount of fines and slivers generated. To maintain effectiveness, hot pond temperatures are increased in cold weather conditions. After conditioning, the logs are debarked and fed into a machine with sharp knives. This stranded or waterier cuts the log pieces into strands or wafers along the grain. The strands or wafers are conveyed to wet storage bins and are screened after drying to remove fine particles. Most mills process core and surface strands and wafers separately and then deposit them together in layers to form the mat.

The strands or wafers are placed in large cylindrical dryers where they are dried to a moisture content of three to seven percent. While in the dryer, the strands or wafers rotate slowly minimizing breakage of the strands while ensuring consistent moisture content. When dry, the strands or wafers proceed to the blender where they are mixed with resin and wax. The small quantity of hot wax (about 1.0 to 1.5 percent of the weight of wafers) sprayed on the wafers helps to distribute evenly the powdered or liquid phenol-formaldehyde resin or polyurethane binder (2.0 percent to 3.5 percent by weight or more). Resins or binders are of the thermosetting type, which means they can't be softened by heat or moisture once fully cured. The strands or wafers are continuously weight metered to ensure the proper quantities enter the blenders so that the correct resin coverage is achieved (SBA 2009).

The forming machine arranges the strands or wafers in several layers to form a mat on stainless steel press sheets or on a continuous belt. For OSB, the strands for the faces are usually oriented parallel with the long direction of the panel (machine direction) and the core layers are either cross-oriented or laid random. For wafer board, the wafers are randomly deposited. The size of the mats varies with the press size, but generally, one mat will be large enough to produce several standard sized panels. In multi-opening presses, the mats are placed in the press accommodating from 10 up to 24 sheets at a time. Each mat sits between a pair of heated platens. When all the mats have been inserted, the press is closed under heavy pressure.

The layup of the mat and the press operation are important in ensuring proper panel thickness. The duration of the press cycle varies from plant to plant and with the desired thickness of the board. For example, a press cycle of 3-1/2 minutes might be required for 6.35mm (1/4) thick panels, and eight minutes for 15.5mm (5/8) panels. The heat and pressure polymerize the resin or binder gluing the strands or wafers together strongly into a rigid panel. In newer plants, some presses are long and continuous rather than the more conventional stacked multi-opening presses. In those presses a continuous mat enters the front end of the press. Finished board exits the rear end of the press, which is then cut to the required size with flying cross-cut saws.

2.5.4 Factors affecting the properties of OSB

There are many factors affecting the final board properties. Among the major factors are wood species and its density, strand quality, strand size, aspect ratio of the strand, strand orientation, resin type, layer structure, pressing parameter, board moisture content and board density (Maloney 1993). Almost all of these factors interact with each other in one way or another. A change in any of these factors will result in a change in many of the other related factors in the board process. Consequently, each factor cannot be thought of as an individual entity which can be manipulated easily to control the board process as one sees fit. However, once it is recognized that there is an interrelationship between a numbers of factors, a more complete grasp of the process can be attained and actual manipulation can be successfully employed for controlling much of the process (Maloney 1993).

2.5.5 Wood species

Species is one of the most significant factors in the OSB process. It interacts virtually with every other variable that can be imagined in the process. It determines how low in density the final board can be. The most important species variable governing board properties is the density of the wood raw material itself. The density or specific gravity has been the important factor in determining which species are used for manufacture of OSB. In general terms, the lower-density woods will produce panels within the present desired specific gravity ranges, usually with strength properties superior to the higher-density species (Maloney 1993). Although it is technically possible to produce OSB from wood of any density, boards made from dense woods become so heavy that they are difficult to handle and expensive to ship (Bowyere 2003). Early OSB mills primarily utilized aspen because of its low density, low cost, and wide availability).

OSB mills can use almost any low-to-medium-density species that is widely available (Bowyer 2003). Aspen (Populus treimiioides), southern pines (Finns spp.), inonterey pine {Finns radiata), sweet gum [Liqitadambar styracijhta). yellow poplar (Linodendron tulipifera), birch (Be/u/a spp.). Spruce (Picea spp.) and fir {Allies spp.) are several wood materials used in commercial OSB (Biblis 1989; Wane 2000; Wu and Piao. 1999). These woods have relatively low density. Species of relatively high density, such as beech, are often mixed with these species to maintain acceptable board properties. The reason for the preferential use of the relatively light species is that they can be compressed into medium-density OSB with the assurance that sufficient antiparticle contact area is developed during the pressing operation to achieve good bonding.

To produce satisfactory contact between strands in the board, it is usually necessary to compress the board to a density 1.2-1.6 times than the strands initial densities

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(Bowyer et al. 2003). This ratio between board density and wood density is called the compression ratio. Maloney (1993) pointed out that a compression ratio of 1.3 is a good guideline for determining the minimum board density for a medium-density board. Using this guideline, it would be expected that satisfactory OSB could be produced using wood with density ranging 0.3-0.5 g/cm^3 (Maloney 1993). Caesar (1997) reported that wood having density less than 0.35 g/cm^3 cannot be densified sufficiently to achieve good strength, whereas very high density board will blow, because the steam generated inside the board during pressing cannot escape. Wood species of density more than 0.75 g/cm^3 may create stranding difficulties and produce a lot of fines. Moreover, the strands are stiff and brittle which make it more difficult to be compressed to form mat.

2.5.6 Strand Geometry

Strand geometry is one of the most important factors determining the properties and appearance of OSB. In general, longer and thinner strands improve properties by providing more actual contact area and better stress transfer. They yield a higher degree of permanent set after densification at elevated temperatures and significantly decrease thickness swelling and linear expansion (industry Canada 2009).

Several aspects of board performance are directly affected by strand geometry (Maloney 1993): 1.Mechanical properties such as bending strength, bending stiffness, tensile strength parallel to the surface, tensile strength perpendicular to the surface (internal bond), wood screw holding power, and nail holding strength. 2. Board surface characteristics, particularly surface smoothness of face and edges, which in turn affect finishing and secondary gluing characteristics. 3. Moisture responses such as moisture absorption from liquid or vapor phase and corresponding changes in dimensions, mechanical properties, and surface characteristics. 4. Behavior in machining operations such as sawing, boring, routing, shaping, planning, and sanding.

Slenderness and aspect ratios can be used to estimate strand orientation and particle behavior of the board. They can be expressed by length, width and thickness information. Slenderness ratio can be described as particle length divided by its thickness. Generally the particle becomes more slender when the ratio is higher. Particle with ratio over one will be longer than its thickness and thus will amenable to orientation. Particle with high slenderness ratio can be aligned to increase the board strength (Maloney 1993). Slenderness ratio can be related to certain board characteristics such as contact area in the mat. Mechanical properties of the finished board, and the consumption of binder in board (Moslemi 1974). Greater quantity of resin per unit surface area of particle is needed if the ratio value is lower.

Aspect ratio is measured by dividing particle or flake length by its width. A particle cannot be oriented if having aspect ratio of one (square shape). Maloney (1993) suggested that good orientation could be achieved in board at aspect ratio of at least three. According to Shuler et al. (1976). and Kuklewski et al. (1985). An aspect ratio of two is enough to produce board with superior properties. The southern pine strands used in three OSB mills in North America were recorded to have size approximately 76.2-88.9 mm. 6.4-38.1 mm, and 0.51-0.64 mm in length, width and thickness, respectively (Biblis 1989). used strands from a commercial mill that consist 85% southern pine (Pinus spp.) and 15% regional medium density hardwoods (sweet gum, tupelo gum. yellow-poplar, willow, etc) with slenderness ratio of 108-152 and aspect ratio of 2-4. Suzuki and Takeda 2000) produced OSB from sugi (Chryptomeria japonica) with the target geometry 20 mm in width. 0.6 mm in thickness, and length of 30. 50 and 70 mm. The study concluded that modulus of rupture (MOR) and modulus of elasticity (MOF.) of the boards in the parallel direction increased with increasing the strands length. In accordance with the Suzuki and Takeda (2000) work, a study by Chen et al. (2008). With average strand length between 71 mm and 128 mm and strand slenderness ratio between 1 and 10. indicated higher slenderness ratio were associated with higher concentrated static load (CSL) ultimate load and MOR, MOE, and shear properties in both major and minor directions and lower CSL deflection.

2.5.7 OSB Structure: Layer and Face to Core Ratio

Mat or layer forming is one of the important stages in OSB manufacturing. Forming in OSB production means mechanical action applied to the strands in order to force them to adopt a desired orientation and position. Strands and layers in OSB can be aligned to provide panel products with much greater bending strength and stiffness in the oriented or aligned direction (Maloney 1993). Layer structures again interact with most of the major parameters involved in producing boards, and manipulation can change the level of strength possible through orientation.

Oriented strand board is normally produced in three layers in which the core layer is perpendicular to surface layers. However, there are also some producer increases the core layers purposely to meet certain product requirements. For example, a company in U.S. produced four layers OSB with two face layers and two core layers bonded with phenol resins (Huber Engineered Woods, 2009). A study used one strand layer was performed by Del Menezzi et al. (2005). And found that thickness swelling of the board can meet the requirement of Canadian Standard (CSA 0437-93) for grade O-1 panels.

Several studies determined the effect of layer structure on the properties of OSB. Sumardi et al. (2007). Produced OSB with three different layer structures. The results revealed that bending strength (MOE and MOR) of unidirectional oriented homogenous board (UNMD) in parallel direction were higher than three-layered OSB with a cross-oriented core layer (3OSB). Conversely bending strength of 3OSB in the

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perpendicular direction was higher than UN1D board. Similar results were obtained by Hermawan et al. (2006).

The layers in OSB production are arranged into some proportion of face to core ratios. Commercial boards normally have face to core weight ratio of approximately 50:50 (Wu and Piao. 1999). Similar ratio was followed by many studies in OSB manufacture (Pichelin et al. 2001; Sumardi el al. 2008: Wang et al. 2000).

2.6 Adhesive for OSB

2.6.1 Poly (Diphenyl Methane Diisocyanate), MDI

MDI has become a common resin used in OSB production, despite costing significantly more than PF. Like PF, it produces waterproof bonds suitable for use in Exposure 1 classified panels. In fact, the nature of its adhesion to wood makes its performance better than PF when exposed to moisture. Unlike PF, MDI does not primarily form mechanical bonds with the wood substrate; it is also capable of forming covalent chemical bonds with wood. These chemical bonds are stronger and more stable than mechanical linkages, so manufacturers can potentially use less resin to achieve similar, or greater, performance with lower adhesive loadings than PF. Lower resin loading saves money, which can help to offset the increased cost per unit of adhesive (wood based panel international 2009). The surface of wood is rich in chemical functional groups called hydroxyl groups (–OH). MDI resins are terminated in isocyanides groups (–N=C=O), which can react with the hydroxyl groups on wood, forming urethane linkages. A combination of factors such as the non-polar, aromatic component of MDI resins, and the existence of the urethane linkages as part of a cross-linked network help to make cured MDI resins resistant to hydrolysis. Some advantages associated with using MDI adhesive include:

- greater tolerance for higher moisture content wood
- lower press temperatures
- Faster press cycles may be possible.

As discussed regarding the use of powdered PF, greater tolerance for higher moisture content wood and lower press temperatures can result in energy savings. The combination of reduced costs (energy savings and lower resin usage) and increased productivity (reduced press cycle time) can help offset the additional cost of the adhesive. Because of the chemistry involved, MDI-bonded products can be used in more demanding applications where increased water resistance is required. Potential disadvantages associated with MDI use include:

- The need to use mold releases since MDI will bond to metal surfaces and stick panels to press platens and calls.
- a greater need to monitor environmental conditions around the press and blenders, due to health risks associated with uncured MDI in aerosol form
- Special storage considerations to protect MDI from contact with atmospheric moisture which can cause procure.
- Questions remain regarding the resistance of MDI-bonded products to deformation under long-term loading conditions.

2.6.2 Board density

Board density is a powerful factor affecting board properties. In most cases, an Increase in board density results in a concomitant improvement in physical properties in particleboard. It has been found that a board density of 0.15 to 0.20 g/cm^3 above that of the whole wood is necessary to achieve minimum physical properties, unless low-density products are purposely being made. Higher density board is associated with higher strengths, more difficult machining characteristics, higher cost per unit volume, and a greater degree of dimensional instability in water soaking and exposure to high humidity. On the contrary, low density board offers better insulating characteristics, higher dimensional stability, lower strength, and less unit cost.

In practice, the easiest way to improve most board properties is usually to increase the board density. Zhang et al. (1998) studied the effects of two different density levels and found out that increase of board density resulted in higher internal bond strength, wood screw holding power, Brinell hardness and also increased thickness swelling of the board. Sumardi et al. (2007). Produced OSB at five density levels: density 0.49, 0.57, 0.65, 0.73, and 0.81 g/cm^3. The study found that the mechanical properties (MOR, MOE, and internal bond (IB) strength) increased with increasing board density.

The increased board density results in more intimate contact between the strands in the mat being compressed into the final board, hence it uses resin effectively. Increasing density also causes more wood to be present to resist mechanical loads. This combination of effects results in board strengths being approximately proportional to the square of board density over the usual density range.

2.6.3 Density Profile

In the manufacture of composite boards, with similar input of raw materials. Hot pressing method is the most significant factor that influences the final board properties. During hot pressing, the interaction among heat, moisture, and pressure gives rise to non-uniform deformation of the elements, and results in an uneven density distribution along the thickness direction of the board. This density profile typically resembles a U-shape. With peak density appearing near the board surfaces, and the lowest density in the core region (Maloney 1993). illustrated typical U-shape density profile and its definitions (Wong 1999). Furnish characteristics, configuration, and compressibility. MC and its distribution; and hot pressing conditions, including type,

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temperature, closing speed, pressure and duration, are among the critical factors affecting the formation of density profile (Maloney 1993).

The presence of this vertical density gradient has been reported to result in higher bending strength, but lower internal bond and interlaminar shear. A steep density gradient in low-density particleboard could cause shear failure to occur before the specimen fails in tension or compression during bending, hence reducing the modulus of rupture (Kawai et al. 1986).

2.6.4 Extractive Substances

All woods contain extractives. These minor components can be readily extracted from wood with neutral organic solvents or water. Extraneous substances are extremely variable in composition and quantity both between and within (sapwood vs. heart wood) species (Maloney 1993). They may include hydrolysable or condensed tannins, flavonoids, and lignin. stilbenes, fatty acids, resin acids, other complex terpenoids, waxes, sterols, sugars, cyclitols and starch. Extractives in wood may range between 5% and 30% in quantity (Maloney 1993). Although extractives occur as minor, non-structural constituents in the cell walls and cell cavities, they often are of decisive importance in contributing to many of the characteristic properties and possible uses of wood, such as its odour, color, light stability, flammability. hygroscopicity. Density, strength properties, decay and insect resistance, and permeability (Hse and Kuo. 1988). Extractives often alter the surface properties of wood, which in turn affects adhesion properties and finishing characteristics.

Difficulties may arise in gluing wood species with high extractive contents. This is especially true in gluing tropical hardwoods. Such gluing difficulties have been attributed to extractive contamination resulting from the migration of extractives to the wood surface during drying. Extractive-contaminated wood surfaces often result in low strength and less durable glue bonds. Extractives may cause gluing difficulties in the following ways (Hse and Kuo. 1988): 1. Heavy deposits of extractives on the gluing surface block the reaction sites, thus preventing the anchoring of adhesives. 2. Chemical incompatibility between the extractives and adhesives results in inferior glue bonds. 3. Extractives influence the wet ability and polarity of the wood surface so that the wet ability -permeability relationship of a particular adhesive is changed. 4. Extractives affect the curing and setting characteristics of adhesives. These gluing interference mechanisms may act individually or they may act as combined effects.

Maloney (1993) reported that extractives affected on adhesive consumption and its curing rate, poor water resistance properties of the finished product, problems with blows during the pressing, delaminating after pressing, and change board color.

3. RESEARCH METHODOLOGY

3.1 Time and Place of Research

This Research was conducted in Laboratory of Bio-composite, Laboratory of Wood Solid, and Laboratory of Wood Engineering, Study area Faculty of Forestry, Bogor Agricultural University, Indonesia. Examination of durability of OSB to against termite attack was done in arboretum of Faculty of Forestry. The research was carried out from October 2009 up to May 2010.

3.2 Material and Equipment

The Material applied in this research was strands Betung bamboo (B), Andong bamboo (A) and Tali bamboo (T) about the ages 3 years comes from Botanic Garden Bogor. Glue applied was Methylene Diphenyl Diisocyanate (MDI) from PT. Polychemi Asia Pacific Jakarta was used as a binder to manufacture OSB with resin content of 5%. Equipments applied consist of chain saw, stick iron, oven, rotary blender, spray gun, temperature press, washbasin, plastic sack; bag, aluminum foil, aluminum foil,, digital weighing-machine, micrometer, caliper, Universal Machine of Brand testing Instrument.

3.3 Procedure for Making OSB

OSB was made by three layers, face layer, core layer, and back layer. Strands Ratio of 50: 50 based on weight strands. Target of density set to 0, 7 g/ cm^3 of the size 30 cm x 30 cm x 1 cm. This research was done nine strand combinations from three strand bamboo Betung bamboo (B), Andong bamboo (A) and Tali bamboo (T) bonded with Methylene Diphenyl Diisocyanate (MDI) amount of 5%. Total OSB made 45 boards (9x5).

3.4 Process of Making OSB

3.4.1 Preparation of Raw Material

Each bamboo strands was made in size 7 cm in length, 2.5 cm in width, and thickness 0.06 cm. Strand was then dried in the oven at temperatures of around 60°C reached moisture content between 5-6%. The dried strand was kept in plastic bags. To determine slenderness and aspect ratios of the strands, 10 strands from each species were randomly selected. Caliper was used to measure the length, width and thickness of the strands. The slenderness and aspect ratios were calculated according to following formula (Maloney 1993),

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Slenderness Ratio =	Strand Length
	Strand Thickness

Aspect Ratio =	Strand Length
	Strand Wide

Fig 1

(a) (b) ©

Fig 2: Strand bamboo (a) Betung (b) Andong (c) Tali

(a) **(b)**

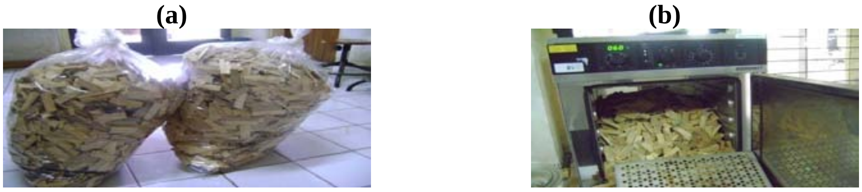

Fig 3: (a) Strand storage (b) oven dryer

3.4.2 Mixing of Strands with Glue (blending)

The Commercial MDI adhesive was used to bond the strands to OSB. Before done blending (material mixing) was done balance strands bamboo. Glue applied amount of 5%, on dry weight strands, Rotary blender drum was used to mix strands with adhesive. Adhesive was applied to strands using a pressurized spray gun. The boards in this study were manufactured with target dimension of 30 x 30 cm and target density of 0.7 g/cm^3. Strands used to manufacture an OSB was 600 g (based on strands oven dried weight), and 5% resin content was prepared based on oven dry weight of strand or about 30 g. The calculation of composition of strand and resin needed to manufacture OSB was follow:

$$\text{Strand} = \frac{100}{105} \times (30 \times 30 \times 1)\ \text{cm} \times 0.7\text{g/cm}^3 = 600\ \text{g}$$

$$\text{Adhesive} = \frac{5}{105} \times (30 \times 30 \times 1)\ \text{cm} \times 0.7\text{g/cm}^3 = 30\ \text{g}$$

Fig 4

(a) (b)

Fig 5: (a) Glue MDI (b) blender machine

3.4.3 Sheet forming (Mate Forming)

The OSB manufactured consisted from three layers: face layer, back layer, and core layer. The mats were manually formed with face and back layers were aligned perpendicular to the core layer. The weight ratio of the face-to-core-to-back layers were set at 50: 50, 1:2:1. Nine strand combinations from Betung Bamboo (B), Andong Bamboo (A), and Tali Bamboo (T) were manufactured (arranged in face, core, and back :layers, respectively), which is:

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- BBB 4. AAA 7. TTT
- BAB 5. ABA 8. TBT
1. BTB 6. ATA 9. TAT

Fig 6: Manual mates forming

3.4.4 Hot Pressing (Hot Pressing)

The Board sheet was pressed by heat (hot temperature) at press machine with temperature of amount 160°C, specific pressure 25 kgf/cm^2 during 7 minutes with movement system of single step. To get the desired thickness hence at press plate is applied by stick iron with thickness of 1 cm as control. Pressure meter gauge value (Pg) was determined by using formula as follow:

$$Pg\ (kgf/cm^2) = \frac{PJ}{r^2 ni}$$

In which P is pressure on board (kgf/cm^2). J is joint area (cm^2), r is radius of cylinder (cm), and n is number of cylinder. And i is machine efficiency.

Fig 7: Hot presser machines.

3.4.5 Conditioning

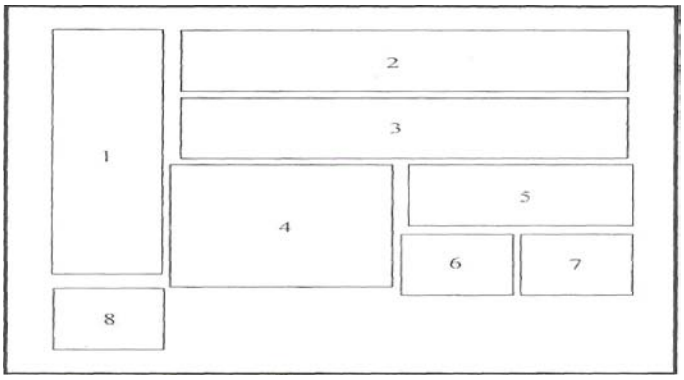
The Sheet condition OSB which is ready made was done during one week at room temperature. The room temperature was ranged 25-30^{0}C with relative humidity of 60-65%. Then was cut to become the test piece based on standard JISA 5908: 2003.

Fig 8: Board conditioning.

3.4.6 Testing of OSB

All boards were cut and tested according to Japanese industrial Standard JISA 5908: 2003 for particleboards to determine the physical properties: density, moisture content, water absorption, thickness swelling and mechanical properties: modulus of rupture (MOR, modulus of elasticity (MOE), internal bond strength (IB) and screw holding power (SHP). Field test were performed to determine resistance of OSB against subterranean termites attack. Four replications were performed for each type of specimen. The test specimens were obtained from each board according to cutting diagram showed in Figure 9.

30 cm



30 cm

Fig 9: Cutting diagram

Notes:

1. MOE and MOR in parallel direction to the grain (20cmx5cm)
2. MOE- and MOR in perpendicular direction lo the grain (20x5cm)
3. Weight loss percentage (20x5cm)
4. Density and moisture content (10cmx10cm)
5. Screw holding power (10x5cm)
6. Internal bond (5x5m)
7. Thickness swelling and water absorption (5x 5cm)
8. Density} parallel (5x5cm).

3.5 Physical Properties Tested

3.5.1 Density

The Density test was performed using specimens with dimension of 10x 10 x 1 cm in length, width and thickness respectively. Initial dimension and weight of the specimens were measured. Density D (g/cm^3) was calculated using this equation:

$$D = \frac{M}{V}$$

In which m_1, and V are weight (g) and volume (cm^3) of specimen before oven drying, respectively.

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Fig 10: Density specimen tests.

3.5.2 Moisture Content

The Determination of board moisture content was done with calculating difference between initial weights of weighing after being dried in oven for 24 h until reaching constant weight at temperature 103±2 ° C. The moisture content (MC) of the board was calculated with the following equation:

$$MC\% = \frac{M1 - M0}{M0}$$

In which m_0 is oven dry weight of specimen (g) and m_1 is weight of specimen before oven drying (g).

Fig 11: Moisture content specimen tests.

3.5.3 Water Absorption

The Determination of water absorbency was done with calculating heavy difference before and after soaking in cool water during 2 and 24 hours. The water absorption (WA) was calculated with the following equation:

$$WA\% = \frac{M2 - M1}{M1}$$

In which m_1 is weight of specimen before soaking (g) and m_2 is weight of specimen after soaking (g).

Fig 12: Water absorption specimen tests

3.5.4 Thickness Swelling

The Thickness swelling test was performed using the same specimens of water absorption test. The thickness of the specimens were measured before and after soaked into water for 2 hours and 24 hours. The formula used to determine the thickness swelling (TS) was calculated with the following equation:

$$TS\ \% = \frac{T2 - T1}{T1}$$

In which t1 and t2 are thickness (cm) of specimen before and after soaking, respectively.

Fig 13: Thickness swelling specimen tests.

3.6 Mechanical Properties Tested

3.6.1 Modulus of Rupture (MOR)

The Determination of MOR and MOE was done in parallel with universal testing machine (instron) of testing machine (UTM). Examination done at direction of long parallel and board wide parallel. Examination was done by giving burden with speed of 10 mm/menit at centered of test piece. Distance applied was 15 cm x board thick (minimum 15 cm). The MOR was calculated using this equation:

$$\mathbf{MOR\ (kgf/cm^2) = \frac{3PL}{2bt^2}}$$

In which P is maximum load at the point of delaminating: L is span length b and h are width and thickness of specimen.

Fig 14: Universal testing machines (instron).

3.6.2 Modulus of Elasticity (MOE)

MOE was done by using the same test piece with MOR. Examination also is done in parallel with examination MOR, but registered in by this examination is change of deflection all changes in certain burden. The MOE was calculated using this equation

$$\mathbf{MOE\ (kgf/cm^2) = \frac{\Delta PL^3}{4\Delta Ybt^3}}$$

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In which P and Y are load deflection at proportional limit: L is span length b and h are width and thickness of specimen.

3.6.3 Internal Bond Strength (IB)

The Examination of Internal bond strength was done by gumming both surfaces of board at iron log then the iron log pulled in at the opposite and hardness of internal bond strength. The formula used to determine the internal bond strength (IB) (kgf/cm^2) as follows:

$$IB = \frac{P}{BL}$$

In which p is maximum load at the point of delaminating, b and L are width (mm) and length (mm) of specimen respectively.

3.6.4 Screw Holding Power (SHP)

The test was performed on the installing long fairish spanner 20 mm and diameter 2 mm. The spanner was stuck to board OSB in 8 mm then was abstracted surface perpendicular with speed of 2 mm/menit. Style required to abstract spanner shows strength of OSB in holding spanner.

3.6.5 Resistance of OSB Against Subterranean Termites Attack

This test was performed at the arboretum of Faculty of Forestry, Bogor Agricultural University. Bogor, Indonesia. Resistance of OSB against subterranean termites attack was determined through field test. It was reported that the species of subterranean termite in tested location was Macrotermes gllvus. Aspects that were observed included damage and weight loss percentages of specimens. The test was performed using specimens with dimension 20 x 5 x I cm in length, width, and thickness respectively. The specimens were dried in an oven dryer with temperature of I 03: 2 °C for 24 hours to get its oven dry weight. The specimens were then buried until leave 50 mm of board length above the ground, with space of 600 mm between each sample. After 3 months, the specimens were taken from the ground, then were cleaned and putted into oven dryer with temperature of I 03: 2°C for 24 hours to get oven dry weight. The formula used to determine the weight loss percentages (WLP) of the board is:

$$WLP = \frac{W1-W2}{W1}$$

In which w_1 and w_2 are weight of specimens (g) before and after buried on the ground, respectively.

Fig 15: Weight loss specimen tests

3.6.6 Data Analysis

To determine the effect of strand combination on the properties of OSB, with completely random design were performed; with factor A were defined as the combination of strands (which is consists of nine levels of combinations). All runs were performed in four replications.

For all the experiments described above, data were analyzed using a SPSS 16.0 software package. Analysis of variance (ANOVA) and Duncan's multiple range test (using significance level or a ™ 0.05).

4. RESULTS AND DISCUSSION

4.1 Strand Geometry

Strand geometry is a prime parameter affecting both board properties and its manufacturing process. Strand geometry is of greater significance in the development of board properties than the actual mechanical properties of the fibers themselves (Suchsland and Woodson, 1990). It has a definite relationship with the compression ratio, and thus it will influence the density of the composite board. The values of length, width, thickness, slenderness ratio and aspect ratio of the strands used in this study are presented in Table 3. Target dimension of strand was set to 7cm in length, 2.5 cm in width, and 0.06 cm in thickness. Their average values which determined using 10 strands from each three different species ranged from 6.2-7.7cm in length, 1.3-2.8 cm in width and 0.02-0.08 cm in thickness, yielded slenderness ratios 92.5- 340, and aspect ratios 2.7-4.7. The strands produced were highly slender as indicated by the slenderness ratio between 92 and 340; the values were higher than one thus amenable to orientation as suggested by Moslemi (1974). Besides, it could be related to better contact area in the mat, good mechanical properties of finished board and less consumption of binder in the board. The strands aspect ratio ranged 2.7-4.7, in which all ratios were above 2. A particle cannot be oriented if having aspect ratio of one (square shape). Maloney (1993) stated that wood strand having aspect ratio greater than one are easily oriented during forming process.

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Table 3: Slenderness and aspect ratios of strand bamboo

Aspect ratio	Slenderness ratio	Thickness	Width	Length		Species
2.740741	92.5	0.08	2.7	7.4	max	Bamboo Betung
4.769231	206.6667	0.03	1.3	6.2	Min	
2.884615	107.1429	0.07	2.6	7.5	Max	Bamboo Andong
3.764706	160	0.04	1.7	6.4	Min	
2.75	96.25	0.08	2.8	7.7	Max	Bamboo Tali
3.4	340	0.02	2	6.8	Min	

4.2 Physical Properties

4.2.1 Density

Density is a measure of the compactness of the individual particles in a board, and it dependent mainly on the density of the wood and the pressure applied during pressing. The density of board has direct influence to its physical and mechanical properties. Most researchers have found a positive relationship between board properties and board density. An increase in board density increases values for MOR, MOE, and IB strength (Bowyer et al. 2003; Hayashi et al. 2003). On the other hand, increases in swelling should be expected with decrease in board density **(**Maloney 1993; Vital et al. 1974). However, increases in mechanical strength with increases in density can be sufficient to offset increased swelling tendency, and high density can increase efficiency of resin usage, therefore reducing thickness swelling (Lehmann 1960). In this study, target density of the board was set to 0.7 g/cm^3. (Bowyer et al. 2003). Stated that in composite panel manufacture, the major objective is not only to produce panel with high density but also how to produce panel with density as low as possible with strength that can meet standard requirements. Standard JIS A5908:2003 all OSB panels had meet the requirement for density, the average values of density ranged from 0.67 - 0.79%.

In this study, maximum load applied to all the boards manufactured was the same (25 kgf/cm^2). A constant pressure load was not suitable to be applied for the board with different strands density; the OSB manufactured were not only homogenous boards (OSB made from mixing bamboo species), which each bamboo density was differed from each other's (Betung bamboo 0.57 g/cm^3, Andong bamboo 0.55 g/cm^3, Tali bamboo 0.63 g/cm^3). Bamboo with lower density is easier to be densified compared to higher density one.

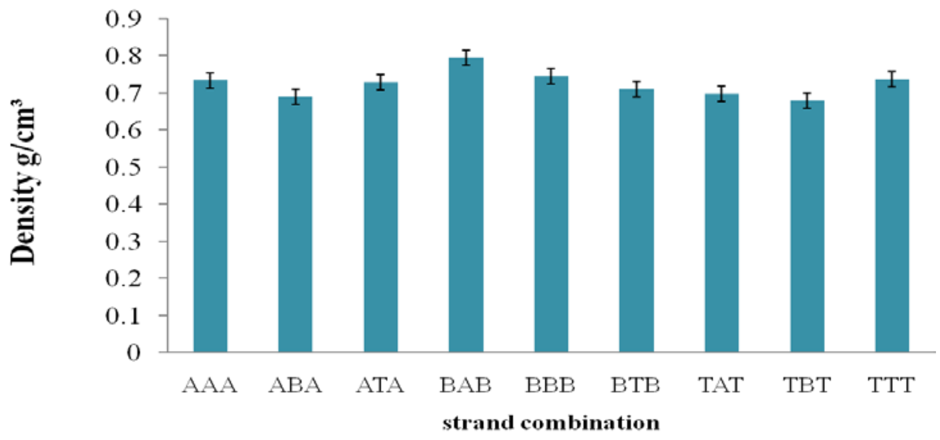

Fig 16: Density of the board

According to the Duncan's multiple range test strand combination factor showed significant effects on the board density. Further analysis on the strand combination factor revealed that there are 2 homogeneous groups, which means most of strand combinations showed no significant differences. Only BAB board showed significant differences. The value of BAB board increased when it's mixed strands from higher bamboo density (Betung bamboo had density of 0.57 g/cm^3), to lowest bamboo density (Andong bamboo had density of 0.55 g/cm^3).

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Table 4: ANOVA value of density

Sig.	F	Mean Square	Degree of freedom	Source
0.000	1.1164	18.877	1	Intercept
0.017	2.924	0.005	8	Strand Combination
		0.002	27	Error
			36	Total

4.2.2 Moisture Content

Moisture content is a physical property expressed the water content of the board in an equilibrium condition with the surrounding relative humidity (RH). Rowell (2005) stated that changes in moisture content of the composite board have a major effect on (mechanical properties of the board-mechanical properties increase with decreasing moisture content with compression parallel to the grain being the most affected**.** The average values of moisture content ranged from 4.5-7.5%. The lowest moisture content value was reached by BBB board made from Betung bamboo, while the highest moisture content value was reached by AAA board made from Andong bamboo. According to standard JIS A5908:2003 all panels had meet the requirement for moisture content. According to Sattar (1995) that the differences in moisture content lead to differences in specific gravity values between species of bamboo allegedly due to differences in anatomy and chemical composition of bamboo sticks. According to Achmadi (1990) that the chemical component causing the cell wall is hygroscopic, Hydroxyl groups on cellulose and hemicelluloses molecules responsible for the affinity of water and the high potential to form hydrogen bonds.

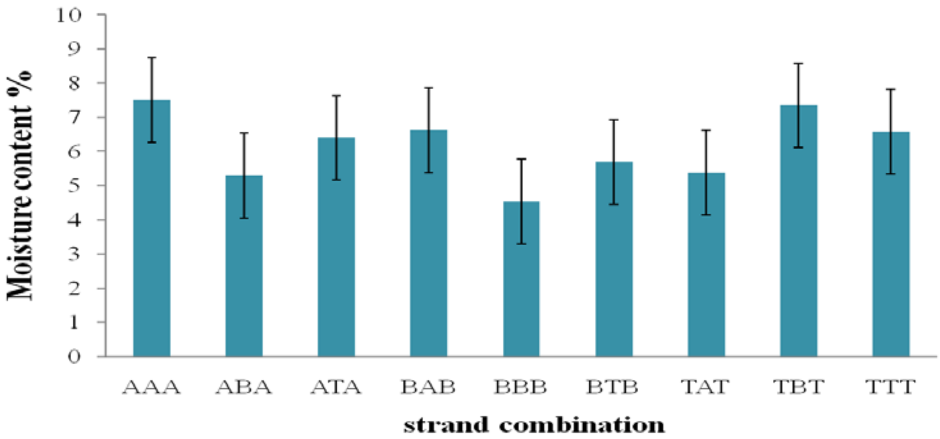

Fig 17: Moisture content of the board

The ANOVA value showed Strand combination factor had no significant effects on the board moisture content at 5% significance level. Further analysis on the strand combination significance variables showed that AAA board made from strands of the lowest bamboo density (Andong bamboo had density of 0.55 g/cm^3) resulted in the highest moisture content value, and the value decreased when its mixed with strands from higher bamboo density, (Tali bamboo had density of 0.63 g/cm^3).

Table 5: ANOVA value of moisture content

Sig.	F	Mean Square	Degree of freedom	Source
0.000	222.029	1361.871	1	Intercept
0.736	0.641	3.934	8	Strand combination
		6.134	27	Error
			36	Total

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4.2.3 Water Absorption

Water absorption is the board ability to absorb water tested by soaking it into water for 2 h and 24 h. The amount of water absorbed determines the dimensional stability of OSB. The average values of water absorption for 2 h and 24 h of water soaking test are showed in Figure 18. According to standard JIS A5908:2003 OSB panels did not set the requirement for water absorption, but water absorption test is needed to determine panel durability on water especially if it will be used for exterior and other utilities related to weather exposure (rain and humidity). The average values of water absorption for 2 h soaking and 24 h ranged 10-22% and 28-47% the lowest water absorption for 2 h and 24h value was reached by BBB-TTT board made from Betunng, Andond bamboo, while the highest water absorption for 2 h and 24 h value was reached by TBT board made from mixing bamboo.

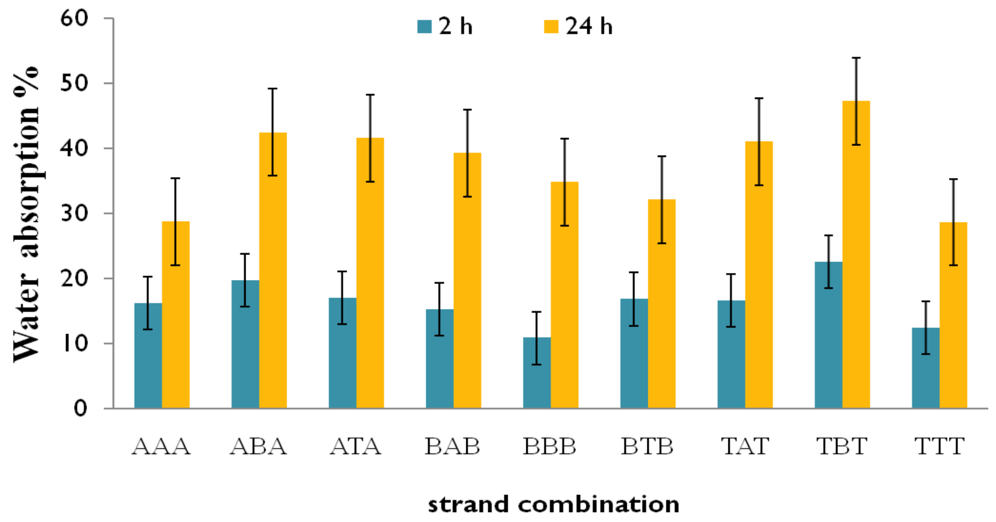

Fig 18: Water absorption of the board

ANOVA values of water absorption for 2 h and 24 h soaking using 95% of significance level revealed that the strand combination, no significant effect on water absorption property. Further analysis on the strand combination factor revealed that there are no significantly different between each other. Similar trend as found in water absorption for 24 h soaking occurred, in which water absorption values for 24 h soaking were higher when strand mixed with lower bamboo density resulted in higher water absorption value occurred in TBT. The differences of water absorption values among and between strand combinations were affected by variation between the board densities and penetration of adhesive into the strands.

Table 6: ANOVA value of water absorption (2 hours)

Sig.	F	Mean Square	Degree of freedom	Source
0.000	146.643	9679.598	1	Intercept
0.663	0.732	48.300	8	Strand Combination
		66.008	27	Error
			36	Total

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Table 7: ANOVA value of water absorption (24 hours)

Sig.	F	Mean Square	Degree of freedom	Source
0.000	281.020	50188.776	1	Intercept
0.487	0.960	171.362	8	Strand Combination
		178.595	27	Error
			36	Total

4.2.4 Thickness Swelling

Thickness swelling is most important factor when considering moisture effect. Thickness swelling is a dimension change of the board caused by the increase in the thickness. The average values of thickness swelling for 2 h and 24 h soaking ranged 7-12% and 13-21% with the lowest and highest values was occurred in BBB-ATA and ABA-TTT board. Standard JIS A5908:2003 all OSB panels had met the requirement for Thickness swelling. According to the Halligan (1970) stated that particle geometry, board density, resin level, blending efficiency, and pressing conditions can improve thickness swelling of composite board.

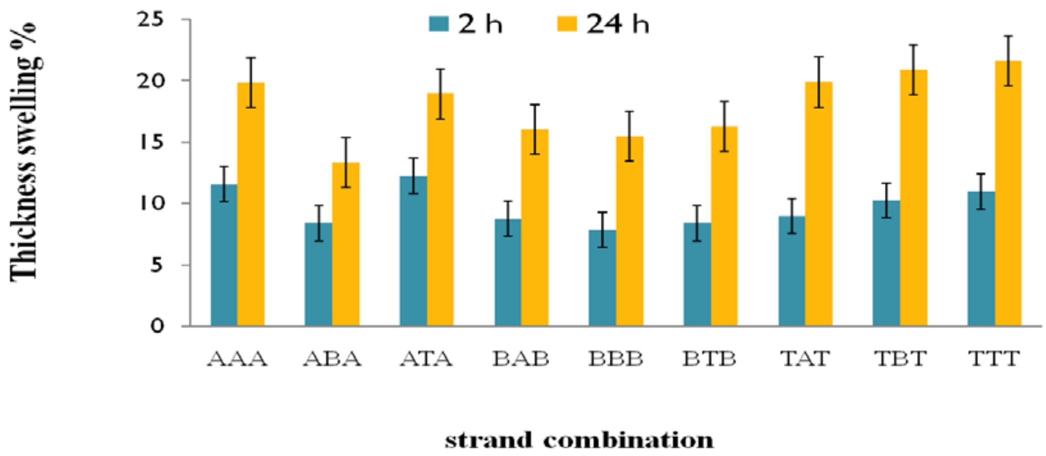

Fig 19: Thicknesses swelling of the board

ANOVA values using 95% of significance level showed that strand combination contributed no significant effect on thickness swelling for 2 h and 24 h, respectively.

Table 8: ANOVA value of thickness swelling 2 h

Sig.	F	Mean Square	Degree of freedom	Source
0.000	413.871	3399.832	1	Intercept
0.324	1.223	10.044	8	Strand combination
		8.215	27	Error
			36	Total

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Table 9: ANOVA value of thickness swelling 24 h

Sig.	F	Mean Square	Degree of freedom	Source
0.000	711.233	11727.905	1	Intercept
0.093	1.952	32.188	8	Strand combination
		16.490	27	Error
			36	Total

Further analysis on the strand combination factor revealed that there are 2 homogeneous groups, which means most of strand combinations showed no significant differences. Only TTT, TBT, and ABA board showed significant differences. The thickness swelling value of TTT board (the highest thickness swelling values) decreased when the strand mixed with the lowest density. According to Ruhendi (2007) that the difference of density distribution in the thickness direction affected the amount of thickness swelling of the boards.

4.3 Mechanical Properties

4.3.1 Modulus of Rupture (MOR)

MOR is one of the most important strength properties of composite panels. MOR is a board ability to hold stress at maximum load limit. The average values of MOR in parallel direction to the grain and MOR in perpendicular to the grain showed in Figure 20. The highest and the lowest values of MOR in parallel direction were 733-420 kgf/cm2 and 376-209 kgf/cm2 in perpendicular, respectively for ABA-AAA board, while in perpendicular BTB-TBT board made from mixing bamboo . Standard JIS A5908:2003 all OSB panels had met the requirement for MOR. According to (Nishimura 2004 and Nuryawan 2007) stated that a high MOR values may be obtained from the strand with Aspect ratio value between 3 and 4. Values of MOR in perpendicular direction to the grain were smaller than this MOR in parallel that related with positions on the sample strand. Weak point of the specimen is located on the outermost regions (face layer and back layer).

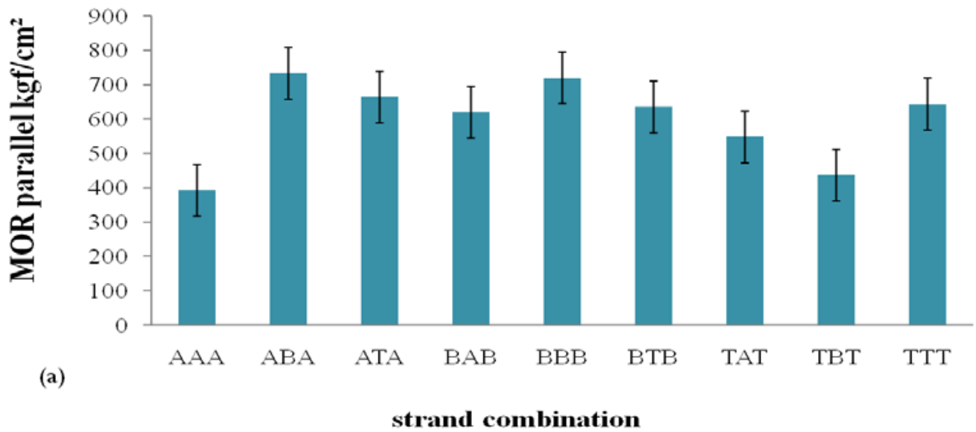

Fig 20: MOR of the board (a) parallel (b) perpendicular

According to the result analysis range tests for the strand combination factor on MOR in parallel direction to the grain showed significant effect on strand combination.

Table 10: ANOVA value of MOR in parallel direction to the grain

Sig.	F	Mean Square	Degree of freedom	Source
0.000	574.690	1.376E7	1	Intercept
0.019	2.881	68964.025	8	Strand combination
		23940.224	27	Error
			36	Total

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Further analysis on the strand combination factor revealed that there are 3 homogeneous groups, which means most of strand combinations showed no significant differences. Only, ABA, BBB and AAA board showed significant differences. The MOR value of BAB board (the highest MOR values) increased when the strand mixed with the lower bamboo density to higher bamboo density.

Table 11: Further analysis for strand combination

Subset			N	combination
3	2	1		
		3.9222E2	4	AAA
	4.3659E2	4.3659E2	4	TBT
5.4815E2	5.4815E2	5.4815E2	4	TAT
6.3523E2	6.3523E2	6.3523E2	4	BTB
6.4299E2	6.4299E2		4	TTT
7.1950E2			4	ABA
7.1958E2			4	BBB
7.2158E2			4	ATA
7.4797E2			4	BAB
.122	.094	.050		Sig.

ANOVA values of MOR in perpendicular direction to the grain using 95% of significance level showed no significant effect of strand combination.

Table 12: ANOVA value of MOR in perpendicular direction to the grain

Sig.	F	Mean Square	Degree of freedom	Source
0.000	378.138	3218072.926	1	Intercept
0.413	1.069	9093.340	8	Strand combination
		8510.306	27	Error
			36	Total

Further analysis on the strand combination factor revealed that there are 2 homogeneous groups, which means most of strand combinations showed no significant differences. Only BTB and TBT board showed significant differences. The MOR value of BTB board (the highest MOR values) increased when the strand mixed with the lower bamboo density to higher bamboo density (Betung 0.57g/cm^3, Tali 0.63g/cm^3).

4.3.2 Modulus of Elasticity (MOE)

The averages values of MOE in parallel direction to the grain and MOE in perpendicular to the grain are showed in Figure 21. The highest and the lowest values of MOE in parallel and MOE in perpendicular direction to the grain were 25353-17803 kgf/cm^2 and 105855-63549 kgf/cm^2 respectively for BAB-TBT board made from mixing bamboo and BAB-TBT board made from mixing bamboo. Standard JIS A5908:2003 all OSB

panels had met the requirement for MOE. According to Janssen (1981) that the difference between the value of MOE effected with specific gravity and high moisture content causes adhesion force between the strands becomes weak so that effect at the time of the OSB is less able to withstand the test given load.

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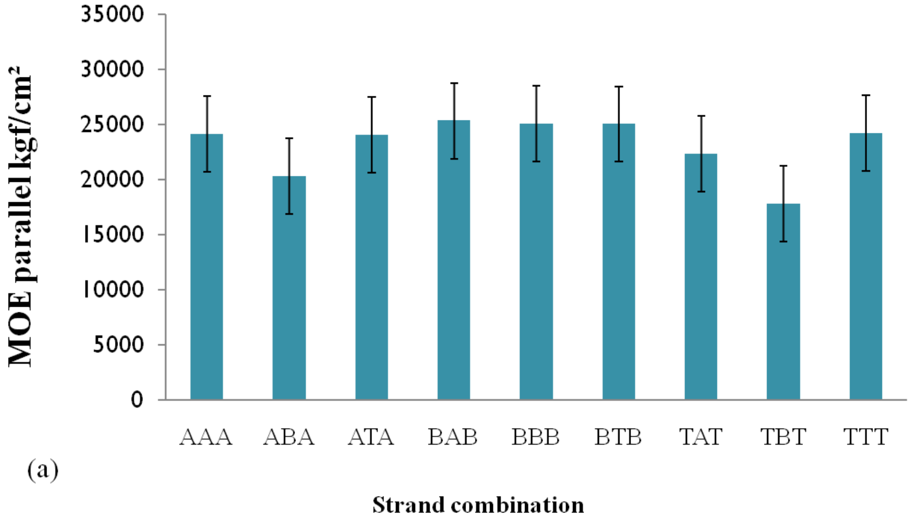

Fig 21: MOE of the board (a) MOE parallel (b) MOE perpendicular

According to result analysis the ANOVA values of MOE parallel and perpendicular direction to the grain showed no significant effect on strand combination.

Table 13: ANOVA value of MOE in parallel direction to the grain

Sig.	F	Mean Square	Degree of freedom	Source
0.000	39.530	3.421E11	1	Intercept
0.103	1.892	1.637E10	8	Strand combination
		8.654E9	27	Error
			36	Total

Further analysis on the strand combination factor for MOE revealed similar trend with that occurred in bending strength (MOR). The values of MOE increased in order from higher bamboo density to lower bamboo density, Betung bamboo 0.57g/cm^3, Andong bamboo 0.55 g/cm^3 (BAB).

Table 14: ANOVA value of MOE in perpendicular direction to the grain

Sig.	F	Mean Square	Degree of freedom	Source
0.000	369.664	1.884E10	1	Intercept
0.198	1.516	7.726E7	8	Strand combination
		5.096E7	27	Error
			36	Total

Further analysis on the strand combination factor for MOE in perpendicular revealed similar trend with that occurred in bending strength (MOE in parallel). The values of MOE increased in order from higher bamboo density to lower bamboo density, Betung bamboo 0.57 g/cm^3, Andong bamboo 0.55 g/cm^3 (BAB).

4.3.3 Internal Bond Strength (IB)

IB strength is one of important strength properties of composite panels, which is the strength in tension perpendicular to the panel of the panel. The average values of IB strength are shown in Figure 22. The highest and the lowest values of IB strength were 4.2 kgf/cm^2 and 1.7 kgf/cm^2. Respectively for TTT board made from bamboo Tali and TBT board made from mixing bamboo.

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Standard JIS A5908:2003 all OSB panels had met the requirement for internal bond. According to Ruhendi (2007) that the high moisture content on the board can inhibit the adhesive bond.

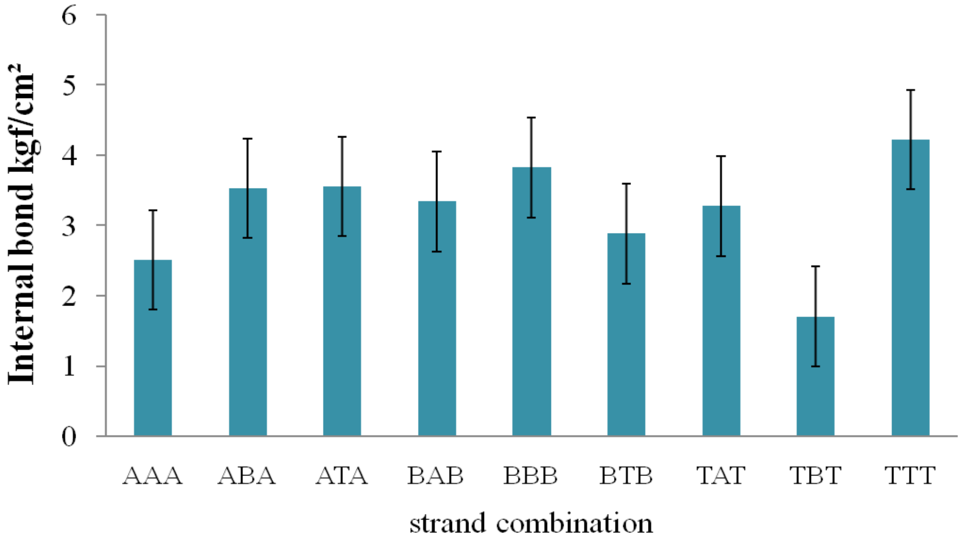

Fig 22: Internal bond of the board

According to result analysis the ANOVA values of IB strength showed no significant effect on the strand combination.

Table 15: ANOVA value of internal bond

Sig.	F	Mean Square	Degree of freedom	Source
0.000	183.835	370.478	1	Intercept
0.380	1.122	2.261	8	Strand combination
		2.015	27	Error
			36	Total

Further analysis on the strand combination factor revealed that there are 2 homogeneous groups, which means most of strand combinations showed no significant differences. Only TTT and TBT showed significant differences. The values of IB strength increased when the strand mixed with strand from higher density, Tali bamboo 0.63 g/cm^3 (TTT).

4.3.4 Screw Holding Power (SHP)

The stability of any building system, composed of interconnected components, is direct related to the performance of the fastening elements. Screws are wide used as joint and fastening components of furniture or floor and construction and since each wood species has its own properties, also have different SHP resistances. Knowledge of the SHP for wooden building elements is important because it will provide useful information about the durability and stability of the whole building system. Besides, it is significant to have information about SHP so as to achieve the efficient

use of materials in the building system. The results of SHP are showed in Figure 23. The average value of SHP ranged from 70.8-40.9 kgf/cm^2 the highest SHP value occurred in ABA board and the lowest value occurred in BAB board made from mixing bamboo. Standard JIS A5908:2003 all panels had meet the requirement for SHP. According to Achmadi (1990) that the high values of SHP related with moisture content of the board, high moisture content of board causes a lower holding power.

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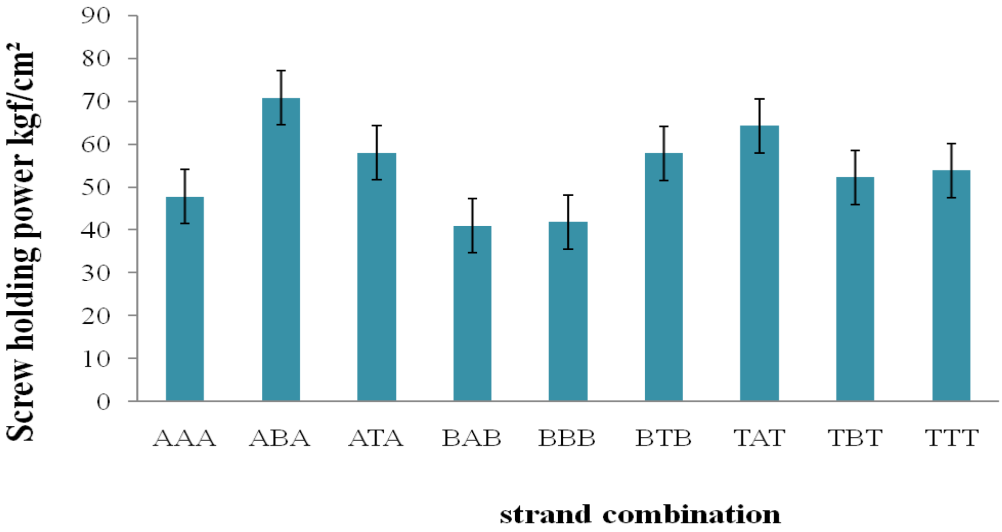

Fig 23: Screw holding power of the board

According to result analysis the ANOVA values of SHP showed significant effect on strand combination.

Table 16: ANOVA value of screw holder power

Sig.	F	Mean Square	Degree of freedom	Source
0.000	664.577	105666.171	1	Intercept
0.039	2.453	390.090	8	Strand Combination
		158.998	27	Error
			36	Total

Further analysis on the strand combination factor revealed that there are 3 homogeneous groups, which means most of strand combinations showed no significant differences. Only ABA, BAB and TAT board showed significant differences. The values of SHP increased when the strand mixed with strand from lower bamboo density to higher bamboo density (ABA).

According to Celebi and Kilic (2007) stated that wood SHP are affected by moisture content, the orientations of grains and section, specific gravity, duration of rising, method of nailing, dimensions, surface smoothness, and the wood species used.

Table 17: Further analysis for strand combination

Subset			N	combination
3	2	1		
		40.9680	4	BAB
		41.8053	4	BBB
	47.7839	47.7839	4	AAA
52.2164	52.2164	52.2164	4	TBT
53.8513	53.8513	53.8513	4	TTT
57.8419	57.8419	57.8419	4	BTB
58.0109	58.0109	58.0109	4	ATA
64.2814	64.2814		4	TAT

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70.8362			4	ABA
.075	.114	.106		Sig.

4.3.5 Resistance of OSB against Subterranean Termites Attack

Resistance of OSB against subterranean termite attack was determined through field test measuring weight loss percentage (WLP). The average WLP values of the specimens tested are showed in Figure 24. The average values ranged from 19.8-5.9%. The highest WLP occurred in TBT board made from mixing bamboo and the lowest value occurred in BBB board made from Betung bamboo. Standard JIS A5908:2003 OSB panels did not set the requirement for WLP. Visually, most of the specimens tested in grave yard test had light to medium damage, in which termites attack reached depth of approximately 30-20%.

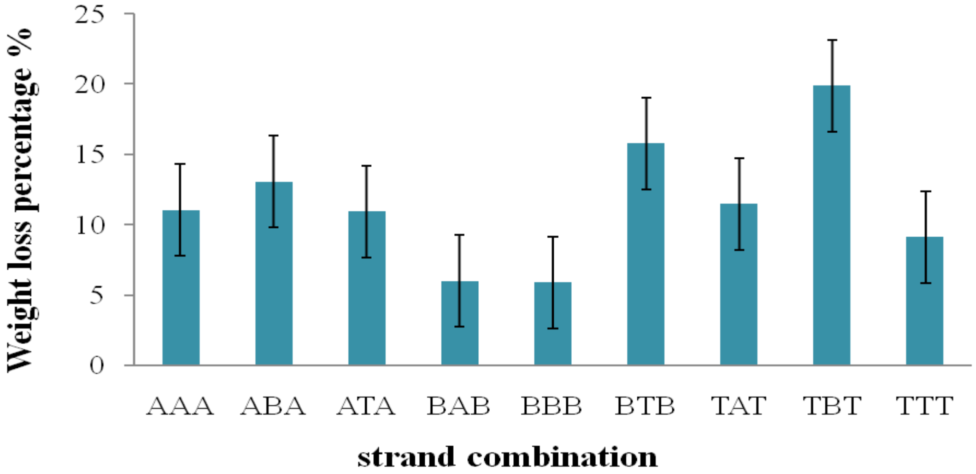

Fig 24: Weight loss percentage of the board

Fig 25: specimens test after taken from the ground

According to result analysis the ANOVA values of WLP showed no significant effect of strand combination.

Table 18: ANOVA value of weight loss percentage

Sig.	F	Mean Square	Degree of freedom	Source
0.000	111.287	4734.214	1	Intercept
0.107	1.870	79.531	8	Strand combination
		42.541	27	Error
			36	Total

Further analysis on the strand combination factor revealed that there are 2 homogeneous groups, which means most of strand combinations showed no significant differences. Only TBT, BBB board showed significant differences.

5. CONCLUSIONS

1. Strand combination showed significant effect on board properties: density, MOR in parallel direction to the grain, and screw holder power.

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2. Bamboo board BAB, ABA, BBB board made from strand combination; produce the best result OSB in terms of physical and mechanical properties. It's fulfilled on JISA 5908: 2003 Standard.
3. Regarding mechanical properties, the internal bond value of BTB, AAA, and TBT board made from mixing bamboo could not meet the JISA 5908: 2003 Standard. Which applied minimum value of 0.3 kgf/cm^2 for internal bond strength. The screw holding power values of BBB, BAB, AAA board, could not meet the JISA 5908: 2003 Standard. Which applied minimum value of 50 kgf/cm^2 for screw holding power.
4. Out of the weight loss percentage tested had light to medium damage, by termites attack this implies that OSB panel was not resistant against subterranean termites Attack.
5. The results of this study showed the feasibility of using Bamboo strands for OSB manufacturing, it is important to qualify appropriate raw material supply for the board industry.

RECOMMENDATION

1. OSB board BAB, ABA, and BBB board made from mixing bamboo, (Betung bamboo and Andong bamboo) can be improved for applied in exterior uses.
2. Application of the rule needs preservative to improved durability of OSB against subterranean termites' attack.

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