An Investigation of Moisture Performance of Sawdust and Banana Peels Ply board as Non-Veneer Panel

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Abstract

The experimental research study aimed to measure the moisture performance of sawdust and banana peels ply board as non-veneer panel for construction projects. The goal was to measure the vapor permeability values of sawdust and banana peels ply board, compare the results with those done for oriented strand board and to investigate the efficiency of structures through these panel products. The research has shown that structures made of different materials have different drying efficiencies under high relative humidity conditions that are representative of their application as non-veneer panel in cold climates.

Keywords: *construction materials**,** non-veneer panel, paneling, ply board*

1. Introduction

From economic and environmental points of view, wood composite products have become increasingly important in replacing solid wood for many applications due to a shortage of high quality timber for making lumber. Some of the products are constructed from recycled or recovered wood waste. Also, wood composite products are completely biodegradable when their service life ends. Besides the environmental benefits, the use of wood composite products instead of solid wood provides many other advantages. Wood composite products can have better durability and quality than solid wood. They can be manufactured with various sizes and can also be easily shaped and molded. Compared to solid wood, the price of wood composite products is typically much lower [1].

A variety of chemicals are used in the manufacturing of wood composite products. The use of adhesives such as urea-formaldehyde (UF), melamine-formaldehyde (MF), phenol-formaldehyde (PF) and isocyanides is essential for bonding wood elements together. Moreover, preservatives are employed to prevent the composite products from biological degradation in such a way that the preservatives are applied separately to the products or mixed with the adhesives. Depending on the intended use of the materials, other chemicals such as waxes and fire retardants are often used [2, 4].

Wood composite products can be largely classified into two categories. Panel products include plywood, oriented strand board (OSB), particleboard and medium density fiberboard (MDF). Lumber and timber products include laminated veneer lumber (LVL), parallel strand lumber (PSL) and oriented stand lumber (OSL), and glued laminated lumber (glulam).

Plywood is one type of the wood composite products and one of the most commonly used materials in the construction industry as well as the manufacturing of household items today. Plywood is made up of thin layers of wood (veneers) by bonding them together with adhesives in such a way that the grain direction of each veneer is perpendicular to that of the adjacent layers. This arrangement provides several advantages to the resulting plywood panel;

it is structurally much stronger in the two directions than plain wood in similar dimensions. Also, it prevents the panel from expanding and shrinking [1].

Today, only one-fourth of the land surface is forested [1]. Nonetheless, with the right planning and conservation of the environment, forests, and wood, a never-ending supply of wood could be available in the future.

The historical records available all over the globe shows that the basic materials used in construction were either derived from the earth made from wood. Wood is one of the construction materials were being used of the civil engineer to build a house, building and bridge [2, 23]. For the most part of the native origin and satisfied environmentally compatibility as well as financial constraint.

Wood has been used throughout human history. However the variety of uses of wood today would amaze our ancestors. These developments in wood technology have been made possible by scientific research [3, 6]. Three growths have been improved. Plywood and its manufacture have been made better .The plywood or ply board is a panel product composed of 3 or more thin layers of wood that are glued and united under high temperature and pressure. The grain of each layer runs at right angles to the grain of the layer it faces. Plywood is light, strong, stable, waterproof and very versatile [5]. These properties make it the product of choice for many construction applications. It is easily cut to size and nailed. The large sheet size is convenient for roofing or flooring jobs.

Structural plywood is used extensively in residential and commercial construction and in industry. Construction uses include light-frame structures, roof and wall sheathing, subfloors, underlayment and siding. Industrial uses include plywood for van liners, furniture, cabinetry, signs, pallets, crates and concrete forms [7, 10]. Plywood is also used in the manufacture of engineered building components such as I-beams. Decorative plywood uses hardwood veneers to face the panels [8]. This type of plywood can be used in wall paneling and for furniture manufacturing. The fiber by-products from sawmills and low grade logs can be used to manufacture a range of particle-based panels and lumber products such as particle board, wafer board, oriented-strand board and composite lumber [9, 12]. Particle board is produced using glue and compression to form small particles of wood into a panel. By varying the wood particle size, the amount of resin is used. The laminations of timbers have been made possible by new glues and adhesives [13]. Thermosetting resins are used in adhesives, finishes, and molded objects [14, 17]. Urea-formaldehyde resin's attribute includes high tensile strength, flexural modulus and heat distortion temperature, low water absorption, mold, high surface hardness, elongation at break, and volume resistance [15]. Urea-formaldehyde foam insulation started being used in the 1950s. In the 1980s, concerns began to develop about the toxic formaldehyde vapor emitted in the cup process, as well as from the breakdown of old foam [18, 20]. Consequently, its use was discontinued. Science will continue to make wood ever more useful in the future.

The manufacturer of the lumber is the oldest industry. Thus, wood technology is highly developed. Waste in forestry and wood processing is now being made into useful products [19]. The increasing demand for wood materials will probably strengthen this trend.

The use of wood and wood products continues to increase even in this age of spacecraft, computers, and unusual alloys. About two million housing units are built every year. The average one-family wood home has about 11,595 board feet ($23m^3$) of lumber and 7510 square feet of plywood and other wood products [21, 24]. The lumber and wood products industries continue to develop and expand, partly because of more efficient forestry practices.

In recent years, there has been a great increase in the use by products of lumber production. Among the wood products that are rapidly expanding in use are particleboard and hard board

[22]. These are used more and more in the production of furniture, cabinets, houses, mobile homes and interior paneling in both residential and commercial buildings.

The never ending demand of wood is inevitable and unstoppable as one of the major commodities, as long as there is an enough trees to be cut out from the forest, but this well also leads to the rapid destruction if we become so much dependable into our forest, and as well know, our forest takes a major role in the balance of our ecosystem.

In the Philippines, deforestation is so rampant and abusive compared to the forestation. The results of the government program is not well implemented and most often violated by corrupt public bribery just to approve the operation of illegal loggers [4, 23]. That's why there is a need to protect it, and one way of protecting is to conserve the use of wood, and preserve the forest by making use of waste materials coming from wood processing.

Sawdust is made available from sawmills and to the large-scale manufacturers of wood product. As a waste it has many uses, it can use for soaking up oil spills. It can be used in pottery making, as firewood for cooking [23].

The researcher attempts to use sawdust and banana peels as one component of a non-veneered panel for interior wall in response to the problem of the growing high cost of different wall materials.

2. Literature Review

The history of laminated wood has been found in the tombs of the ancient Egyptians. A thousand years ago, the Chinese shaved wood and glued it together to make furniture. They used veneered surfaces and glued thin sheets of high quality wood over a sheet of lower quality wood in order to obtain special effects such as appearance and structural benefits. A modern form of plywood was invented in the mid-1800s. It was made from decorative hardwood and used primarily for household items such as cabinets, desktops and doors. However, structural plywood made from softwood did not come out on the market until the 20th century. The commercial production of plywood was established in 1905 in Portland, Oregon and became a major industry in the US in the early 1900s. In the 1940s and 1950s, softwood plywood was promoted for residential construction in North America, and the production was at its peak in 1960s. However, with the advent of oriented strand board (OSB) technology, softwood plywood was largely replaced by OSB in housing construction. In 2005, softwood plywood accounts for only one-third in the residential construction market in the U.S [2, 4].

Plywood is classified broadly in two categories: construction (softwood) and decorative (hardwood). Construction plywood is generally made from softwood species such as Douglas fir, spruce, pine or fir. It is typically used for construction and industrial purposes such as wall siding, roof decking, floors, and containers. Since construction plywood is generally required to have strength, stiffness, and construction convenience, thermosetting adhesives including phenol-formaldehyde (PF) and melamine-formaldehyde (MF) are employed for the plywood. Decorative plywood, which typically has hardwood veneer faces, is used for interior applications such as furniture, cabinets, and doors. Its face layers have good-looking hardwood including red oak, birch and maple. Decorative plywood is typically produced with a less expensive urea-formaldehyde (UF) adhesive that has limited water resistance [5].

Plywood production can typically be divided into three manufacturing stages: veneer manufacture; drying and up-grading; and panel lay-up, pressing and finishing [1].

The process of rotary veneer cutting is essentially to produce veneers from logs, which are peeled perpendicular to the grain. The thickness of veneers depends on their intended use, ranging from 1.6 to 4.8 mm (1/16 to 3/16 in.) for softwood plywood and much thinner for hardwood and decorative plywood. The continuous sheet of veneer is then moved by a conveyor to be clipped into usable sizes and remove defects. After peeling, veneers are too wet to glue, and they need to be dried to 3-6 % moisture content. Properly dried veneers are then sorted into many different grades according to the size and number of knots and other natural and processing defects [1].

An adhesive is spread on the veneers in the lay-up area by spraying, curtain coating, roller coating, extrusion, or foaming. Once built up, panels are moved by the conveyer to the pressing area. The panels are cold pre-pressed for 3-5 minutes for flattening the veneers and transferring the adhesive from one surface of an adhesive-coated veneer to the adjacent uncoated veneer. Hot-pressing is then applied to the cold-pressed panels and cure the adhesive. Press temperature and press time may vary depending on wood species and resins used; a typical press time is 2 to 7 minutes, and the press temperature generally ranges from 132 to 165 ºC (270 to 330 ºF) for softwood plywood and from 107 to 135 ºC (225 to 275 ºF) for hardwood plywood [1].

After pressing, the pressed panels are cooled and then taken to a finishing process, where they are graded and trimmed according to the types of the final product, and finally sanded [6].

Together with softwood plywood, oriented strand board (OSB) is one of the major types of structural wood panels and is mainly used for exterior walls, roof sheathing and floor decking. The manufacturing of OSB starts by processing a log into strands that are typically 100 to 150 mm long in the grain direction, 13 mm wide, and 0.6 to 0.7 thick [4]. The strands are then dried below 10% moisture content and mechanically blended with adhesives such as phenol-formaldehyde or isocyanides, to form a 3- or 5-layered mat. In the same way as veneers of plywood are oriented, the adjacent two layers of the mat are aligned at right angles to each other for maximum strength, stiffness and stability [6].

Unlike the plywood industry, the OSB industry does not depend on large diameter logs since small diameter, irregular softwood, or previously unutilized hardwood is generally used for the manufacturing of OSB. In addition to the flexibility of log choices, the competitive cost of OSB in the structural panel market, as compared with softwood plywood, has caused the rapid increase of its production.

Particleboard (PB) is a non-structural, engineered, wood panel that is manufactured from wood particles of various sizes. Either green or dry wood residues are used as the raw materials to produce PB; green wood residues contain shavings and sawdust from green lumber, and dry residues contain shavings and sawdust from kiln-dried lumber as well as plywood trim. Wood particles are combined with an adhesive, and sometimes wax in a blender, and then bonded together under heat and pressure in a hot press. Urea-formaldehyde (UF) is predominantly used as an adhesive since PB is mainly used for non-structural, interior applications [7].

In the early production of MDF, the same process for manufacturing PB was used for producing MDF in such a way that fibers were dried and then mixed with an adhesive in a blender. However, the process caused dark resin spots in the resulting panels. Today, MDF is manufactured by a very different process, a so-called blow line blending process, which can reduce the problem (dark resin spots). In the process, fibers are carried from a refiner to a flash tube dryer through the blow line, and an adhesive is added before the dryer in the blow line [8].

The raw materials are broken down into wood fibers using a pressurized disk refiner under certain conditions (typically a pressure of 7 to 8 bars and a temperature of 170ºC), and wood fibers are then blended, typically with an aqueous urea-formaldehyde (UF) adhesive. Some wax, less than 2% by weight of oven-dry fibers, is often added to the fibers to increase water resistance. The fibers are formed into a mat, and the mat is pressed at temperatures ranging from 160 to 170 ºC [2].

MDF is considered as an excellent alternative for solid wood and is widely used in many interior applications. With the employment of phenol-formaldehyde (PF), or urea-melamine-formaldehyde adhesives, MDF can also be used in exterior applications [2].

Laminated veneer lumber (LVL) is a wood-veneer based composite that is used for either structural or nonstructural applications, but is primarily used as the structural framing for residential and commercial construction. LVL is made by bonding thin sheets of wood veneer together with an adhesive under controlled heat and pressure. While the grain in plywood lies at right angles to each other in alternate plies, the grain of each layer of veneers in LVL runs in the same (long) direction [9]. Thus, the main difference between plywood and LVL takes place in the lay-up stage in their manufacturing processes.

Common species used to produce LVL are Douglas fir, larch, southern yellow pine and poplar, which are the same as those for plywood. Typically, veneer thickness varies from 0.10" (2.5mm) to 3/16" (4.8mm) [10]. Its structural use is for support beams, headers, rafters, and I-beams, and nonstructural LVL is used for furniture, window, door frames, and cabinets.

Like plywood manufactures, LVL panels use a variety of adhesives depending on their primary applications. Generally, phenol formaldehyde (PF) resins are used for exterior applications. LVL production is an energy intensive process that requires extensive wood drying (moisture contents of 6-8%) and high temperature hot-pressing (about 200 °C) [11].

In plywood, the way in which the grains alternatively lie in the length and width directions gives the similar strength and stiffness properties in the two directions. LVL can maximize strength and stiffness in the spanned direction because the grain of all veneers is parallel to the long direction.

Parallel strand lumber (PSL) is constructed from long wood veneer strands in the orientation parallel to the length of the member. The strands are bonded together with an adhesive, typically phenol-resorcinol formaldehyde (PRF), to form a finished structural lumber. The veneer strands are cut to 3 mm in thickness, 20 mm in width, and 100-300 mm in length. This product is used for beam and header applications in construction like LVL, and frequently as load bearing columns [12].

Similar to PSL, oriented strand lumber (OSL) consists of flaked wood strands that have a high length-to-thickness ratio. An isocyanate-based adhesive is generally used for making this product, so is a steam-injection pressing. The steam-injection press results in a short press time, and uniform and increased density of the final product. OSL is commonly used for studs and millwork components [13].

Glulam, which is an excellent substitute for lumber, is an engineered stress-rated product fabricated by bonding individual pieces of lumber, with a thickness of 2 inches (50 mm). Larger and longer structural wood members can be obtained, which are not available from small trees. Adhesives used for glulam are generally resorcinol-formaldehyde (RF) or phenol-resorcinol-formaldehyde (PRF). Glulam can be shaped into a straight beam or a complex, curved member, which allows the final product to be used in a variety of construction applications such as headers, floor girders, arches, domes, and bridges [14].

An adhesive is defined as a substance that can hold the surface of each side of at least two materials together in a strong and permanent manner [15]. Adhesives virtually surround us, as an essential part of our lives. Wood adhesive is a polymeric substance capable of bonding surfaces of wood together through chemical or physical reaction, or both. Wood adhesives have played a central role in the growth and prosperity of the wood products industry and have been attributed to the efficient use of wood materials especially in the construction and housing industries. The demand for wood adhesives has rapidly increased with the increased prosperity of the wood products industry, and the consumption of wood adhesives around the world reached nearly 13.3 million metric tons in 2001 [16]. Currently, the wood adhesive market has largely been dependent on formaldehyde-based adhesive systems including amino resins, and phenolic resins.

A large number of adhesives are now used in the manufacture of wood composite products. Adhesives can be grouped in a variety of ways, including source, function, chemical composition, physical form, and application. A simple classification of wood adhesives is based on whether an adhesive is manufactured from natural or synthetic materials. Also, synthetic adhesives include thermosetting and thermoplastic adhesives.

Natural adhesives are produced from organic materials such as animal, casein, vegetable, and blood. Also, adhesives from lignin, tannin, and carbohydrates have been studied for replacement of synthetic adhesives that are dominatingly used in the manufacture of wood composite products. These adhesives are generally used for non-structural applications, due to their poor water resistance and low strength properties. This type of adhesive has a long shelf life, ease for applying, and relatively low price. Most of these adhesives are supplied as aqueous solution or as powder that is mixed with water prior to their application. Cross-linking agents are occasionally added to the adhesives [14].

The term “animal glues” can be normally defined as glues derived from collagen, which is a main constituent of animal skin, bone and sinew. Animal glues are classified into two categories depending on where the collagen is obtained: bone glues from animal bones and hide glues from tannery waste. Animal glues are manufactured by the hydrolytic degradation of water-insoluble collagen and composed of approximately carbon (50.7%), hydrogen (6.5%), oxygen (24.9%), and nitrogen (17.9%) [17]. These glues are initially provided as liquid, jelly, or solid, and are then reconstituted with water for the application [17].

The uses of animal glues were limited to furniture woodworking. However, in the furniture industry, they have been mostly replaced with synthetic and other strong adhesives from natural sources due to their inadequate attributes: low water resistance, degradation by molds and fungi, inconvenience to use, relatively high manufacturing costs, and temperature-sensitive viscosity [18].

Most casein, the main protein of milk, used for adhesives is manufactured by acid precipitation of milk, but a very small amount is naturally obtained from milk by rennet. These adhesives are provided as powders and are required to mix with water prior to their use. Casein-based adhesives are normally used at room temperature and cured by loss of water through the void volume of wood (porosity) and by cross-linking.

For several decades, casein has been widely used as a wood adhesive for furniture and plywood. In spite of superior properties of synthetic adhesives, these adhesives are still used as wood adhesives. Casein-based adhesives are generally limited to interior structural uses due to several properties. These adhesives have a poor resistance to water, and the attack of molds and fungi, but these properties can be improved by using additives. However, casein-based adhesives have an excellent gap filling and high strength in a cured bond line. These adhesives are resistant to heat (up to 70ºC), and organic solvents [18].

Blood-based adhesives are preferably produced from soluble dried blood, a by-product of slaughterhouse operation. These adhesives are sold as light colored powders, and powders must then be mixed with water, hydrated lime or sodium hydroxide for their application. Blood-based adhesives have moderate resistance to water and heat, but are subject to being attacked by microorganisms under wet conditions. Phenol-formaldehyde resin can often be added as an antifungal agent, which also provides additional strength [19].

Blood-based adhesives can be hardened by hot-pressing and by loss of water. In the manufacture of softwood plywood, panels bonded with these adhesives are generally hot-pressed at 70-230ºC for 10-30 minutes, with pressures ranging from 0.5 to 0.7 MPa [15].

Soybeans as one of the most valuable crops are used for a variety of products, ranging from food for human consumption, and animal feed, to industrial products. Soybeans were originally cultivated in Eastern Asia and later introduced to Korea and Japan. Although soybeans were brought to the United States in the late 1800s or early 1900s, the U.S. has been the largest producer in the world for last decades. In 2005-07, the world production of soybeans was approximately 217 million metric tons per year, and the U.S. solely accounted for 37.0% of the world production [20].

Soybeans consist of approximately 40% protein, 20% lipid, 30% carbohydrates and 4.9% ash, but the chemical composition of soybeans can vary according to conditions under which they grow [21].

In the amino acid composition of soy proteins, acidic amino acids (aspartic and glutamic acids) account for 30% of the total amino acids. The remaining composition includes amides (asparagines and glutamine), non-polar amino acids (alanine, valine and leucine), basic amino acids (lysine and arginine), and uncharged polar amino acid (glycine).

"Kaatoan Bangkal" was made into a three-layer type particle board bonded with banana peel extract [4, 22]. Three board densities (200, 300, and 400 kg/m^3) were produced varying their pressing conditions depending on the densities. The highest board density gave the largest values for all the mechanical properties. Dimensional stability determined particularly water absorption was also lowest compared with the lower board densities. At 400 kg/m^3 board density, the following values were obtained: modulus of rupture= 6.65 MPa, modulus of elasticity =1.48 x 103MPa, internal bond strength= 0.34 MPa, screw withdrawal = 16.4 kg, thickness swelling = 11.8% and water absorption = 68.8% [5]. Analysis of variance and Duncan multiple range test showed that all the data were highly significant [22]. The use of "isocyanate" resin adhesive as a new binder in the production of particle board lowered down the compaction ratio of the board produced without sacrificing its properties and qualities [21]

Stylex Research Institute states that the particle board such as veneers which are constructed from high quality sawdust and banana peel extract is being selected for their suitability in all commercial situations [22]. All panels are made from 33mm Highly Moisture Resistant (HMR) particle board, laminated both sides with a decorative hard wearing melamine surface. The HMR core is manufactured from Australian Plantation Pine to Australian Standards 1859 for HMR grade particle board/veneers and meets the specification of the international V313 test [18, 22].

The HMR core board is sandwiched between layers of decor paper which provides the colored finish. The board is being impregnated with banana peel extract resin and dried [18]. The sandwich is then brought together in a press where the treated mixture are thermoset and polymerized under high pressure ($28kg/cm^2$) and at high temperature (18^0c) creating a hardened surface and an extremely powerful bond[19,21].

3. Experimental Investigation

3.1. Project Design

As shown in figure 1, research study is done by the use of sawdust and banana peel derived as non-veneer panel for interior wall. These materials undergo series of test by collecting all the materials being used and discard all the foreign materials. Separate the sawdust and sun dried, and sieve in #10. Wash the banana peels sample and discard all the unused materials.

Grin until the texture as smooth as the sawdust, squeeze to separate the resin and place in an oven dry stage. Combine all the components of dried sawdust and dried banana peels with resin of banana peels as additives. Mixed gradually, then place into the molding pan. After the process of making non-veneer and has been cured for seven days. Remove from the molding pan. The result of the product is called sawdust and banana peels derived as non-veneer.

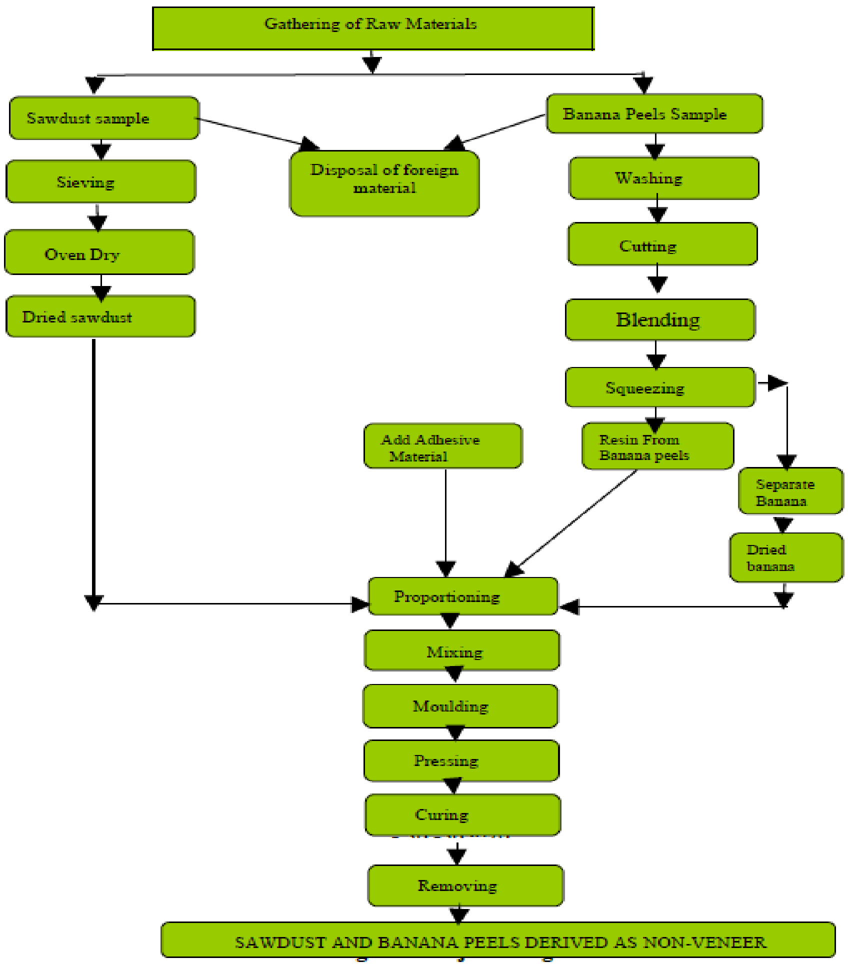

Figure 1. Project Design

3.2. Products used in the Experiment

Table 1 presents the sawdust and banana peels ply board products used in the experiments. Nine different products were studied: Four sawdust and banana peels ply board products and five oriented strand board products. One of both products were Philippines (code PH), the other products were Asia (code AS). All the products were meant to be used also as panel board. The dry densities of sawdust and banana peels plywood products were 497- 897 kg/m^3 and that of oriented Strand board 680.4 kg/m^3. The measured average product thickness was in the range of 9.5 mm – 16.7 mm.

Table 1. Products used in the Experiments

Product Code	Thickness, (t), mm	Dry density, (p), kg/m^3
Sawdust & banana peels ply board PH (3 PLY)	10	520.6
Sawdust & banana peels ply board PH (5 PLY)	13.5	520.1
Sawdust & banana peels ply board PH (2 PLY)	9.8	530.4
Sawdust & banana peels ply board PH (4 PLY)	13.7	497.2
Oriented Strand board	9.5	706.5
Oriented Strand board AS	13.9	680.4
Oriented Strand board AS 2	13.4	695.5
Oriented Strand board AS	16.7	690.3
Oriented Strand board PH	12.3	678.8

3.2.1. Water Vapor Diffusivity Measurements: Water vapor transmission properties were determined by a cup method based on standard EN 12086, All nine materials were tested in four different humidity conditions at constant temperature T = 22 °C (Table 2) using five parallel samples and one 'blind cup' without salt solution in the cup.

Table 2 shows that dry and wet cup tests, one very wet (110/87% RH) and one moisture safe set of relative humidity conditions (90/69 % RH) were used. The conditions 90/69 % RH represent high, but still safe level of humidity because a humidity level of 90% RH is considered to be the pivot value for the starting risks of fungal growth. When the temperature is lower than 15ºC, this critical level of relative humidity starts to increase [21, 22]. Typically the temperature of the ply board panel is close to outdoor air temperature, and thus the relative humidity conditions that are less than or equal to 90% RH can be considered safe in cold and moderate climate conditions. This level can be exceeded for some periods without causing moisture risks to structures. Higher humidity levels mean also higher vapor permeability level of the panel board and better drying efficiency for the structure.

Table 2. Conditions used in the Water Vapour Permeability Tests

RH (1)	RF (2)	RH_{ave}
10	60	35
69	90	79.5
59	103	81
87	110	98.5

3.2.2. Cup Test Results: The dry cup conditions correspond to those near the inside surface of a structure during the heating period in cold and moderate climates. Under these conditions, the vapor permeability of sawdust & banana peels ply board was about half of that of the oriented strand board products. Under high but safe humidity conditions (90/69% RH), however, the vapor permeability of the plywood products is 3 to 4 times higher than that of the oriented strand board products. In these representative drying conditions, the vapor permeability of sawdust & banana peels ply board was in the range 3.8 – 6.0 , 10-12 kg/(m.s Pa) while that of oriented strand board products was 1.4 - 2.6 ·10-12 kg/(m.s Pa) shown in table 3. The vapor resistances from wet cup tests were in same level as those measured under the so called safe conditions.

Table 3. Measured Water Vapour Permeability values under 90%/69% RH Conditions

Product Code	Minimum δp (kg/m.s.Pa)10^{-12}	Maximum δp (kg/m.s.Pa)10^{-12}	Mean δp (kg/m.s.Pa)10^{-12}
Sawdust & banana peels ply board PH	5.70	6.12	5.90
Sawdust & banana peels ply board PH	3.11	4.51	3.81
Sawdust & banana peels ply board PH 2	4.73	5.30	5.02
Sawdust & banana peels ply board AS	4.90	4.87	4.89
Oriented Strand board	2.35	2.71	2.52
Oriented Strand board PH	2.20	2.90	2.55
Oriented Strand board PH 2	1.50	3.00	2.25
Oriented Strand board PH	1.25	1.62	1.44
Oriented Strand board	2.35	2.94	2.05

3.3. Experimental Method in Drying Efficiency

A simplified test method has been developed to study the drying efficiency of structures exposed to a temperature gradient [20]. In this test, the 1-dimensional intersection of the building envelope structure is sealed in a chamber, open from above to the cold side air.

The warm side of the structure section is closed with a water vessel. This water vessel is bounded to the warm side air. The drying of the structure is based only on diffusive moisture transport through the outer material layers and it is monitored by periodical weighing of the whole installation frame of each structure section together with the initially set additional water.

3.3.1. Drying Set Up: The test device consisted of 20 frames in which the different structure sections were installed. Due to the sealing of the sides and the edge insulation, the temperature and moisture flow fields were as 1-dimensional as possible. The top surface of each test structure was in contact with the controlled cold side air. The warm side temperature below the test frames was maintained constant with controlled heating of the air space shown in Figure 2.

As shown in Table 1, drying efficiency of all the products was studied using two parallel structure components for each product.

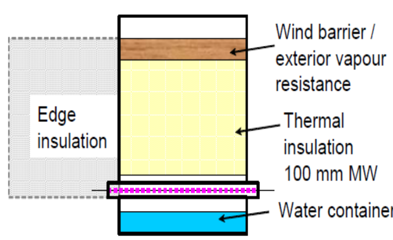

Figure 2. Test Device for Drying Efficiency Experiments

3.3.2. Test Conditions: In the experiments the warm side air temperature was maintained at +25 °C with less than 19°C range of variation. The tests consisted of two measuring periods having different cold side air temperatures shown in Table 4. The cold side temperature had about 20°C variation from the set value. After the first period one of each parallel structure was removed to determine their moisture distribution.

The other parallel structures were maintained in the tests till the end of second period. The first cold period represented rainy conditions which caused moisture to condense and cold surface of the wind barrier. The following period with just above rainy conditions represented close to yearly average temperature conditions in Philippines. Due to continuous moisture source, moisture flow and condensation on the cold side of the structure the experiments represent quite extreme conditions.

Table 4. Cold Side Temperature in Drying Experiment

Cold side temperature)	Measuring period, days
21℃	55
24℃	34
24℃, 2nd set	30

4. Conclusions

The results show clearly the differences between oriented strand boards and, sawdust and banana peels ply board products. The products are not interchangeable and the climate conditions and moisture loads have to be studied to evaluate their suitability and moisture safety aspects in different applications. In additions to drying efficiency, there are other performance properties that have to be considered when applying exterior sheathing products.

The vapor permeability values and vapor resistances determined in 90/69% RH conditions represent the safe level that can be used when analyzing the performance of the ply board products under continuous conditions. These results were in the same range as those derived from wet cup tests and thus the wet cup results give a good approximation for the possible continuous vapor resistance of the exterior ply boards during drying conditions in a cold climate.

The drying experiments confirmed what was found in the vapor permeability measurements. When the exterior sheathing board is under freezing conditions, the drying efficiency was quite low both with sawdust and banana peels ply board and oriented strand board. In above freezing conditions the amount of moisture dried from the structures with ply board sheathing were about 10 times higher than that dried from the structures with oriented strand board.

References

[1] S. Ebnesajjad, "Adhesives Technology Handbook", 2nd Ed. William Andrew Inc, New York, **(2008).**
[2] Y. Fu, J. Chen, H. Guo, A. Chen, J. Cui and H. Hu, "The role of non-timber forest products during agroecosystem shift in Xishuangbanna", Southwestern China, Forest Policy and Economics, vol. 11, no. 1, **(2009)**, pp. 18-25.
[3] B. J. Greber and D. E. White, "Technical change and productivity growth in the lumber and wood products industry", Forest Science, vol. 28, no. 1, **(1982)**, pp. 135-147.
[4] R. F. Hearmon, "The elasticity of wood and plywood", Special Report, vol. 7, **(1948)**.
[5] H. Hirota, U.S. Patent No. 3,654,044. Washington, DC: U.S. Patent and Trademark Office, **(1972)**.
[6] M. Ajmal, A. H. Khan, S. Ahmad and A. Ahmad, "Role of sawdust in the removal of copper (II) from industrial wastes", Water Research, vol. 32, no. 10, **(1998)**, pp. 3085-3091.
[7] T. H. Emaga, R. H. Andrianaivo, B. Wathelet, J. T. Tchango and M. Paquot, "Effects of the stage of maturation and varieties on the chemical composition of banana and plantain peels", Food chemistry, vol. 103, no. 2, **(2007)**, pp. 590-600.
[8] M. Sakurai, U.S. Patent No. 3,758,370. Washington, DC: U.S. Patent and Trademark Office, **(1973).**
[9] D. V. Hudson, U.S. Patent No. 5,968,625. Washington, DC: U.S. Patent and Trademark Office, **(1999).**
[10] E. L. Bryan, "Photoelastic evaluation of the panel shear test for plywood", ASTM STP, vol. 289, **(1961)**, pp. 90-94.
[11] I. Takami, "Panel and Plate Shear Test of Plywood", Mokuzai Gakkaishi, vol. 10, no. 0, **(1964)**, pp. 19.

[12] J. J. H. Nusselder and H. M. C. Stijnen, European Patent No. EP 1681147. Munich, Germany: European Patent Office, **(2006)**.
[13] I. Wentworth, U.S. Patent No. 4,364,984. Washington, DC: U.S. Patent and Trademark Office, **(1982**).
[14] M. W. Pollock, J. J. Wetula and B. M. Ford, U.S. Patent No. 5,443,894. Washington, DC: U.S. Patent and Trademark Office, **(1995)**.
[15] S. H. Radcliffe, T. L. Lee and R. D. Palardy, U.S. Patent No. 6,136,408. Washington, DC: U.S. Patent and Trademark Office, **(2000).**
[16] B. Madsen, "Behaviour of timber connections", Canadian Journal of Civil Engineering, vol. 28, no. 3, **(2001)**, pp. 546.
[17] A. B. Henson, K. J. Fridley, D. G. Pollock and C. J. Brahler, "Efficacy of interactive Internet-based education in structural timber design", Journal of Engineering Education, vol. 91, no. 4, **(2002)**, pp. 371-378.
[18] A. Kermani, "Structural timber design", Blackwell Science Ltd., **(1999)**.
[19] N. Nugroho and N. Ando, "Development of structural composite products made from bamboo I: fundamental properties of bamboo zephyr board", Journal of Wood Science, vol. 46, no. 1, **(2000)**, pp. 68-74.
[20] R. D. Adams and D. G. C. Bacon, "Effect of fibre orientation and laminate geometry on the dynamic properties of CFRP", Journal of Composite Materials, vol. 7, no. 4, **(1973)**, pp. 402-428.
[21] I. Aydin, "Activation of wood surfaces for glue bonds by mechanical pre-treatment and its effects on some properties of veneer surfaces and plywood panels", Applied surface science, vol. 233, no. 1, **(2004)**, pp. 268-274.
[22] P. Bekhta, S. Hiziroglu and O. Shepelyuk, "Properties of plywood manufactured from compressed veneer as building material", Materials & Design, vol. 30, no. 4, **(2009)**, pp. 947-953.
[23] M. D. MacPeak, L. F. Burkhart and D. Weldon, "Mill study of the quality yield, and mechanical properties of plywood produced from fast-grown loblolly pine", For. Prod. J.;(United States), vol. 37, no. 2, **(1987)**.

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