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SUSTAINABLE USE OF CASSAVA PLANT WASTE (BRANCHES) AS RAW MATERIAL FOR BIO-COMPOSITE DEVELOPMENT: PARTICLEBOARD PROPERTIES DUE TO PLANT MATURITY

Farhah Rahimi[1], Mazlan Mohamed[1,2], Mohd Mustafa Al Bakri Abdullah[2], Noorhafiza Muhammad[2,3], Rozyanty Rahman[2], Mohd Nazri Omar[3], Mohamad Bashree Abu Bakar[1], Mohammad Khairul Azhar Abdul Razab[1], Zairi Ismael Rizman[4]
[1]Advanced Material Research Cluster, Faculty of Earth Science, Universiti Malaysia Kelantan, Jeli, Kelantan, Malaysia
[2]Center of Excellence Geopolymer & Green Technology, School of Materials Engineering, Universiti Malaysia Perlis, Malaysia
[3]School of Manufacturing Engineering, Universiti Malaysia Perlis, Malaysia
[4]Faculty of Electrical Engineering, Universiti Teknologi MARA, Dungun, Terengganu, Malaysia
E-Mail: mazlan.m@umk.edu.my

ABSTRACT

This research is to study the sustainable use of Cassava Manihot Esculenta Crantz waste from branches parted as a raw material for bio-composite development. Bio-composite is component phase that derived from biological origin for both reinforcement (fiber) and matrices (resin) with significantly different physical, mechanical and chemical properties. In this research, bio-composite use is natural fibers or bio fibers derived from cassava plants with polymer matrices which is polyurethane. Cassava plant is a woody perennial shrub, the composite product created is from wood fiber. Fiber of cassava plant used is in the particle form to create particleboard. This research focuses on the comparison of the most suitable age of cassava plant waste for making particleboard by comparing the final product chemical, mechanical and physical properties using density, moisture content, water absorption, thickness swelling, XRD (crystallinity percentage of fiber) and bending tests (modulus of rupture and elasticity). The manipulated variable is 3 different ages of white cassava plant waste and only one age of yellow cassava varieties of trees.

Keywords: bio-composites, water absorption, thickness swelling, mechanical properties, cassava branch.

1. INTRODUCTION

Background of Study

Sustainable production and consumption (SPC) or sustainable use can be defined as a systemic change on a global level between production and consumption, and between consumption and other social activities. SPC can be determined in the observation of product life cycle assessment which determine the material flow or environmentally extended input-output analysis. SPC research commonly addresses improving the environmental performance of production processes and supply chains such as product, service, system innovation for sustainability, mechanisms for barriers to and making consumption more sustainable [1].

Cassava (Manihot esculenta Crantz) is considered as an important source of food for large populations in tropical countries in Asia, Africa and Latin America. It is a bushy woody plant or perennial woody shrub which able to produce tubers underground. The aerial part is made up of main stem and branches and leaves on it, and it can be as high as 2 ± 4 m [2]. Cassava can grow in different region and in different amount of rainfall. It can grow in a region that have 500 to 5000 mm rainfall per year, but most major production regions generally have an average of rainfall between 1000 and 2000 mm per year. Cassava can tolerate long drought periods and cultural neglect by restricting growth through leaf shedding and assuming a dormant like stage [3]. Rainfall in Kelantan, Malaysia for Kota Bharu in 2013 was 2,234.8 mm and in Kuala Krai is 3,134.0 mm. In 2012, rainfall in Kota Bharu was 3,139.0 mm [4] and Kuala Krai was 2,454.8 mm [5]. Based on these data, plantation of cassava in Kelantan is suitable. Malaysia had a lot of cassava plantation, so it also produces a lot of waste from cassava. Malaysia harvest 400000 tan per year of cassava from an area of 39 000 hectares [6].

Waste from cassava plant can be processed to be bagasse for making pallet for animal feed and as manure. It does not require any pretreatment and can be easily attacked by micro-organisms in the manure process [2]. Cassava plant waste from the aerial part has potential to be raw material for particleboard manufacture because it has ligno-cellulosic fiber. Cassava plant has high content of lignin which make it the woody. Its hemicellulose is differ from other agricultural residues such as wheat straw, rice straw and sugarcane bagasse because the hemicellulose contain mannose and galactose heteropolymers which present in wood hemicellulose [7].

Lignin and cellulose increase with tissue maturation with a maximum rate of lignin deposition following of that cellulose [8]. Particleboard is generally made from recovered and recycled wood waste. Particleboards is a composite panel that composed of cellulosic materials, generally in the form of discrete pieces or particles as distinguished from fibers, bonded together with a bonding system. It may contain additives (binder)-ASTM D 1554 terminology, which relating to wood-based fiber and particle panel material.

The properties of a board vary due to many

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variables which are characteristics of raw fiber materials, wood species, wood density, board compaction, fiber length, steam time and pressure, disc diameter, plate pattern, loading rate, the gap between the grinding plates, rotation speed of the plates and age of the wood [9]. Tension parallel to surface test (tensile test), static bending test, X-ray diffraction (XRD), thickness swelling test, water absorption test, density test and the moisture content test was conducted to determine the influence of cassava plant waste age on mechanical and physical properties of the particleboard.

Problem statement

The global market demand for wood and wood products creates pressure on tropical countries to destroy their forests and produce cheap timber and pulp to fulfill all the demand [10]. This demand has increased logging of tropical forests and is a major driver of deforestation. So, to add some sources of wood product which making cassava waste product (branches) that also have high lignin content (woody) like tropical forest wood as a raw material for making particleboard.

Cassava is widely planted in Malaysia [6], which produce a lot of end products including waste that can be derived from the cassava plant aerial part. Cassava waste or secondary product from stems have the possibility to be raw material or being utilized in the manufacture of particleboard. Recently, it has been investigated [11] where the stem can be replanted. Cassava branches are used for making pallet and directly consume for animal feed. But, it contains hydrogen cyanide [12] and have low protein compared to other pallet, so the best product can be made from cassava waste (branches) for sustainable use is board product.

Normally, cassava harvested at 6, 9, 12 and 15 months based on the climate of the region and variety of cassava. But, the problem is there is no data shows the age of cassava plant waste that suitable to use as a raw material for particleboard or bio-composite development. This study also conducts to determine the most suitable age of cassava branches as a raw material for making particleboard. Cassava branches or sample took from Lemal, Pasir Mas, Kelantan, Malaysia

Bio-composite materials

Bio-composite have one or more material phase that derived from biological origin. In terms of the reinforcement, this could include plant fiber or fiber from recycled wood or waste paper, or even by-products from food crops. Regenerated cellulose fiber also included, since they come from a renewable resource, as a natural ‘nano fibrils’ of cellulose and chitin. Matrices or resin or adhesive may be polymers, derived from renewable resources such as vegetable oils or starches. Composite materials are made from two or more constituent materials which are the reinforcement and matrix with significantly different physical or chemical properties. It remains separate and distinct on a macroscopic level within the finished structure. Figure-1 [18].

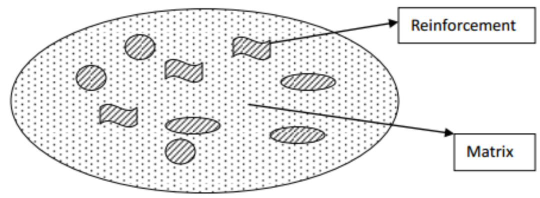

Figure-1. Composite [18].

There are several advantages of using composite material because they have lightweight, high strength, corrosion chemical resistance, elastic and non-conductive. The reinforcement impacts their special mechanical and physical properties to enhance the matrix properties. Fibers are a class of hair-like material that are continuous filaments or are in discrete elongated pieces, which similar to pieces of thread. They can be spun into filaments, thread or rope. They can be used as a component of composite materials. The interest in natural fiber-reinforced polymer composite materials are rapidly growing because they are renewable, cheap, completely or partially recyclable and has a high tensile stress [13-17]. Ligno-cellulosic fibers from plant waste is increasingly popular as reinforcement of composites because of the availability, renewability, low density and cheap [18].

Bio-composite also divided into 2 types which are green composite and hybrid composite. Hybrid composite is the incorporation of several different types of fibers into a single matrix has led to the development of hybrid bio-composite. Hybrid composite contains two or more types of fiber, the advantage of one type of fiber could come lament with what are locking in the other. Green-composites are the combination of natural fiber with biodegradable resins and they are environmentally friendly, fully degradable and sustainable [18].

The plant fibers mainly used in the part of car interior and truck cabins. Thus, it is used as based automotive parts such as various panels, trim parts, shelves and brake shoes which are attractive for automotive industries worldwide [19]. This is because of its reduction in weight about 10%, energy production by 80% and cost reduction of 5%. It also will increase thermal resistance and some natural fiber, which usually used in electronic industry [20-21]. Besides, bio composite materials those coming from forestry and agricultural wastes are not new to the world. Moreover, development of advanced bio-composite materials made is increasing worldwide. There are a few kinds of bio composite which are cement board, oriented strand board and particleboard (hardboard, medium density board and insulation board) [22-23].

The natural fiber reinforced polymer composites had been contributed to environmentally friendly materials at the stage of production, processing and waste and environmentally friendly production of natural fibers [19]. Moreover, there is relatively cost effective to have a low coefficient of friction, exhibit good thermal conductivity

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and dimensional stability and low density. In addition, they have thermal resistance which resulting in a higher specific strength and stiffness than glass fiber and other renewable sources [24-30].

Particleboard

Particleboard is one of particle panel materials which is a board materials manufactured from wood or other ligno-cellulosic fibers or particles with binding agents and other materials may be added during manufacture to obtain or improve certain properties. Particleboards are a composite panel generally in the form of discrete pieces or particles, as distinguished from fibers, bonded together by a bonding system and may contain additives. Particleboard is classified by the density. It is divided into low-density particleboard, medium-density particleboard and high-density particleboard.

Particleboard is called particle because the component is manufactured by mechanical which means from wood or other lignocellulosic material including all small subdivisions of wood such as chips, curls, flakes, sawdust, shavings, slivers, strands, wood flour and wood wool. Particle size can be measured by the screen mesh that permits passage of the particles, and another screen upon which they are retained or by the measured dimensions as for flakes and strands-ASTM D 1554 terminology relating to wood-based fiber and particle panel material.

Particleboard testing

Particleboard quality can be determined by testing the particleboard chemical, physical and mechanical properties and compare it to the standard use for qualifying particleboard. American National Standard Particleboard ANSI A208.1-1999 and Indian Standard specification for high density wood particleboard IS: 3478 -1966 are used as references of the particleboard requirement grades. ASTM D 1037-99, ASTM D 1037-06A, ASTM D 4442 and ASTM D 2395-07A are used as a reference in testing board.

Mechanical properties test suitable for wood panel material is tensile test and bend test base on ASTM D 1037-99. Tensile test use to determine the strength, also known as tension test, is probably the most fundamental type of mechanical test that can be performed on material [31]. Bend or flexure testing is common in springs and brittle materials whose failure behaviors are linear. Bend test is suitable for evaluating the strength of brittle materials, where interpretation of tensile test result of the same material is difficult due to breaking of specimens around the specimen gripping.

Physical properties test that is suitable for particle panel is thickness swelling and water absorption, density test and moisture content. Water absorption and thickness swelling were tested to evaluate the water resistance properties [32]. Chemical properties can be tested by using XRD to identify orientation, crystallite size and structure, high resolution diffraction and layer thickness measurements [33].

Figure-2. Samples of cassava branches.

Preparation of making board

The particleboard produced was in 15 cm square by 0.6 cm of thickness. After separation process, the cassava waste was chopped about 2 inches long. Then, the sample was dried in a laboratory oven between 3% to 5% moisture content. It was dried at 105^{o}C in 24 hours. The moisture content was determined by using standard oven dry method ASTM D4442. Green weight is the weight of fresh sample and oven dry weight is weight of sample after drying in oven. It was calculated in gram unit. Then, about 5% of the dry solid weight of cassava plant waste was calculated for each sample by using formula:

5% Moisture content = (5/100) X the dry solid weight (1)

After that, the sample was crushed (Figure-3 (a)) and grind into 2 mm in size (Figure-3 (b)). Then, the particle will be sieved in 2 mm to 0.5 mm (Figure-3 (c)). Next, the sample was treated for 30 minutes in the hot water at 80°C to remove parenchyma cells and inhibit fungus in the sample before it was mixed with adhesive manually (Figure-3 (d)).


(a) (b)

(c)

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(d)

Figure-3. (a) Crushing (b) grinding (c) sieving (d) treatment

After treatment, the sample was dried in the oven again using 105°C for 24 hours. But, three replicate of a 100 g sample of each cassava plant age is used as references to achieve only 5% moisture content for making particleboard (Figure-4).

(a)

(b)

Figure-4. (a) Oven drying sample after treatment (b) 9 month dried sample.

The target density was produced in laboratory condition by referring to particle fixed density. Next step, the sample was mixed to 40% polyurethane resin of the dry solid weight of raw material. The ratio used for resin to hardener was 1.6:1. Polyurethane binder used for part A was polyol resin and part B was an isocyanate curing agent or hardener. The board expected outcome density and preparation of resin is calculated using several steps. Density of cassava and resin was calculated to know the ideal mass to fill in mold when using the compressing mold machine.

After that, the sample being compressed into 10 minutes with 1500 Psi/10.34214 MPa pressure under 100^{o}C, hot press was conducted by compression molding machine before the resin of the particle dried (Figure-5 (a)). Next, post cure was conducted under 50^{o}C for 24 hours before putting the sample in the conditioning room for 24 hours more (Figure-5 (b)). The last step for sample preparation was mark the size and cut the board according the test needed size. Board quality was analyzed by using several tests [35].

(a) (b) (c) (d)

Figure-5. (a) Sample in mold ready to compress (b) sample post-cure (c) mark on sample (d) 9 month specimen needs to be tested.

Test

In this research several tests have been conducted which are bending test, density test, moisture content test, thickness swelling, water absorption test and XRD. Particleboard then was cut into specimen test size for all tests referred to ASTM D 1037-99 which is a standard test method for evaluating properties of wood based fiber and particle panel material. Each test was repeated for 3 times. These test methods cover small-specimen tests for wood-base fiber and particle panel materials that are made to provide data for comparing the mechanical and physical properties of various materials. Data from this test is for determining the influence on the basic properties of raw material to the board.

Firstly, cassava plant raw material moisture content and density was tested to compare and relate the result to the particleboard properties result. Density and moisture content test is the test to know the physical properties of particleboard and the raw material. The moisture content test was tested according ASTM D4442 oven drying method and ASTM D 1037-99 Particleboard Properties. The moisture content test was tested in two conditions which are the moisture content of cassava plant branches and moisture content of particleboard.

Cassava plant branches are cut into small pieces and weighted for 100 g each sample, where each sample

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has 3 replicate. Moisture content test for cassava raw material was conducted according ASTM D 4442 by weight wet cassava plant raw material and weight until 3 last reading was not change which shows there is no water in cassava raw plant raw material. Moisture content of particleboard was conducted by following both ASTM, specimen size and test method which according to ASTM D 1037-99. The formula used to calculate this test was referred to ASTM D 4442. Mass before and after oven-dry of particleboard was taken for a moisture content test of particleboard. A specimen of particleboard for density test and the moisture content test is same. The specimen was cut into 20 × 20 mm.

Figure-6. (a) 12 month cassava plant raw material moisture content test (b) particleboard specimen for moisture content and density test.

2. RESULTS AND DISCUSSION

Moisture Content and Density of Cassava Plant Waste

Physical properties test of a particleboard are the moisture content, density, thickness swelling and water absorption. Chemical properties influence the plant or raw material physical properties, but the manufacturing of particleboard will influence the particleboard physical properties. This difference defines by comparing 6, 9 and 12 months white variety to see the difference in age of the same variety. 12 month yellow variety cassava plant is used to compare the differences in the variety.

Based on the moisture content test of cassava plant waste by using standard oven dry method ASTM D4442 (Figure-7), the result is decreasing as the plant grows older and moisture content percentage between variety is not same. The moisture content result of cassava plant waste that planted in Malaysia is slightly higher from cassava plant waste in Thailand due to many variables related to the environmental condition of plantation area because the plantation method used is same. Normally, soil moisture stress affected the dry weight production and fresh weight yield as well [36] as the plant. This happens because the cassava plant grows together due to the tuber development [37].

Cassava plant moisture content decrease in 6 to 9 month cassava plant is 22.97% for Malaysia and 39.93% for Thailand. But, between 6 to 12 month cassava plant showed a greater value where it had been 46.79% for Malaysia and 48.54% for Thailand. Yellow 12 month cassava plant waste has highest moisture content which is 224.15% compared to 12 month white cassava from Thailand with 189.27% due to the species variation factor (growth of lignin) (Figure-7).

Table-1. Average moisture content data for cassava plant waste in Thailand and Malaysia.

Age of Cassava Plant (Month)	Thailand (%)	Malaysia (%)
6 white	236.06	268.77
9 white	213.09	228.84
12 white	189.27	220.23
12 yellow	224.15	-

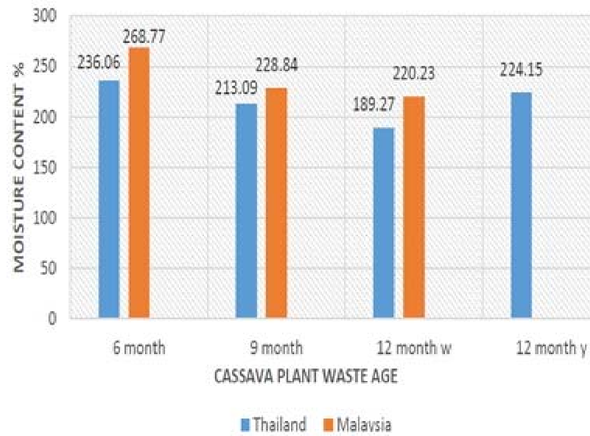

Figure-7. Average moisture content data for cassava plant harvest in Thailand and Malaysia (%).

Result in Table-1 and Figure-7 showed the older the plant the more decrease in moisture content percentage, but increases in density. The older plant has less moisture content and higher density due to the growth of fiber in the plant [38]. The density of wood and water content also varies within and between species [39]. Density of wood normally reflects the moisture content in wood [40].

Based on the density of dry solid cassava plant waste with 5% moisture content (MC) experiment by using the standard specific gravity of wood and wood based materials method B mode IV ASTM D 2395-07a density that have obtained were increased as the plant grow older (Figure-7). Cassava white variety plant waste density that harvests in Thailand varied from 238 kg/m^3 for 6 month sample, about 347 kg/m3 for 9 month sample and 431 kg/m^3 for 12 month sample. Cassava white variety plant waste density that harvests in Malaysia varied from 384 kg/m3 for 6 month sample, almost 447 kg/m^3 for 9 month sample and 465 kg/m^3 for 12 month sample. For 12 month sample of cassava yellow variety density result value is 375 kg/m^3, where it shows a lower density than white cassava plant variety. By referring to the moisture content result (Figure-7), the density result obtained from both countries is the opposite to a moisture content of cassava plant. The yellow cassava plant is from

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a different species, where the density can vary between species [40].

The result shows different density in yellow variety and white variety because of the growth rate, genetic entry and aging rate of vascular cells between species is not same [41].

Table-2. Average density data of dry solid cassava plant with 5 % moisture content harvest in Thailand and Malaysia (kg/m^3).

Age of Cassava Plant (Month)	Thailand (kg/m^3)	Malaysia (kg/m^3)
6	238	384
9	347	447
12	431	465
12 yellow	375	-

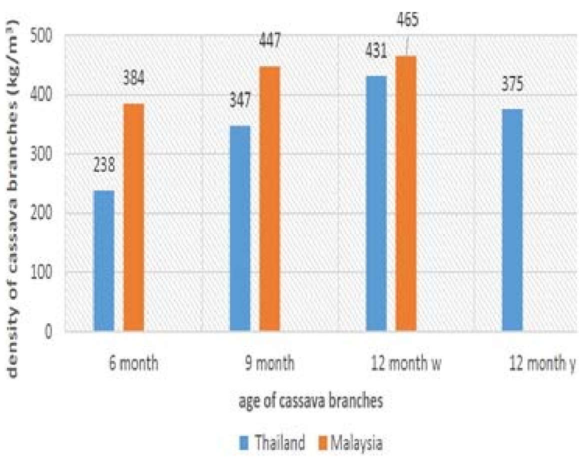

Figure-8. Average density data of dry solid cassava plan waste with 5 % MC in Thailand and Malaysia (g/ml).

The latewood or older wood are stronger because the wall thickness strongly related to wood density [42]. The density and moisture content also related because the older the plant will grow more lignin, reduce tracheid cell and reduce size of lumina. Tracheid cell which present in all vascular plants (xylem) turn into lignin as the plant grows older. When cells actively divide to grow roots and shoot tips (apical meristems), xylem formation begins to raise the primary xylem. In cassava plants, secondary xylem constitutes the major part of a mature stem or root. It is formed as the plant expands and builds a ring of new xylem around the original primary xylem tissues.

In this situation, the primary xylem cells die and lose their function and forming a hard skeleton that serves only to support the plant grow taller. The older branches of a large tree are only the outer secondary xylem (sapwood) serves in water conduction, while the inner part (heartwood) is composed of dead but structurally strong primary xylem. The age of a tree may be determined by counting the number of annual xylem rings formed. Lignin acts as a glue to attach cellulose and hemicellulose and forming a honeycomb porous structure of cell walls [43]. This structure provides high mechanical strength and present highest at the inner part of thick branches or the lowest part of the stem [44].

Lignin content is only one aspect of wood quality. In the wood industry, wood density is used as a parameter to qualify wood product since wood density correlated with wood strength (lignin content). In addition, the late wood cell has smaller cells lumina and thicker cell wall than the early wood cell which cause higher density [45] and lower moisture content. This fact has been proven by the result obtained in Figure-7 and Figure-8. Moisture content in wood is the weight of water in the lumina and cell wall that expressed as a percentage of oven dry weight. So, moisture and density and density vary depending the age of cassava plant [46].

Moisture content and density of particleboard from cassava plant waste

The data obtained for moisture contain of particleboard do not have significantly different because all results obtained is in the same grade. In addition, based on ASTM D1037-99, almost 0.3% error can be ignored because the size of specimen can be in error accuracy in about 0.3%. Values of moisture content for yellow variety is 5.10%, and for white variety the result obtained increased slightly as the age increase which values from 5.30% to 5.66%. But, the result defined for the moisture content of all particleboard is at 5% (Figure-9). All of the specimen percentages of moisture content different are still at 0.3%, except for particleboard from 12 month yellow cassava plant varieties which have different in 0.56%. This shows that the moisture content of raw material from white cassava is better. Indian Standard IS: 3478-1966 states that moisture content percentage of the particleboard shows for grade A particleboard varies from 5 to 10%. In American National Standard Particleboard ANSI A208.1-1999, for high density and medium density particleboard moisture content must not exceed 10%. All ages of the cassava particleboard are in grade A and high density, which according to both standards where it has only 5% moisture content.

There are several factors that can be the cause of different value when manufacturing a particleboard, even using the homogenous raw material. There are two prime factors that can affect the wood product which are its density and moisture content of the wood [44]. But types of wood treatment, type of resin, amount of resin or binder use, the pressure applied in hot press, size of particle use to make particleboard and age of wood also can affect both physical and mechanical test of a particleboard [47].

Table-3. Moisture content test of particleboard.

Month of Cassava Plant	Moisture Content (%)
6	5.30
9	5.63
12	5.66
12 yellow	5.10

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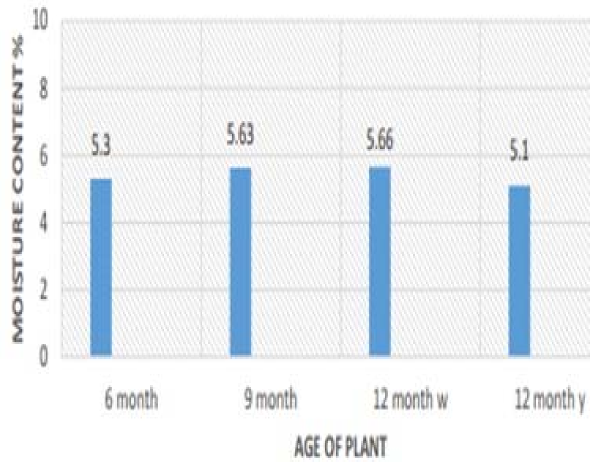

Figure-9. Moisture content of particleboard test.

Hot-pressed board product which including particleboard usually has different moisture content that not same as lumber product. High temperature used to produce these particles assumes to produce lower moisture content for a given relative humidity [44]. Particle absorbed more water in humid condition when mixed with resin, water is condensed and drying during the hot press. Correct balance of moisture content is extremely complicated to achieve because the short press will cause not perfect particleboard, but too long press can cause burns to the particleboard surface. High quality boards normally have almost same moisture content [48].

Resin types and viscosity also influence final board moisture content. A dry solid particle with known moisture content normally mixed to the resin. Some resin can be cured with water, which exceed moisture content in the particle in humid condition will produce excess moisture content in particleboard [49]. In order to improve quality of board, high content of resin has been used in the particleboard manufacturing. This amount is allowed in IS: 3478-1966 to produce high quality and high density particleboard, but must be used non-formaldehyde release resin. So, 40% polyurethane binder is used due to its high water resistance, able to cure moisture and facilities in high compression. This amount is used to achieve same moisture content value for all particleboard, and to see if there is largely different moisture content between different age of cassava waste particleboard.

Result of particleboard moisture content not correlated to result of moisture content in the cassava plant which caused by the hot pressure applied, the resin surface contact with the wood particle and treatment applied to the particles. Fiber is not holding tightly after treatment and drying process cause lack of proper wetting. During the treatment, parenchyma cell was removed and these allow resin to fill the place. Parenchyma function is to absorb nutrients, so it is very excellent in transporting water. Its cell wall is thinner than xylem cell but when water resistance resin replaces, this cell humidity in the environment will not influence the particleboard moisture content greatly. Younger plants have lower fiber than in the older plant because the lignin content is lower and fiber is not tightly holding [22]. The lower moisture content in the particleboard made the free space already filled with the resin. These phenomena cause only a slight increase of particleboard moisture content as the plant grows older.

Density of particleboard test

The target density of the particleboard is about 14000 kg/m^3. Based on density test using ASTM D 2395-07A standard test method for specific gravity of wood and wood-based material, method A-measurement, the result achieve for the average of the test data where the density of particleboard from 6 month cassava plant waste is 992.47 kg/m^3, a density of particleboard from 9 month cassava plant waste is 1001.25 kg/m^3 and a density of particleboard from 12 month cassava plant waste is 1088.7 kg/m^3. In Figure-10 shows the resultant increase slightly as the age of the cassava plant waste increase, but the density of particleboard from 12 month yellow cassava plant waste is 967.85 kg/m^3. It is not same as the 12 month white cassava plant waste, the density of particleboard from yellow cassava plant waste have the lowest density among the entire sample. However, all the particleboard density is related to the density of the cassava plant waste.

The density of particleboard increase as the density of cassava plant increase, so the age of raw material influences the density of the final product. Based on ANSI A208.1-1999 particleboard by using 40% polyurethane binder to these particleboards, the density of the board can be classified as high density particleboard which is above 800 kg/m^3 where the density test result of these particleboard is about 967 kg/m^3 to 1088 kg/m^3. Based on IS: 3478-1966, density of those particleboards is in type 1 grade A particleboard. The target density of the particleboard is 1400kg/m^3, but it is not achieving due to the error in the manufacturing. For example, when mixing particle with glue, there is some particle left in the mixing bowl. And when pressing, there are some particle left between mold when pressing.

Particleboard failed to meet the targeted density also because it is contained larger quantity of fine particles on both top and bottom surfaces of the particleboard. Hence, it caused less space void in the particleboard. The board is practically denser than that particleboard with less fine particles [50]. Particle size used for all these particleboards is from 0.5 to 2.0 mm, so smaller and only one size should be selected to achieve the target density to reduce space void in the particleboard. Moreover, after cutting some specimen there are spaces between the first pre-press particleboard and the full press, the space void also causes reduced of the density of particleboard. Density of particleboard not correlated to the moisture content because drying and treatment occurs is removing the parenchyma cell, but not the lignin so the density of the board keeps in increasing order as the plant grows older [51].

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Table-4. Density test average data for particleboard from cassava plant waste in Thailand (%).

Month of Cassava Plant	Thailand (kg/m³)
6	992.47
9	1001.25
12	1088.7
12 yellow	967.85

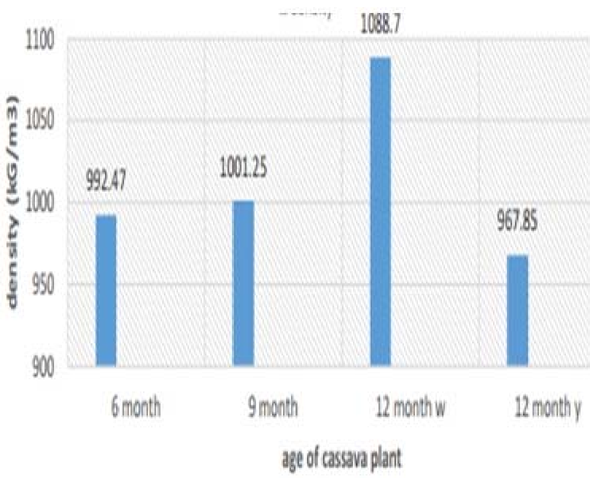

Figure-10. Average density test data for particleboard from cassava plant harvest in Thailand (%).

Water absorption and thickness swelling test of particleboard

Water absorption and thickness swelling test was conducted by following ASTM D1037-99. Based on the average data that have been obtained, data of the result related to the age of the cassava plant waste. The data of water absorption test shows increase of water absorption is according the age of the cassava plant waste which shows 14.03% for 6 month, followed by 11.58% for 9 month, about 10.58% for 12 month white cassava and yellow variety resulted highest water absorption which value at 17.40% (Figure-9). According to Indian Standard IS: 3478-1966, all particleboard from the white variety cassava plant is in grade A type 2 high density wood particleboard where the percentage values of water absorption is lower than 15%. For particleboard from yellow cassava plant raw material, it is classed in grade type 2 high density wood particleboard because the percentage values of water absorption is lower than 25% but higher than 15%.

Table-5. Water absorption test average data for particleboard from cassava plant waste in Thailand and Malaysia (%).

Month of Cassava Plant	Water Absorption (%)
6	14.3
9	11.58
12	10.18
12 yellow	17.40

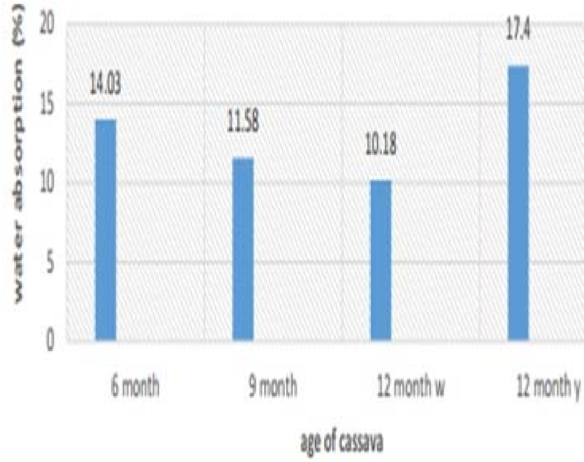

Figure-11. Average water absorption test data for particleboard from cassava plant harvest in Thailand (%).

Water absorption is increase which according to the age and not correlated but reflect the moisture content result although parenchyma cell was removed. Hot water treatment was used to remove only parenchyma cells, which have high capacity in absorbing water compared to sclerenchyma cell [51]. Parenchymas perform many basic plant cell functions, including storage, photosynthesis and the secretion of nutrient. Sclerenchyma cells have a thick cell wall and reinforced with lignin, which is a tough molecule found in wood. The cell walls of sclerenchyma cells are so thick, where mature sclerenchyma cells die because they cannot get food or water across their walls via osmosis. But, early produce sclerenchyma (primary xylem) is not removed so its function to transport water still can operate.

Younger plant branches will have more primary xylem and bigger lumen, so the water absorption result is higher than the mature plant [44]. Primary xylem cells availability become retarded in moisture content because resin holds fiber tighter than their original starch and resin replaces the free space from removing parenchyma. But, when soaked in water for 24 hours, dimension of particleboard will increase when a thermal change as a result of the taking up of another phase [52]. Thickness swelling and water absorption also occur because there are possibility the cohesion of the material (parenchyma) is diminished, but not eliminated during particle treatment. When soaked in the water, the particle stress which have been compressed and glued will straightening and expanding.

High pressure which is from 3 N/mm^2 or more will cause severe compression crushing of cell wall (xylem and lignin) in particles, which lead to regaining the original shape before pressing when exposed to water or vapor that can cause the breakage of the glue bond hence swelling occurs. Interaction between moisture and the particleboard leads to the development of swelling stresses that cause the failure of the resin bond and the dislocation of the particles within the panel [52].

Resin role as water resistance is very important. Previous study determines the lowest swelling was observed when phenol-formaldehyde or polymeric isocyanate (PMDI) adhesive (polyurethane resin) were used. Low swelling is when using melamine or melamine-urea-formaldehyde adhesive and the highest swelling was observed when urea-formaldehyde adhesive was used [52]. It related to previous study where the results obtain for both water absorption and thickness swelling test is correlated.

Thickness swelling test shows almost same result, where only a very small decrease according to the age of cassava plant waste. All particleboard swell of 7%, particleboard using 6 month raw material swell in 7.68%, 9 month with 7.63%, for 12 month about 7.45% but 12 month yellow cassava plant raw material swells higher than all white cassava plants which value of 7.83%. Result among white cassava plant particleboard show different less 0.3%, based on ASTM D1037-99 error could occur in this value. So, the difference is not considered significant. Moreover, American National Standard Particleboard ANSI 208.1-1999 state that high density particleboard should not swell more than 2.0 mm. All these particleboard only swells about 0.65 mm to 0.73 mm (Figure-10). So, all these particleboard thicknesses swelling are parallel to ANSI 208.1-1999 high density particleboard requirement. Thickness swelling of particleboards is influenced by the water absorption.

Bending test of particleboard

Based on the result of the test obtain, modulus rupture and modulus elasticity result obtained from 3 point flexural bending of the cassava particleboard are increasing parallel to the age maturity. Particleboard from 6 month raw material have 30.066 N/mm^2 flexural strength MOR and 1904.827 N/mm^2 for MOE result, particleboard from 9 month raw material have 37.429 N/mm^2 for MOR and 2812.790 N/mm^2 for MOE result, particleboard from 12 month raw material have 44.681N/mm^2 for MOR and 2968.463 N/mm^2 for MOE result, for particleboard from 12 month yellow variety cassava plant raw material have only 28.115 N/mm^2 for MOR and 1891.689 N/mm^2 for MOE. Based on this result, particleboard from 12 month yellow variety cassava plant raw materials have the lowest flexural strength.

MOR result obtained was correlated to all physical test results of particleboard and cassava plant raw material because the increase and decrease value pattern is parallel as expected (Figure-12). This shows chemical properties of cassava plant influence the mechanical properties of a particleboard. MOE result also correlates to all physical properties of particleboard (Figure-13). However, there are several factors that might affect the elastic moduli which are the resin elasticity and plastic deformation at the rollers supports or the loading points might not be sufficiently small in comparison to the beam deflection. In this study, MOE results show clear correlate to other results, so MOE results influence by the chemical properties of cassava plant.

Lignin content in the plant is the major factors influence the result of mechanical properties of a particleboard. Tracheid cell walls will be thicker and denser as the plant grow older until it becomes not permeable to water, where cell die and turn to dense fibrous material called lignin. Lignin will hold other fibrous material in plant to support plant grow taller, so present of lignin increase the mechanical properties of plant [18].

Based on American National Standard Particleboard ANSI A208.1-1999, particleboard from 9 month and 12 month white cassava plant raw material fulfill the MOE requirement for high density particleboard. But, particleboard from 6 month white and 12 month yellow does not fulfill the requirement for high density particleboard but only meet the MOE requirement for medium density particleboard. The MOE requirement for high density particleboard is from 2400 for high density particleboard grade (H-1).

Next, the MOR result of all particleboard made meet the requirement of high density particleboard grade (H-1) in American National Standard Particleboard ANSI A208.1-1999 which is from 16.6 N/mm^2. In addition, all particleboard from white cassava also meets the need of MOR in Indian standard for high density particleboard grade A type 2 which is from 29.42 N/mm^2, but 12 month yellow cassava only meets the need of high density particleboard grade B type 2 which is from 24.5 N/mm^2.

Table-6. Modulus rupture (MOR) and modulus elasticity (MOE) of particleboard bending test.

Age of Cassava Plant (Month)	MOR (N/mm^2)	MOE (N/mm^2)
6	30.006	1904.827
9	37.429	2812.790
12	44.681	2968.463
12 yellow	28.115	1891.689

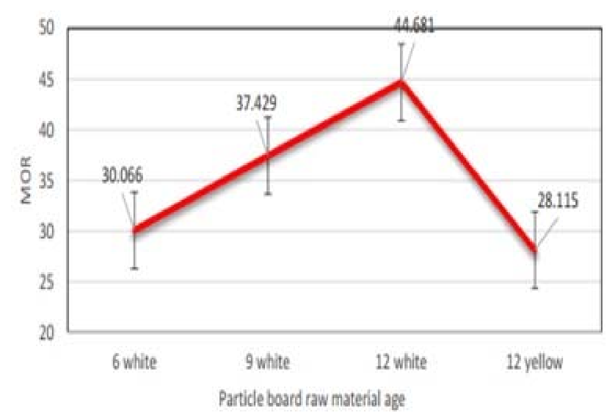

Figure-12. MOR graph for particleboard from cassava plant harvest in Thailand (%).

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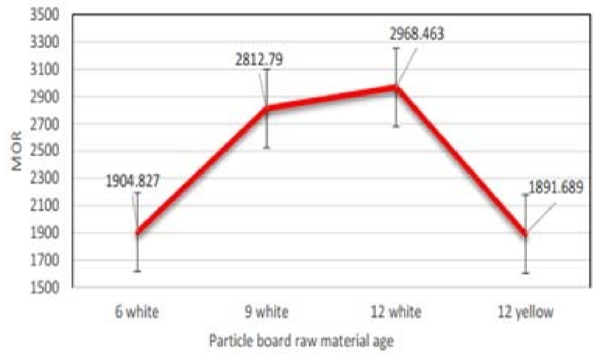

Figure-13. MOE graph for particleboard from cassava plant harvest in Thailand (%).

XRD Test

The graphs only show the crystallinity in the cassava plant waste material. Previous studies state that the increase the fiber content will result the decrease the degree of crystallinity [18]. Based on Figure-11, cassava plant waste has percentage crystallinity decrease as it matures, so this shows that the older the plant will produce more fiber. 12 month yellow variety have higher fiber compare to 6 month and 9 month white variety, but lower than 12 month white variety. White variety cassava plant waste material percentage of crystallinity values for 6 month is 18%, 9 month is 17.6% and 12 month is 16.2% while 12 month yellow cassava plant value is 16.6% (Figure-11). XRD test is done to prove that fiber in the cassava plant increase as the plant grows older and white variety cassava plant contain more fiber than yellow variety cassava plants. Based on this result, all physical properties and mechanical properties are related because of the growth of fiber, which has chemically changed in the plant cell structure.

Table-7. Crystallinity of fiber in cassava plant.

Month of Cassava Plant	Crystallinity (%)
6	18.0
9	17.6
12	16.2
12 yellow	16.6

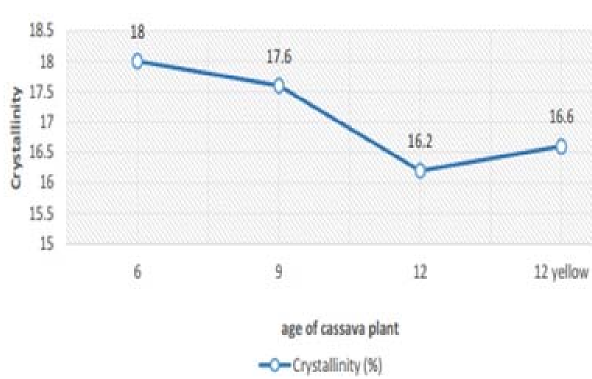

Figure-14. XRD test data for particleboard from cassava plant harvest in Malaysia (crystallinity %).

3. CONCLUSION AND RECOMMENDATIONS

Conclusion

In conclusion, based on all physical, mechanical and chemical properties of raw material and particleboard, the best raw material should be used in the development of bio-composite which is a particleboard is 12 month white cassava plant branches. 12 month yellow cassava variety also the mature plant but by comparing to 12 month white cassava plant branches, large differences in all properties test were shown so different variety of cassava plant also influence the properties of a board. It is proven that all objective in this study can be fulfill by using data from all properties test which are mechanical (static bending test), chemical (XRD) and physical test (moisture content, density, thickness swelling and water absorption)

Recommendations

In this research, several recommendations should be applied to improve the result of research. Usually in other research of bio-composite, scanning electron microscopy (SEM) is applied to see the cross section of particleboard in microscopic size. SEM should be used in this research to see the fiber composition in a different age of cassava plant and the modification of fiber after manufacturing processing, so the result explained will be prove visually. Moreover, about 40% usage of resin is high compared to other research, lower usage of resin should be applied and compare the mechanical, physical and chemical properties. In addition, when handling the raw material, time management is very important to avoid repeating experiment that caused by raw material over raw material exposed before the test and over oven-dry.

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