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POTENTIAL OF CASSAVA ROOT AS A RAW MATERIAL FOR BIO COMPOSITE DEVELOPMENT

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ABSTRACT

In recent years, a lot of researches have done by domestic and foreign scholars to enhance and improve the development of man-made board production that based on natural fiber and agricultural residues. Due to a worldwide shortage of forest resources which have been excessive cutting, man-made board production has become one of the alternative ways to solve wood supply problems. Particle board is a panel product manufactured under pressure from particles of wood or other ligno-cellulosic materials and an adhesive. In Malaysia, the demand and trend of uses wood panel product such as particle board is increasing in the market. The purpose of this study is to identify the potential use of cassava root as a raw material for bio-composite development. In this research, cassava root from different ages (6, 9 and 12 months) were used for production of bonded particle boards by using polyester as a binder. Constant resin content, temperature, time pressing and pressure were applied during boards' production. Moisture content, density, water absorption and thickness swelling test were carried out to determine dimensional stability of the boards while static bending tests were carried out to assess the mechanical strength of the boards. Particleboard from 12 month cassava root gave the best results in term of physical and mechanical properties. But, particleboard from 12 month cassava root did not meet the ANSI/A208.1-1999 standard for general-purpose boards. For this reason, additional research needs to be done on improving the physical and mechanical properties produced from different ages of the cassava root.

Keywords: bio-composites, composite wood product, mechanical properties, cassava root.

1. INTRODUCTION

Cassava

Cassava, Manihot esculenta Crantz (Euphorbiaceae) is a perennial shrub that belongs to the family Euphorbiaceae. Besides, there are 98 species of genus Manihot which M.esculenta is the most widely cultivated members [1]. For English speaking countries of Africa, it is commonly known as cassava while mandioca and yucca in Latin America; tapioca in Tropical Asia and manioc in Francophone Africa.

Some studies indicate that cassava has multiple centers of origins, but others suggest that the cultivated species originated on the southern edge of the Brazilian Amazon [2]. It also becomes staple food and animal feed in tropical and subtropical with an estimated total cultivated area greater than 13 million hectares where 70% is in Africa and Asia [3].

Generally, the simple leaves consist of the foliar lamina and the petiole in which the foliar lamina is palmate and lobate. But, completely developed leaves are in different colors and depending on the cultivar. The basic colors are purple, dark green and light green. Moreover, there are marked differences in leaf size according to different varieties and age of the cassava. There are a few shapes of cassava leaf lobes which are elliptic, lanceolate, straight or linear, obovate-lanceolate, pandurate and arched [4]. In fact, Manihot esculenta Crantz, cassava is a monoecious plant in which male and female flowers on the same plant [5]. In addition, there are great differences in the time of flowering and the number of flowers produced from cassava. While the cross pollination usually occurs and accomplished by insects.

Composition of cassava root

Generally, composition of cassava (Manihot esculenta Crantz) in Table-1 depends on the specific tissue (root or leaf) and several factors such as geographic location, variety, age of the plant and environmental conditions. Besides, roots and leaves which constitute 50% and 6% of the mature cassava plant are the nutritionally valuable parts of cassava. So, nutritional value cassava roots are important because becoming the main part of the plant consumed in developing countries [3]. Cassava tuber is originally high in starch and carbohydrates but contains small amounts of protein, vitamins and minerals [6].

Fiber in cassava root

The term of "fiber" can be defined as any single unit of matter characterized by flexibility, fineness and a high aspect ratio. It also broadly classified as natural and man-made [7]. But, plants that produced the natural fiber are classified into primary and secondary. Besides, their classification also depending by utilization**.** There are 6 basic types of natural fibers based on Table-1 [8]. Cassava root is categorized underwood fibers.

Table-1. Composition of cassava root [6].

Composition	Unit	Fresh Weight	Dry Weight
Moisture	%	62-66	15-19
Starch	g	18-32	81
Carbohydrate	%	35	ND
Protein	g	1	1
Calcium	mg	26	96
Fiber	g	1.10	1.20
Ash	g	0.9-1	2

ND = not determined

Application of cassava

Cassava is extensively used for various industrial applications apart from food and feed consumption [9]. About 70% to 80% of cassava produced is used exclusively for making flour in Brazil. Cassava starch is used in many sectors including the food industry, pharmaceutical industry, foundry, textiles, paper and adhesives. Cassava also has three potential bio-fuels that can be generated at an industrial scale from its biomass. For examples bio-ethanol, biodiesel and biogas [7].

Leaves, stalks and waste from cassava also can be a source of by-products. By-product usually refers to a product which is produced in addition to the major industrial product. Cassava stem could be a source of by-products such as plywood and particle board. The cutting of the stem is mixed with resins and could be used as particle board for local and external markets. Besides, this by-product could reduce the waste of the cassava plant to the barest minimum. It also helps reduce the cutting of trees from the forest for similar use as well [10].

Classification of bio composite

In fact, bio composite have been used for sustainability and considerable advancements have been made to perfect the physical and mechanical properties. Besides, bio-composites are typically made by combining two or more constituents (natural fiber and natural/synthetic polymers) which have different physical and chemical properties too [11].

Green composites

Developing a fully biodegradable “green” composites by combining (natural/bio fiber) with biodegradable resins are currently being harnessed by research effort. Green composites have major attraction because they are environmentally-friendly due to fully degradable and sustainable. In addition, they can be easily disposed of or composed without harming the environment [12-16].

Advantages of natural fiber bio composite

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 [17]. Moreover, there are relatively cost effective have low coefficient of friction, exhibit good thermal conductivity and dimensional stability and low density [18-19]. In addition, they have thermal resistance which resulting in a higher specific strength and stiffness than glass fiber and other renewable sources [20-26].

Application of natural fiber bio composite

The plant that 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 [17]. 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, usually used in electronic industry [27-28]. 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 particle board (hardboard, medium density board, insulation board) [29-30].

Particleboard

Generally, particleboard can be defined as a wood-based panel product manufactured from varying particles of wood or other lignocellulosic materials and a binder, consolidated together under pressure and temperature [31]. Particle board is a small piece of wood or other lignin, cellulose material as the basic unit of the applied adhesive in hot-pressing process conditions of hot press forming a man-made plank. Besides, it has good mechanical stiffness, mechanical strength and physical properties instead of low cost. Moreover, it has been used widely for furniture manufacturing industries, construction and effective way of saving forest resources [32].

2. MATERIAL AND METHOD

Particleboard is a wood-based panel product manufactured under the temperature and pressure from other lignocellulosic fibrous materials or particles of a wood and a binder [33]. In this study, the materials that used for the production of particleboard are cassava root and adhesive as a binder.

Cassava roots

Cassava root was used instead of cassava baggase. This is because cassava baggase is very difficult to get and there are lack of reports about the use of cassava roots as a raw material for bio composite development. Chalk-white cassava root that categorized as a bitter cassava root was selected instead of yellowish cassava root. It is because most of bitter cassava roots were used in industrial production such as cassava pellets for animal feed, glue and fuel [34].

Adhesive

Polyester resin was used as an alternative resin for binding purposes. Unsaturated polyester resins or commonly known as polyester resins are the group of

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polyesters in which the acid component part of the ester is partially composed of fumaric acid, a 1,2-ethylenically unsaturated material. Besides, they are widely used commercially as a fiber, plastics, composites and for coatings applications too [35]. Methyl ethyl ketone peroxide (MEKP) liquid was used as a hardener. When MEKP liquid hardener is mixed with the resin, the resulting chemical reaction causes heat to build up and cure or harden the resin.

Material collection and sample preparation

Figure-1 shows the different ages of chalk-white cassava root between 6, 9 and 12 months that were obtained from cassava plantation located at Mardi Bachok, Kelantan. In this research, ages of cassava root had been used as a parameter.

Figure-1. Chalk-white cassava root of 6, 9 and 12 months.

The cassava roots were cleaned and chopping into a smaller size by using chipped machines. For sample preparation, the cassava root chips (Figure-2) for each age were air drying in a laboratory oven with a moisture ratio of 3%-5% moisture content. They were dried for 48 hours at 103 ± 2^{0}C.

Figure-2. The cassava root chips.

The cassava root chips had been ground into 2mm in size. Then, the particles were screened by using standard sieves to obtain particles in the size range 0.5-2.0 mm. Based on previous studies, the optimal sieve sizes (4 and 2 mm) were used for the classification. The particles were then classified using an automatic shaker (Figure-3) with sieves to remove oversize and undersize (dust) particles.

Figure-3. Automatic shaker.

Pre-Treatment process

After screening, the particles had been undergoing the pre-treatment process. The particles were transferred into hot water in the water bath at a constant temperature of 80^{0}C. Hot water was used to extract inhibitory sugar compounds [36]. So, proper setting of the board can be ensured after the extraction [37]. Then, the extracted materials (Figure-4) were air drying in a laboratory oven for 48 hours at 105^{0}C.

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Figure-4. The extracted material after pre-treatment process.

Resin addition process

Preparation of polyester as the resin and MEKP was prepared as a hardener. Polyester was mixed with MEKP by 15: 5 (the liquid content) in a glass beaker. Then, the mixture was mixed with cassava root particles of 6, 9 and 12 months in a tray. The particles and resin were mixed manually for 5 minutes to ensure that the particles are evenly mixed with the resins [38].

Particleboard production

The cassava root particles were removed from the tray and were spread evenly into mold (Figure-5), with a dimension of 150 mm x 150 mm x 8mm by using an upper and base metal plate. A thin layer of wax was placed onto the plate to prevent the particleboard from sticking to the plate during the hot press process [39].

Figure-5. Mold that used for the hot press process.

A total of 9 particleboard with the target density, 900 kg/m^3 with 3 replicates for each age of the cassava root. In this research, high density particleboard had been expected to be produced for general purpose use. The mold was compressed by pressure method. Pressure method is very popular in the manufacture of natural fiber composites due to lower cycle time and high reproducibility [8]. The mold was pressed by hot press that uses hydraulic system (Figure-6), under standard molding conditions: temperature, 100^{0}C; pressure during heating 5 MPa; heating time, 10 minutes [40]. Constant resin content, temperature, heating time and pressure were applied during production of the boards.

Conditioning process

For conditioning process in Figure-7, the particleboards were then cooled under room temperature and left for one hour [41]. The main purpose of this process is to stabilize the particleboards before undergoing property evaluation later on [39].

Figure-6. Hot press that used during particleboard production.

Figure-7. Conditioning process of different ages of cassava root particleboards.

Methods of Testing

In order to evaluate the properties of the particleboards produced, physical (moisture content; density; water absorption and thickness swelling) and mechanical (bending test) assays were carried, according to the American Society for Testing and Materials-ASTM D 1037 standard with modification of size of test specimens. The average values from those testing were compared with the minimum required for particleboard production by the norm of the American National Standards Institute-ANSI/A208.1-1999. X-ray diffraction (XRD) analysis was carried out to identify the chemical properties by determination of crystallinity in percent from different ages of the cassava root.

Determination of moisture content of dried solid cassava root and cassava root particleboard

Three replicate samples of 100 grams were taken from each age of cassava root (Figure-8) to determine the moisture content of dried solid cassava root. While, three replicates of the cassava root particleboard with the dimensions of 20 mm x 20 mm were cut to determine the moisture content of each age.

Figure-8. Samples of 100 grams from each age of cassava root.

Oven-drying method was applied according to the ASTM D 4442-07 [42]. The samples and boards were dried for 24 hours at 105 ± 2^0C. After 24 hours, the oven dry weight for each sample and boards were weighed. They were weighed again for every 4 hours until constant mass. The moisture content for each sample were calculated as follows:

$$MC (\%) = [(A - B) / B] X 100 \quad (1)$$

where A is the original mass (g), B is the oven-dry mass (g) and MC (%) is the moisture content of the samples in percentages.

Determination of density of dried solid cassava root and cassava root particleboard

Flotation tube method was used to determine the density of different ages of dried solid cassava root in accordance with the procedures stipulated in ASTM D 2395-07a [42]. While, cassava root particleboards with the dimension of 20 mm x 20 mm (Figure-9) were cut to determine the density.

Figure-9. The square samples of 20 mm x 20 mm from different ages of cassava.

The density of each board was determined by using the method of volume by measurement according to ASTM D 2395-07a [41].

Water absorption and thickness swelling

The determination of 24 hours water absorption (WA) and thickness swelling (TS) tests were performed according to ASTM D 1037-06a [39]. The tests were carried out in order to investigate the physical properties of the particleboard reinforced with polyester resin. A thickness swelling test was conducted to determine any changes in specimen dimension [41].

The square samples of 15 mm x 15mm were left submerged 3 cm under the distilled water at room temperature for 24 hours to determine long term water resistance properties, respectively [43]. The samples were taken out and surfaces were dried using a clean dry cloth after going through an immersion process [39].

The weight and thickness of the samples were measured before and immediately after soaking. Water absorption and thickness swelling were calculated as follows:

$$WA(t) = [(W(t) - W_o) / W_o] X 100 \quad (2)$$

where WA(t) is the water absorption (%) at time (t), W_0 is the initial weight and W(t) is the weight of the samples at a given immersion time, t [44].

$$TS (\%) = [(T_f - T_i) / T_i] X 100 \quad (3)$$

where T_f is the final thickness after soaking in the period of 24h and T_i is initial thickness

3. RESULTS AND DISCUSSION

Comparison of moisture content between dried solid cassava root and cassava root particleboard

Table-2. Average value of moisture content for different ages cassava root.

Samples (Months)	Moisture Content of Dried Solid Cassava Root (%)	Moisture Content of Cassava Root Particleboard (%)
6	205.73	8.50
9	196.92	7.60
12	191.47	7.18

Based on Table-2, it showed that the highest and lowest moisture content for dried solid cassava root from different ages were 205.73% and 191.47%, respectively. The lowest moisture content for particleboard was 12-month cassava root with 7.18 % ; while, 6-month cassava root particleboard obtained the highest moisture content, 8.50%. Based on ANSI/A208.1-1999 standard, to achieve the requirement of high –density grade particleboard (H-3) for general use, average moisture content is shall not exceed 10% (based on the oven dry weight of the board). The results showed that particleboards with 6, 9 and 12 month cassava root passed to achieve the requirement.

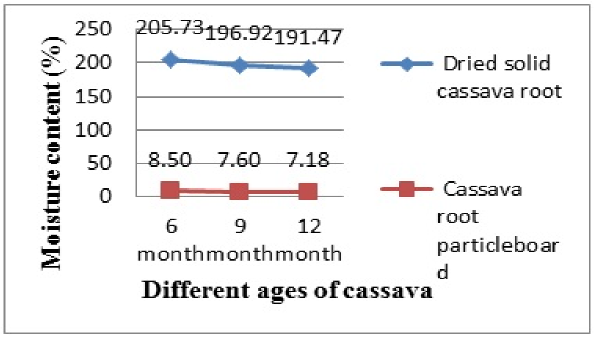

Figure-10. Percentages of moisture content from different age's cassava root.

Based on Figure-10, the moisture contents of dried solid cassava root and cassava root particleboard were decreased by their ages. The average values of moisture content for dried solid cassava root ranged from 191.47% to 205.73%. Generally, if the moisture content is greater than 100%, the water weighs more; but, if the moisture content is less than 100%, the water weighs less. Clearly, it shows that the water weighs more in 6, 9 and 12 month of dried solid cassava root. The 6-month dried solid cassava root has the highest moisture content compared to others. While, the lowest moisture content was 12-month dried solid cassava root.

Based on the study made [45], it was proved that the rate of accumulation of water content and the rate of formation of fiber was increased parallel with the increased of ages cassava root. However, the water content decreased when the roots become more fibrous and woody with time. The higher the fiber content, the lower the water content of the cassava root. It was reported that the water content decreased due to the granule size, granule structure, granule size distribution and hydration properties by the age of the root. The average values of moisture content from different ages of cassava root particleboards ranged from 7.18% to 8.50%. 12-month cassava root particleboard has the lowest moisture content; while, the highest moisture content was 6-month cassava root particleboard. Previous study made [46] loss of moisture content in cassava particleboard due to the behavior of particles during pressure and resin type used.

In order to make sure that the particle were exposed to high temperature which can cause degradation to hemicelluloses. Hemicelluloses are one of the fiber components that also associated with the moisture content. Fibers that contain high hemicelluloses content should absorb more moisture and degrade at a lower temperature [47].

12-month cassava root particleboard has the lowest rate of moisture content loss. It was due to the stronger bond created between cross-linked and overlapped particles of 12 month cassava particleboard with polyester resin. It caused the degradation of hemicelluloses to be lower, although exposed to high temperature.

For 6-month cassava root particleboard, it shows that there were presence of incompatibility with the resin type used, which was polyester. Since polyester was a hydrophobic matrix polymer [48], the bond between particles and the polyester used (resin) could easily break down because of high water content in the 6-months cassava roots. The particle configuration of younger cassava root was not compact as 12-months cassava root particle because there were empty surfaces between it.

Comparison of density between dried solid cassava root and cassava root particleboard

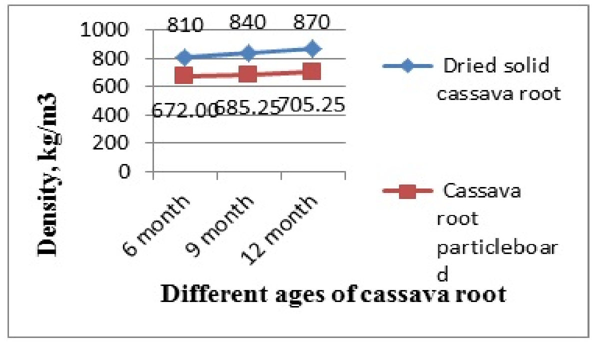

Figure-11. Density, kg/m^3 of different ages cassava root.

Based on Figure-11, densities of dried solid cassava root and cassava root particleboard were increased by their ages. The average values of density for dried solid cassava root from different ages was ranged from 810 kg/m^3 to 870 kg/m^3. 12-month dried solid cassava root has the highest density value; while, the lowest density value was 6 months dried solid cassava root.

6-month dried cassava root has the lowest value of density because consist many parenchyma cells. Parenchyma cells have high capacity in absorbing water of water absorption. As food storage elements, the cells contain sugar and starch, which is soluble in water. Proper treatment had been used to remove parenchyma tissues of the particles to be utilized effectively [49]. According to Figure-11, densities of 6, 9 and 12 month cassava root particleboard were 672, 685.25 and 705.25 kg/m^3 respectively. The actual densities were varied from the target density (900 kg/m^3). Based on ANSI/A208.1-1999 standard, particleboard from 6, 9 and 12 month cassava root can be classified as medium density particleboard. Medium density particleboards usually have a general density between 640 -800 kg/m^3.

Therefore, particleboards from 6, 9 and 12 months were overlapped and cured effectively with the adhesive (resin was used), constant temperature (100^{o}C) during the pressing process was needed. During pressing, particles cassava root do not obtain the general density for high density particleboard. Producing the particleboards manually may have led to uneven density distribution, so that the actual mean panel density varied from target density. In this study, 12-month cassava root was the densest board. It shows that particle configurations of 12-month cassava roots were compatible with resin content used [50]. The lowest value of density board was 6-month cassava root. It shows that particle configurations of 6-month cassava root were incompatible with resin content used in this study. Particleboard made from younger ages was less compact and tight when binding together with resin. It was because of the rate of water being absorbed or released into particle board was high [51].

Previous study made by [44] shows that the density profile depended on the particle configuration, hot press of temperature and rate of closing, resin reactivity and the compressive strength of the particles. The condition was due to an uneven density distribution along the thickness direction of the board due to the interaction between the heat, moisture and pressure [52].

Water absorption and thickness swelling of cassava root particleboard

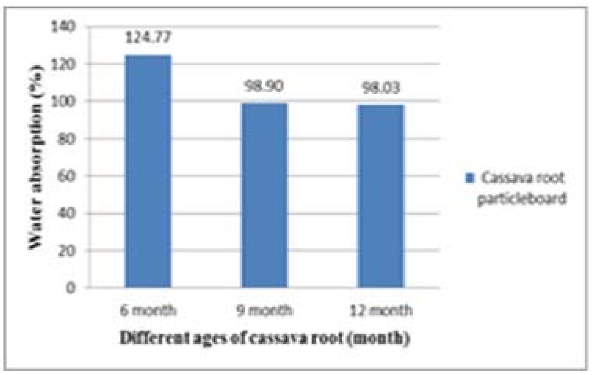

Figure-12. Water absorption of different age's cassava root particleboard.

The dimensional stability of the boards was assessed through water absorption and thickness swelling tests. The ability of composites to absorb water was an indicator for their porosity [39]. Figure-12 shows the values of water absorption of particleboards produced from different ages of cassava root after 24 hours. After 24 hours period post-immersion, the results show the decreased in percentages of water absorption by ages. The average values of water absorption from different ages of cassava root particleboards were ranged from 98.03% to 124.77%.

The highest water absorption was from 6 month cassava root particle board; while, the lowest water absorption was particleboard from 12 month cassava root. The relative high value obtained when 6 month cassava root was used could due to difficulty in compression and the presence of voids in the boards which allowed the boards to take in water [37].

Particles of 6 month cassava root had bigger spaces between each other caused the water molecules to easily substitute the space. 12-month cassava root particleboard was more resistant to the permeation of water. It shows good inter-particle bonding between the particles and matrices; polyester during the hot press process. The smaller spaces between the particles made it difficult for the water molecules to penetrate into the particleboard. So, it reduced the porosity of the board which made the board to become more water repellent [39].

The curing reagent and board density have a significant effect on water absorption. 12-month cassava root particleboard has the highest value of board density (refer Figure-12) than others [53]. Water absorption decreased in term of tight and compact structure and difficult diffusion, when the board density was higher [54]. So, it can be concluded that the higher the density, the lower the water absorption. Highest level of board density also can resist the hydrostatic force against the bonds [53].

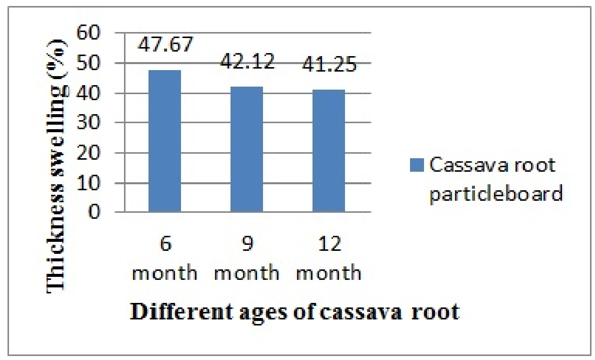

Figure-13. Thickness swelling of different age's cassava root particleboard.

Figure-13 shows the values of thickness swelling for particle boards produced from different ages of the cassava root. It shows that the decreased in percentages of water absorption by the ages. The values of thickness swelling ranged from 41.25% to 47.67%. Previous researches had been reported that thickness swelling was affected by the presence of void spaces in the boards in the same way as water absorption. These spaces enhance the absorption of water by the boards which leads to internal swelling [37].

The lowest value of thickness swelling was particleboard of 12-month cassava root. Higher compaction that had reduced the porosity caused the diffusion rate in a particleboard to be lower. Thus, it lowered the capacity of a particleboard in absorbing water to its limited surface area. Higher compaction reduced water penetration into the particleboard and consequently, the water needs a longer time to diffuse into the particles and panel [39].

Particleboard of 6-month cassava root has the highest value of thickness swelling. It caused by the lower compaction due to the chemical compound in the resin that is incapable of cross-linking with the hydroxyl group of the fibers, hence increasing hygroscopicity of the board. It had been reported that board density also affected the thickness swelling [46]. The report presented were also in agreement with those reported by [44, 53] who observed that board density increased, the thickness swelling will be decreased. 12-month cassava root particleboard has the highest value board density (refer Figure-13) than others. This was due to low porosity and difficult diffusion on the high board density [44].

Various factors of the resin such as the monomer, the polymerization rates, the cross-linking and pore size of the polymer network, the bond strength, the interaction between polymer and water, the filler and the resin filler interface can affect the hygroscopic expansion [39]. Based on previous study made by [46], particles highly bonded together if greater area was covered by adhesive. Therefore, the percentages of water penetration will be less between particles.

4. CONCLUSION

From the result that have been analyzing, the physical and mechanical strength were increased parallel with the increased of age cassava root. From the results, 12-month cassava root obtained the highest values in term of physical (moisture content, density, water absorption and thickness swelling). In this study, 12-month cassava root particleboard did not meet most of requirements that recommended in ANSI/A2 08.1-1999 standards. But, further researches can be done to achieve the requirements. In conclusion, the best age of cassava root which can be used as a raw material for bio-composite development is 12-month cassava root. Moreover, 12-month cassava root has potential to become one of the alternative ways to reduce wood demand in bio composite development.

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