INFLUENCE OF VARYING MIX DESIGN AND FIBER LENGTH ON THE PROPERTIES OF WATER HYACINTH PARTICLE BOARD

MELITO A. BACCAY[1]

[1]*Technological University of the Philippines*

Abstract: This study is focused on the investigation of the influence of varying mix design and fiber length on the properties of water hyacinth particleboard. A total of nine mixtures were considered using three resin-fiber ratio (70:30, 75:25 and 80:20) and three varying fiber lengths (13 mm, 26 mm and 52 mm) to produce 30 cm by 30 cm by 1.2 cm sample boards. The samples were prepared and tested for Water Absorption and Thickness Swelling Test, Modulus of Rupture Test, Face Screw Holding Strength Test, Internal Bond Strength Test and Edge Screw Holding Strength Test based on the Philippine Agricultural Engineering Standards – 320 (PAES – 320) for Type 100 particleboards. Based on the test results, the amount of resin and the size of fibers used in the mix have an influence on the physical and mechanical properties of the particleboard. The more resin used in the mix the lesser the particleboard absorbs water. Moreover, the use of large amount of resin makes the particleboard brittle. On the other hand, the use of small and long fibers in the mix showed a significant effect on the properties of the board. Incorporating smaller sizes of fibers causes higher thickness swelling due to the larger exposed contact area that absorbs water. Consequently, the use of short fibers resulted to a low holding strength in the board and less continuous bond in the fibers, while the use of longer fibers caused difficulty and consistency in the mix which affected the even distribution of the binder. Hence, voids are formed causing lower strength in the particleboard. Generally, the particleboards having a resin-fiber ratio of 70:30 with 26 mm fiber length reinforcement exhibited the best performance among the nine mixtures satisfying the PAES - 320 for Type 100 high-density particleboard.

***Keywords**: fiber, water hyacinth, resin, particle board*

1. INTRODUCTION

Today, the construction industry is rapidly growing at an enormous pace due to the increasing population around the world. As a consequence, shortage of construction materials led to the investigation and development of viable alternative materials that are environment-friendly and technically sound. Presently, particleboard is one of the most popular construction materials commonly used for interior and exterior applications such as walls, ceiling panels, office dividers, bulletin boards, cabinets, furniture, countertops and desk tops (Guru *et al.*, 2008). The most common type of particleboard is made from wood chips which came from timber waste, shavings and mill waste (Odozi *et al.*, 1986). For the last few years, the demand for composite wood products such as particleboards, plywood, fiberboard and veneer board products has increased substantially (Ashori *et al.*, 2009). The increase in the demand for wood products led to the depletion of timber resources. Thus, the depletion of wood resources promotes the use of alternative raw materials for wood products. Agricultural residues comprise an alternative source for wood which would otherwise be used. There are a number of studies which evaluate different agricultural residues as raw materials for a particleboard such as rice husk, walnut shell, almond shell, sunflower stalks, bagasse, corn pith, and tea leaves. On the other hand, many types of natural fibers have been investigated for use in plastics including flax, hemp, jute, straw, wood fiber, rice husks, wheat, barley, oats, rye, cane (sugar and bamboo), grass reeds, kenaf, ramie, oil palm empty fruit bunch, sisal, coir, water hyacinth, pennywort, kapok, paper-mulberry, raphia, banana fiber, pineapple leaf fiber and papyrus. Natural fibers have the advantage that they are renewable resources and have commercial and marketing appeal (http://paspk.org/downloads/Proc44-2/proc44-2-7.pdf).

In this study, the potential of water hyacinth as a viable alternative material for particleboard is being investigated. Water hyacinth (*Eichhornia crassipes*) according to Olal *et al*. (2001) is a floating aquatic plant with fibrous root system and dark green rounded leaves. He also described water hyacinth as the most predominant, persistent and troublesome aquatic weed in the world that posed ecological and biological problems in several countries around the world. The Pasig River and Laguna de Bay are local prime examples of the havoc caused by the aquatic plants in clogging waterways, choking oxygen from the water and also became a breeding area for mosquitoes (Back Packing Philippines, 2007).

According to Davies (2011) one way to increase the utilization of water hyacinth is to turn its apparent disadvantage into opportunities and that everyone wins when we turn this terrible weed into biofuel, organic fertilizer, livestock feeds or furniture. Some alternatives have been done to utilize the vast population of water hyacinth, such as for furniture, fiber boards, geo-textiles and biogas (Appropedia, 2013). Utilizing its strips into products with economic importance is a good solution in dealing with the problem and earlier researches proved that water hyacinth has a potential as a construction material (Ghosh, 1984).

In this purview, the study was conducted to evaluate the influence of varying mix design and fiber length of water hyacinth on the engineering properties of the particleboard produced. Specifically the study aims 1) to determine the physical properties of water hyacinth particleboard through Density, Thickness Swelling and Water Absorption Test; and 2) to determine the mechanical properties of the water hyacinth particleboard through Modulus of Rupture Test, Face Screw Holding Strength Test, Edge Screw Holding Strength Test and Internal Bond Strength Test.

2. CONCEPTUAL FRAMEWORK

The figure below illustrates the logical process on how the research was conducted. In the first phase, determination of environmental problems, studies and concepts, and gathering of relevant materials were undertaken. The second phase is focused on the preparation of materials, production of boards followed by the physical and mechanical property characterization of the samples. Finally, the results were analyzed and interpreted to determine the influence of varying mix and fiber length on the properties of the particleboard.

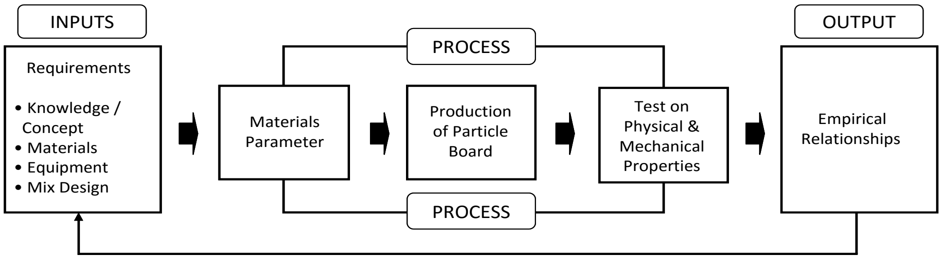

Figure 1. Conceptual Framework of the Study

3. METHODOLOGY

The water hyacinths used in this study were gathered from the Pasig River, Floodway, Pasig City. The stalks from the stems of the water hyacinth were split lengthwise and the fibers were soaked in a solution of caustic soda and water to avoid rotting. It was allowed to dry under the sun for a week until its color turned brown. After drying, the spongy part inside the stalk was removed and then sun-dried to remove excess moisture. The sun-dried water hyacinth stalks were shredded into desired thickness and were cut into three different lengths: 13 mm, 26 mm and 52 mm.

As shown in Table 1, a total of nine mixtures were considered using three resin-fiber ratio (70:30, 75:25 and 80:20) and three varying fiber lengths (13 mm, 26 mm and 52 mm) to produce 30 cm by 30 cm by 1.2 cm sample boards having a density of 0.8 g/cm3. A hardener-resin ratio of 0.03:1 was used for all mixtures. The boards were pressed for 30 minutes under pressing pressure of 20 kg/cm2. The boards were then air-cured and conditioned under ambient temperature for four days to make sure that the resin is hard and it completely binds with the fiber. Each board was cut into 3 - 5 cm x 5 cm for Water Absorption and Thickness Swelling Test, 3 – 5 cm x 23 cm for Modulus of Rupture Test, 3 – 5 cm x 10 cm for Edge Screw Holding Strength Test, 3 – 5 cm x 10 cm for Face Screw Holding Strength Test and 3 – 5 cm x 5 cm for Internal Bond Strength Test. All the tests conducted were in accordance with the standards set forth by the Philippine Agricultural Engineering Standards – 320 (PAES – 320) for Type 100 particleboards.

Table 1. Mix Design Proportion

Mix Design	Resin-Fiber Ratio	Fiber Length (mm)	Hardener-Resin Ratio
1	80:20	13	0.03:1
2	75:25		
3	70:30		
4	80:20	26	
5	75:25		
6	70:30		
7	80:20	52	
8	75:25		
9	70:30		

3.1 Determination of Density

The density of the board was determined using the Mercury-Displacement Method. Mercury was used instead of water for it does not penetrate into the board specimen.

Figure 2. Mercury – Displacement Method for Volume Determination

The density of the board is computed as;

$$\text{Dboard} = \frac{m_{board}}{V_{board}} \quad (1)$$

The volume of the board is determined by;

$$\text{DHg} = \frac{m_{Hg}}{V_{board}} \quad (2)$$

$$\text{Vboard} = \frac{m_{Hg}}{D_{Hg}} \text{ ; } \quad D_{Hg} = 13.55 \text{ g/cu. cm.}$$

Where:

- D_{board} = Density of the board (g/cu. cm)
- m_{board} = Mass of the board (g)
- V_{board} = Volume of the board (cu. cm)
- D_{Hg} = Density of mercury (g/cu. cm)
- m_{Hg} = Mass of mercury (g)
- V_{Hg} = Volume of mercury (cu. cm)

3.2 Thickness Swelling and Water Absorption Tests

Thickness Swelling and Water Absorption Tests were performed to determine the amount of water that the panel can absorb when immersed in water for 24 hours under ambient temperature. The tests provide baseline information about the shrinkage and swelling properties of the board. The initial thickness and weight of the specimen were determined including its final properties after soaking.

The percentage of thickness swelled is computed as;

$$\text{TS (\%)} = \frac{T_f - T_i}{T_f} x100\% \quad (3)$$

The percentage of water absorbed is computed as;

$$\text{WA (\%)} = \frac{W_f - W_i}{W_f} x100\% \quad (4)$$

Where:

- T_f = final thickness (cm)

- T_i = initial thickness (cm)
- W_f = final weight (g)
- W_i = initial weight (g)

Figure 3. Soaking of Specimen in Water

3.3 Modulus of Rupture Test

Modulus of rupture is a property that is used to measure the bending strength of various construction materials such as particleboard. Majority of the works done on the bending strength of the particleboard products are part of an effort in developing high-strength fiber-reinforced particleboard. The test determines the maximum load that can be sustained by the particleboard before rupture.

$$\mathrm{MOR} = \frac{3PL}{2bd^2} \quad (5)$$

Where:

- MOR = Modulus of Rupture in kg per sq. cm.
- P = load based in the UTM (kg)
- b = width of the sample (cm)
- d = height of the sample (cm)
- L = length of the sample (cm)

Figure 4. Modulus of Rupture Test Set – Up

3.4 Face Screw Holding Strength Test

Face screw holding strength test evaluates the performance of the holding strength of the screw at a certain depth of insertion on the face of the board. Subsequently, the screw threaded on the center of the board surface is withdrawn using a Universal Testing Machine until the load capacity of the board is reached.

Figure 5. Face Screw Holding Test Set – Up

3.5 Edge Screw Holding Strength Test

Edge Screw Holding Strength Test evaluates the performance of the holding strength of the screw at a certain depth of insertion on the edge of the board. Subsequently, the screw threaded at the edge of the board is withdrawn using a Universal Testing Machine until the load capacity of the board is reached.

Figure 6. Edge Screw Holding Test Set – Up

3.6 Internal Bond Strength Test

The Internal Bond Strength Test determines the adhesiveness of the material with the binder used. The internal bonding of the particleboard is important because other properties are dependent on this factor. Samples were glued using a special adhesive on both sides and were subjected to load using UTM.

$$\mathrm{IB} = \frac{P}{LW} \quad (6)$$

Where:

- IB = Internal Bond (kg/sq. cm.)
- P = load based from the UTM (kg)
- L = length of the sample (cm)
- W = width of the sample (cm)

Figure 7. Test Specimen for Internal Bond Strength Test

4. RESULTS AND DISCUSSION

4.1 Density of the Board

The density of each mix design was determined through volume displacement. The graph below shows the corresponding density for each mix design.

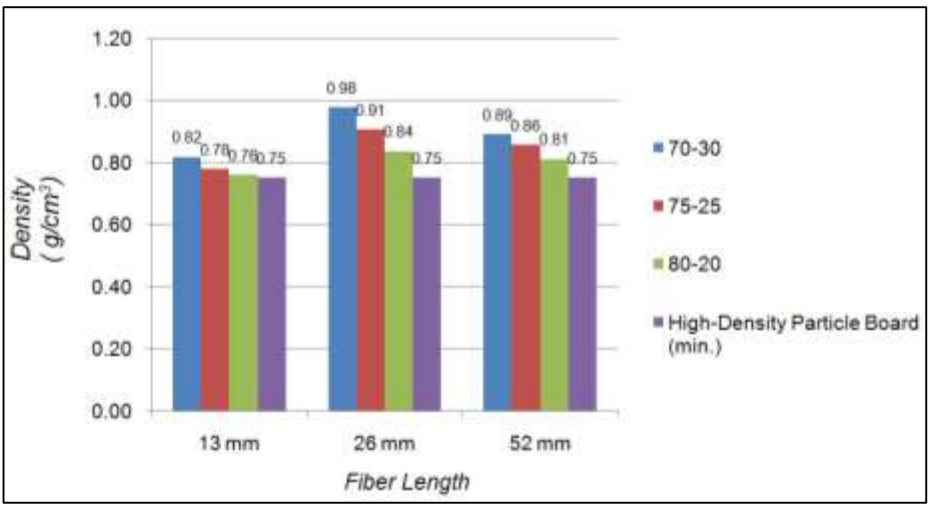

Figure 8. Density of Water Hyacinth Particleboard

Figure 8 shows that the mixes with 26 mm fiber length are relatively dense among the other resin-fiber ratios. The 70:30 mixes have the highest recorded density (0.98 g/cc for 70:30 with 26mm fiber) and this can be attributed to the amount of fiber used, making it more compressible resulting to a lesser pressed volume. The board can be classified as high-density particleboard (0.75 – 1.3 g/cc).

4.2 Thickness Swelling and Water Absorption Tests

Thickness Swelling and Water Absorption tests were performed to determine the amount of water being absorbed by the specimen after soaking for 24 hours. This is to determine how much water is absorbed and how thick it can swell when subjected to the above conditions.

Figure 9 shows the thickness swelling and water absorption in the specimen after 24 hours of soaking. As shown, the specimen with fiber length of 26 and 52 mm mixes passed the maximum tolerable water absorption of 20% as set forth by the PNS. However, the 70:30 mixes with 13 mm fiber failed to satisfy the said requirement. This can be attributed to the greater exposed area that permits more absorption of water. Collectively, the 80:20 mixes were the least absorptive. The 80:20 mixes with 26 mm fibers showed the least moisture absorption of 11.22%. The amount of resin is a determining factor on its ability to absorb water, the more resin content, the less it gets absorptive. As shown, there is a slight increase in the water absorption in the specimens having 26 mm and 52 mm fibers. Since the fibers are too long (52 mm), void spaces were observed due to the uneven distribution of resin on the fiber surfaces. The figure also showed a decreasing pattern of water absorption as the resin content increases (fiber content decreases). This is due to the increased ability of the resin to cover the surface area of the fibers which are absorbent.

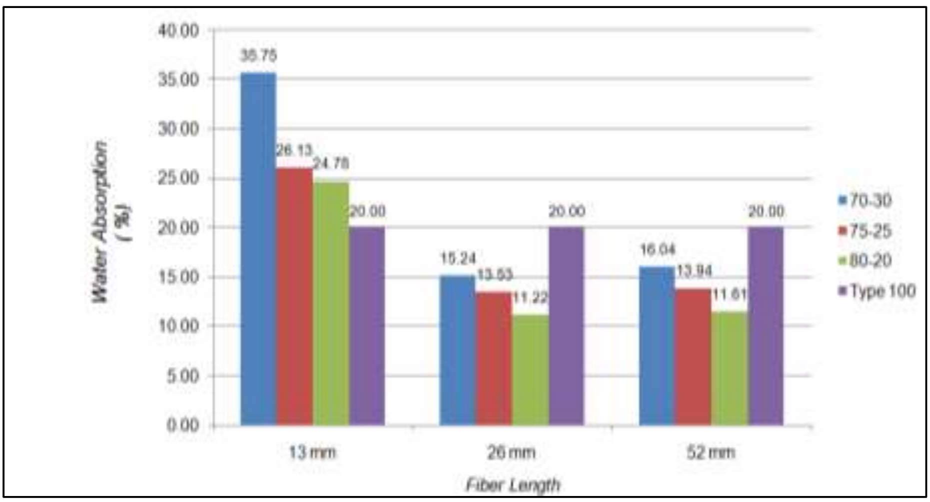

Figure 9. Water Absorption of Water Hyacinth Particleboard

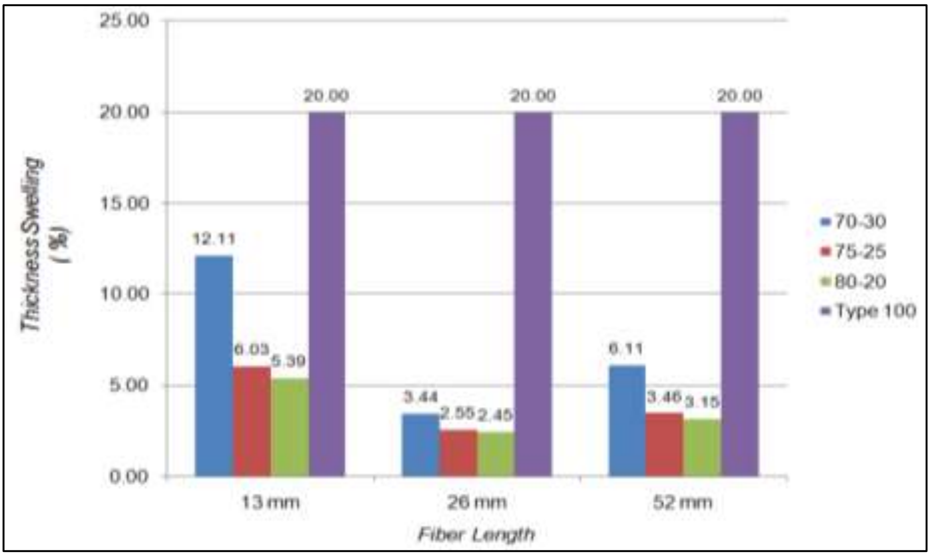

Figure 10. Thickness Swelling of Water Hyacinth Particleboard

Figure 10 shows that all of the design mix satisfied the maximum allowable 20% thickness swelling set forth by the PNS. Collectively, the mixes with 13 mm fibers have the highest thickness swelling which is due to the ability of smaller cut fiber to absorb water as shown in the previous test. The 70:30 mixes with 13 mm fibers has the highest value for thickness swelling that reached 12.11% which is attributed due to the increased fiber content which resulted to increased absorption. Generally, the 80:20 mix with 26 mm fiber has shown the lowest percentage of swelling (2.45%) and this can be attributed due to the greater amount of resin used.

4.3 Modulus of Rupture Test

The graph presents the flexural strength of the boards with varying resin-fiber ratio and fiber lengths.

As shown in Figure 11, only the specimen with 26 mm fibers exhibited the highest MOR value. Based on the result, only the 70:30 mix (MOR = 94.81kg/cm^2) passed the minimum requirement in accordance with the PNS standard. The 70:30 mix with 26 mm fiber can be classified as Type 100 (MOR = 80 kg/cm^2 min.). The other mixes that failed can be attributed due to the influence of the fiber length and resin-fiber ratio. The 75:25 mixes with 13 mm fiber exhibited the poorest results having a flexural strength of 22.68 kg/cm^2. In the mixes containing 13 mm fiber, the length of the fiber (developed length) did not strongly resist slipping brought by the tensile force applied due to the insufficient resin-fiber bond that causes easy cracking. While in the 52 mm mixes, the problem can be attributed to the difficulty and consistency of mixing that affects the proper distribution of the binder. Thus, the resin did not properly bond with the fibers. In general, all the 75:25 and 80:20 mixes failed to comply with the minimum MOR, and this can be attributed to the higher resin content used which made the boards more brittle.

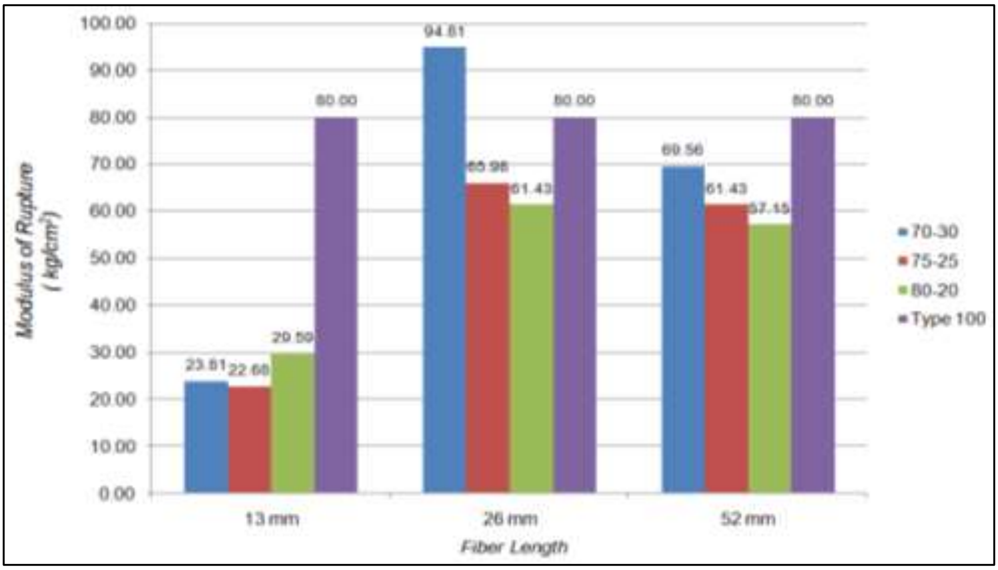

Figure 11. Modulus of Rupture of Water Hyacinth Particleboard

4.4 Face Screw Holding Strength Test

The ability of a panel to hold screw, especially when subjected to load is a significant aspect in evaluating its characteristics. This property is usually assessed by the Face Screw Holding Strength Test, which measures the magnitude of force corresponding to the extent that the screw head is already pulled out from the board. The figure below shows the holding force of the boards with corresponding resin-fiber ratio and fiber lengths.

Figure 12 shows that all of the mixes satisfied the minimum face screw holding strength for Type 100 (20 kg) as provided by PNS. Moreover, all the mix designs passed the required FSHS for Type 200 particleboards (50 kg).

Based on the result, the mixes with 26 mm fibers have the greatest holding capacity of 217.62 kg as compared with the other mixes. This is due to the good bonding of the resin and fiber, as a result of the even distribution of the fibers making it more slip-resistant. The graph also shows that the specimens having 80:20 mix proportions and reinforced with 13 mm fibers exhibited the lowest value of 66.80 kg. The mixes with 13 mm fiber has relatively low holding strength and this can be attributed due to the insufficient fiber length for a stronger bond with the binder. In the mixes with 52 mm fiber, the FSHS were slightly lower than the 26 mm mixes and this can be attributed due to the difficulty of resin penetration and distribution over the fiber length.

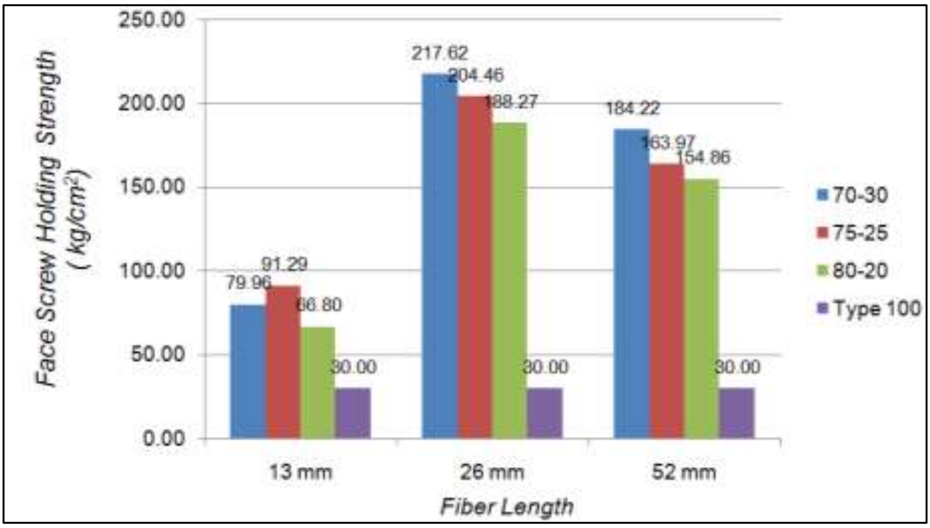

Figure 12. Face Screw Holding Strength of Water Hyacinth Particleboard

4.5 Edge Screw Holding Strength Test

The Edge Screw Holding Strength Test was performed on screws threaded into the edge of the board to measure the resistance to withdrawal in a plane normal to the edge in particular. The graph represents the holding force of the board edge with corresponding resin-fiber ratio and fiber lengths.

Figure 13 shows that all of the mixes had satisfied the minimum edge screw holding strength as set forth by PNS for Type 100 particleboards (15 kg). The 70:30 mix with 26 mm fibers exhibited the best result (92.42 kg). Collectively, the mixes with 26 mm fibers have shown the highest ESHS passing the minimum requirement for Type 200 boards (50 kg). This can be attributed to the proper bonding of the fibers with sufficient amount of resin. The 80:20 mix design proportion with 13 mm fibers had shown the least result with an ESHS of 23.44 kg. The said mix has failed to comply with the requirement for Type 200 board. Moreover, the mixes with 13 mm fibers showed the lowest ESHS and this can be attributed to the short fiber length which made the bond less continuous resulting to the easy bond slippage. While in the 52 mm mixes, the difficulty of resin distribution over the fiber length was observed to be the prime factor for the decrease in strength. The 75:25 mixes and 80:20 mixes have lower ESHS because of the large amount of resin content used which increases the brittleness of the board hence resulted to the premature bond breakage.

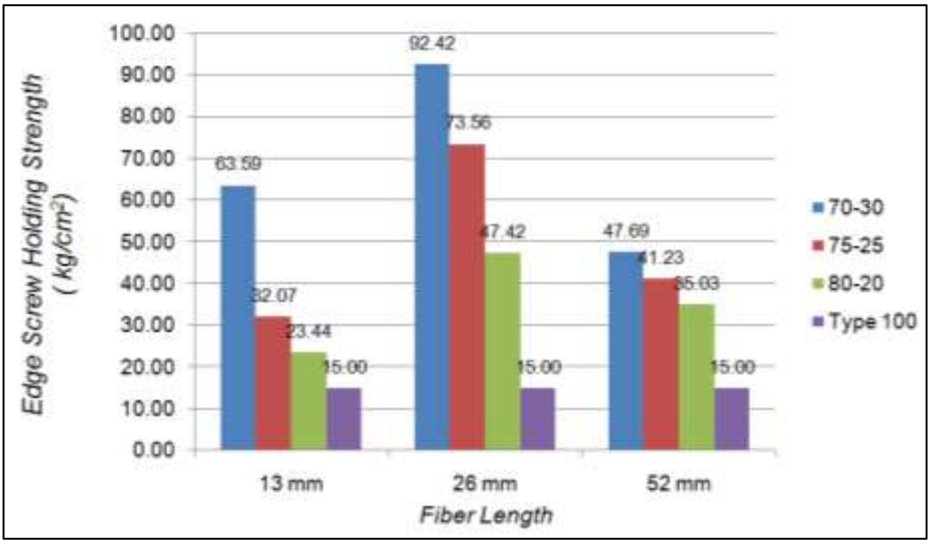

Figure 13. Edge Screw Holding Strength of Water Hyacinth Particleboard

4.6 Internal Bond Strength Test

The Internal Bond Strength Test was included in the study due to the increased use of fiberboards, hardboards, and particleboards where wood, plywood, or other materials are glued to the board, or where the internal bond strength of the board is an important property. The figure below presents the internal bond strength of the boards with their corresponding resin-fiber ratio and fiber lengths.

Figure 14 shows that the 70:30 and 75:25 mix both having 26 mm fiber and the 70:30 mix with 52 mm fiber complied with the minimum requirement for internal bond strength for Type 100 particleboards (2.0 kg/cm^2). The 70:30 mix with 26 mm fiber exhibited the highest internal bond strength and it was recorded to be 2.32 kg/cm^2, while the other 6 mixes failed to satisfy the minimum requirement. The 80:20 mix with 13 mm fiber has shown the lowest internal bond strength (0.53 kg/cm^2). The results can be attributed to the resin-fiber ratio and the fiber length. In the 13 mm mixes, the length of the fiber is too short and not enough to resist the pulling force because of the inadequate bond of the fiber with the binder. In the mix with 52 mm fiber, the distribution and penetration of the binder to the fibers were not effective thus resulting to the decrease bond and strength of the boards. All the 80:20 mixes failed to comply with the PNS IBS requirements, and this can be due to the large amount of resin used which when increased makes the board more brittle thus sudden breakage and slippage occurs.

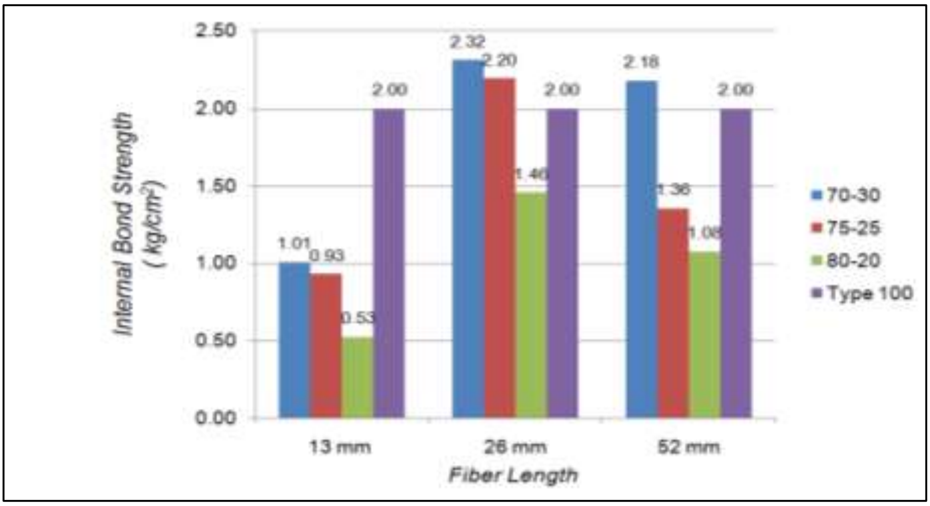

Figure 14. Internal Bond Strength of Water Hyacinth Particleboard

3. CONCLUSIONS

Based on the results of the test conducted, the following conclusions were derived:

1. The density test results recorded the extreme values of 0.76 g/cc and 0.98 g/cc for the 80:20 mix with 13 mm fibers and 70:30 mix with 26 mm fibers, respectively. Generally, all the mixes are within the range of (0.75 – 1.30 g/cc) classified as high density particleboard. Water Absorption results of the mixes showed that all the specimen with 26 mm and 52 mm fibers satisfied the maximum allowable water absorption requirement of 20% for all types of particleboard as prescribed by PNS. Likewise, the thickness swelling results showed that all the design mixes satisfied the maximum allowable thickness swelling of 20% based on the PNS. The 80:20 mixes with 26 mm fibers recorded the least water absorption value of 11.22% while the 80:20 mixes with 26 mm fiber exhibited the least thickness swelling of 2.45%. The decreased ability of the boards to absorb and to swell can be attributed due to the amount of resin used that covers the absorbent contact area of the fibers.

2. In the four mechanical property tests, only the board with 75:25 mix having 26 mm fibers exhibited the largest Modulus of Rupture value (94.81 kg/cm^2) passing the minimum standard of 80 kg/cm^2. In the Face Screw Holding Strength Test, all mixes passed the minimum requirements for all types of particleboards. The best result was recorded to be 217.62 kg for the 70:30 mix with 26 mm fibers. In the Edge Screw Holding Strength Test, all the mix designs satisfied the minimum standard of 15 kg and showed satisfactory results as high as 92.42 kg for the 70:30 mix having 26 mm fibers. In the Internal Bond Strength Test, the 70:30 and 75:25 mixes both having 26 mm fibers and the 70:30 mix with 52 mm, satisfied the minimum standard of 2 kg/cm^2 having an internal bond strengths of 2.32 kg/cm^2, 2.18 kg/cm^2 and 2.20 kg/cm^2, respectively.

Generally, the specimen having a resin-fiber ratio of 70:30 reinforced with 26 mm fiber length exhibited the best performance among the nine mixtures satisfying the PAES - 320 for Type 100 high-density particleboard. Results showed that the mechanical strength of the boards is enhanced as the resin content decreases in the boards reinforced with average size of fibers (26 mm).

4. RECOMMENDATIONS

To further improve the study, the proponent would like to suggest the following:

1. To conduct further laboratory investigation on the effects of weathering, exposure to sunlight and heat, and severe change of humidity to determine the suitability of the boards not only for interior but also for exterior purposes.

2. To characterize the physical and mechanical properties of the water hyacinth board produced through hot pressing.

5. REFERENCES

Ashori, A. and Nourbaksh, A. 2009. Mechanical Behavior of Agro-residue-reinforced polypropylene Composite. *Journal of Applied Polymer Science*. 111(5), 2616-2620.

Davies, R. M., and Mohammed, U. S. 2011. Moisture-dependent Engineering Properties of Water Hyacinth Parts. *Singapore Journal of Scientific Research*, 1: 253-263.

Ghosh, S. R., Saikia, D. C., Goswami, T., Chaliha, B. P. and Baruah, J. N. 1984. Utilization of Water Hyacinth (*Eichhornia crasipes*) for Paper and Board Making. *Proceedings of the International Conference on Water Hyacinth, February 7-11, UNEP, Nairobi*, 436-460.

Guru, M. Atar, M., and Yildrim. R. 2008. Production of polymeric matrix composite particleboard from walnut shell and improvement of its requirements. *Materials and Design*, 29, 284-287.

Natural Fibers. Retrieved on January 2012, from http://www.pask.org/downloads/Proc442/proc44-2-7.pdf

Odozi, T. O., Akaranta, O., and Ejike, P. N. 1986. Particleboards from Agricultural Wastes. *Agricultural Wastes*, 16, 237-240

Olal, M. A., 2005. Handicrafts prepared from water hyacinth. Organic Resources Management in Kenya, perspectives and Guidelines, forum for Organic Resoruces Management and Agricultural Technologies (FORMAT).

Philippine Agricultural Engineering Standard (PAES) 320. 2002. *Engineering Materials – Wood-based Panels* – Specifications from Philippine National Standards.

Water Hyacinth Control and Possible Uses. (n.d). In Appropedia. Retrived on January 15, 2013, from www.appropedia.org/Water_Hyacinth.

Water Lily, Water Hyacinth (Eichhornia Crassipes). 2007. Retrieved on January 15, 2013, from http://www.backpackingphilippines.com/2007/water-lily-water-hyacinth- eichhornia.html