

UTILIZATION OF BAMBOO FIBER AND COCONUT COIR IN THE PRODUCTION OF CEMENT--BONDED BOARD

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Abstract

Each year, the amount of agricultural wastes is growing faster than the rate of urbanization in the country. People from different parts of the country and the world are mostly unaware on how to utilize these wastes and recycle them into useful and sustainable materials. One of the approaches in reusing these agricultural wastes is to utilize them as a substitute for wood in the fabrication of panel products. Cement--bonded boards, for instance, is one of those restoration inventions of the 20th century which can be an alternative to timber products in constructing internal and external walls, partitions, ceilings, roof sheathing, to name a few. This research aimed to contribute to these small but growing empirical literatures and studies on particleboard technology by to utilizing agricultural wastes such as bamboo and coconut coir fibers in the production of cement--bonded particleboards. Using an experimental research design, the researchers produced three experimental samples with three different fiber -- cement ratios. These samples underwent several tests that determined their physical and mechanical properties. Based on the results, it was found out that the sample boards with 3.2% fiber obtained the highest strength of 5.31 MPa, which was higher than the standard strength for particle boards. It also passed the nail head pull through test and obtained an optimum result of 223.88 kg. Furthermore, it also exhibited 1.03% thickness swelling and 8.58% water absorption which was way better compared to commercially available particle boards.

Keywords: Bamboo Fiber, Coconut Coir, Cement Board, Cellulose Fiber

1.0 INTRODUCTION

Wood is one of the most important natural resources on earth and plays a vital role in the lives of every human being. It is being used to make furniture, fiber board, pulp and paper, plywood, and also has a value for wood construction. However, for developing countries like the Philippines, wood is continuously depleting due to widespread deforestation brought about by a significant increase in construction activities and demand for wood products (Hasnin et al., 1997). Because of this, it is therefore imperative to use alternative materials for wood and utilize renewable, abundant and sustainable non--woody resources like coconut husk and bamboo in order to prevent the continuous depletion of wood.

Residues of agricultural industry as a substitute for wood in fabrication of panel products has become dominant in the industry of making boards for it may be an alternative to timber. However, people from different parts of the world are mostly unaware of this technology of utilizing agricultural wastes and recycling them into useful and sustainable materials. The Philippines, for instance, is an agricultural country in which 40% of its land area is intended for agricultural use. Unfortunately, the wastes derived from different agricultural products just go to dump sites and landfills. It is a missed opportunity as appropriate and proper management of these agricultural leftovers could generate a lot of employment, increase the earning of farmers and can also provide other services and business opportunities.

Aladenola et al. (2008) claimed that using raw materials in the production of cement bonded boards would start a wide research activity in finding and translating other available agricultural remainders to a more valuable product. Cement bonded board is one of those restoration inventions of the 20th century which can be an alternative to timber products in constructing furniture, internal and external walls, partitions, ceilings, roof sheathings, to name a few (Ajayi, 2011). For instance, instead of laying beds of mortar in the job site, one can simply screw in pre--formed and already--set sheets of cement boards. Moreover, Wallender (2017) concluded that unlike other wood--based material like drywall and plywood, this kind of material is considered one--hundred percent inorganic and therefore there will be no organic matter that will promote mold, rot, shrinkage, and decomposition. Among other typical cement bonded boards, cement fiber board lasts for a longer period of time. Cement fiber board uses synthetic fiber or natural fiber which acts as reinforcement to cement. Although it is not totally waterproof, it has, however, an excellent drying property and is highly resistant in absorbing moisture.

The major raw materials that are currently being used in the production of cement fiber boards consist mainly of wood, cement and water, with or without a catalyst (Aladenola, 2008). However, several studies have already proven that different natural fibers can replace wood as a fiber substitute to cement boards. These fibers include coconut coir, bamboo fiber, rice husk, and bagasse, among others. Addition of these fibers improved the physical and mechanical of cement fiber boards according to some researches (Khedari et al., 2003;; Sivaraja et al., 2009;; Abraham et al., 2016). And among the aforementioned natural fibers, the researchers chose to use coconut coir and bamboo fiber because, aside from their abundance, they also exhibit excellent

properties which are comparable to wood. Coconut coir is the seed-hair fiber extracted from the thick outer shell or husk of the coconut. Asasutjarit et al. (2007) found that the coconut coir fiber contains high hemi-cellulose, alpha-cellulose, holocellulose and lignin ratios. These compositions are the ones which make the fibers stiffer and tougher. Bamboo, on the other hand, has a high natural tensile and flexural strength. It also has the thinness and whiteness close to finely bleached viscose and has strong durability, stability, high absorbency, and firmness. Bamboo can be made as a textile by extracting its fiber and can also be used in construction and furniture industry. It is suitable for a variety of purposes because of its abundance, good strength, lightness, hardness, varying sizes, easy workability and quick maturity made it suitable (Huan-Ming, 1996;; Yuming and Jian, 1994).

Based on the foregoing, this research aimed to contribute to the small but growing empirical literatures and study on cement fiber boards by utilizing bamboo fibers and coconut coir in the production of cement bonded boards.

2.0 LITERATURE REVIEW

For the past years, there have been a substantial increase in awareness and knowledge in using natural fibers in cement composites. A number of researches have already been made in this topic and are now available in different textbooks and journals. Various studies (Morrissey et al., 1985;; Do et al., 1995;; Semple et al., 1999;; Bilba et al., 2003) revealed that some of the advantages of using natural fibers in cement composites are the following: higher flexural strength and load-bearing capacity, increased impact toughness and bending strength, among others. Aside from these, natural fibers also offer significant reduction in the cost of production which makes them more favorable than synthetic fibers (Thielemans et al., 2004;; Ali, 2011). And today, due to an increased awareness on environmental protection and conservation of energy, development of composite materials for buildings using natural fibers such as bamboo fiber and coconut coir are now being considered as an alternative material to synthetic fiber in order to solve energy and environmental concerns. Khedari et al. (2003) reported that the addition of natural fibers reduced the thermal conductivity of composite specimens thus reducing energy consumption and utility costs. Another study conducted by Sivaraja et al. (2009) on the durability of natural fiber concrete composite revealed that natural fiber greatly improves the flexural performance, modulus of rupture, split tensile strength and compressive strength of concrete. Several researches (Abraham et al., 2016;; Mohr et al., 2004;; Liu and Pan, 2009) also observed similar findings that the addition of natural fibers in cement composites resulted in the reduction of self-weight and improvement in mechanical properties such as breaking load, ductility, toughness, and crack-resistance. In addition to this, Liu and Pan (2009) also concluded that the flexural strength of cement board with natural fibers is 80% higher than that of typical and commercially-available materials.

In this particular study, the researchers utilized coconut coir and bamboo fiber to produce a cement-bonded board. Coconut coir is the seed-hair fiber extracted from the thick outer shell or husk of the coconut. Asasutjarit et al. (2007) found that the coconut coir fiber contains high hemi-cellulose, alpha-cellulose, holocellulose and

lignin ratios. These compositions are the ones which make the fibers stiffer and tougher. Several studies were already made in using coconut coir fibers in making cement boards. Asatjarit et al. (2007), for instance, studied the properties of board panels with treated coconut coir fiber. It was observed that there was an improvement on the mechanical and thermal properties as compared to commercial flake board composite. Abdullah et al. (2011), on the other hand, investigated the effects of coconut fiber on the physical and mechanical properties of composite cement boards. It was observed that the composite with coconut fiber demonstrated the highest compressive strength and modulus of rupture. Aside from coconut coir, bamboo fiber is also one of natural fibers that being used as reinforcement to cement boards. At present, bamboo is considered a significant plant fiber in cement fiber board industry because of its great potential and favorable characteristics and properties. Aside from being fast growing, bamboos are also perennial and abundant bio--resource which belong to Bambusae family. Bamboo fiber is a regenerated cellulosic fiber which comes from starchy pulp produced from bamboo stems and leaves through a process of alkaline hydrolysis and multi--phase bleaching (Das, 2016). Wang et al. (2015) also stated that the bamboo fiber's structural variation, thermal and mechanical properties, modification of its chemical properties and fiber extraction make it versatile for various composite--industry applications. Furthermore, Okubo et al. (2004) analyzed the mechanical properties of composites with bamboo fiber and found out that the addition of bamboo fibers significantly improved the composite's mechanical properties such as the tensile strength and stiffness. Similar findings were also observed in the study of Akinyemi and Osasona (2017) which concluded that among all the performance parameters, cement board with bamboo fiber performed better and was therefore more versatile.

2.1 RESEARCH OBJECTIVES

The objectives of the study were as follows:

1. To determine the physical properties of bamboo and coconut coir fiber cement--bonded board specifically its density, water absorption and thickness swelling.
2. To determine the mechanical properties of bamboo and coconut coir fiber cement--bonded board specifically its nail head pull--through strength, and modulus of rupture.
3. To determine which among the ratios of bamboo and coconut coir fiber will yield the best result.

2.2 CONCEPTUAL FRAMEWORK

In order to attain the objectives of the study, this research has been conceptualized to determine the physical and mechanical properties of bamboo and coconut coir fiber cement--bonded board. Figure 1 presents the Conceptual Framework.

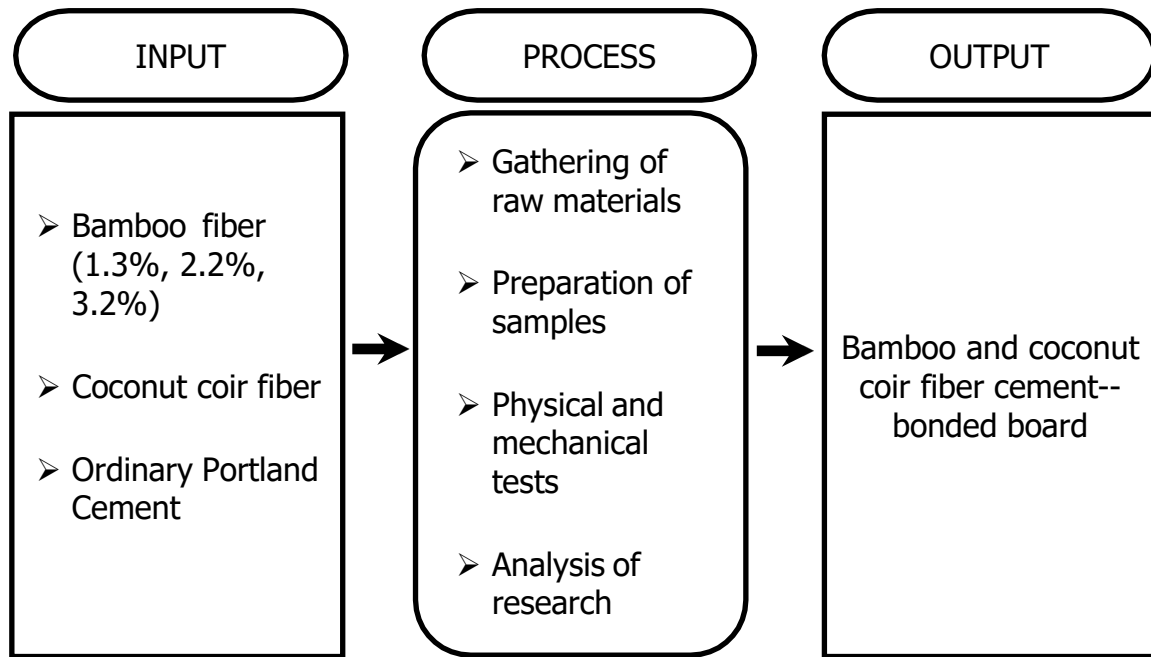


Figure 1: Conceptual Framework of the Study

As shown in Figure 1, the inputs for this study were bamboo fibers in varying percent inclusions of 1.3%, 2.2% and 3.2%, coconut coir and portland cement. These inputs were the main materials utilized in the production of cement fiber boards. The process portion of this study includes gathering and preparation of raw materials, preparation of samples, testing of cement boards and analysis of research findings. The output of this study is bamboo and coconut coconut coir fiber cement--bonded board.

2.3 SIGNIFICANCE OF THE STUDY

The findings of this study benefit the following:

1. Community. This research will provide valuable information in turning agricultural wastes into useful material which redounds to more opportunities for employment, additional earnings for the farmers and other service and business opportunities for the people.
2. Environment. It is hoped that the research findings and suggested cement fiber board can help the environment by lessening the agricultural wastes and preserving natural wood reserves. This research can also be a basis for future studies on developing alternative materials for wood and wood products.
3. Construction industry. This research will also help the construction industry by providing them an alternative construction material which is comparable to commercially available cement bonded boards but at a lower production cost which will redound to a higher profit.

2.4 SCOPE AND DELIMITATIONS

This study focused on the utilization of bamboo fiber and coconut coir as main material in making cement fiber board. For bamboo fiber, the researchers used *bambusa blumeana* – a scientific name for spiny bamboo and are locally known as “kawayang

tinik". The length of the fiber was maintained at 50 millimeters. Coconut coir, on the other hand, was obtained from a coconut tree (*cocos nucifera*). The researchers used the brown coirs that came from the mature ripe coconuts and were cut into 50 millimeters length. This study was limited to the analysis of three experimental percent inclusions (1.3%, 2.2% and 3.2%) of bamboo and coconut coir fibers with water--cement ratio of 2:1. It was also limited to the following tests: density, flexural strength test, thickness swelling and nail head pull--through.

3.0 METHODOLOGY

Research Design

This research utilized an experimental research design wherein a set of variables were kept constant while the other set of variables were measured as the subject of the experiment. In this study, bamboo fiber and coconut coir were mixed with cement to produce a cement--bonded board. Coconut coir was set to a constant, while bamboo fibers were the experimental variables whose percentage inclusion was set to 1.3%, 2.2% and 3.2%. The boards were tested for durability and bending, nail--head pull--through, and thickness swelling. The results of each test were compared to Philippine National Standards and ASTM Standards for cement--bonded boards.

Gathering and preparation of Raw Materials

Bamboo plant that had a maturity of about one year old was obtained from Indang, Cavite, Philippines, while the coconut coir was gathered from a coconut manufacturer also located in Cavite. Other materials such as cement, common nails, and forms were bought from a local hardware store. Coconut coirs were extracted manually from coconut husks. Bamboo fibers, on the other hand, were brought to Philippine Textile Institute and were extracted using a decorticating machine. After fiber extraction, the fibers were then dried under the sun and were prepared for mixing.

Batch Formulation

In this study, three experimental samples were used. The batch formulation showing the composition and mass distribution of each sample was shown in Table 1.

Table 1: Material Mass Distribution

MATERIALS	MIX DESIGN		
	1	2	3
Bamboo Fiber	1.3%	2.2%	3.2%
Cement	65.8%	65.2%	64.53%
Water	32.9%	32.6%	32.27%

As shown in Table 1, there were three different mix percentage inclusions of bamboo fiber that were used in producing the cement board samples. The first sample

had 1.3% of bamboo fiber, 65.8% of cement and 32.9% for water. Design mix 2 had 2.2% bamboo fiber, 65.2% cement and 32.6% water. And lastly, design mix 3 had 3.2% bamboo fiber, 64.53% cement, and 32.27% of water. Meanwhile, coconut coir fiber, being the constant material in this study, was fixed at a percentage of 2.2% with 65.2% of cement and 32.6% of water.

Preparation of Test Samples

Coconut coir and bamboo fibers were cut into 50 mm long, submerged in tap water for 24 to 48 hours and then dried under the sun. The form for mat, which was a square wooden box, was then assembled following the dimension of 400 mm by 400 mm and a thickness of 100 mm.

The coconut coir and bamboo fiber were then mixed separately in different containers before placing them into the mold. There were three layers of mat in each sample board. The outer layers were mixtures of cement and bamboo fibers with varying percent mix while the inner layer was a constant mix of cement and coconut coir fibers. After placing the mats, one on top of the other layer, the board was then pressed into the desired thickness using hydraulic press, guide bars and clamping apparatus. After 18 to 20 hours, the boards were removed from the clamping apparatus and were carefully stored in a cool dry place in order to provide air circulation, drying and conditioning.

Physical and Mechanical Tests

The physical and mechanical test of board samples were conducted in accordance with the existing ASTM Test Standards. Density test was done in accordance with ASTM C1186--85 with reference ASTM C1185--08 using water displacement method. Thickness Swelling and Water Absorption, on the other hand, were done in accordance with ASTM D -- 1037, wherein a test was made to determine the water absorption characteristics of cement boards and to see the reaction of the materials after submerging them to water. Another test, the Nail--Head Pull Through test (ASTM D – 1037) was made to measure the resistance of a panel to having the head of a nail or other fastener pulled through the board. This test was intended to simulate the condition encountered with forces that tend to pull paneling or sheathing from a wall. Lastly, the Modulus of Rupture (ASTM D – 1037) was made to gauge the strength of the materials based on the given load. This measures the maximum load that may carry by the materials. Specimen was prepared with the long dimension perpendicular to the long dimension of the board.

Statistical Treatment of Data

Statistical analysis was used in order to interpret the gathered data. The statistical tools that were used in this study were mean and standard deviation in order to measure the center of a numerical data set and to determine how the measurements for a group are spread out from the average, respectively.

4.0 RESEARCH FINDINGS

Physical Properties

Density

Table 2: Density of bamboo fiber and coconut coir cement--bonded board

Mix Design	Density (g/ cm ³)	Remarks
1	1.64	Medium--weight
2	1.56	Medium--weight
3	1.62	Medium--weight

Table 2 presents the results of density test of the three mix designs of coconut coir and bamboo fiber cement--bonded boards. The first mix design with 1.3% bamboo fiber obtained a density of 1.64 g/cm³. The second mix design with 2.2% bamboo fiber had a density of 1.56 g/cm³. And lastly, the third mix design with 3.2% bamboo fiber attained a density of 1.62 g/cm³. Based on the results, all the specimens fell under the medium--weight category for cement particle boards whose minimum standard density is 1.2 g/cm³.

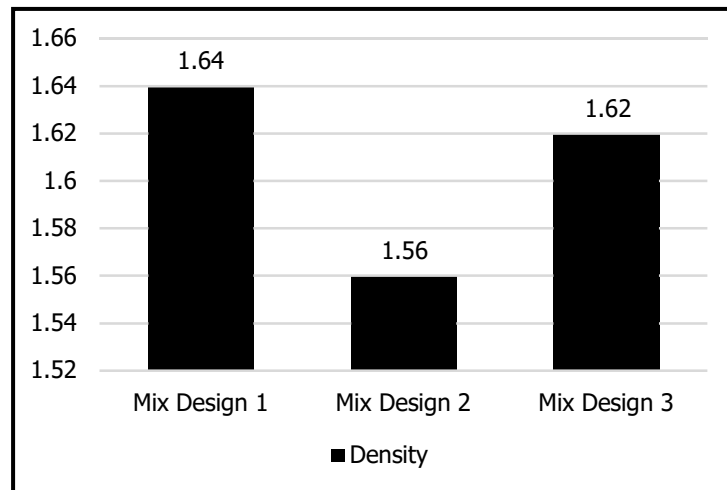


Figure 2: Effects of varying amount of bamboo fiber to density of cement fiber board

Figure 2 shows the effects of varying amount of bamboo fiber to the density of cement fiber board. The results revealed that the lesser amount of fiber in design mix, the higher the density of the cement board was. This was due to the amount of voids caused by the presence of fibers in cement boards. Higher amount of fiber in cement

boards tend to create a lot of voids thus resulting to a lower density. The same finding was observed in the study of Asasutjarit et al. (2007) wherein an increase in the amount of fiber decreases the density of the cement boards. However, Figure 2 seems to contradict this finding as mix design 2 got the lowest density. This may be due to the inconsistency of the mix thus producing a lot of voids in the cement board.

Water absorption

Table 3: Water absorption of bamboo fiber and coconut coir cement--bonded board

Mix Design	Water Absorption (%)	Remarks
1	8.58	Passed
2	9.30	Passed
3	8.65	Passed

*Water absorption < 40% (PNS 230--1989)

Table 3 presents the results of water absorption test of the three mix designs of coconut coir and bamboo fiber cement--bonded boards. The first mix design with 1.3% bamboo fiber obtained water absorption of 8.58%. The second mix design with 2.2% bamboo fiber had water absorption of 9.30%. And lastly, the third mix design with 3.2% bamboo fiber attained water absorption of 8.65%. Based on the results, all the specimens passed the requirement of Philippine National Standard for particle board (PNS 230--1989) which sets the maximum limit for water absorption at 40%.

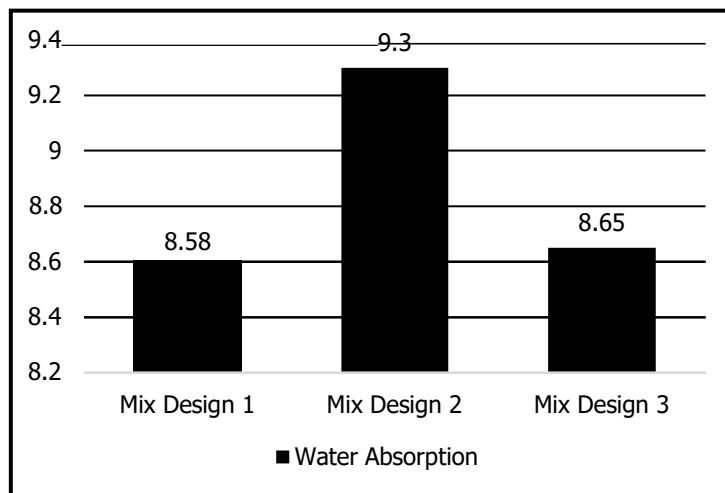


Figure 3: Effects of varying amount of bamboo fiber to water absorption of cement board

As shown in Figure 3, the results revealed that the lesser amount of fiber in design mix, the lower the water absorption of the cement board was. The amount of voids present in cement boards affected the water absorption. Based on the results, it can

be observed that cement board with more bamboo fibers or those that have lower densities tend to have higher water absorption than low density boards. Low density cement boards tend to have more space and void than high density boards (Asasutjarit et al., 2007). However, mix design 2 seems to contradict these findings as it got the highest water absorption rate. This may also be attributed to the inconsistency in the mix which produced a lot of voids in the cement board.

Thickness swelling

Table 4: Thickness swelling of bamboo fiber and coconut coir cement--bonded board

Mix Design	Thickness Swelling (%)	Remarks
1	2.71	Passed
2	1.03	Passed
3	2.87	Passed

*Thickness Swelling < 20% (PNS 230--1989)

Table 4 presents the results of water absorption test of the three mix designs of coconut coir and bamboo fiber cement--bonded boards. The first mix design with 1.3% bamboo fiber obtained a thickness swelling of 2.71%. The second mix design with 2.2% bamboo fiber had a thickness swelling of 1.03%. And lastly, the third mix design with 3.2% bamboo fiber attained a thickness swelling of 2.87%. Based on the results, all the specimens passed the requirement of Philippine National Standard for particle board (PNS 230--1989) which sets the maximum limit for thickness swelling at 20%.

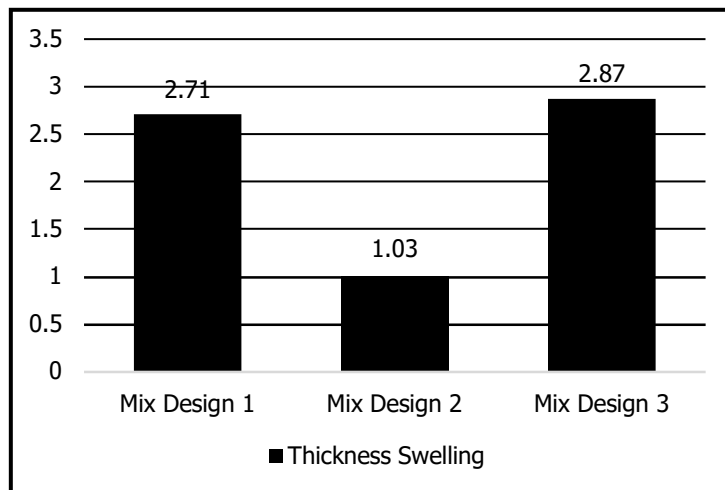


Figure 4: Effects of varying amount of bamboo fiber to thickness swelling of cementfiber board

Figure 4 shows the effects of varying amount of bamboo fiber to the thickness swelling of cement fiber board. It can be observed that the lesser amount of fiber in design mix, the lower the thickness swelling of the cement board was. In other words, thickness swelling was directly proportional to the amount of fiber and density in cement boards. The same findings were also observed by Asasutjarit et al. (2007), which concluded that low density cement boards had a high thickness swelling while high total mass or high density of cement boards had a low thickness swelling value. However, the results showed different results particularly mix design 2 as it got the lowest thickness swelling. This, once again, was because of the inconsistency of the mix.

Mechanical Properties

Nail head pull--through

Table 5: Nail head pull--through of bamboo fiber and coconut coir cement--bonded board

Mix Design	Nail head pull--through strength (kg)	Remarks
1	223.88	Passed
2	221.35	Passed
3	178.88	Passed

*Nail Head Pull--through Strength requirement: 30--50 kg. (PNS 230--1989)

Table 5 presents the results of nail head pull--through test of the three mix designs of coconut coir and bamboo fiber cement--bonded boards. The first mix design with 1.3% bamboo fiber was able to resist a load of 223.88 kg. The second mix design with 2.2% bamboo fiber resisted a load of 221.35 kg. And lastly, the third mix design with 3.2% bamboo fiber was able to sustain a load of 178.88 kg. Based on the results, all the specimens passed the requirement of Philippine National Standard for particle board (PNS 230--1989) which sets the standard value for nail head pull--through load requirement to 30--50 kg.

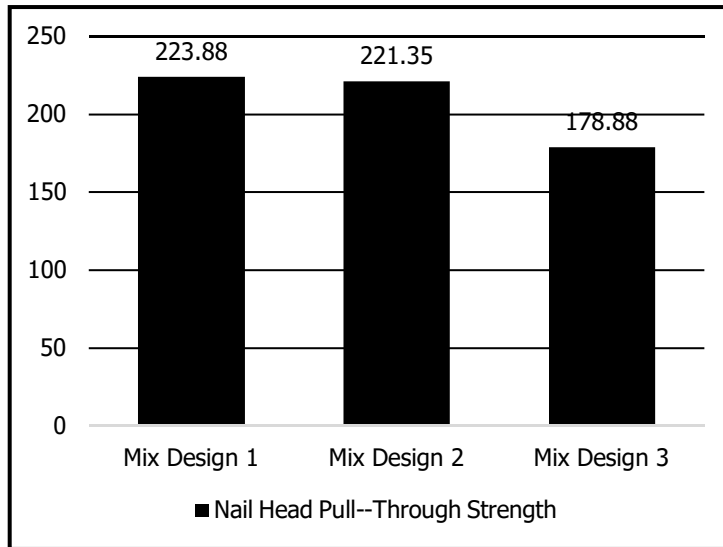


Figure 5: Effects of varying amount of bamboo fiber to nail head pull-through of cement board

Figure 5 shows the effects of varying amount of bamboo fiber to the thickness swelling of cement fiber board. It can be seen from the figure that the lesser amount of fiber in design mix, the higher was the resisting capacity of cement boards from forces due to pulling of nails. These findings can also be related to the density of boards. Higher density boards tend to have more strength than low density boards because of the amount of cement in the mix. Based on the results, boards with higher cement content seemed to be denser and have more resisting strength capacity. Also, Asasutjarit et al. (2007) further states that the internal bond of cement acts as an adhesive and increase the overall strength of the cement bond.

Modulus of Rupture

Table 6: Modulus of Rupture of bamboo fiber and coconut coir cement-bonded board

Mix Design	Modulus of Rupture (MPa)	Remarks
1	3.80	Failed
2	4.47	Passed
3	5.31	Passed

Table 6 presents the results of modulus of rupture test of the three mix designs of coconut coir and bamboo fiber cement-bonded boards. The first mix design with 1.3% bamboo fiber obtained a modulus of rupture of 3.80 MPa. The second mix design with 2.2% bamboo fiber had a modulus of rupture of 4.47 MPa. And lastly, the third mix design with 3.2% bamboo fiber attained a modulus of rupture of 5.31 MPa. Based on

the results, mix design 2 and 3 passed the requirement of ASTM C-1288-99 which sets the minimum value for modulus of rupture at 4 MPa. However, mix design 1 was not able to meet the said requirement.

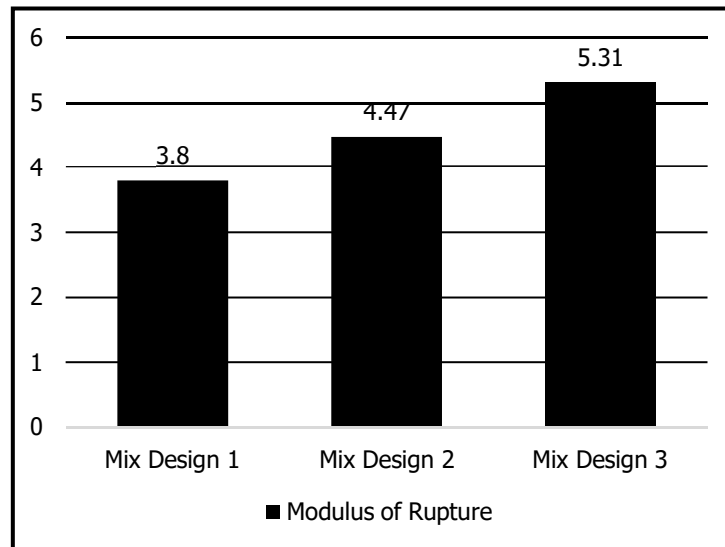


Figure 6: Effects of varying amount of bamboo fiber to modulus of rupture of cement board

Figure 6 shows the effects of varying amount of bamboo fiber to the modulus of rupture of cement fiber board. Based on the results, it was observed that as more fibers were being added in the design mix, the modulus of rupture or bending strength of cement boards increased. These findings can be related to the exceptional tensile strength of coconut coir and bamboo fibers which contributed to the improvement of bending strength of cement boards. Similar findings were also observed in the several studies (Asasutjarit et al., 2005;; Macatangay et al., 2012;; Shaduzzaman et al., 2011) in which the addition of natural fibers to cement boards greatly enhanced their bending or flexural strength.

5.0 CONCLUSIONS

In the light of the foregoing findings, the following conclusions were drawn:

1. Coconut coir and bamboo fiber cement--bonded board obtained a density of 1.64 g/cm³, 1.56 g/cm³ and 1.62 g/cm³ for Mix Design 1, 2 and 3, respectively. These densities were classified as medium--weight cement boards.
2. The result for water absorption test revealed that Mix Design 2 with 2.2% bamboo fiber obtained the highest absorption percentage of 9.3%. It was found out that the higher the content of bamboo fiber, the higher was the water absorption.
3. In terms of thickness swelling, it was found out that Mix Design 2 with 2.2% bamboo fiber attained the highest percent increase in thickness once submerged in water. Based on the findings, it was concluded that adding more bamboo fibers in cement boards would result to higher thickness swelling.

4. After undergoing the nail head pull-through capacity test, it was found that Mix design 1 with 1.3% bamboo fiber performed best and was able to resist a 223.88 kg of load. Results also revealed that boards with higher cement content, or contains low fiber content, seemed to be denser and have more resisting strength capacity.

5. As for modulus of rupture, test results showed that Mix Design 3 with 3.2% bamboo fiber got the highest value of 5.31 MPa. It was revealed that more amount of fiber added in the design mix, the higher was the modulus of rupture or bending strength of cement boards. These findings were related to the exceptional tensile strength of coconut coir and bamboo fibers which contributed to the improvement of bending strength of cement boards.

6. Among the three mix designs considered in this study, the researchers therefore conclude that the optimum percentage inclusion of bamboo fiber was at 3.2% (Mix Design 3) due to moderate thickness swelling and water absorption and exceptional performance in nail head pull through capacity test and modulus of rupture test.

6.0 RECOMMENDATIONS

In the light of the foregoing findings and conclusions, the following recommendations are proposed:

1. Adopt and use the produced bamboo and coconut coir fiber cement-bonded as a substitute for wood in constructing internal and external walls, partitions, ceilings, roof sheathing, furniture and many other applications in order to properly manage increasing amount of agricultural wastes as well as to preserve our natural wood reserves.

2. Manufacturing of bamboo and coconut coir fiber cement-bonded board with 3.2% bamboo fiber shall be pursued for commercialization thru the help of government and various socio-civic organization concerning the environment and waste minimization.

3. A better process of production should be standardized in order to solve the strength-deficiencies of the boards and to prevent inconsistencies of the mix. Furthermore, longer curing time must also be considered in order to attain the ultimate strength of cement fiber boards.

4. Immediate turnover of this study to the industry for mass production and commercialization of cement fiber boards in order to realize the possible benefits that can be derived from the use of agricultural wastes such as coconut coir and bamboo fiber.

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