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WOOD-TILE QUALITY COMPOSITE BOARD FROM COCO COIR DUST AND UNPLASTICIZED POLYVINYL CHLORIDE WASTE MATERIALS

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ABSTRACT: Gearing on sustainable technology, two waste materials, coco coir dust and $_U$PVC were utilized to produce a wood-tile quality, high density composite board material. Adopting the technology in producing fiberboards, the use of $_U$PVC as binder to combine with dried coir dust (5% moisture content) was investigated. Three mix ratios of $_U$PVC: Coir Dust were used: 80:20, 70:30 and 60:40. The produced board from each combination was then subjected to mechanical and physical property tests. Their properties were compared using the analysis of variance. The mixing process involves the use of two-roll mill machine operating at 204^{O}C while the pressing involves the heat press machine at 108^{O}C and pressure of 450 psi for 3minutes. The finished products highlight a glossy brown surface comparable to a wood tile, and can be readily manufactured without the additional veneer coating. Physical properties of the 3 ratios were tested against ordinary board. All 3 ratios exhibit 0% Water Absorption (WA) and Thickness Swelling (TS) while ordinary board showed 28.5% WA and 16.5% TS. Mechanical tests for the 80:20 ratio yielded a highest mean value of 55KPa·m on Impact Strength (IS) and 68.85MPa on Modulus of Rupture (MOR) while ordinary boards yielded 50KPa·m on IS and 7.51MPa on MOR. The least mean on different properties of the bio-composite material were compared with the means of commercial board product. This study found that the PVC-Coir Dust combination exhibited highly satisfactory performance based on the physical and mechanical properties as compared to the ordinary board.

Keywords: High density board, Coco peat, PVC pellet, Modulus of Rupture, Impact Strength

1. INTRODUCTION

Today's industry demands various sources of construction materials. Since the increasing problem in the supply of materials goes with the increasing problem in solid waste management, the use of technology in producing composite board materials out of plastic wastes like PVC and agricultural wastes like coco peat can be a practical alternative. Recycled materials converted to good use and reducing the energy required to make them are called "green building materials" (Kubba, 2010).

The intent to create green building materials from wastes and the opportunity to utilize the available technology, like technology in making Medium Density Fibreboard (MDF) and High Density Fibreboard (HDF), led to creating a composite board material using coco peat and PVC wastes.

The $_U$PVC waste was chosen as binder in making a composite High Density Board since among various waste materials, plastic wastes and municipal solid wastes are of great concern. Municipal solid wastes containing PVC when burnt gives rise to toxic gases like dioxins. In fact, disposal of plastics in an eco-friendly way is one of the thrusts of today's research (Vasudevan, 2012). Polyvinyl Chloride (PVC) at global level exceeds a demand of 35 million tons per year, second only to the leader Polyethylene in the plastic industry. It is one of the most commonly used thermoplastic materials in worldwide polymer consumption (Sadat-Shojah M., 2011).

The Crown Asia Compounders Corporation (CACC) is one of the manufacturing companies in the Philippines. It manufactures plastic compounds and other plastic products for direct and indirect use in the construction and telecommunications industries. The company is currently located in Guiguinto Bulacan with an operating cost of 1,800 metric tons per year (Crown Pipes, 2011). Being a producer of PVC plastic pipes, the company yields residual PVC waste materials particularly on its plastic injector and converted into PVC pellets.

In this study, the base material for the bio-composite High Density Board product is the coco coir dust, also known as coco peat. A large amount of coir dust is produced in the process of extracting coco fiber. Coir dust is described as a brown spongy light weight particle which falls out when the fiber is shredded from the husk. It is estimated that the coir dust composed about 70% of the weight of the coconut husk (Tejano, 1985). The company Soriano Multi-Purpose Fibre Corporation (SMPFC) is one of the companies that produce coconut products in the Philippines. Being a subsidiary of the famous Foundation for a

Sustainable Society, Inc. (FSSI), the company also operates in fibre-making particularly in Laguna, Quezon and Albay (School, 2011). The coco peat waste products derived from the production of coconut products of a factory at San Mateo, San Pablo, Laguna were utilized in this study.

2. METHODOLOGY

2.1 Materials and Equipment

2.1.1 Materials for High Density Composite Board

The materials in producing the high quality HDB were sourced from the Soriano Multi-Purpose Fibre Corporation (SMPFC) in San Pablo, Laguna for the coco peat base material and Crown Asia Compounders Corporation (CACC) in San Miguel Bulacan for the unplasticized binder uPVC waste material. Figures 1a and 1b shows the appearance of the coco peat and PVC pellet upon purchase from SMPFC and CACC.

Fig. 1a: Coco Peat

Fig 1b: PVC pellets

The moisture content of the coco peat was determined using the oven-dry method. Oven-dry method is the most commonly used method in determining moisture content of a sample. The moisture content of the coco peat was determined by subtracting the weight of the coco peat before placing in to the oven to the weight of the coco peat after oven drying, this process will continue until the difference approximately reach zero. The equation below determines the percent of moisture content (MC), where it depends on the original weight (W_o) and the final weight (W_f) after oven drying.

$$MC = \frac{W_o - W_f}{W_o} \, x \, 100\% \qquad (1)$$

A moisture content of 5% or less qualifies for the HDB production. The use of sieves was employed to note the particle size of the coco peat, and the sieving procedure followed the AASHTO T 27, Sieve Analysis of Fine and Coarse Aggregate.

The commercial board, plywood, with similar thickness was used to compare with the mechanical and physical properties of the HDB composite boards. this plywood is commercially available at hardware stores in the Philippines.

2.1.2 Machines for the composite board production

The machines used in the production of HDB are the two roll mill and the heat press. The two roll mill is equipped with rolls made of corrosion resistant steel and its surface is hardened and polished. The two rolls run at fixed speed at a fixed temperature. The temperature of the two roll mill was set at 204-210^{O}C a bit higher to the melting point of the PVC. The mixing process for the coco peat and PVC was done as these components were continuously fed to the roll mill.

The heat press machine compress the HDB composition using two parallel plates. The heat press machine was set at 180^{O}C and pressure of 3.11MPa sufficient to form the desired HDB.

The machines used, are found in the Industrial Technology Development Institute (ITDI) **DOST** Compound, Gen. Santos Ave., Bicutan, Taguig City, Philippines**.**

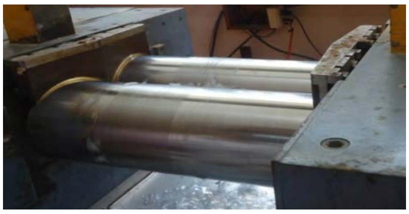

Fig. 2: The 2-Roll Mill Machine

Figure 2a shows the 2 roll mill machine used in this study.

2.2 HDB Production and Handling

2.2.1 Manner of Mixing and Percent Adhesion

The 2-roll mill machine was used in mixing the PVC and coco peat. It rotates with temperature set at 204ºC – 210ºC, same as the melting point of PVC. The ratios of the PVC binder to the coco peat used were 60:40, 70:30, and 80:20. The PVC pellets were poured between the two roll mill to melt and the coco peat mixed as repeatedly kneaded by the rotating roll mill. After mixing, the mixture was placed in a 200 x 200 x 9.5 mm molder.

2.2.2 Heat Press on Mixtures

The molder containing mixture was then placed between two parallel plates of the heat press machine with the temperature that was set at approximately 180ºC and subject to a pressure of around 3.11MPa applied for 3 minutes. Trial mass mixtures were tested for hot compress to identify which density will provide a high quality board material which was judged according to appearance and texture.

Fig. 3: The finished HDB product with wood tile quality.

Figure 3 shows the physical appearance of the HDB composite product derived from the mixed coco peat and PVC binder.

2.2.3 HDB Specimen Handling

After heat press, the molder was removed from two parallel plates of heat press machine; the HDB was extracted from the molder with the use of hand protection to avoid breakage or damage to the HDB, and to avoid burn due to early contact between newly pressed HDB and the handler. The boards were cooled at room temperature and carefully sealed in plastic bag container upon cooling, before testing. The boards were then conditioned for 3 weeks in a room with temperature of 25^{O}C and relative humidity of 65, before subjecting to physical and mechanical testing.

2.3 Physical Property Tests

2.3.1 Physical Property test

The physical property tests employed for HDB and commercially available boards were *water absorption* and *thickness swelling*. The results of these tests were compared to determine if they are significantly different.

*2.3.2 Water Absorption (WA) Test (*ASTM D1037-99, 100-107*)*

The water absorption test measures the moisture content of HDB and the commercially available board (plywood). Portions of sample boards derived from the 200 x 200 mm boards were cut into 50 mm x 50 mm for each mix ratio. The specimens were weighed and placed in a container and immersed in water for 24 hours. When retrieved, the water at the surface of the sample boards were wiped out using filter paper or tissue and then weighed. The moisture content of each sample boards were computed using equation 2:

$$\boldsymbol{MC} = \frac{\boldsymbol{Ww}}{\boldsymbol{Ws}} \text{ x } \mathbf{100\%} = \frac{\boldsymbol{W_A - W_S}}{\boldsymbol{W_s}} \boldsymbol{x}\ \mathbf{100}\% \qquad (2)$$

where MC is the moisture content, *Ww* is the weight of the water being absorbed equivalent to the difference of W_A and W_S, the weight of the board before immersing in water and the weight after immersing in water respectively (Hlaing and Kyi, 2011).

2.3.3 Thickness Swelling (TS) Test (ASTM D1037-99, 100-107)

The Thickness swelling test was conducted right after the water absorption test. After immersing the sample boards in water for 24 hours, the thickness of each board were measured using a Vernier Caliper. The measured thickness was compared to the thickness of the sample before immersion in water (Hlaing and Kyi, 2011). The test for TS and WA were based on the ASTM standard method D1037-99 (American Society for Testing and Materials, 200).

2.4 Mechanical Property Tests

The mechanical property tests for HDB and commercial board consists of tests for *modulus of ruptures(MOR)* and *impact strength (IS)*. The tests for strength were based on the ASTM code D1037. The results of these tests were compared to determine the significance of differences between HDBs and the least performing HDB with that of the CB performance.

2.4.1 Modulus of Rupture (MOR)

The *modulus of rupture* was determined using the *three point bend test*. The flexural test measures the force required to bend the HDB and the commercial board under three point loading conditions. Portions of the 200 x200mm boards were cut into 50mm x 200mm to serve as specimen for testing in each mix ratio.

The MOR is used as an indicator of the sample boards' stiffness when flexed. Each sample board was subjected to a concentrated or breaking load at the centre of the sample board using the universal testing machine (UTM) with the bend fixture. After obtaining the value of the breaking load in each sample board, the MOR of each sample board was determined using the formula:

$$\boldsymbol{M} = \frac{\boldsymbol{3PL}}{\boldsymbol{2bd^2}} \qquad (3)$$

where M is the modulus of rupture, P is the breaking load, L is the span between the two supports, *b* and *d* are the width and the depth of the board samples respectively (Based on ASTM Code D1037).

2.4.2 Impact Strength (IS) Test (ASTM D256)

The impact strength (IS) test measured the amount of energy or load required to break the board specimens. The method of un-notched impact strength was used for the IS test where the sample board was held horizontally supported at its ends with dimension 50mm x 10mm area and hit at its center by a pendulum. The IS was measured by the amount of energy per unit thickness of the specimen. The Humburg Pendulum Impact Tester was used in this study and the procedure was based on ASTM D256 standard.

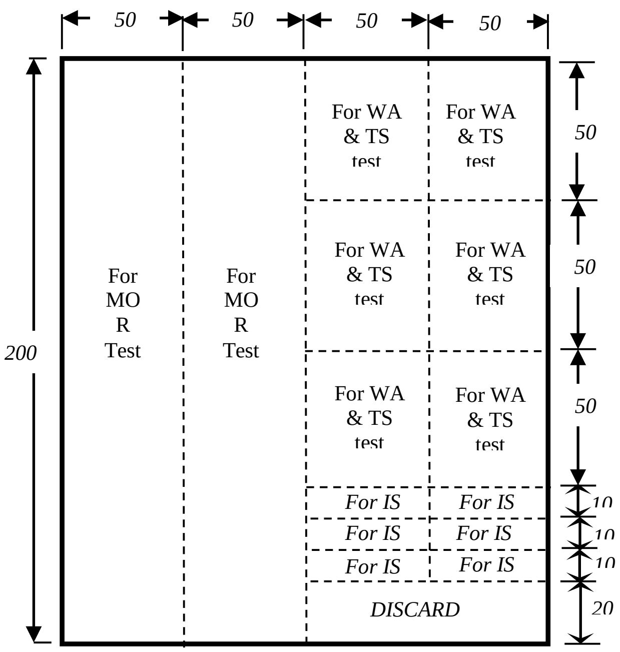

Fig. 4: Cutting pattern of test specimens for physical and mechanical testing (dimensions in mm.)

2.5 Statistical Tool

The Analysis of Variance was utilized to determine if there is a significant difference on the means of the HDBs produced using the 60:40, 70:30 and 80:20 ratio for the physical tests (WA and TS) and the Mechanical Tests (MOR and IS). The t-test was used to determine whether there is a significant difference on the means of HDB having the lowest value among the three mix ratios and the commercial board for each test.

3. RESULTS AND DISCUSSIONS

3.1 Physical Property Tests Results

3.1.1 Water Absorption and Thickness Swelling Test

Table 1. Number of board materials, number of specimens, sizes for the physical and mechanical testing

Type of Board	Type of Test		No. of Specimen	No. of Board Required
HDB	Physical Test	WA	12	2 X 3 (mix ratios) = 6 boards
		TS	12	
	Mechanical Test	MOR	4	
		IS	12	
Plywood	Physical Test	WA	12	6 boards
		TS	12	
	Mechanical Test	MOR	4	
		IS	12	

The distribution of specimens produced for various tests of physical and mechanical properties of HDBs is shown in Table 1.

The 12 specimens - 50mm x 50mm for each 3 mix ratios of HDB and the commercial board (plywood) yields the mean Water Absorption shown in Table 2.

Table 2 Data on the Mean Water Absorption and Thickness Swelling (24 hours after immersion on water for all board' mix ratios).

Board Type	Ave. Density (g/cm^3)	Mean WA (%)	Mean TS (%)
HDB (60:40 ratio)	1.3	0	0
HDB (70:30 ratio)	1.2	0	0
HDB (80:20 ratio)	1.3	0	0
Plywood	0.6	28.5	16.5

Based on results, the HDBs regardless of the mix ratio, exhibit the ability to prevent water absorption and thickness swelling, both registering zero percent! The commercial board records 28.5% and 16.5% on WA and TS, respectively. This is a promising quality of a developed product out of these materials.

3.2 Mechanical Property Tests Results

3.2.1 Modulus of Rupture

The 4 pcs – 200mm x 50mm specimens cut in each mix ratio and commercial board yield the following means as shown in Table 3.

Results showed that the HDB, which yielded the highest and lowest MOR were the 80:20 and 70:30, respectively. The commercial board records a low 7.51MPa, which indicates that the composite HDB has a flexure quality far exceeding that of the commercial board.

Table 3 Means of the Modulus of Rupture Test for the different board specimens (HDB and Plywood)

Type of Board	Mix ratio	MOR Mean (MPa)
High density Board	60:40	53.91
	70:30	51.71
	80:20	68.85
Plywood	Not Applicable	7.51

Using one way Analysis of Variance with 5% significance level for the 3 mix ratios of HDB, it shows that there was *no significant difference between the means of the MOR* derived from the 3-point bend (flexure test). Table 4 shows the ANOVA results of calculation.

Table 4 One Way ANOVA for the 3 composite boards

SOURCE	SS	df	MS	F	p
Between Groups	695.77	2	347.89	56.22	> 0.05 (Accept Ho) Null Hypothesis)
Within Group	55.69	9	6.19		
Total	751.46	11			

Table 5 showed that the 70:30 mix ratio yielded the lowest MOR (51.71MPa). This value was compared to the MOR performance of the commercially available plywood, which yielded 7.51MPa. Using the one-tailed test and 5% level of significance, the result shows that the lowest performing HDB has an MOR significantly, which is greater than that of the plywood. Table 5 shows the values in computing the test of significance.

Table 5 One-tailed t-test with 5% level of significance between 70:30 HDB and CB

BOARD TYPE	No. of Specimen	MEAN (MPa)	STD DEV	p value
70:30 HDB	4	51.71	1.91	$p_{comp} = 1.02 \times 10^{-5}$
Plywood	4	7.51	0.06	

The MOR of HDB 70:30 ratio is significantly greater than that of the plywood. Since $p_{comp} < 0.05$, which means that the flexural stress of the HDB far exceeds that of the plywood material.

The values in Table 5 show that the MOR of HDB 70:30 ratio significantly exceeds that of the plywood, therefore the HDB exhibits good quality in terms of flexure or bending stress resistance.

3.2.2 Impact Strength (IS)

The 12 pcs – 50 mm x 10 mm test specimens for each type of board (60:40, 70:30, 80:20 mix ratios and plywood) were tested using the *Humburg Pendulum Impact Strength Test*. The results of the IS means are shown in Table 6.

Table 6 Mean of the Impact Strength Test for the different board specimens of HDB and CB

Type of Board	Mix Ratio	No. of Specimens	IS (KPa-m)	STD DEV
High Density Board	60:40	12	39.38	2.65
	70:30	12	51.88	3.54
	80:20	12	55.00	2.30
Plywood	Not Applicable	12	50.00	1.28

Table 6 shows that 70:30 yields the highest mean on IS, while 60:40 yields the lowest. Plywood has an IS mean comparable to the IS of any HDB mix ratio. This result suggests that plywood exhibit good quality in terms of impact resistance which is comparable to the IS of the HDBs.

Table 7 shows the values for the test of significance among the 3 mix ratios of the HDB.

Table 7 One Way ANOVA test for the 3 mix ratios of HDB

SOURCE	SS	df	MS	F	p
Between Groups	1639.875	2	819.938	99.010	
Within Groups	273.285	33	8.281		> 0.05 , therefore accept Ho
Total	1913.160	35			

The difference on the means of the HDBs produced is not significant among the 3 mix ratios, though the 60:40 ratio emerged as the highest, followed by the 80:20 ratio and least performing is the 70:30 ratio as shown in Table 7

The variation in values of the mechanical properties of the boards is summarized and shown in Figure 5, where the HDBs are noted to excel in the MOR performance while the plywood excel in the IS performance. HDBs with 80:20 mix ratio demonstrate highest performance in MOR while the 70:30 ratio is the least. The 60:40 ratio demonstrate the highest performance in IS while the 70: 30 is the least.

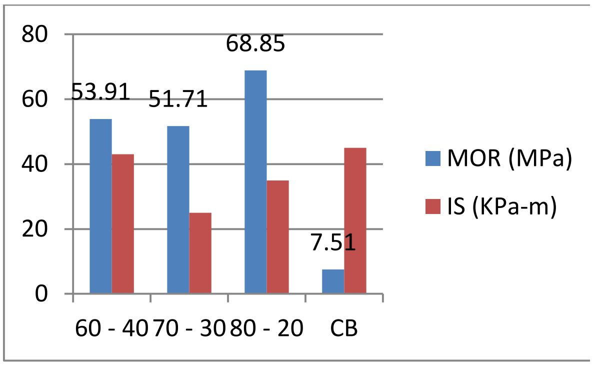

Fig. 5: Combined graph of the MOR and IS Means

4. CONCLUSION

Based on the results on Physical and Mechanical Properties of the bio-composite HDB made of PVC waste and Coco Peat waste, the following conclusions were drawn:

1. The WA and TS of the composite HDB had shown excellent quality regardless of the mix ratio used. All specimens demonstrated 0% on both WA and IS tests. These results can be attributed to the plastic property of the binder PVC which comprises the greater percentage of the HDB component.
2. The mechanical test of the HDBs in resisting flexure or bending exhibit good performance compared to plywood. Among the mix ratios 60:40, 70:30 and 80:20, the best mixture was 80:20 recording an MOR of 68.85 MPa, while the 70:30 was the least performing with an MOR value of 51.71 MPa. Though statistics show that the MOR values of the 3 mix ratios do not differ significantly, the plywood had shown weak resistance in bending as reflected by its low MOR value of 7.51 MPa.
3. The plywood demonstrated impact resistance comparable to the HDBs. The 60:40 ratio exhibits best IS while the ratio 70:30 exhibited the least. The plywood has an IS mean of 50.00 KPa-m, which is quite high as compared to the 39.38 KPa-m value of the 60:40 HDB. The resistance of plywood against impact can be attributed to its physical structure since the board was produced through adhesion of wood ply, whereas the HDBs are of homogenous mixture bonded though heat and pressure.
4. The physical appearance of the HDB bio-composite product shows a quality comparable to a fine wood-tile. The surface exhibits a glossy surface which enhances the aesthetic feature of the composite material.

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