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Physical and Mechanical Properties Evaluation of Particle Board Produced From Saw Dust and Plastic Waste

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Abstract. The current work reports on the fabrication of composite matrix from saw dust (SD) and recycled polyethylene terephthalate (PET) at different weight ratio by flat-pressed method. Wood plastic composites (WPCs) were made with a thickness of 15 mm after mixing the saw dust and PET followed by a three phase press cycle. Physical properties (Density, Water Absorption (WA) and Thickness Swelling (TS)) and Mechanical properties (Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)) were determined base on the mixing ratios according to the standard. WA and TS were measured after 2 h and 24 h of immersion in water. The results showed that as the density increased, the SD content decreased from 90 % to 50 % into the matrix. However, WA and TS decreases when the PET content increased in the matrix. Remarkably, the MOE and MOR attained a maximum point at 964.199 N/mm^2 and 9.03 N/mm^2 respectively in 50 % SD content. In comparism with standard, boards D and E can be classified as medium density boards while A, B and C are low density boards. The results indicated that the fabrication of WPCs from sawdust and PET would technically be feasible for indoor uses in building due to favorable physical properties exhibited. The mechanical properties response showed that it cannot be used for structural or load bearing application.

Introduction

Reused and waste thermoplastics are a portion of the real segments of worldwide municipal solid waste (MSW) and they display a promising crude material hotspot for wood-plastic composites (WPC) development, particularly in view of the extensive volume and ease of these materials. Primarily, polyethylene terephthalate (PET), polystyrene (PS), polyvinyl chloride (PVC), and high-density polyethylene (HDPE) are essential constituents of plastics in MSW [1]. The mix of the blended waste plastics can be changed relying upon the provincial propensities and periods of a year and on the method of waste gathering [2]. Reutilizing the post-devoured polymeric materials lessens the natural effect and the utilization of virgin plastics. Most single polymer plastics produced using oil are moderately simple to reuse. In this manner, with a productive accumulation, detachment and reusing framework, disposal of plastics can be reused into new items with just the expansion of vitality [3, 1]. The administration of plastics waste is one of the significant issues confronting current society as it is non-degradable and poisonous when consumed. Polyethylene terephthalate (PET) is one of the exceptionally asked for plastic on the planet and among the most well-known plastics waste. PET has low water ingestion, high hardness and quality and PET utilized as a part of different applications like sustenance compartment, bottle, plastic strands, toys, wrapping materials, movies, and tars, in spite of the majority of the advantages, however, PET stay in nature [4, 5, 6]. Waste plastics can also be considered as potential material in the development of WPCs relying upon their softening temperature [7]. In order to enhance the compatibility of constituents' materials, a binder is thus necessary to improve the quality of product formed. In this way, expanding interest has of late been centered on the reusing of plastic waste, particularly PET for these different purposes which could keep the natural contamination.

Previously, wood has been reported in the development of composites panel with specific attention to hardwoods, softwoods and the mixtures of various species [8]. However, due to ranger service controls, wood deficiency, and practical utilization of timberland assets have asked specialists everywhere throughout the world to find elective approaches to utilize various types of lignocellulosic biomass for composite board creation [9]. Urea-Formaldehyde (UF) has been the real adhesive for wood-based particleboards. In spite of the fact that Formaldehyde containing tar is broadly utilized today as a glue in the fabrication of particleboard, researchers are looking for elective cement frameworks because of the exceptionally lethal nature of formaldehyde [10]. Particle board have being produced from agricultural waste such as sugarcane, wheat straw [8], tree leaves [11], sunflower stalks [12], maize cobs [13], maize husks [14], coconut [15], banana bunch [16], palm kernel shell [17], saline Jose tall wheatgrass [18] and rice husks [19]. Currently, an increase in the demand of wood composite panels as necessitated the choice for an alternative material which is economically viable, with less processing technique. This demand has made the potential use of sawdust a viable particulate material an option in the manufacture of WPCs.

Materials and Methods

Materials: The materials used for this work are sawdust, waste plastic (Polyethylene terephthalate (PF) bottle) and urea formaldehyde resin (Top Bond). Sawdust was obtained from the local saw mills in Kwara state, Nigeria and screened to remove the impurities thereafter air-dried to a moisture content range of between 2 % to 8 %. Clean consumer drinking water bottles were collected locally and shredded by shredding machine and a pair of scissors, the shredding machine gives fine particles while the scissors give bigger sizes of the PF. The PF was then air dried for 24 h.

Composites Mix Design: The boards were made in panels of sizes $\mathbf{350\ mm} \times \mathbf{350\ mm} \times \mathbf{30\ mm}$ by varying the amount of wood sawdust (SD) and the shredded Polyethylene terephthalate (PF) bottle. Two different sizes of waste plastic were used, the fine form and the coarse form, the coarse form was measured to be the 20 % of the total PF volume. The binder also was measured in volume as 20 % of the board volume.

Table 1: Experimental design of boards

Sample		Mix Ratio [SD:PF]	Sawdust [ml]	Plastic Fibre (PF) [ml]	Fine Sizes [ml] (80 % of PF)	Coarse Sizes [ml] (20 % of PF)	Adhesive [ml]
A	$SD_{90}PF_{10}$	90:10	2268	252	201.4	50.4	630
B	$SD_{80}PF_{20}$	80:20	2016	504	403.2	100.8	630
C	$SD_{70}PF_{30}$	70:30	1764	756	604.8	151.2	630
D	$SD_{60}PF_{40}$	60:40	1512	1008	806.4	201.6	630
E	$SD_{50}PF_{50}$	50:50	1260	1260	1008	252	630

The materials for each of the boards were measured according to Table 1 and mixed thoroughly to have an even mix with the binder before spreading it into the mould to form a mat. The formed mat in the mould went through a press cycle of three phases; pressing in an hydraulic jack to reduce the board height, afterwards in an oven and allowed to dry for 1h at 80 °C and lastly cold pressing to facilitate the setting of the thermoplastic resin. Afterward, the mould was opened and placed under room temperature for 24 h and then placed in the oven for 3 h at 110 °C. After the oven drying, the formed panels were conditioned to 74 % humidity and a temperature of 24 ℃ for two weeks to give boards as presented in Figure 1. before carrying out the physical properties tests (density, water absorption and thickness swelling) and the mechanical properties determination (modulus of rupture and modules of elasticity). From each batch sample, three (3) test pieces measuring 50 mm x 50 mm x 15 mm were cut for the physical tests and three (3) other test pieces measuring 50 mm x 50 mm x 300 mm were cut for the mechanical tests to ensure reproducibility.

Fig. 1: Samples of boards produced from sawdust and plastic waste

Physical Tests

Density Test: Density test were carried out on the particleboards to determine the mean density for each board type. It was carried out based on the British code of standards BS EN 323 [20].

$$\sigma = \frac{m}{v}$$

$$\sigma = density, m = mass\ of\ each\ test\ piece\ (kg), v = volume\ of\ the\ test\ piece\ (m^3)$$

Water Absorption Test: The water absorption test was carried out to determine the amount of water the particle board can absorb within a given time duration.

$$WA = \frac{W_f - W_i}{W_i} \times 100\%$$

$$W_f = final\ weight, W_i = initial\ Weight, W_A = Water\ Absorption\ (\%)$$

Thickness Swelling Test: This is a dimensional analysis test which is used to determine the change in the thickness of the sample after it has been immersed in water for a given period of time. It is used to determine the effect of water on the thickness of the board. It was carried out based on the British code of standards BS EN 317 [21].

$$Ts = \frac{t_2 - t_1}{t_1} \times 100$$

$$t_1 = initial\ thickness, t_2 = final\ thickness, T_s = thickness\ swelling\ (\%)$$

Mechanical Tests

Static Bending Tests: The universal testing machine was used to carry out the tests following the central concentration loading method. From this test, the modulus of the rupture (MOR) and modulus of elasticity (MOE) of the specimen will be determined. MOR and MOE are measured in N/mm^3. It was carried out based on the British code of standards BS EN 310 [22].

$$MOE = \frac{(F_2 - F_1)l_1^3}{4bt^3(a_2 - a_1)}$$

$$MOR = \frac{3F_{max}l_1}{2bt^2}$$

- F_2-F_1 is the gradual increase of load on the straight-line portion of the load deflection curve ad is measured in newton, N. F_1 is approximately 10 % of the maximum load while F_2 is approximately 40 %.
- F_{max} is the maximum load measured in newtons.
- b is the breadth of the specimen, measured in millimeters, mm.

- t is the thickness of the specimen, measured in mm.
- l_1 is the distance between the centers of the support which is also measured in mm.

a_2-a_1 is the deflection of the specimen at mid span, corresponding to $F_2 - F_1$ and is also measured in mm

Results and Discussion

Physical Properties: The Results of the Density test, Water Absorption and Thickness Swelling tests in mean values were as presented in Table 2.

Table 2: Mean Values of Density, Water Absorption and Thickness Swelling Tests

Board Sample		Density [Kg/m^3]	Water Absorption Test		Thickness Swelling Test	
			%WA after 2 h	%WA after 24 h	%TS after 2 h	%TS after 24 h
A	$SD_{90}PF_{10}$	430.6269±31.705	90.8612±1.578	148.5009±4.440	8.9372±1.389	21.92±0.766
B	$SD_{80}PF_{20}$	483.1574±31.767	81.0475±4.346	115.2342±0.858	7.0501±1.714	18.2897±3.409
C	$SD_{70}PF_{30}$	537.2446±47.704	74.4787±4.031	110.3844±5.491	6.0081±0.434	16.1441±3.412
D	$SD_{60}PF_{40}$	623.2246±92.847	66.6119±6.955	105.9443±13.371	5.5803±1.444	13.3452±2.437
E	$SD_{50}PF_{50}$	710.8903±30.181	63.6233±6.955	100.7137±10.349	5.4851±0.389	11.7645±0.647

A representative trend showing the density of composites and board samples is presented in Fig. 1.

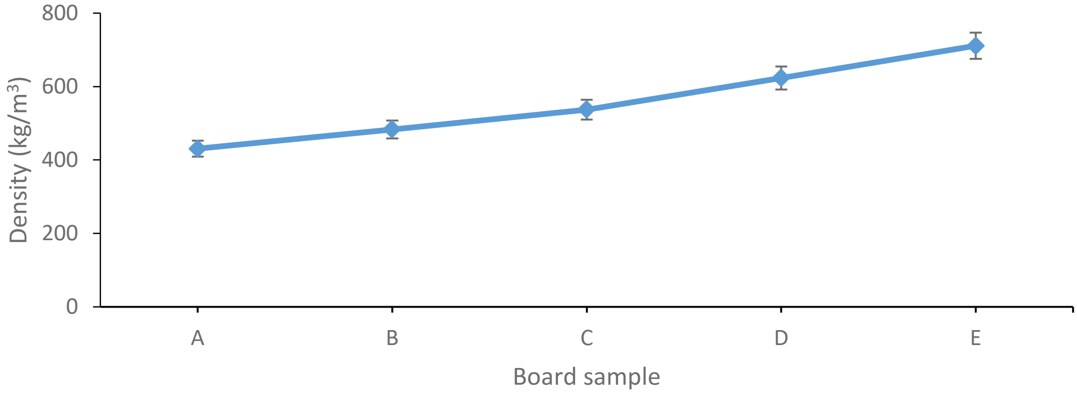

Fig. 1: Variation in density against board samples

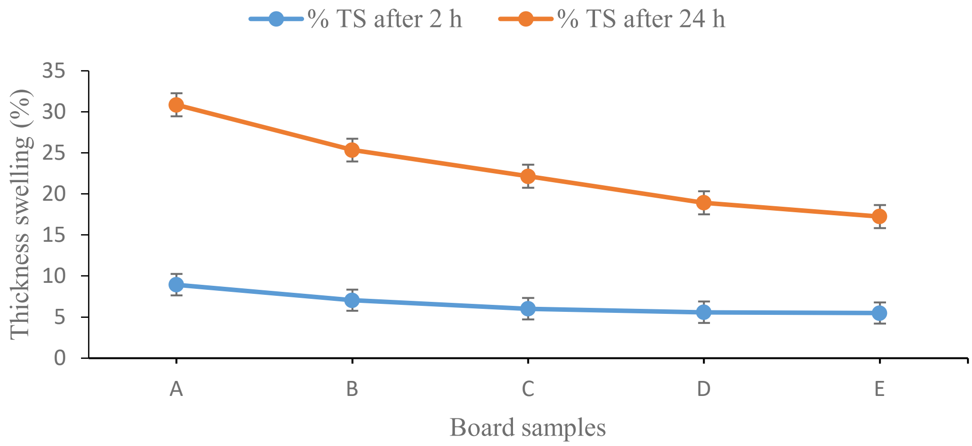

Fig. 2: Variation in thickness swelling against board samples

The density value of a composite material system is an important property which determine its performance in service environment. As presented in Figure 1, the density of the developed particleboards decreased with the increase in weight percent of SD. The board sample with the lowest density (430.6269 Kg/m^3) is $SD_{90}PF_{10}$ of weight ratio 90:10 while the board with the highest density (710.8903 Kg/m^3) is board $SD_{50}PF_{50}$ with 50 % SD and 50 % plastic fibre. At this interphase, there was an evenly distribution of fibre within the matrix of the SD. According to ANSI 208 [23] standard, board $SD_{90}PF_{10}$, $SD_{80}PF_{20}$ and $SD_{70}PF_{30}$ can be classified as low density particle boards with densities less than 600kg/m^3 while boards $SD_{60}PF_{40}$ and $SD_{50}PF_{50}$ are classified as medium densities particle board [23].

The WA of the particleboards at temperature (20 °C) after 2 h and 24 h of immersion in water shows that the rate of water absorption decreases with reduction in the SD content. This is as a result of the hydrophilic nature of wood which consist of cellulose, lignin and hemicellulose polymer and is so rich in hydroxyls; thus, readily reacts with water molecules. A similar trend was obeserved in the thickness swelling, however, from the result shown; the boards having lower percentage of plastic fibre were more susceptible to the thickness swelling than those having higher plastic fibre content. The lowest thickness swelling was found for E composites which might be as a result of the higher compatibility between SD and PF when compared to the other formulations. Previous report by autthors shows that wood has a critical surface energy in the range of 40–60 MJ/m^2 [24] which is higher than that of plastic fibre. This large difference in surface energy between plastic fibre and wood might make the plastic fibre to be water repellent or hydrophobic.

Mechanical Properties: The Results of the Modulus of Rupture and Modulus of Elasticity tests in mean values are as presented in Figure 3 and 4.

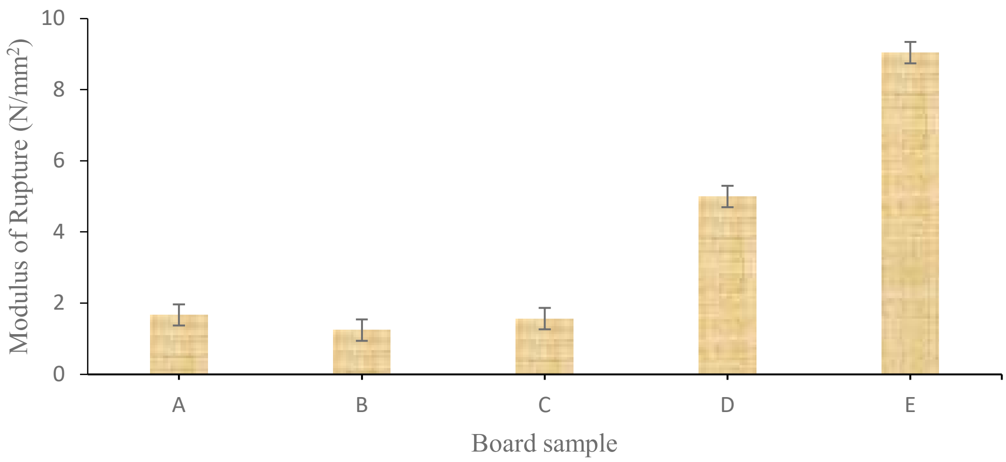

Fig. 3: Variation in Modulus of Rupture against Board sample

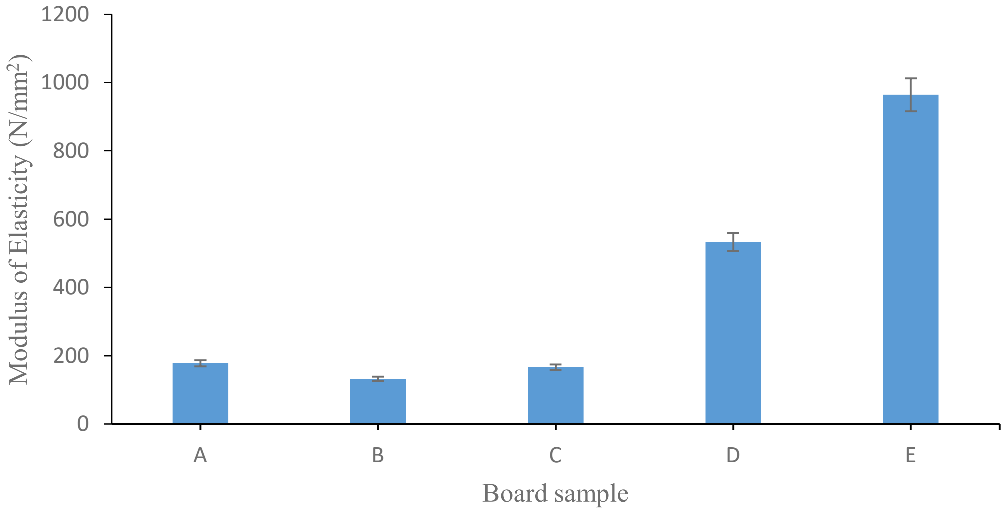

Figure 4: Variation in Modulus of Elasticity against Board sample

From Figure 3, it was observed that the value of MOR decreased by 25.5 % with a decrease in SD value from 90 % to 80 % (Sample A and B). Although, there was an increase from 1.242 to 9.039 N/mm^2 as the SD content reduces to 50 %. The board with 50:50 ratio of SD to PF had the highest MOR value compared to the other formulations. However, from Figure 4, the value of MOE also decreased by 25.5 % with the decrease of SD value from 90 % to 80 % (Sample A and B). Moreover, there was a further increament with further decrease of SD content ranging between 132.428 and 964.199 N/mm^2. The optimum MOE value was attained in a batch mix of 50:50. Based on BS EN 13353 [25], panels intended for structural purposes that have densities greater than the minimum requirement were also required to have their minimum values for MOR and MOE to be 5 N/mm^2 and 400 N/mm^2 respectively [25]. From the result obtained in Figure 4, Boards A-C did not meet up with the minimum requirement for MOR and MOE while D and E met the minimum requirement with MOR values of 4.997 and 9.039 N/mm^2 respectively and MOE values of 532.966 and 964.999 N/mm^2 respectively.
The MOE of composites decreased along with higher SD loading from 90 to 50 % in the formulation. This variation might be due to the poor interfacial interaction between the sawdust and plastic fibre. [26] reported that the low MOE of the composites could be mainly attributed to the poor interfacial interaction between the polymeric matrix and wood particle, not allowing efficient stress transfer between the two phases of the material though the modulus of the natural fibers are higher than the polymeric materials. Moreover, [27] reported that the relatively large surface area of the fine materials might be another cause of strength loss of the composites.

The effects of PF content on SD-PF composites illustrates that the higher content of PF in the wood plastic composite (WPC) formulation increases the density and bending strength of composites. In the mean time, the increasing PF content in the formulation decreases the moisture content, WA and TS at temperatures of 20 °C. This shows that the effect of PF content on moisture content, WA and TS of wood plastic composite is positive

Conclusion

The conclusions drawn from the present investigations are as follows:

- the variations in physical and mechanical property is as a result of dissimilar materials used in the development of WPCs as well as the formulation through the ratio.
- increase in the PF contents increases the board densities, boards with minimum of 40 % PF attained the strength of a medium density board as classified by American National Standard Institute.

- increase in PF contents also causes decrease in the moisture content, water absorption and thickness swelling of composite boards.
- the Modulus of Rupture and Modulus of Elasticity of the board produced increased significantly as the sawdust content reduces and the plastic fibre content increases.
- generally, addition of the plastic fibre increases the bending strength of the composite board. Particleboards made from sawdust and plastic waste can suitably be used for making furniture, door and other wood products as approved for medium density boards so as to reduce the pressure on solid board and the natural forest.

References

[1] S. K. Najafi, "Use of Recycled Plastics in Wood Plastics Composites - A Review," *Waste Management,* 2013.

[2] M. Chanda and S. K. Roy, Plastics Technology Handbook, Fourth ed., CRC Press, 2007.

[3] K. Jayaraman and D. Bhattacharya, "Mechanical performance of wood fibre-waste plastic composite materials," *Resources, Conservation and Recycling,* vol. 41, pp. 307-319, 2004.

[4] D. A. Wahab, A. Abidin and C. H. Azhari, "Recycling Trends in the Plastics Manufacturing and Recycling Companies in Malaysia," *Journal of Applied Sciences,* vol. 7, pp. 1030-1035, 2007.

[5] A. R. Oromiehie and A. Mamizadeh, "Recycling PET Beverage Bottles and Improving its Properties," *Journal of Polymer International,* vol. 53, pp. 728- 732, 2004.

[6] V. Sinha, M. R. Patel and J. V. Patel, "Pet waste management by chemical recycling: a review," *Journal of Polymers and the Environment,* vol. 18, pp. 8-25, 2010.

[7] N. M. Stark, Z. Cai and C. Carll, "Wood-based composite materials panel products, glued-laminated timber, structural composite lumber, and wood–nonwood composite materials," US Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, 2010.

[8] S. Halvarson, H. Edlund and M. Norgen, "Manufacture of non-resin wheat straw fibre boards," *Industrial Crops and Products,* vol. 29, pp. 437-445, 2009.

[9] N. Saari, R. Hashim, O. Sulaiman, S. Hiziroglu, M. Sato and T. Sugimoto, "Property of steam treated binderless particleboard made from oil palm trunks," *Composites Part B: Engineering,* vol. 56, pp. 344-349, 2014.

[10] W. Peng, G. Fanta and K. Eskins, "Particleboard made with starch based adhensives," *TEKTRAN United States Department of Agriculture, Agricultural Research Service,* 1997.

[11] H. Pirayesh, P. Moradpour and S. Sephvand, "Particleboard from wood particles and sycamore leaves: physic-mechanical properties," *Engineering in Agriculture, Environment and Food,* vol. 8, no. 1, pp. 38-43, 2015.

[12] P. Khristova, N. Yossifov, S. Gabir, I. Glavche and Z. Osman, "Particleboards from sunflower stalks and tannin-modified UF resin. Cellul. Chem. Technol. 32,," *Cellulose Chemistry and Technology,* vol. 32, p. 327–337, 1998.

[13] A. A. Raheem, A. P. Adewuyi, L. O. Azeez, O. D. Atoyebi and O. M. Akanbi, "An Investigation of the use of Corncob and sawdust in Ceiling production.," *Lautech Journal of Engineering and Technology (LAUJET),* vol. 6 , no. 1, p. 149 – 155, 2010.

[14] A. Sampathrajan, N. C. Vijayaraghavan and K. R. Swaminathan, "Mechanical and thermal properties of particleboards made from farm residues," *Bioresource Technology,* vol. 40, p. 249–251, 1992.

[15] V. G. V. D. Jan, J. A. V. D. O. Martien and R. P. K. Edwin, "Production process for high density high performance binderless boards from whole coconut husk. Ind. Crop Prod. 20,," *Industrial Crops and Products,* vol. 20, no. 1, pp. 97-101, July 2004.

[16] Q. German, V. Jorge, B. Santiago and G. Piedad, "Binderless fiberboard from steam exploded banana bunch," *Industrial Crops and Products,* vol. 29, pp. 60-66, 2009.

[17] O. D. Atoyebi, T. F. Awolusi and I. E. Davies, "Artificial neural network evaluation of cement-bonded particle board produced from red iron wood (Lophira alata) sawdust and palm kernel shell residues,," *Case Studies in Construction Materials,* vol. 19, pp. 2340-2343, 2018.

[18] Y. Zheng, Z. Pan, R. Zhang, B. Jekins and S. Blunk, "Particleboard quality characteristics of saline jose tall wheatgrass and chemical treatment effect," *Bioresource Technology,* vol. 98, pp. 1304-1310, 2007.

[19] A. Temitope, A. Onaopemipo, A. Olawale and O. Abayomi, "Recycling of rice husk into a locally made water-resistant particleboard," *Industrial Engineering and Management,* vol. 4, no. 3, pp. 1-6, 2015.

[20] BS EN 323:1993, "British Standard Institution, Wood-based panels. Determination of density," British Standard Institution, London, 1993.

[21] BS EN 317:1993, "Particleboards and fibreboards. Determination of swelling in thickness after immersion into water," British Standard Institution, London, 1993.

[22] BS EN 310:1993, "Wood-based panels. Determination of modulus of elasticity in bending and of bending strength," British Standard Institution, London, 1993.

[23] ANSI 208-1-1999, American National Standard Institute. American National Standard -- Particleboard, Gaithersburg: Composite Panel Association, 1999.

[24] B. S. Gupta, I. Reiniati and M. P. G. Laborie, "Surface properties and adhesion of wood fiber reinforced thermoplastic composites," *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* vol. 302, no. 1, pp. 388-395, 2007.

[25] BS EN-13353:2003, "British Standard Institution. Standard Wood Panels (SWP) - Requirements.," European Committee for Standardization, London, 2003.

[26] M. Shibata, K. I. Takachiyo, K. Ozawa, R. Yosomiya and H. Takeishi, "Biodegradable polyester composites reinforced with short abaca fiber," *Journal of Applied Polymer Science,* vol. 85, no. 1, pp. 129-138, 2002.

[27] T. M. Maloney, Modern particleboard & dry-process fiberboard manufacturing., San Francisco: Miller Freeman Publications, 1977.