Mechanical Properties of Hybrid Wood/Clay Plastic Composites

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***Abstract* - This paper seeks to put waste materials from plastic (low density polyethylene), Forestry (sawdust) and clay to alternative uses, which are economically viable. The composites produced are hybrid in nature because of the twin fillers used. The mechanical properties of the material were evaluated with emphasis on tensile strength, young modulus and flexural strength. The results showed a modest increase in rheological properties and young modulus as the filler ratio increased in the samples. For instance, at 50% filler ratio, the young modulus value was 248.17 N/mm^2. This was the optimum value, though at 40% filler ratio, relatively high values were possible. Also, 50% filler ratio gave the optimal tensile strength of 417.3 N while at filler ratio 40%, the least tensile strength value was recorded at 113.7 N. The fillers used also had significant impact on the stiffness of the composites as seen in the flexural strength values. At filler ratio 50% the flexural strength was 9.68 N/mm^2 which was higher than all other samples.**

Keywords: Sawdust, Clay, Hybrid Composites, Coupling Agents,

INTRODUCTION

In the face of rapidly changing global climate, the effect of industrial logging of the world's primary forests is felt even more. The destruction of natural habitats of thousands of animals and plant species, depletion of atmospheric oxygen and its attendant health hazards, calls for a halt to the destructive exploitation of hard wood and deforestation. The development of Wood Plastic Composite is of great relieve in this regard[1].

Now more than ever, plastic and wood wastes have become a major environmental concern as regards degradability and pollution. Wood Plastic Composites (WPC) with its wide range of application helps to put these wastes into meaningful and commercially viable use thereby, reducing pollution considerably. It is a fast growingresearch area. It has found uses in fences, sidings, deckings, park benches,landscaping timbers, windows and door frames, ponds, indoor furniture, pellets and manyothers.

The term "wood-plastic composites" WPC widely refers to any number of composites that contains wood (of any form) and either thermoset-or thermoplastic-polymers.
More specifically, the term refers to thermo-plastically processible composites that consist of varying contents of wood, plastic and additives, and are processed by thermoplastic shape forming techniques such as extrusion, injection moulding, rotomoulding or pressing [2].
The birth of the WPC industry involved the interfacing of two industries that have historically known little about each other and have very different knowledge bases, expertise, and perspectives. The forest products industry has greater experience and resources in the building products market and its production methods center around the typical wood processes; sawing, veneering, chipping, flaking and gluing. The plastics industry has knowledge of plastics processing that centers around extrusion, compression-molding and injection-molding technologies.

Many trials of obtaining a WPC product were basically built on the concept of a cradle to cradle approach where the material is recycled at the end of its life cycle to produce a cradle (new) product and thus close the loop and imitate the natural ecosystem [3].

A high potential of using WPC in a large scale to produce pallets is raised [4]; whereas the amount of consumed wooden pallets is huge (400 million pallets) accounting for about 86% of all pallets sold worldwide. In addition, product degradation due to environmental factors, which is one of the main disadvantages of wood, makes WPC well acceptable. According to [5], they can be molded easily in variety of shapes and angles to produce desired designs.

CONCEPT OF PRODUCTION

Thermoplastic processing operations involve the process of moving melted (viscous) materials with thermoplastic characteristics (soften when heated) into some form or mold and then cooling (solidifying) the materials for the purpose of making desired shapes. One of the major driving forces behind this trend is to replace metal or thermoset plastics with thermoplastic materials that can be reused and are lighter in weight. Although most forms of thermoplastic processing involve some type of extrusion, the processes go under a variety of names, have slightly different parameters, utilize different equipment and require different processing aids.
Thermoplastic processes are constantly evolving, due to continuous innovation in materials. However, five major processes are most often employed. The common theme among all of the processes is the use of a thermoplastic polymer that is transformed by heat into a different shape, which can then be reversed.

COMPOSITION OF THE HYBRID WOOD/ CLAY PLASTIC COMPOSITE

A typical WPC consists of wood (Particulate or Fine), Thermoplastics (PP, PE e.t.c), UV protective agents, coupling agents, lubricants and pigments [2]. For this work, the main components includes:

RECYCLED POLYETHYLENE

Low-Density Polyethylene (LDPE) is a thermoplastic made from the monomer ethylene. It was the first grade of polyethylene, produced in 1933 by Imperial Chemical Industries (ICI) using a high-pressure process via free radical polymerization [6]. The LDPE used has recycling number 4. Despite competition from more modern polymers, LDPE continues to be an important plastic grade. Its comparatively low density arises from the presence of a small amount of branching in the chain (on about 2% of the carbon atoms). This gives a more open structure [7].

CLAY

Clay is a general term including many or more clay minerals with traces of metal oxides and organic matter [8]. Clay is one of the oldest building materials on earth, among other ancient naturally occurring geologic materials like wood. Clay exhibits plasticity when mixed with water in certain proportions, when dry, clay becomes firm and when fired in a kiln, permanent physical and chemical changes occur. These reactions among other changes cause the clay to be converted into a ceramic material. Because of this property, clay is used for making pottery items, both utilitarian and decoration, and construction products [6]. Where brittleness is required, clay plays an important role. Also, it serves a great purpose in terms of thermal conductivity.

WOOD

Mahogany is the specie of wood used. It has played an essential role in woodworking for centuries. It is highly prized for its exotic red color and grain pattern. Its consistency in density and hardness makes it an easy wood to work with, and it is commonly used for furniture making, cabinetry and paneling [9]. The choice of mahogany was due to its low density and low moisture content. This makes it less susceptible to rot than many hardwoods. Since mahogany is a rain forest wood, it is naturally water and pest resistant. It is many times less susceptible to termites and rated among the best hardwoods in terms of durability and it used in park benches, indoor furniture, doorframes among others [10]. Mahogany has a tendency to split, particularly Honduran mahogany which is force-dried. Proper treatment with oils, such as tung oil and boiled linseed cut with turpentine, can help to prevent this.

RAW MATERIALS AND METHODOLOGY

Recycled low density polyethylene, mahogany sawdust (wood flour), clay (fine particles), plast modifier (coupling agent), saumya two-roll mill, saumya hydraulic compression molding machine, hand rubber gloves, weighing balance, stopwatch, paper tape, scissors, beakers, aluminum foil, distilled water, kerosene, toluene, petrol.

METHODOLOGY

MILLING

Melt blending of wood and thermoplastics usually requires an input of physical energy via high shear force for the polymer to melt [11].

A two – roll mill machine was used. The rolls rotate at different speeds (speed ratio = 1.375) to create a shearing action to the trough formed between them. Plastics generally have poor thermal conductivity, so this shearing action is very important to achieve a melt. The rolls are fitted with internal heating elements designed to have a safe operating temperature range of 500^{o}F. No external heater, or pump, or special thermal fluid was required.

MOLDING

A compression molding hydraulic machine was used. The molten material generally preheated was first placed in an open heated mold cavity. The mold was closed with a top force or plug member, pressure was applied to force the material into contact with all mold areas, while heat and pressure were maintained until the molten material has cured. The process employs thermosetting resins in a partially cured stage either in the form of granules or putty–like mass.

Pelletised recycled low density polyethylene (LDPE) and plast modifier (coupling agent) was obtained from a plastic production company (Poly Product, Oshodi). Mahogany sawdust was gotten from a local wood sawmill situated at Bariga, Shomolu area of Lagos State. Clay was obtained from the Clay Industry, Ojota, Lagos. Before sample preparation, clay and sawdust were oven dried at 60^{o}C for 2 hrs. The clay and sawdust were milled separately using an electric milling machine and sieved separately with a mesh of size 0.75mm to obtain a fine powder used in the production of hybrid wood plastic composite.

The recycled LDPE, sawdust flour, fine clay powder and plast modifier were weighed and bagged according to formulations given in Table1.

The sawdust, recycled LDPE, clay and coupling agent (plast modifier) were milled together using the two–roll mill at 150˚C and 60 revolution per minute (rpm). The wood plastic composite formed was passed into the hydraulic compression-molding machine at 130˚C for 6 minutes. The specimens were then stored under controlled conditions (50% relative humidity and 26˚C) for at least 40 hrs prior to testing. The coupling agent enhanced the milling process.

The composition of the formulationsare as shown in tables 1,2,3, and 4

TABLE 1

Sample Code	Recycled LDPE (g)	FILLERS (15g)		Plast Modifier Content (g)	Filler Ratio
		Sawdust	Clay		
A1	50	10.5	4.5	1	7:3
A2	50	9	6	1	6:4
A3	50	7.5	7.5	1	5:5
A4	50	6	9	1	4:6
A5	50	4.5	10.5	1	3:7

Ratio of LDPE to Filler is 1:0.3

TABLE 2

Sample Code	Recycled LDPE (g)	FILLERS (20g)		Plast Modifier Content (g)	Filler Ratio
		Sawdust	Clay		
B1	50	14	6	1	7:3
B2	50	12	8	1	6:4
B3	50	10	10	1	5:5
B4	50	8	12	1	4:6
B5	50	6	14	1	3:7

Ratio of LDPE to Filler is 1:0.4

TABLE 3

Sample Code	Recycled LDPE (g)	FILLERS (25g)		Plast Modifier Content (g)	Filler Ratio
		Sawdust	Clay		
C1	50	17.5	7.5	1	7:3
C2	50	15	10	1	6:4
C3	50	12.5	12.5	1	5:5
C4	50	10	15	1	4:6
C5	50	7.5	17.5	1	3:7

Ratio of LDPE to Filler is 1:0.5

TABLE 4

Sample Code	Recycled LDPE (g)	FILLERS (30g)		Plast Modifier Content (g)	Filler Ratio
		Sawdust	Clay		
D1	50	21	9	1	7:3
D2	50	18	12	1	6:4
D3	50	15	15	1	5:5
D4	50	12	18	1	4:6
D5	50	9	21	1	3:7

Ratio of LDPE to Filler is 1:0.6

RESULTS

MECHANICAL TESTING

Specimens were tested for tensile and flexural strength. The flexural properties were measured in three-point bend tests using a Universal Tensile Testing Machine and their results are shown in tables 5, 6, 7 and 8.

TENSILE TESTS OF SAMPLES

TABLE 5

SAMPLES	FORCE AT PEAK (N)	ELONGATION AT PEAK (mm)	YOUNG MODULUS (N/mm^2)
AI	234.50	4.0190	61.591
A2	254.50	5.1010	104.87
A3	280.00	6.8321	108.20
A4	315.00	7.7890	76.910
A5	370.50	6.6390	95.537

Results for sample A

TABLE 6

SAMPLES	FORCE AT PEAK (N)	ELONGATION AT PEAK (mm)	YOUNG MODULUS (N/mm^2)
B1	248.00	3.0800	88.024
B2	113.70	3.2270	79.484
B3	327.70	4.0030	123.53
B4	325.60	3.8330	112.76
B5	357.80	5.6850	103.63

Results for sample B

TABLE 7

SAMPLES	FORCE AT PEAK (N)	ELONGATION AT PEAK (mm)	YOUNG MODULUS (N/mm^2)
C1	367.30	4.5600	116.02
C2	382.60	4.6370	195.06
C3	371.00	4.9420	123.25
C4	417.30	5.5110	248.17
C5	357.50	5.4450	102.43

Results for sample C

TABLE 8

SAMPLES	FORCE AT PEAK (N)	ELONGATION AT PEAK (mm)	YOUNG MODULUS (N/mm^2)
D1	356.30	3.6700	136.77
D2	288.00	2.4810	133.21
D3	329.90	2.4650	105.954
D4	378.30	3.8270	139.73
D5	194.20	2.7890	68.118

Results for sample D

DISCUSSION

In fig. 1, at 30% filler, the tensile strength increased steadily. It peaked at A5 with filler ratio 3:7, though not the optimum strength. At 40 % filler, the least Tensile strength was recorded at B2 with filler ratio 6:4 where sawdust was considerably higher. When the filler was increased to 50%, the highest Tensile Strength was recorded at C4 with filler ratio 4:6. At 60% filler, D4, with filler ratio 4:6 has the highest Tensile Strength in the range though considerably lower than that of C4 at 50%.

It becomes obvious that as the filler ratio increased, the tensile strength also increased but the samples with higher clay ratio gave the best tensile values. Hence, clay as filler has more impact on tensile strength of the hybrid composite. Because of this property, clay is used for making pottery items, both utilitarian and decoration, and construction products [6]. Also, it was observed that at 30% filler, A1 with filler ratio 7:3 has the least value. The high proportion of sawdust in the composition accounts for this.

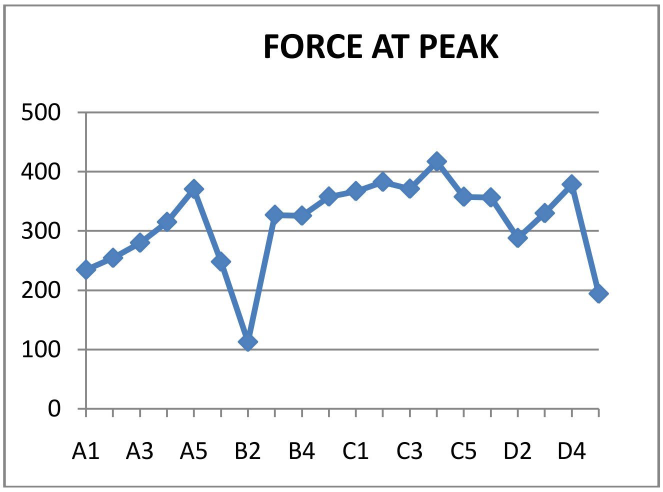

Fig 1. Plot of Tensile Strength against samples

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Fig. 2 shows that as the filler increases to 40%, B4 with filler ratio 4:6 gave the highest young modulus in the range while at filler proportion of 60%, D4 with filler ratio 4:6 has the highest young modulus values in that range though this is considerably lower compared to C4. Thus, the stress-strain value at 50% filler gives optimum values of Young Modulus.

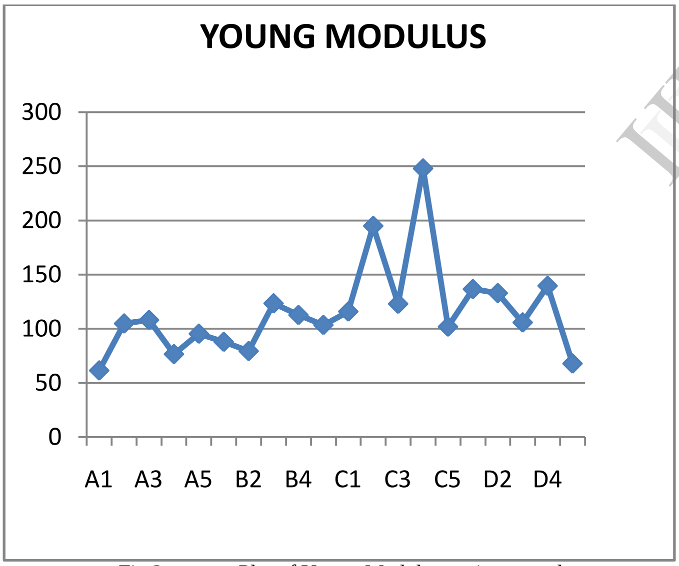

Fig 2. Plot of Young Modulus against samples.

FLEXURAL TESTS OF SAMPLES

TABLE 9

SAMPLES	FORCE AT PEAK (N)	BENDING STRENGTH AT PEAK (N/mm^2)	BENDING MODULUS (N/mm^2)
A1	1.9	0.9	3
A2	7.100	3.4170	46.61
A3	13.300	6.4009	87.187
A4	13.900	6.6897	96.564
A5	11.061	7.3224	55.168

Results for sample A

TABLE 10

SAMPLES	FORCE AT PEAK (N)	BENDING STRENGTH AT PEAK (N/mm^2)	BENDING MODULUS (N/mm^2)
B1	13.900	6.6897	109.12
B2	14.9	7.29	120.10
B3	13.800	6.6416	114.72
B4	12.400	5.9678	106.76
B5	12.800	6.1603	98.529

Results for sample B

TABLE 11

SAMPLES	FORCE AT PEAK (N)	BENDING STRENGTH AT PEAK (N/mm^2)	BENDING MODULUS (N/mm^2)
C1	12.900	6.2084	112.81
C2	14.800	7.1228	103.60
C3	20.12	9.6842	156.348
C4	14.600	7.0266	113.10
C5	14.700	7.0747	120.61

Results for sample C

TABLE 12

SAMPLES	FORCE AT PEAK (N)	BENDING STRENGTH AT PEAK (N/mm^2)	BENDING MODULUS (N/mm^2)
D1	11.500	5.5346	75.867
D2	15.200	7.3154	129.05
D3	16.800	8.0854	174.94
D4	16.900	8.1335	124.03
D5	8.700	4.1871	62.409

Results for sample D

Fig. 3 shows that for all the samples A1-D5 tested, the flexural strength were relatively uniform except for D3 at filler ratio of 60% which showed a marked increase from other samples. This may be attributed to the balanced ratio of the fillers in the composition.

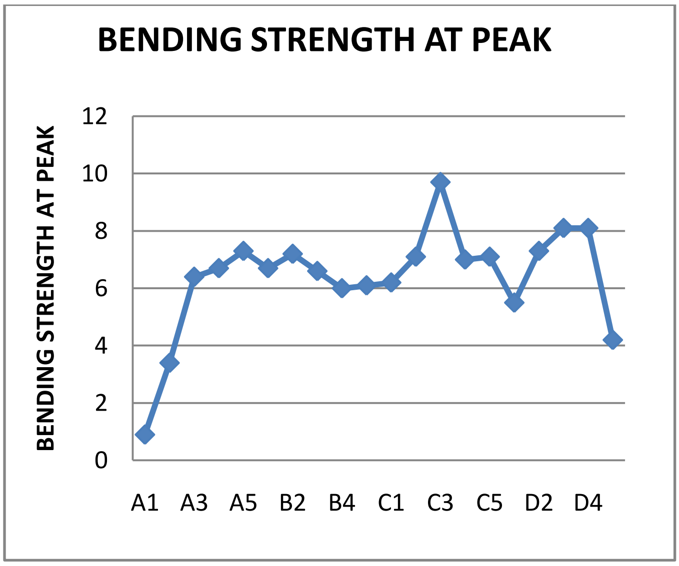

Fig 3. Plot showing Bending Strength of samples.

In fig. 4, D3 with 60% filler of equal ratio, has the Bending Young Modulus

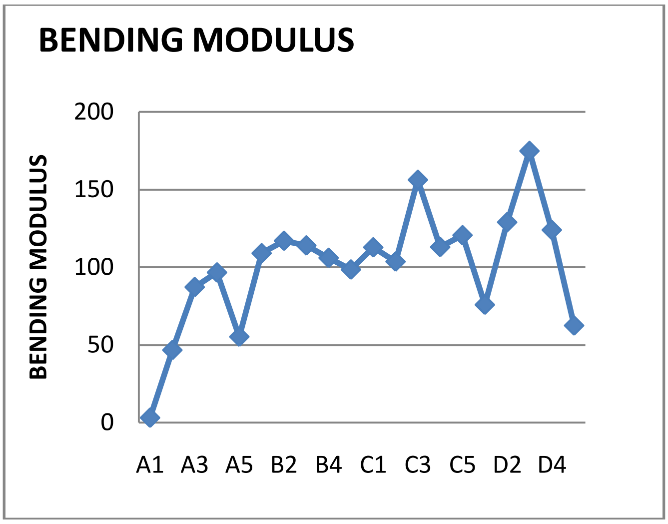

Fig 4. Plot showing Bending Modulus of samples.

RECOMMENDATION

Plastic and wood wastes have been a major environmental concern because of high amount of waste generated which affect the sustainability of natural resources. Wood Plastic Composites (WPC) made out of wood waste, plastic waste and clay have been a fast growing research area because of its wide range of applications such as fences, siding, park benches, landscaping timbers, windows and door frames, ponds, indoor furniture, pellets and many others. The fact that WPC ingredients are manly composed from clay, wood and plastic wastes has led to the rapid increase of its production due to their high availability of it being non-utilized. WPC will close the loop for conserving the natural resources, according to cradle-to-cradle concept. The use of clay, plastic waste and wood waste in WPC helps to overcome disposal (through landfill) and burning hazardous material through incinerators and reduce the cost of environmental degradation as well as depleting the natural resources and the indirect cost of health hazardous materials.

CONCLUSION

Clay exhibits plasticity when mixed with water in certain proportions, when dry, clay becomes firm and when fired in a kiln or when subjected to high temperature treatment, permanent physical and chemical changes occur. This property of clay makes the composites more compact and stronger thereby adding to the property of wood/clay plastic composite made of only sawdust or clay and low density polyethylene. Therefore, the use of clay, sawdust and low density polyethylene in the production of hybrid wood plastic composite is effective, efficient and stronger compared to only sawdust or clay and low density polyethylene.

REFERENCES

1. Wood Plastic Composite Catalogue. 2010. WPC Corporation, Japan.
2. Carus .M and Gahle .C. 2008. “Market & Future trends for Wood-Polymer Composites in Europe: The example of Germany. Woodhead Publishing Ltd, Cambridge, England.
3. McDonough, W., and M. Braungart. 2002. *Cradle to Cradle: Remaking the way we make things.* Northpoint press, DuraBook.
4. Soury, E., A.H. Behravesh, E. RouhaniEsfahani, and A. Zolfaghari. 2009. "Design, optimization and manufacturing of wood–plastic composite pallet." *Materials and Design*, no. 30: pp 4183–4191.
5. Takatani, Masahiro, Kohei Ikeda, and Kei Sakamoto.2007. "Cellulose esters as compatibilizers in wood/poly(lactic acid) composite." *The Japan Wood Research Society*, no. 54: pp 54-61.
6. Ehlers, Ernest G, and Blatt, Harvey 1982. “Petrology, Igneous, Sedimentary, and metamorphic San Francisco: W.H. Freeman and Company. ISBN 0-7167-1279-2.
7. Clemons, C. 2002 "Wood-plastic Composites in the United States: The interfacing of two Industries" *Forest Products Journal* 52(6).
8. Guggenheim, Stephen, Martin, R.T .1995. “Definition of clay and clay mineral; Journal report of the AIPEA nomenclature and CMS nomenclature committee”, Clay and Clay Minerals 43 [2]: 255-256, doi: 10.1346/CCMN. 1995.0430213.
9. Wechslera, Andrea, and SalimHiziroglu. 2009. "Some of the properties of wood–plastic composites." *Materials and Design*, no. 30: pp 4183–4191
10. Winandy, J.E., N. M. Stark, and C. M. Clemons.2004. "Consideration In Recycling Of Wood-Plastic Composites." *5th Global Wood and Natural Fiber Composites Symposium.*Kassel-Germany.
11. Wolcott M.P and Englund K. 2004. “ A Technology Review of Wood-Plastic Composites.