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Development of Wood-Plastic Composite at Dedan Kimathi University of Technology, Kenya

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ABSTRACT
Disposal of plastics and other solid wastes has been a major problem in Kenya. Most of these wastes can be recycled through various ways and methods to produce new products. Plastics can be combined with sawdust to develop composite materials for applications such as in building. In this project, a wood-plastic composite (WPC) was developed from sawdust and plastic solid wastes.

The composite bore the advantages of both wood and plastics which can be applied in various sectors including interior design work and in automotive among others, thereby curbing the problem of garbage accumulation in the environment. The project provides eco-friendly solutions by making best use of the available resources (wood and plastic resins) thus, finding sustainable solutions to the problem of limited waste dumping sites and deforestation in the country. The composites were made from PP and HDPE thermoplastics and mahogany sawdust obtained from our wood workshop in Dedan Kimathi University. From the tests carried out and results obtained, it was found that, the composite has more advantages than the individual constituent materials.

Water absorption test revealed that all the samples took up water though not as much pronounced as for plain sawdust. Additionally, the rate of water reduction was found to be excellent. They took less time to release the absorbed water to the environment meaning that they can be applied in humid or wet environ. The composite samples were easy to machine since they were easily shaped using a handsaw.

Keywords – Wood, plastic, wood-plastic composite, HDPE, PP, water absorption

I. INTRODUCTION

Plastic and wood wastes have been a global environmental concern. Plastics offer the biggest challenge because of their non-biodegradability. The same applies to wood though to a lesser degree, causes depletion of trees and forests. Plastics and wood wastes are either burned or disposed resulting in extra consumption, depletion and pollution of nature and its resources. Production of WPC from wastes will minimize the solid waste from plastics in major towns and conserves the natural resources hence reducing costs; energy and depletion of available materials. The development of a wood-plastic composite project aims to ensure that used materials (plastics, polyethylene bags and paper) that could have gone into wastes are recycled for other important uses.

Many attempts have been developed globally; - especially in developed countries, to utilize these wastes as alternatives to virgin materials. Wood-plastic composite (WPC) is a product which is obtained from plastic and wood and its application is rapidly growing in the modern world.

According to Salah, WPC has currently attracted interest of many researchers in material engineering due to the important properties it offers [1]. These properties include; high durability, low maintenance, relative strength and stiffness, lower prices relative to other competing materials. Also, resistance to biological deterioration by these composites makes them suitable for outdoor applications. This is not the case with timber products that must be treated for such applications. The high availability of fine particles of wood waste is a main point of attraction which guarantees sustainability, improved thermal and creep performance relative to unfilled plastics. As such, they have various structural applications in building such as profiles, sheathings, decking, roof tiles, and window trims. WPCs are not nearly as stiff as solid wood; however, they are stiffer than plastics. In addition, they do not require special fasteners or design changes in application as they perform like conventional wood [2].

According to a recent survey by UNEP, Nairobi with a population of 4.0 million generates 3,200 tons of waste daily. Only 850 tons reach Dandora dumpsite with the rest remaining unaccounted for [6]. Currently, there is no much plastic and wood recycling in Kenya. The purpose of this paper is to report the properties of an attempt to come up with wood plastic composites from the Kenyan wood and plastic wastes.

II. EXPERIMENTAL METHODS

The mould consisted of the mould cavity that accommodated the homogeneous mixture of molten thermoplastics and sawdust and a press that was used to provide force/ pressure for compacting the mixture into the required shape and sizes. Figure 1 shows the mold and press used in fabricating the wood plastic composite.

Figure 1 Mold cavity and the press

During fabrication of the composite the proportions of raw materials were mixed in the order of; - 50gwood: 50g plastic, 50g wood: 100g PP plastic, 50g wood: 100g HDPE plastic and two composites of each ratios were fabricated without additives. Tests were carried out on each and comparisons between the composite drawn. The samples fabricated were rectangular in shape.

Wood and plastics (recycled) of various types, grain sizes, and conditions were the main materials utilized in the production of the samples. The composites made composed mainly of plastic matrix reinforced with wood flour/fiber according to the outlined processing procedures below.

Stage 1: Sorting the plastic

The plastic wastes were first sort into their specific types (that is, polyethylene terephthalate (PET), high density polyethylene(HDPE), polyvinyl chloride(PVC) low density polyethylene(LDPE) , polypropylene (PP), polystyrene(PS). This is because plastic recycling is more complex than metal or glass recycling because of the many different types of plastic that exists thus thorough sorting. They were sort according to their resin identification codes. In this project two types of thermoplastics were used that is HDPE and PP.

Stage 2: Washing Waste Plastic

After the plastic wastes had been identified and sorted into many forms, the cleaning process began. This involved washing them with hot water and detergents to remove paper labels, adhesives and other impurities, all the labels on the plastic containers, and bottles.

Stage 3: Shredding the Plastic

The shredding stage is where plastic wastes are taken and loaded onto conveyor belts or directly into huge hoppers that funnel the clean scrap towards rotating metal teeth that rip the plastic into small pellets which are bagged up afterwards ready for testing. In this case the shredding will was done manually. The big plastic wastes were cut into small pieces using a sharp cutting edge. This was done so as they can be accommodated into small melting pan.

Figure 2 Shredded HDPE

Figure 3 : Shredded PP

Stage 4: Collection and grading of saw dust

The saw dust was collected from the university carpentry workshop. The sawdust used was from mahogany wood which lies in the hardwood class of wood and is widely used in Kenya. The wood fiber was dried for quite some time to remove any moisture present in the wood-fiber. Since the saw dust was a mixture of different grades, it was graded using the grading sieve which graded it into various grades by passing it through 4.0mm, 2.0mm and 1.0mm sieves which were arranged in similar order to obtain the different grain sizes (course-grained, intermediate and fine grained). The sawdust (graded wood fiber) was weighed and bagged according to various formulations mostly 50g. This is shown in Table 1.

Table 1 Different grades of sawdust

	The sawdust mixture before grading
	Sawdust grain size greater than 4 mm

	Sawdust grain size between 2 mm and 4 mm
	Sawdust grain size between 1 mm and 2 mm
	Sawdust grain size less than 1 mm

Stage 5: Melting

Before melting, the mass of the shredded plastic was first measured so as one is aware of the amount he/she is using. The plastics were then put in a melting pan then placed in an oven. The rate of melting was found to depend on type of plastic. The PP melted faster than the HDPE. This is because of their in their molecular structures. The melting temperatures were found to range between 150°C and 180°C.

Stage 6: Compounding and forming

The manufacturing of WPC's was done by a forming process; however, the key to making WPC's was through efficient dispersion of wood component into the thermoplastic matrix. It involved blending of organic plant fiber (wood flour) with an inorganic thermoplastic. The percentage of wood fiber used in this process was very important as it directly affects the tensile strength and Young's modulus of the product. During the process, thermoplastics were heated up to molten temperatures. After melting, compounding (mixing) step took place. The wood flour or wood fibers were combined with the molten thermoplastic to produce a homogeneous composite material.

Stage 7: Fabrication of the composites

This was the final stage in the wood-plastic composite formation. Once the constituent materials of the composite had sufficiently mixed into a homogeneous consistency and as it cooled, the mixture was transferred into the mold in which they were compressed in the process compression molding (pressing molten composite between mold halves).

The process involved a pre-shape charge material, pre-measured volume of the mixture of molten plastics and filler material (wood flour) is placed directly into a heated mold cavity that typically is around 200˚C but can be much higher. The mold gave desired shape and size of the composite product.

The compression process was opted since many experiments have suggested that the WPC composites produced from compression molding give better tensile modulus than those produced by other methods. Also, researchers claim that composites manufactured by compression molding have higher specific density, which results in less void and air making it stronger than its counterpart methods.

Material testing

The tests carried out on the fabricated composites included: machining test, water absorption and reduction tests and microstructure test analysis.

1. Microstructure test

This was done to determine or check grain orientation and porosity for the different samples manufactured. This process was done by carrying out both visual and microscopic observations.This was to predict the elasticity and also the strength of the materials by observing their grain arrangement and the sizes of holes left by air during the manufacturing and cooling processes. The specimens of the samples were first cut both longitudinally and transversely before any observation. After cutting visual examination was done after which the specimens were viewed under a microscope whose magnification had to be varied to get a better and clear view of the grain alignment. The microscope relayed the image on a desktop in which images were taken. One was able to orient the images at different angles so as to get a good view. The magnification that gave a good and clear view was found to be 260M.

2. Water absorption and reduction test

Water absorption and the consequent thickness swelling are the most important physical characteristics of wood-plastic composites exposed to environmental conditions and thus affecting their end-use applications. Water absorption can deteriorate both mechanical properties and dimensional stability in such composites. Therefore, hygroscopic characteristics have to be taken into account as limiting parameters in the design with regard to their final applications.

In this part, specimens from each processed type of composite were obtained and there initial masses were measured using a digital balance before submerging them in water. Also the room and the water temperatures were recorded. The samples were then placed in water and kept at room temperature. For each measurement, the samples were removed from the water and surface water was wiped off. The mass of each sample was measured at time intervals of 30 minutes for a period of two hours. The values of the water absorption in percentages were calculated using the following equation.

$$WA(t) = (W(t) - Wo)/Wo \times 100\%$$
Equation 1

Where $WA(t)$ is the water absorption at time t, Wo is the initial mass of the dried specimen, and W(t) is the mass of the sample at a given immersion time.

The same formula was also applied in determining the water reduction rates for each sample as follows:

$$WR(t) = (Wo - W(t))/Wo \times 100\%$$
Equation 2

Where $WR(t)$ is the water reduction at time t, Wo is the mass of the sample taken immediately after removed from water, and $W(t)$ is the mass of sample after drying time.

III. RESULTS AND DISCUSSION

Table 2 Information on the constituent materials

S.no.	Materials used			
	Saw dust		Plastics	
	Wood Grain sizes (mm)	Mass(g)	HDPE(g)	PP(g)
1	Less than 1.0mm	50	100	100
2	Less than 1.0mm	50	50	-
3	2mm< grain size ≤ 4mm	50	100	100

Table 2 : Different types of composites manufactured and their images

	Composite formed from 50g of coarse grained sawdust mixed with 50g of HDPE
	Composite formed from 50g of coarse grained sawdust mixed with 100g of HDPE
	Composite formed from 50g of fine grained sawdust mixed with 100g of HDPE
	Composite formed from 50g of fine grained sawdust mixed with 100g of PP
	Composite formed from 50g of coarse grained sawdust mixed with 100g of PP

WATER ABSORPTION

Table 3 Water absorption

Composite type		Mass of the composite after immersed in cold water				
Grain size	Composition: Plastic/wood (g)	Initial Mass (t=0)	t=30 min	t=60 min	t=90 min	t=120 min
< 1.0 mm	100PP/50W	7.9	8.67	9.80	9.074	8.72
	100HDPE/50W	11.3	12.63	11.62	12.07	11.63
2mm-4 mm	100PP/50W	9.2	10.87	8.43	11.16	10.53
	100HDPE/50W	5.47	6.78	7.11	6.75	7.12
	50HDPE/50W	6.59	8.39	8.26	8.80	8.42

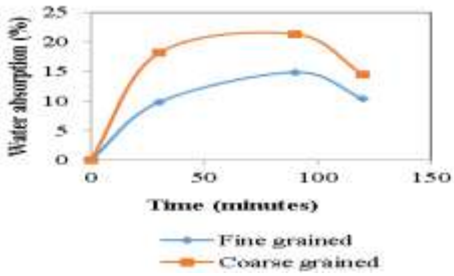


Figure 4 Water absorption (%) against time (minutes) for 100PP/50W

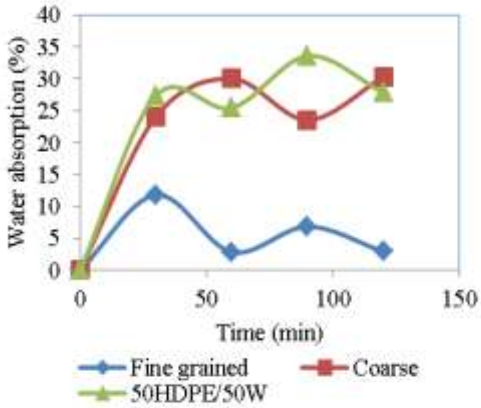


Figure 5 Water absorption versus time for HDPE/wood composite

Water absorption test was carried out for the different plastic/wood composite samples summarized in Table 4. The samples were soaked in 300ml cold water. The mass of each sample was then measured after every 30 minutes for a span of 2 hours. The initial mass of each sample was determined before immersing them in water for comparison purposes. The room and water temperatures were measured to be 25°C and 22°C respectively. During the mass measurement, the specimens were removed, the surface water wiped before the mass measurement. The change in mass indicated the amount of water absorbed by the composite.

Generally, the mass measurement results revealed that all the samples absorb water. This can be observed in Table 3, Figures 4 and 5. This observation can be attributed to the presence of wood chemical composition in the composite. Wood (or

sawdust in this case) contains cellulose and hemicelluloses which have numerous hydroxyl groups. The hydroxyl groups in the wood make them water hydrophilic [18]. Furthermore, the poor adhesion between the wood fiber particles and polymer matrix generates void spaces exposing the sawdust to moisture which leads to high water uptake. From this observation, it can be noted that water absorption additives and coupling agents should be added to reduce water uptake by the plastic/wood composite. The preliminary water absorption tests and literature review revealed that the rate of water uptake for sawdust is higher than that of all other materials.
As shown in Figures 4 and 5, the rate of absorption for a wood-plastic composite of equal ratios (1:1) was found to be higher than that of different ratios (1:2). It was also found that the ratio of plastic matrix to sawdust should always be greater to keep water uptake at minimum possible. This is because the polymer matrix reduces water absorption rate of the plastic/wood composite [18].
Figures 4 and 5 further reveal that for all the samples water absorption increases with immersion time up to a certain value where no more water was absorbed. This would be the saturation water absorption region of the composite. It can also be seen that finer grained wood (less than 1.0 mm) has lower water absorption rate than the coarse grained wood (2.0 mm-4.0 mm).

MOISTURE REDUCTION
From the Table 4 and Figure 6 below, it can clearly be seen that the water reduction rate in coarse grained is much more than in fine grained. This could be due to the fact that there are large pores in coarse grained than in fine grained hence allow water to seep through easily. This property is important in determining the drying rate of the composite.

Table 4 Water loss measurement in the composite samples

Time (min)	PP/wood coarse	PP/wood fine	HDPE/wood fine	HDPE /wood coarse	HDPE (50-50)
0	0	0	0	0	0
30	10.27	4.74	1.37	6.84	5.33
60	13.15	6.78	1.67	11.79	9.51
90	15.58	8.19	1.95	16.08	14.78
120	16.87	8.86	1.99	18.06	17.95

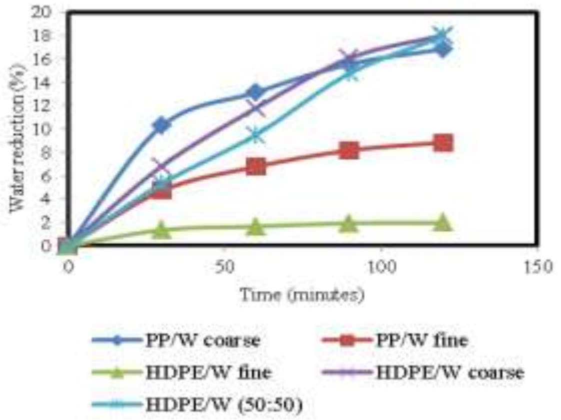


Figure 6 Water reduction in Plastic/wood composite

MACHINING
To evaluate the composite for machinability, the composite samples were cut both longitudinally and cross-sectional using a handsaw (Table 5). It was found that there was no much difference while cutting in either way due to the fact that the particles were discontinuously and randomly arranged. Additionally, there was no difficulty in cutting the composite; hence the composite is easy to cut into the required shapes and configurations for different applications. The same tools used for machining normal wood were found to be applicable. Thus, the composite does not require specialized machine tools.

Table 5 Images obtained after cutting

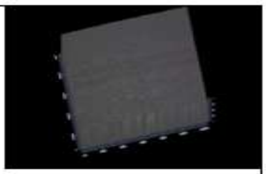
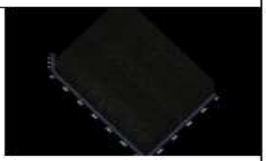
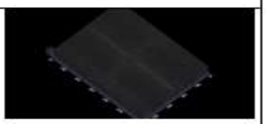
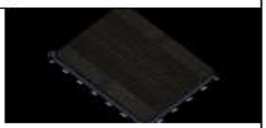
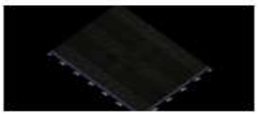
composite	Longitudinal cut	Cross cut
PP coarse grained		
PP fine grained		
HDPE fine grained		
HDPE coarse grained		
fined grained with50g sawdust/50g HDPE		

MICROSCOPY

The microstructural investigations were carried out on the samples where porosity and grain orientation of each sample were observed. This was performed both physically through visualization using the normal eye and using an optical microscope with a magnification of 260. There was no much difference for the two observations. It was found that the samples made from fine sawdust were much lesser porous as compared to those made using from coarser sawdust as shown in Fig. 4. This was as a result of the bonding between the polymer matrix and the fiber particles. The fine particles tend to leave a less void when force is applied but the voids left by the coarse ones after compression is much bigger. Similar results have been reported in literature [16] [19]. This observation explains the graphs of the rate of water absorption versus time presented as Figures 4, 5 and 6. The coarser samples have a higher rate of water absorption than the finer ones implying that they are much porous.

The grain orientation for each sample was also checked using the high definition microscope with a magnification of 260. The grains were found to align themselves in a discontinuous manner. It can also be observed that some sections had higher concentration of sawdust and others of the polymer matrix. This can be attributed to the fact that the mixing was not uniform and also the force applied was not enough. All these observations can be seen in Table 6. As seen in the images, the dark background corresponds to the thermoplastic matrix whereas the shiny dots indicate the arrangement/distribution of the sawdust particles.

Table 6 Microscopy of WPC samples

PP coarse grained	
PP-fine grained	
HDPE-coarse grained	
HDPE(50w/50HDPE) fine grained	 

IV. CONCLUSION

A plastic matrix-wood fiber composite of various composition and grades was successfully fabricated in this project. From the analysis of the results, it can be seen that the rate of water absorption depends on the grain size of the natural fiber (sawdust) and on the ratio of polymer matrix to sawdust. If the particles are fine, the rate of water absorption is less than that of coarse ones and vice versa when it comes to the rate of losing water to the atmosphere. Also there was no much change on the overall mass of the composites. The composite was less dense than water. It was also of the same mass as the total polymer matrix and sawdust that was mixed and pressed.

The porosity can be reduced by adding coupling agents and water resistant additives. Vacuum venting can also be useful since it will help to reduce the number of pores formed as hot air looks for an escape route. The composite also loses water faster which makes it convenient for several architectural interior applications.

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