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Effect of Wood Fibre Characteristics on the Properties of Wood Polymer Composites

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***Abstract*—The purpose of this study was to investigate the effects of wood fibre loading ranging from 20 to 60% mass fraction on the properties of wood polymer composites (WPCs) and assessment of the resulting composite for suitability for use in the construction industry. Using compression moulding technique, virgin low density polyethylene (matrix) was reinforced with sawdust from akpontu. Sodium hydroxide binder was used. Upon examination of the test specimens manufactured, 40% was found to be the optimum reinforcement loading. Increasing fiber load of akpontu improves the strength and stiffness of the composites but decreases impact strength. It was found out that water uptake increases with increasing fiber content in agreement with similar work by other researchers. The result however suggests that water absorption rate of WPCs is high in the first few hours. For akpontu reinforcement, 50 wt% fraction showed the least absorption in the first 100 hours. WPC with 40 wt% reinforcement has the highest overall water absorption.**

***Keywords*—Wood, Low Density Polyethylene, Mechanical Properties, Wood Polymer Composite, SEM**

I. INTRODUCTION

A composite is any multi-phase material that exhibits a significant proportion of the properties of both constituent phases such that a better combination of properties is realised (Callister, 2001). In Wood Polymer Composites (WPCs), for example, wood fibre is used as reinforcement within a polymeric matrix in the presence of a compatibiliser which modifies the surface of the wood fibre used for an improved fibre/polymer interfacial adhesion. Wood consists of strong and flexible cellulose fibres surrounded and held together by a stiffer material called lignin. When added as reinforcing fillers to virgin low density polyethylene (vLDPE), waste wood in the form of wood flour, fibres or pulp possess physical and mechanical properties that can enhance the properties of resulting composite (Shinoj *et al.*, 2011).

Over the past decades, polymers have replaced many conventional materials, such as metal and wood, in many applications. This is attributable to the advantages of WPCs over conventional materials (Nunez *et al.*, 2003). Some of these advantages include low energy consumption during manufacturing activities, easy recyclability after design service life and chemical resistance. Other advantages include light weight, high strength to weight ratio, corrosion resistance, environment friendliness over established materials, for these reasons, natural-fibre-reinforced composites (e.g. WPCs) have recently caught the interest of researchers.

Compatibility between wood and polymer host matrix is a great concern in the production of WPCs (Ndiaye *et al.*, 2008). Wood is hydrophilic in nature (high surface tension) which lowers the compatibility with hydrophobic polymeric materials (low surface tension) during composite preparation. Earlier researchers reported that in order to achieve the required combination of properties, interfacial interactions are often modified in the composites. The wood particles which have high strength and modulus with good adhesion and uniform dispersion can impart better mechanical properties to the host polymer in order to obtain composites with better properties than those of the unfilled polymer (Armin and Alan, 2013). A coupling agent reduces the surface tension of wood fibres approaching that of the molten polymer (Sombatsompop *et al.*, 2005). Therefore wetting and adhesion are improved through diffusion and mechanical interlocking between the two entities.

The production of WPCs for various technological applications necessitates the understanding of the influence of variability of the wood species, component ratio of the reinforcing material, polymer matrices, surface modification treatment of the reinforcing wood fillers and the processing techniques and parameters, on their functional and microstructural properties (Yeh and Gupta, 2008, Kuo *et al.,* 2009, Bouafif *et al.,* 2009, Rocha *et al.,* 2009, Mano *et al.,* 2010; Mylsamy and Rajendran, 2010).

Structural differences exist in WPCs due to the varying anatomical structures in different wood species, fibre dimensions, and contents of wood fibres in WPCs. This assertion was corroborated by Maldas, *et al* (1989) who confirmed that variation in the mechanical properties of WPCs obtained when thermoplastics were reinforced with fibres from different wood species could be attributed to the morphology, density, and aspect ratios across wood species. Neagu *et al.,* (2006) also established that the longitudinal modulus of WPCs is dependent on the lignin content of the various wood species.

Moreover, the roles of wood particle sizes/distribution, and wood reinforcement or fibre content in influencing the properties of WPCs had been emphasised by Zhang *et al.,* (2007); Bouafif *et al.,*(2009), and Afrifah *et al.,*(2010). Zhang *et al.,* (2007) explored how the contents of wood fibres affected the processability of WPCs. The outcome of their investigation revealed that increased wood fibre content resulted in increased steady state torque and viscosity. Lu *et al.,* (2005) also found that tensile and flexural strengths of WPCs reached a maximum at 15 wt% and 35 wt% wood particle contents respectively and gradually decreased with a further increase in wood particle content. On the basis of their finding, they concluded that mechanical properties of WPCs are enhanced only when it contained lower proportion of wood fibres. Danyadi *et al.,* (2007) attributed this behaviour to the occurrence of particle segregation when WPCs have larger proportion of wood powder or fibre, thus, leading to lower strength due to the filler's failure to sustain the stress transferred from the polymer to the matrix.

Furthermore, Bouafif *et al.,* (2009) reported that higher fibre size increased strength and elasticity; lowered energy to break and elongation of WPCs; while its effect on water uptake is minimal. They also discovered that increasing the fibre content increased the strength and stiffness of the WPCs but decreased its elongation and energy to break while its water uptake increased with increasing fibre content. Despite the large amount of literature detailing the properties of WPCs from various wood species domiciled in various countries of the world, it is surprising to note that much attention has not been paid to the development of WPCs by using abundantly available wood species from Nigeria. This study seeks to bridge the gap in our knowledge of the processing and functional properties of WPCs developed from the locally available wood species in Nigeria.

II. METHODOLOGY

A. Preparation of Wood Reinforcements

The wood particles were collected from Akpontu wood specie from a wood-mill in Bida, Nigeria. The saw-dust samples were sun-dried for two days to remove excess moisture from them. The samples were soaked in hot water (100^{o}C) for 1 hour, washed thoroughly and air-dried for three days at room temperature. They were then reduced to irregularly formed particles 75µm in size in a plastic mill equipped with two rotating knives. The saw-dust particle size, time of alkaline treatment, compression moulding parameters (time, pressure, and temperature), concentration of NaOH solution and HCl acid solution were held constant while only the wood sample contents were varied.

B. Chemical Treatment of Wood Reinforcements

20 wt% concentration sodium hydroxide solution and 10 wt% concentration hydrochloric acid solution were prepared for the samples treatments. 25g of samples were introduced into 150ml of the NaOH solution and stirred vigorously with a mechanical stirring machine for about 30 minutes to enable the sample get well soaked with the alkali solution. The mixture was then filtered and the residue again reintroduced into 100ml of the prepared diluted HCl acid to remove excess NaOH. The mixtures were again stirred using the mechanical stirrer. The mixtures were then filtered and the residues collected. Using distilled water the treated samples were thoroughly washed five times. The procedure is repeated until enough samples for the reinforcement of polymer is obtained. The treated fibre samples were air-dried at room temperature for three days. This modified wood sample was sieved with a smooth mesh sieve to obtain an average grain size of 75µm.

C. Compounding of Wood Polymer Composite vis Compression Moulding Tecknique

A 200 tons capacity compression moulding machine was used to compound the wood polymer composites. At first the female part of the mould was fixed on the carrier seat of the machine. The LDPE was poured into the oven system where it was melted and maintained at 180^{0}C. At this stage the polymer was ready and the mixing of the wood particles with the molten polymer took place inside the oven system at 180°C, pressure of 35kg/cm^2 and pressing time 10 minutes.

The hopper again released some of the LDPE into the oven for melting and the wood fibre was added in the required proportion by weight. The procedure was repeated for the various fraction loading of the wood reinforcement.

D. Scanning El,ectron Miscroscopy/Electron Dispersion Spectroscopy

The surface morphology of the WPC samples were examined directly by scanning electron microscope JEOL 6010LA. The digitalized images are recorded in figures 1.4 – 1.8.

III. RESULTS AND DISCUSSION

A. Hardness

Figures 1.1 represents the results of the hardness tests carried out on the samples produced. For each percentage by weight of fibre reinforcement, three tests were run and the average was value taken to enhance accuracy.

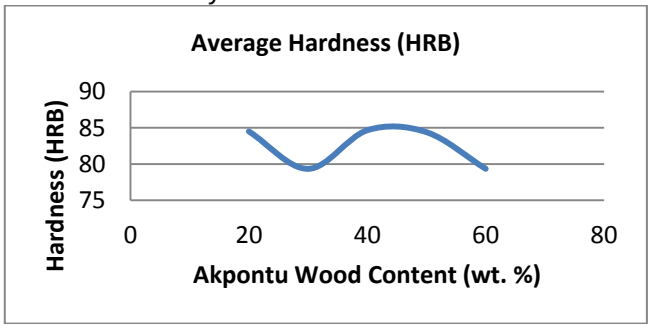

Fig. 1.1: Variation of Hardness with Wood reinforcement.

40 wt% reinforced WPC has proven to be the hardest of the five samples of composite with 84.67HRB showing higher hardness than 30 wt% reinforced and 60 wt% reinforced WPC. As the wood fibre content increases the samples' hardness assume a sinusoidal waveform as shown in figure 4.1. This experimental result indicates that the addition of wood fibre into the matrix affected the performance of WPCs made with LDPE matrix. The 40 wt% optimum level of reinforcement agrees with level reported in literatures reviewed for similar WPC (Budynas and Nisbett, 2008, ASTM, 1990).

B. Impact Strength

The results of the impact tests are presented in figure 1.2. The trend in akpontu fibre reinforced WPCs is slightly different from the hardness results with the highest impact strength as 8.65J/m at 30 wt%. It is also seen in the second half of the curve that, as the wood content is increased, the impact strength is reduced. Results of previous researches have also shown that surfactants can improve the mechanical properties of the product by increasing the adhesion between the matrix and reinforcement (Budynas and Nisbett, 2008, ASTM, 1990).

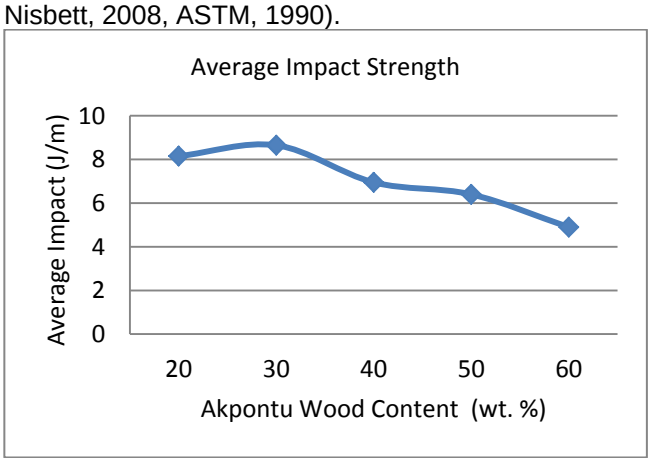

Fig. 1.2: Variation of Impact Strength with Wood Reinforcement.

C. Compressive Strength

Compression testing results represent the behavior of the WPCs under compressive loads. 30wt% reinforcement loading have the peak of compressive strength with akpontu.

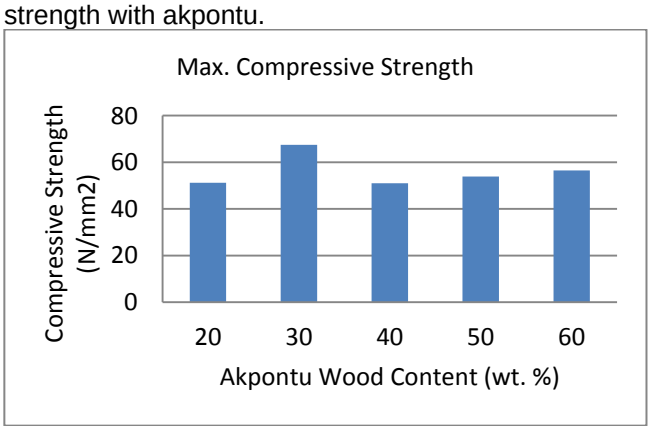

Fig. 1.3: Changes in Compressive Strength with Wood Reinforcement.

D. Water Absorption Analysis

The rates at which the samples absorb water are tabulated in Table 1.1. The exercise lasted for 480 hours and the test results were taken every 96 hours. Accordingly the decrease of the water absorption capacity of wood used in composites would have positive effect on the lifetime of the product and on its application properties. The first 96 hours of samples in water witnessed a high level water intake (up to 1.3% on the average). And subsequently this water absorption rates decreased considerably until after 480 hours when the water absorption almost stopped.

Table 1.1: Water Absorption for Akpontu Particles Reinforced LDPE

	Water Absorption (%)				
Time (hr)	**20% AKP**	**30% AKP**	**40% AKP**	**50% AKP**	**60% AKP**
96	1.37	1.45	1.4	0.79	1.54
198	1.37	1.45	1.4	1.19	1.92
288	1.37	1.45	1.4	1.19	1.92
384	2.39	1.45	2.8	1.98	1.92
480	3.07	1.45	4.2	2.38	3.08

30% fraction reinforcement represents the most stable sample in water as its water absorption does not increase beyond the set 96 hours. This means that it may last longer than the other samples in use in a humid environment. The sample with 40% fraction reinforcement absorbed the same quantity of water in the first half of the time period, but has the steepest gradient in the second half, which is an indication of uniform water absorption rate. The samples with 50% and 60% fraction reinforcement also behaved in a similar manner.

E. Surface Morphology of the Wood Polymer Composites

The morphologies of the composite samples by SEM with EDS are shown in Figures 1.4 to 1.8. Morphological analysis using SEM clearly showed differences in morphology of the WPCs produced by varying the wood fibre contents. The microstructure clearly showed that when the wood particles were added to virgin LDPE (resin), morphological change in the structure took place. The microstructure revealed that there were small discontinuities and a reasonably uniform distribution of wood particles in the LDPE matrix. The particles phase is shown as white phase, while the vLDPE phase is dark for all the images.

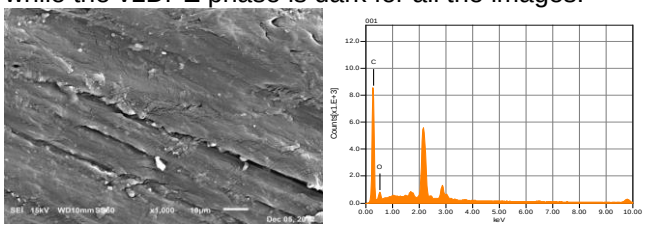

Fig. 1.4: SEM/EDS Microstructure for 20 wt%AKP in LDPE

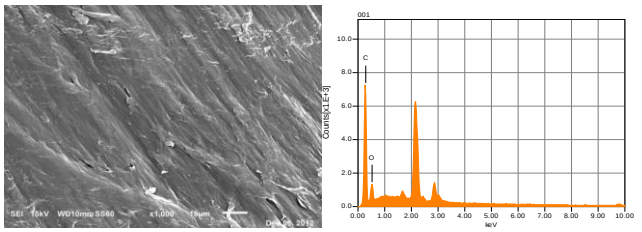

Fig. 1.5: SEM/EDS Microstructure for 30 wt%AKP in LDPE

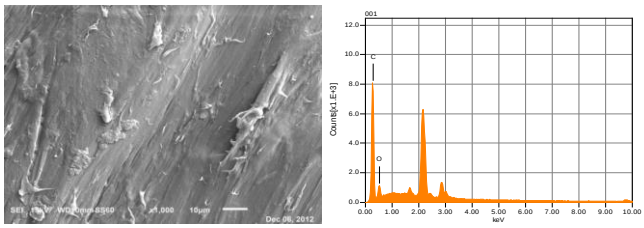

Fig. 1.6: SEM/EDS Microstructure for 40 wt%AKP in LDPE

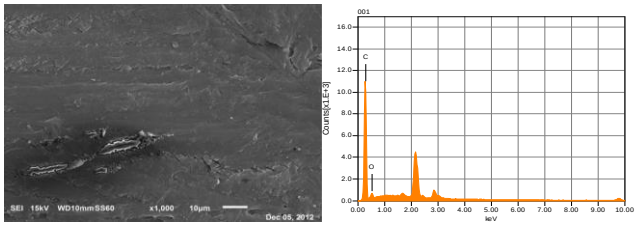

Fig. 1.7: SEM/EDS Microstructure for 50 wt%AKP in LDPE

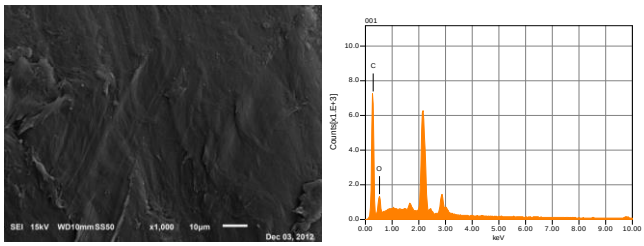

Fig. 1.8: SEM/EDS Microstructure for 60 wt%AKP in LDPE

F. Visual Observation of Miscrostructure

Macrostructural examination of the images showed a uniform distribution of wood fibres with the virgin LDPE. Obviously, the distribution is influenced by the compounding of the particles and the binder and good interfacial bonding as reported by many literatures reviewed. The only cases of non-uniform distribution were those in figures 1.7 and, 1.8 where there were agglomerations of the wood fibres. It can be seen that the wood particles are not detached from the resin surface as the weight fraction of wood particles increased in the resin. This is due to fairly interfacial bonding between the resin and the particles.

The EDS analyses show that there are no chemical interfacial reactions between the wood particles and the vLDPE. This is as a result of the temperature of processing that was not high enough to cause any chemical reactions. The major elements revealed by the EDS are C and O. These elements are the major functional group in the wood particles as depicted.

IV. CONCLUSION

This study set out to examine the effect of wood waste particles on both functional and microstructural properties of the WPCs with particular focus on akpontu wood particles contents to determine the optimum level at which the reinforcement particles are effectively incorporated into the vLDPE matrix and the level of adherence of the constituents at the interfacial boundaries.

The best of mechanical properties for akpontu particles stands between 30 to 40 wt%. Therefore 40% by weight of the fibres is the overall equilibrium point for mechanical efficiency of the wood polymer composites compounded. The second major finding was that the deviation from the expected highest value of compressive and impact strength of 40 wt% could be as a result of the non-uniform particle distribution as alluded to by the SEM images.

The study has also gone some way towards enhancing our understanding of how WPCs behave when the reinforcing phase is akpontu particles. The result suggests that water absorption rate of WPCs is high in the first few hours. 50 wt%AKP absorbed the slowest in the first 100 hours while 30 wt%AKP completely stops absorbing water after the first 100 hours. However 40 wt%AKP has the highest overall water absorption.

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