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Effects of geometric particle sizes of wood flour on strength and dimensional properties of wood plastic composites

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Abstract: The effect of different wood flour sizes on strength and dimensional properties of wood-plastic composites were examined. Wood flour of different particle sizes viz; 1.00mm, 2.00mm and >2.00mm were compounded with recycled low-density polyethylene (LDPE) at different wood/plastic ratio of 1: 1, 2: 3 and 3: 2. The results obtained showed that wood flour size > 2.00mm has the highest MOR and MOE values of 1.206N mm^{-2} and 2484.72Nmm^{-2} while wood flour size of 1.00mm had the lowest MOR and MOE values of 0.505Nmm^{-2} and 2195.89Nmm^{-2} respectively. Also the results of the physical properties showed that wood flour size of 1.00mm had the lowest thickness swelling percentage with mean values of 0.28% and 2.08% while water absorption percentage has mean values of 0.91% and 10.58% after 2 hours and 24 hours of water immersion respectively. It was observed that wood flour size of 2.00mm and particle size >2.00mm had the highest thickness swelling and water absorption percentages. This showed that strength properties of wood plastic composites increased with increased particle sizes whereas its dimensional properties increased with decreased particle sizes. The results of analysis of variance carried out on mechanical and physical properties showed that particle sizes and wood/plastic ratio had a significant effect on the mechanical and physical properties of wood plastic composites (p   0.05).

Keywords: Dimensional stability, Geometric particle sizes, Low-density polyethylene, Wood flour, Wood plastic composite

INTRODUCTION

There have been a considerable increase in recent years on the production and application of wood–plastic composites (WPCs). Their properties and environmental advantages have made them a good choice for many applications (Wang and Zhang, 2007; Bledzki and Faruk, 2004). WPCs are made by combining wood and thermoplastic polymer, which results in a composite that combines the best properties of both components (Yang *et al.,* 2007). Wood often imparts strength and stiffness and is biodegradable, while the plastics afford ease of formation and moisture resistance (Bentsson *et al.,* 2005). WPC are widely used in USA, the most common type of such panels are produced by mixing wood flour and plastics to produce material that can be processed similar to 100% plastic based products (Charrier, 1991; Groom *et al.,* 1996; Ballerini, 2004).

Polyethylene (PE) is a popular choice as polymer matrix, with several studies focusing on properties of low-density polyethylene (LDPE)–wood composites (Bentsson *et al.,* 2005; Kuan *et al., 2006*). The geometric particle size of the wood used in WPCs affects the properties of the WPCs (Bledzki *et al., 1998*). But little work is documented on the effect of geometic particle size on low-density polyethylene wood composites, particularly the ubiquitous polyethylene materials (sachet nylon) in the world today. This polyethylene is a source of potential raw materials for the production of WPCs. They also contribute greatly to environmental pollution through littering of road sides, blocking of drainage system, river and oceans. The recycle of this plastic waste has led into new innovating building materials, which has led to a major breakthrough in the area of environmental control and structural materials improvement.

The use of WPCs have many advantages over the other particle boards. Such advantages are extreme moisture resistant with low or less thickness swelling, extreme resistance to fungal attack, improved strength properties, environmental friendly, highly elastic with high impact resistance (English and Falk, 1995). The sustainability of this technology becomes more attractive when the low cost and high availability of fine particles of wood waste is considered. These composites are transformed by extrusion processes to obtain applications including profiles, sheathings, decking, roof tiles, and window trims, with improved thermal and creep performance compared with unfilled plastics (English and Falk, 1995; Verhey *et al.,* 2002). In general, properties of WPCs depend on various factors, including the inherent properties of the

constituent materials, interactions among these materials and processing methods. The amount, geometric sizes, and surface characteristics of the wood component and the interfacial properties between the wood and plastic influence the mechanical and physical properties of the WPCs.

There is a gradual increase in the trend of research on WPCs in Nigeria with the use of different plastic binders, being assessed. The effect of some wood species on strength properties of WPCs has also been investigated. Ajigbon and Fuwape (2005); Fuwape and Aina (2008) investigated the possibility and potentials of tropical wood species and agro-residue for the production of wood plastic composites in Nigeria, using manually fabricated compounding hot press machine.

The objective of the study was to determine the best suitable size of wood flour that will be required for the production of wood plastic composites as well as determine the effects of these geometric particle sizes of wood on strength and dimensional properties of wood plastic composites.

MATERIALS AND METHODS

Study area: The study was carried out at the wood product research laboratory of Forestry Research Institute of Nigeria Ibadan, Oyo State. The state is located between latitude N $7^0 23'$ and E $3^0 54'$. Sawdust of *Ceiba pentandra* wood was collected from the sawmill section of the Forest Products Development and Utilization Department of the institute. The sawdust was air dried to a constant moisture content of 12% in a controlled laboratory. Thereafter it was sieved to obtain the different geometric particle sizes of 1.00mm, 2.00mm and above 2.00mm, using the standard laboratory sieve. The Plastic binder used was the low-density polyethylene (LDPE) plastic (water sachets) collected within the premises of University of Benin campus in Benin City. The low-density polyethylene plastics were shredded into flakes using pelletizing milling machine in the laboratory.

The sawdust and the LDPE plastic was weighed using electronic weighing balance while appropriate quantities of the materials were thoroughly mixed and formed into a mat in the production plate with a dimension of 300mm x 300mm x 6mm. The WPC boards were produced using fabricated hot press compounding machine at a temperature of 100 - 120^{0}C for a period of 10minutes under constant pressure of 1.23N/mm^2. Samples were produced using the following production factors 0.8Kg/m^3 (constant) geometric particle sizes of 1.00mm, 2.00mm and above 2.00mm with sawdust/plastic ratio of 1:1, 2:3 and 3:2. WPC boards measuring 200mm x 200mm were formed after trimming. Test samples were collected from each board for physical and mechanical properties determination. The experiment was carried out as three

factor factorial in a completely randomized designed. Mechanical properties determination was carried out in accordance with ASTM standard (2004). The static bending test from which the modulus of rupture (MOR) and modulus of elasticity (MOE) were evaluated was carried out using specimen size 194 x 50 x 6mm. The test was a centre-loading supported on a span of 280mm while the force was applied on the radial face at mid span using a loading rate of 0.1mm/minute on a Hounsfield Tensiometer Machine. The MOR was calculated from the maximum load at which the test sample failed. The MOE was calculated using load to deflection curve plotted on a graph by the Tensiometer Machine.

Physical properties determination was carried out using test samples measuring 100mm x 100mm x 6mm. The thickness of the test samples was determined using electronic digital caliper while the weight was determined, using an electronic weighing balance before and after water immersion. The test specimens were submerged in water bath in a horizontal position to the depth of 25mm for a period of 2 hours and 24 hours respectively.

RESULTS AND DISCUSSION

Mechanical properties: The results obtained for MOR of wood plastic composites are presented (Table 1). The mean values obtained for wood plastic composites produced from wood particle size of 1.00mm were 0.524, 0.352 and 0.640N mm^{-2}. MOR values of wood plastic composites produced from particle size of 2.00mm were 0.620, 0.563 and 0.742N mm^{-2} while that of particle size above 2.00mm were 1.285, 0.846, and 1.486N mm^{-2}. Similarly, the MOE values for wood plastic composites produced from particle sizes of 1.00mm were 2157.26, 774.35 and 3656.06 N mm^{-2}. MOE values of wood plastic composites of 2.00mm particle size were 2165.28, 1193.11 and 3653.46N mm^{-2} while the MOE values of wood plastic composites produced from particle size above 2.00mm were 1400.84, 903.33 and 5149.98N mm^{-2}. The results showed that mechanical properties increased with increased particle sizes (Table 1). Wood flour size of above 2.00mm has the highest MOR and MOE values of 1.206N mm^{-2} and 2484.72N mm^{-2} respectively. This was followed by wood flour sizes of 2.00mm while wood flour size of 1.00mm had the lowest MOR and MOE values of 0.505N mm^{-2} and 2195.89N mm^{-2} respectively. These findings agree with previous results reported in literature (Zaini et al., 1995; Liew *et al.*, 2000; Stark and Rowlands, 2003;). The reasons for this could be attributed to the interaction between the hydrophilic wood flour and the hydrophobic polyethylene matrix (Zaini *et al.*, 1995; Liew *et al.*, 2000; Stark and Rowlands, 2003). Increase in mechanical properties of wood plastic composites were found to correspond with increase in aspect ratio, length/width ratio of wood flour, (Stark and Rowlands, 2003). The larger

Table 1. Mechanical properties of wood plastic composites.

Particle sizes	Mixing ratio wood : plastic	Mechanical properties	
		MOR (N mm^{-2})	MOE (N mm^{-2})
1.00 mm	1 : 1	0.524 + 0.020	2157.26 + 49.48
	2 : 3	0.352 + 0.028	774.35 + 47.85
	3 : 2	0.640 + 0.039	3656.06 + 411.53
2.00 mm	1 : 1	0.620 + 0.018	2165.89 + 65.79
	2 : 3	0.563 + 0.017	1193.11 + 3.93
	3 : 2	0.742 + 0.050	3653.46 + 77.69
2.00 mm	1 : 1	1.285 + 0.122	1400.84 + 17.23
	2 : 3	0.846 + 0.050	903.33 + 95.35
	3 : 2	1.486 + 0.014	5149.98 + 181.03

Table 2. Analysis of variance for mechanical properties of wood plastic composites.

Sources of variance	df	Fcal		Ftab	Significant	
		MOR	MOE		MOR	MOE
Particle sizes(S)	2	481.25	7.45	3.55	0.000*	0.004*
Mixing ratio(MR)	2	120.38	962.71	3.55	0.000*	0.000*
S x MR	4	19.13	54.89	2.93	0.000*	0.000*
Error	18					
Total	26					

*significant (P < 0.05) probability level

Table 3. Duncan new multiple range test for modulus of rupture and modulus of elasticity of wood plastic composites.

Particle sizes	MOR	MOE
1.00mm	0.5053 [c]	21995.89 [b]
2.00mm	0.6416 [b]	2337.28 [a b]
2.00 mm	1.2060 [a]	2484.7 [a]
Mixing ratio Wood : Plastic		
1 : 1	0.8097 [b]	1907.79 [b]
2 : 3	0.587 [c]	956.93 [c]
3 : 2	0.9561 [a]	4153.17 [a]

Means in columns with the same superscript are not significantly different (p < 0.05)

the wood flour particle sizes, the larger the stress concentrations along the naturally weak interface of the hydrophilic wood flour and hydrophobic polypropylene (Stark and Rowlands, 2003). Notched impact energy increased with increasing particle size, crack propagation occurred at the polypropylene/wood flour interface as a result of the poor interface between the hydrophilic wood flour and the hydrophobic polypropylene. Consequently, composites made with larger wood flour particles had higher notched impact capacity (i.e., higher critical crack propagation energy) as a result of the increase in fracture surface area (Stark and Rowlands, 2003).

The mixing ratio (wood/plastic) also affects the mechanical properties of WPC produced independently

Table 4. Physical properties of wood plastic composites.

Particle sizes	Mixing ratio wood : plastic	Physical properties			
		TS% 2 hours	TS% 24hours	WA% 2hours	WA% 24hours
1.00mm	1 : 1	0.29 + 0.01	1.85 + 0.53	0.91 + 0.02	12.26+1.56
	2 : 3	0.23 + 0.02	1.34 + 1.02	0.73 + 0.02	6.81 + 0.60
	3 : 2	0.31 + 0.04	3.04 + 1.71	1.08 + 0.09	12.58+4.15
2.00mm	1 : 1	0.33 + 0.01	2.75 + 1.04	0.99 + 0.01	15.00+1.60
	2 : 3	0.26 + 0.01	1.44 + 0.35	0.78 + 0.01	7.41 + 1.97
	3 : 2	0.39 + 0.02	3.18 + 1.37	1.26 + 0.07	15.69+2.63
	1 : 1	0.42 + 0.02	4.85 + 1.51	1.07 + 0.11	18.37+1.01
2.00mm	2 : 3	0.30 + 0.01	3.93 + 1.52	0.82 + 0.02	8.83 + 2.04
	3 : 2	0.55 + 0.03	6.39 + 0.89	1.38 + 0.33	20.82+1.57

Table 5. Analysis of variance for physical properties of wood plastic composites.

Sources of variance	df	Fcal				Significant			
		WA (2hrs)	WA (24rs)	TS (2hrs)	TS (24hrs)	WA (2hrs)	WA (24rs)	TS (2hrs)	TS (24hrs)
Particle sizes(S)	2	22.69	15.34	16.79	129.52	0.000*	0.000*	0.000*	0.000*
Mixing ratio(MR)	2	153.23	45.07	6.18	131.42	0.000*	0.000*	0.009*	0.000*
S x MR	4	2.91	1.717	0.237	16.08	0.051^{ns}	0.190^{ns}	0.914^{ns}	0.000*
Error	18								
Total	26								

*significant at (P < 0.05) probability level, ns – not significant at (P < 0.05) probability level

Table 6. Duncan new multiple range test for thickness swelling and water absorption of wood plastic composites**.**

Particle sizes	TS % 2hours	TS % 24hours	WA % 2hours	WA % 24hours
1.00mm	0.28^{c}	2.08^{b}	0.91^{c}	10.58^{c}
2.00mm	0.33^{b}	2.47^{b}	1.01^{b}	12.70^{b}
2.00 mm	0.42^{a}	5.06^{a}	1.09^{a}	16.01^{a}
Mixing ratio				
1 : 1	0.27^{c}	2.24^{b}	0.78^{c}	7.68^{c}
2 : 3	0.34^{b}	$3.15^{a, b}$	0.99^{b}	15.21^{b}
3 : 2	0.41^{a}	4.20^{a}	1.24^{a}	16.36^{a}

from the particle sizes. The results presented (Table 1) showed that mechanical properties increased with increase in the proportion of wood with respect to plastic. Wood/plastic ratio 2:3 has the lowest MOR and MOE values of 0.587 and 956.93N mm^{-2} respectively. This was followed by wood/plastic ratio 1:1 while wood/plastic ratio 3:2 has the highest MOR and MOE values of 0.956 and 4153.17N mm^{-2} respectively. This observation may be as a result of the higher strength properties of wood compared to the plastic matrix. Similar observation has also been reported with polymer, increase in polymer content resulted in decrease in tensile modulus and as polymer decreases, wood flour increases, and ultimately resulting in observed increased in modulus of elasticity (Liew *et al.*, 2000).

The results of analysis of variance carried out at 5% probability level to test for significant differences among particle sizes and mixing ratio of wood plastic composites are presented (Table 2). The results showed there were significant differences in wood plastic composites produced from different particle sizes and mixing ratio (p < 0.05). Also the interaction between particle sizes and mixing ratio were significant at 5% probability level.

Duncan New Multiple Range Test was used in the separation of means at 5% probability level (Table 3). The results showed that the mean values obtained for MOR and MOE of wood plastic composites produced from different wood particle sizes and mixing ratio were significantly different (p < 0.05).

Physical properties: The results obtained for the physical properties of wood plastic composites are presented

(Table 4.4). The mean values of thickness swelling of wood plastic composites produced from particle size of 1.00mm after immersion in water for 2hours and 24hours respectively were 0.29, 0.23, 0.31% and 1.85, 1.34, 3.04 % while the mean values of thickness swelling produced from particle size of 2.00mm were 0.33, 0.26, 0.39 % and 2.75, 1.44, 3.18 % respectively. The mean values of thickness swelling of wood plastic composites produced from particle size of above 2.00 mm were 0.42, 0.30, 0.55 % and 4.85, 3.93, 6.39 % respectively. Similarly, the mean values obtained for water absorption of wood plastic composites produced from particle size of 1.00mm after immersion in water for 2hours and 24hours respectively were 0.91, 0.73, 1.08 % and 12.26, 6.81, 12.58 % respectively. The mean values obtained for particle size of 2.00mm were 0.99, 0.78, 1.26 % and 15.00, 7.41, 15.69 % respectively while the mean value of water absorption for wood plastic composites produced from particle size of above 2.00 mm were 1.07, 0.82, 1.38 % and 18.37, 8.83, 20.82 % respectively. The results showed that thickness swelling and water absorption of wood plastic composites increased with increase in particle sizes. Therefore, the smaller the wood flour size, the better the dimensional stability of wood plastic composites.

The results in Table 4 showed the effects of wood/plastic ratio on physical properties of the board produced independently on particle sizes. The results showed that water absorption and thickness swelling of wood plastic composites increased with increased reinforcing filler (wood flour). This situation could be attributed to the hydrophilic nature of wood flour and an increase in water

sorption is expected from wood plastic composites with more wood flour content. As the wood flour loading increased, the cellulose content also increased resulting in the absorption of more water (George *et al.,* 2001; Khan *et al.,* 2003; Adhikary *et al.,* 2008; Ghasemi and Kord 2009). This showed that the higher the quantity of plastic/wood ratio in wood plastic composites, the better the moisture resistant and its dimensional stability.

The results of analysis of variance carried out at 5% probability level to test for significant differences among particle sizes and mixing ratio on physical properties of wood plastic composites are presented in Tables 5. The results showed that, there were significant differences in wood plastic composites produced from different particle sizes and mixing ratio. However the interaction between particle sizes and mixing ratio were not significant at 5% probability level except for thickness swelling which showed some level of significance after been immersed in water for 24 hours.

Duncan New Multiple Range Test was used in the separation of means at 5% probability level (Table 6). The results showed that thickness swelling and water absorption of wood plastic composites produced from different wood particle sizes and mixing ratio were significant.

Conclusion

The properties considered in investigating the effects of geometric particle sizes of wood flour on strength and dimensional stability of wood plastic composites were those of modulus of rupture, modulus of elasticity, thickness swelling and water absorption. The study showed that wood flour sizes of 2.00mm and wood/plastic ratio 1:1 produced the best effect on the strength properties and dimensional stability of wood plastic composites boards. Wood flour sizes 1.00mm and wood/plastic ratio 2:3 had low strength properties and high dimensional stability while wood flour sizes above 2.00mm and wood/plastic ratio 3:2 had high strength properties but low dimensional stability.

Therefore an increase in geometric particle sizes and the amount of particle in wood plastic composites resulted in a corresponding increase in strength properties and a decrease in dimensional stability was due to the hygroscopic nature of the wood component.

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