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Improving Wood Mechanical Properties Using Guinea Grass, Wood Sawdust, Crack Filler and Wood Adhesive

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Abstract

Inadequate strength of plywood as a structure material have posed great challenges in its use. This research focused on the use of Guinea grass (GG), wood sawdust (SD), crack filler (CF), and wood adhesive (WA) to enhance the mechanical properties of plywood. The plywood with dimensions of 450 mm x 450 mm x 135 mm was used to produce lightweight composite slab laminates of the following dimensions: 450mm x 450mm x 145mm, 450mm x 450mm x 170mm, 450mm x 450mm x 195mm, 450mm x 450mm x 220mm, and 450mm x 450 x 245mm, respectively. To ensure tenacious bonding and lamination between the composite slab and the plywood, a wood adhesive or glue was applied evenly on the top and bottom faces of the laminates at 2.5mm thickness. Ten (10) lightweight composite slabs each were produced with mix ratios of 0.5:0.5:1.5:0.5 and 0.5:0.75:1.5:0.5 (WA: CF: SD: GG), respectively. The results obtained show that the mean compressive strength, tensile strength, density, hardness, flexural strength, and deflection of the developed laminate composite range from 74.6 N/m² to 76.5 N/m², 89.50 N/m² to 93.53 N/m², 1246.92 kg/m³ to 1334.81 kg/m³, 59.5 kgf to 63.5 kgf, and 7.06 N/m² to 7.52 N/m², 29.0 mm to 86.52 mm while that of plywood only ranges from 35 N/m² to 65 N/m², 45 N/m² to 79 N/m², 500 kg/m³ to 811 kg/m³, 32kgf to 56kgf, 2.5 N/m² to 6.5 N/m², and 20.7 mm to 45.6 mm for average compressive strength, tensile strength density, flexural strength, and deflection respectively. The results obtained show that the introduction of guinea grass, wood sawdust, crack filler, and wood adhesive improved the mechanical properties of the lightweight composite slabs developed from plywood.

Keywords: Crack Filler, Guinea Grass, Light-weight Composite Slab, Mechanical Properties, Sawdust, Wood Adhesive.

1. Introduction

In adequate investigation and production of composites made from wood as a structural material have posed great challenges in construction industries. High-performance engineered structural systems are crucial for sustainable development in the field of construction [1]. Material needed to support a weight while in use is referred to as a structural composite. Structural composites in the housing sector include load-bearing walls, roof systems, sub-flooring, staircases, framing elements, and furniture. The majority of the time, municipal or national groups' codes and specifications will outline the performance requirements for these composites [2]. The performance requirements for structural composites vary from those for the aerospace industry's high-performance materials to those for wood-based composites with lower performance demands [3]. The performance of wood-based composites differs, from expensive particle board to multi-layered plywood and laminated lumber. The low-cost adhesive used to create the structural wood-based composites meant for interior use is typically unstable to moisture. The thermosetting resin used in exterior-grade composites is more expensive than internal-grade resin but is more stable to moisture [4]. Performance can be improved in wood-based as well as agro-based composites by using chemical modification techniques to modify fiber properties such as dimensional stability, biological resistance, ultraviolet resistance, and stability to acids and bases [5]. The designed goals of fiber-reinforced composites include high strength or stiffness on a weight basis [6]. These characteristics are expressed in terms of specific strength and specific modulus parameters, which correspond to the ratios of tensile strength to specific gravity and elastic modulus to specific gravity [7].

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A slab, otherwise known as a plate, is an essential part of a structure usually found in buildings, walkways, and other civil structures. A slab that is not part of a structural frame is usually referred to as a low-sensitivity element in a structure when compared with others like beams and columns [8]. This is due to the fact that it has a larger surface area [9]. Slab as a structural element can be cast using various structural materials; some of these materials are exorbitantly priced, have a high dead weight, a high rate of yielding, have low bending strengths, degrade the environment in the course of their mining, and have other related limitations [10]. Plywood, fiber-based bamboo stick slabs, timber slabs, and composite elements such as concrete-steel reinforced slabs, steel stud-concrete decks, and particle-fibre boards are a few examples of these varied building materials [10]. The earliest type of slab was a bamboo stick slab, which was frequently employed in mud-clay homes in the 1920s and is thought to be more resistant to tensile stress than its contemporaries [11]. Physically, it has a low unit weight and high shock absorbency. The aforementioned characteristics support its application in the creation of light, self-weighted structures. In contrast to bamboo's positive attributes, it is stiff only at the nodal zone and lacks transverse strands, making it less stiff in a direction parallel to the nodes [12]. Additionally, it has a low elastic modulus [13]. Because bamboo is made up of gum, resin, and starchy materials, it needs to be properly treated with the right chemicals before being used for construction or other applications [14].

Additionally, a concrete-steel-reinforced slab is typically constructed from cement, fine aggregate (sand), coarse aggregate (often granite), steel, and water in a predetermined ratio. High compression stress resistance and resistance to microbiological and acidic assaults are two characteristics of concrete-steel-reinforced (CSR) materials. As a composite element, steel has strong tensile strength and high compression strength; therefore, being referred to as "reinforced concrete" makes it a tenacious and durable composite, cast in diverse patterns. Due to this, civil engineering projects like walkways, cover slabs, tank stands, culverts, drainage systems, bridges, and pavements have a wide range of applications [15]. Contrary to what was stated above, reinforced concrete slabs (RC) have a high dead weight, which directly raises the structure's gross weight that is transferred to the foundation and results in expensive foundation structures [16]. In a similar view, due to the rise in demand for reinforced concrete slabs, its component materials, such as granite, cement, rivers, and steel, have become highly expensive and unaffordable to average citizens [17]. Thus, the utility of industrial and agricultural waste products (such as sawdust and guinea grass) becomes valuable as they are cheap, possess a low self-weight, and pose no ecological harm [18].

This study focused on the improvement of wood mechanical properties using Guinea grass, wood sawdust, crack filler, and wood adhesive.

2. Material and Method

The materials utilized in this study are: (i) crack filler (ii) crushed guinea grass (iii) water (iv) plywood with thickness 135mm (v) wood glue.

2.1. Introduction of Materials

Crack Filler: Crack filler was purchased from the saw-mill located along airport road in Benin City, Edo State, Nigeria. The crack filler was divided into groups based on the outcomes of laboratory tests done on its physiochemical characteristics. Talc (magnesium hydroxide), kaolin, carbon, calcium carbonate, and calcium oxide (quicklime) are the chemical components of crack filler.

Plywood: The plywood was procured from a wood mill in Benin City, Edo State, Nigeria. The plywood's grade was C-grade exterior and interior veneer, and its dimensions were 450 mm x 450 mm x 135 mm (three plies, each 135 mm thick). The plywood was physically inspected to ensure there were no cracks, knots, or other defects on it. The plywood has a rough outer surface in accordance with BS EN 855-1:1994. They were sawn to 450mm by 450mm and then used to create laminated slabs with the following measurements: (a) 450mm by 450mm by 145mm; (b) 450mm by 450mm by 170mm; (c) 450mm by 450mm by 195mm; (d) 450mm by 450mm by 220mm; and (e) 450mm by 450mm by 245mm.

Wood Glue: The laminated composite slab was put together using artificial wood glue that was purchased from a wood mill in Benin City, Edo State, Nigeria. The artificial adhesive complies with ISO 656-2010 and BS 5560 [4]. The shear strength, high viscosity, high resistance to moisture, and compatibility with fillers like sawdust and powdered guinea grass were all factors in the choice of the wood glue.

Crushed Guinea Grass: The natural habitats for *Megathyrsus* maximus include open grasslands, typically in or near bushes and trees, and along riverbanks. The grass can endure both drought and wildfire. The plant exhibits significant morphological and agronomic variation, with stem lengths varying from 5 to 10 cm (2.0 to 3.9 in) and heights between 0.5 and 3.5 m (1.6 and 11.5 ft). The plant can also reproduce through apomixis, which is akin to self-cloning through seed. Panicles are open, with each plant bearing up to 9,000 seeds. This grass, when dried, possesses a light weight that can be added as a composite for structural materials.

2.2. Production Processes

Preparation and Processing of the Crushed Guinea grass: The harvested grass was washed and soaked with dilute sodium hydroxide (NaOH) of concentration 0.10 mol/dm^3 for 6 hours to ensure effective bonding between the crushed grass, sawdust, crack filler, wood glue, and plywood. The grasses were air-dried in the sun and later transferred to an oven, where they were dried at 105^{o}C. It was continuously monitored until a moisture content of about 4$\pm$0.2% was obtained [6]. The grass was crushed to granules of size 0.5 μm using a crushing machine. The crushed grass was screened to a particle size of 300 μm in diameter using a vibrating sieve machine.

Production of Plywood Laminated Composite Slab: The plywood with dimensions of 450 mm x 450 mm x 135 mm was used to produce lightweight composite slab laminates of different thicknesses (Figure 1). To ensure tenacious bonding and lamination between the composite slab and the plywood, a wood adhesive or glue was applied evenly on the top and bottom faces of the laminates at 2.5mm thickness. A total of 20 composite slabs of 10 each were produced with mix ratios of 0.5:0.5:1.5:0.5 and 0.5:0.75:1.5:0.5, respectively. The pre-mentioned water/cement ratio and blend ratio were obtained based on the high water absorption rate of the individual materials, their unit weight, their workability nature, and the need to reach the optimum strength of a light-weight composite. A manual mixing method was adopted for all slabs in order to attain good compact. The dimensions of the laminated composite slab developed were 450mm x 450mm x 145mm, 450mm x 450mm x 170mm, 450mm x 450mm x 195mm, 450mm x 450mm x 220mm, and 450mm x 450mm x 245mm, respectively (Figure 2).

Figure 1. Plywood

Figure 2. Light-weight Composite Slab

2.3. Testing Methods

Compression strength Test: The compressive strength of the lightweight composite slab was determined using a compression testing machine; a type of universal testing machine (UTM) designed specifically to assess a material's strength and deformation behavior under compressive (pressing) pressure (Figure 3). The components of this device are a load cell, a crosshead (or crossheads), compression test equipment, electronics, and a drive system. Testing software that defines machine and safety settings and stores test parameters according to testing standards like ASTM and ISO is in charge of controlling it. It is crucial to take into account both the material to be tested and the standard(s) that must be adhered to when selecting the compression test equipment. The slabs were subjected to compression test using a Magnus frame, with an attached Enerpac hydraulic pressure jack to detect its flexural strength. The compression load at yield point was recorded and was utilized to derive the flexural strength for all the slab types.

Figure 3. Digital Compression Testing Machine, Capacity: 10-300 Ton

Measurement of Density: According to ASTM D4442-92 (2003) and ASTM D2395 (2017), the density was tested. The physical characteristics of the samples were assessed on a wooden cube with the following measurements: 450 mm in length, 450 mm in thickness, and 135 mm in width. The samples were weighed to acquire the mass (m), and the sample volume at moisture content (VM) was measured using dimensional analysis. The samples were subsequently dried for 24 hours in an oven at 103 y was tested. The physical characteristics of the samples were assessed on a wooden cube with the following measurements: 450 mm in length, 450 mm in thickness, and 135 mm in width. The samples were weighed to acquire the mass (m), and the sample volume at moisture content (v) was measured using dimensional analysis. The samples were subsequently dried for 24 hours in an oven at 103 °C. They were then placed in a desiccator for about 15 minutes, or until the sample had attained a consistent oven-dry mass (m0). Using Eqn. 1, the density (ϱ) was obtained:

$$\rho = \frac{m}{V} \tag{1}$$

Tensile Test: Various samples of the lightweight laminated composite were produced at different mix ratios and were tested with strain gauge testing machines according to the requirements of the American Society for Testing and Materials (ASTM), tensile test specimens were prepared to a specified design length. ASTM E8-09 tensile standard specimens were prepared for testing. The samples prepared according to the ASTM E8M standard were carefully cleaned again from external factors such as dirt, oil and rust before the tensile test. Tensile tests were performed with a 250 kN Shimadzu universal tester at room temperature, 50±5 % humidity and 2 mm/min crosshead speed [1]. The tensile testing machine used in the experimental study is shown in Figure 5. Three individual wasted test specimens were machined from the stock having a diameter of 9 mm and a gauge length of 45 mm. The dimensions of the tensile specimens are exhibited in Figure 1. The tensile test specimens were machined to the required dimensions using the universal Lathe machine. The lightweight composite slab samples developed were evaluated for their mechanical strength (tensile strength) according to Eqn 2 [4].

$$Tensile\ Strength = \frac{\text{Maximum Load}}{\text{Original Cross−Sectional Area}} \tag{2}$$

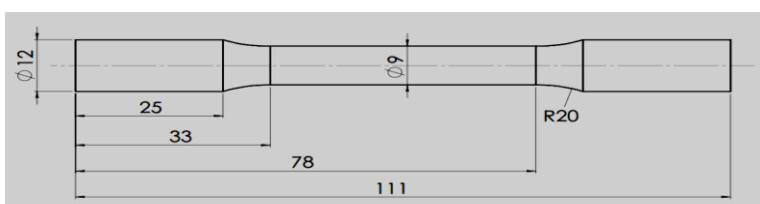

Figure 3. Dimensions of the tensile testing specimen as regard to ASTM E8-09 [1].

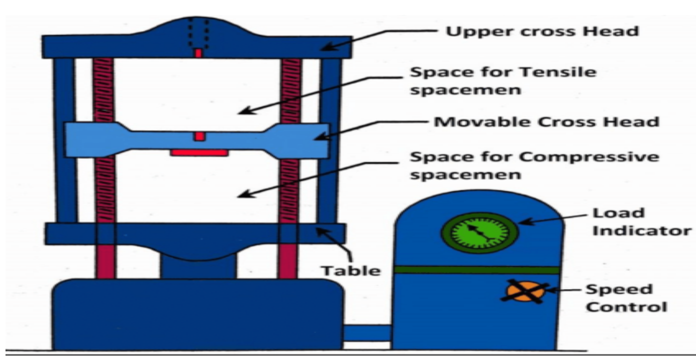

Figure 4. Universal Testing Machine

Flexural strength Test: To assess a material's ductility, bend strength, fracture strength, and resistance to fracture, bend test machines were typically universal testing devices was used. Beam specimens with the following measurements: 450 mm x 450 mm x 135 mm were made. According to IS 516-1959, two-point loading was used during testing on a 400-mm effective span. Eqn. 3 was used to compute flexural strength.

$$F = \frac{PL}{bd^2} \quad (3)$$

Where, F= Flexural strength of composite (in MPa or N/mm^2).

P= Failure load (in N).

L= Effective span of the beam (in mm).

b= Breadth of the beam (in mm).

Figure 6: Flexural Strength Testing Machine

The Brinell Hardness Test: The Brinell scale characterizes the indentation hardness of materials through the scale penetration of an indenter, loaded on a material test piece. The Brinell hardness number (HB) was then obtained using Eqn. 4 [14].

$$Brinell\ Hardness\ Number\ (BHN) - \frac{2P}{\pi D\left[D-\sqrt{D^2-d^2}\right]} \quad (4)$$

Where P is the load in kilogram, D is the steel ball diameter in millimeter, and d is the depression diameter or indentation diameter.

Figure 7. The Brinell Hardness Test Machine

3. Results and Discussion

Results for structural characteristics of composite slab made with sawdust, Crack-filler, and wood adhesive**.** The results of the structural characteristics of composite slab made with sawdust (SD), crack-filler (CF), and wood Adhesive (WA) are presented in Tables 1 to Table 4:

Table 1. Results on Compressive Strength for the Developed Light-weight Composite Slab

Mix ratio (WA:CF:SD:GG)	Sample Number	Area of Sample (mm^2)	Mass of Sample (kg)	Yield load (kN)	Compression Strength (N/mm^2)	Mean Compression strength (N/mm^2)
0.5:0.5:1.5:0.5	X1	40000	9.83	2984	74.60	
0.5:0.5:1.5:0.5	X2	40000	9.98	2980	74.50	**74.60**
0.5:0.5:1.5:0.5	X3	40000	10.13	2988	74.70	
0.5:0.75:1.5:0.5	Y1	40000	10.67	3060	76.50	
0.5:0.75 :1.5:0.5	Y2	40000	10.61	3056	76.40	**76.50**
0.5:0.75:1.5:0.5	Y3	40000	10.75	3068	76.70	

Table 2. Results on Tensile Strength for the Developed Light-weight Composite Slab

Mix Ratio (WA:CF:SD:GG)	Sample Number	Area of Sample (mm^2)	Load (kN)	Tensile Strength (N/mm^2)	Mean Tensile Strength (N/mm^2)
0.5:0.5:1.5:0.5	X1	40000	3528	88.20	
0.5:0.5:1.5:0.5	X2	40000	3580	89.50	**89.50**
0.5:0.5:1.5:0.5	X3	40000	3632	90.80	
0.5:0.75:1.5:0.5	Y1	40000	3724	93.10	
0.5:0.75:1.5:0.5	Y2	40000	3740	93.50	**93.53**
0.5:0.75:1.5:0.5	Y3	40000	3760	94.00	

Table 3. Results of Mean Density for the Developed Light-weight Composite Slab

Mix Ratio (WA:CF:SD:GG)	Sample Number	Volume of Sample (m^3)	Mass of Sample (kg)	Density (kg/m^3)	Mean Density (kg/m^3)
0.5:0.5:1.5:0.5	X1	0.008	9.83	1228.15	
0.5:0.5:1.5:0.5	X2	0.008	9.98	1245.93	**1246.92**
0.5:0.5:1.5:0.5	X3	0.008	10.13	1266.67	
0.5:0.75:1.5:0.5	Y1	0.008	10.67	1334.81	
0.5:0.75:1.5:0.5	Y2	0.008	10.61	1325.93	**1334.81**
0.5:0.75:1.5:0.5	Y3	0.008	10.75	1343.70	

Table 4. Results on Brinell Hardness for the Developed Light-weight Composite Slab

Mix Ratio (WA:CF:SD:GG)	Sample Number	Area of Sample (mm^2)	Mass of Sample (kg)	Brinell Hardness Number (N/m^2)	Mean Brinell Hardness Number (kgf)
0.5:0.5:1.5:0.5	X1	0.04	9.83	58.2	
0.5:0.5:1.5:0.5	X2	0.04	9.98	59.5	**59.5**
0.5:0.5:1.5:0.5	X3	0.04	10.13	60.8	
0.5:0.75:1.5:0.5	Y1	0.04	10.67	63.1	
0.5:0.75:1.5:0.5	Y2	0.04	10.61	63.5	**63.5**
0.5:0.75:1.5:0.5	Y3	0.04	10.75	64.0	

Table 5. Results on Flexural Strength for the Developed Light-weight Composite Slab

Slab Symbol	Mix ratio	Thickness (mm)	Yield load (kN)	Flexural strength (N/mm²)	Mean Flexural strength (N/mm²)
X1	0.5:0.5:1.5:0.5	135	225.16	7.34	**7.34**
			225.39	7.35	
X2	0.5:0.5:1.5:0.5	170	286.64	7.53	**7.52**
			285.96	7.51	
X3	0.5:0.5:1.5:0.5	195	349.44	7.43	**7.44**
			349.90	7.44	
X4	0.5:0.5:1.5:0.5	220	413.80	7.23	**7.24**
			415.00	7.25	
X5	0.5:0.5:1.5:0.5	245	484.24	7.06	**7.06**
			483.48	7.06	
Y1	0.5:0.75:1.5:0.5	135	228.44	7.48	**7.49**
			228.91	7.50	
Y2	0.5:0.75:1.5:0.5	170	286.98	7.54	**7.55**
			287.65	7.56	
Y3	0.5:0.75:1.5:0.5	195	348.52	7.41	**7.42**
			349.44	7.43	
Y4	0.5:0.75:1.5:0.5	220	415.60	7.26	**7.25**
			414.40	7.24	
Y5	0.5:0.75:1.5:0.5	245	486.52	7.09	**7.08**
			485.00	7.07	

Table 6. Results on Deflection for the Developed Light-weight Composite Slab

Slab Symbol	Mix ratio	Thickness (mm)	Yield load (kN)	Flexural Strength (N/mm²)	Deflection (mm)	Average deflection (mm)
X1	0.5:0.5:1.5:0.5	135	225.16	7.34	87.4	**86.52**
			225.39	7.35	85.9	
X2	0.5:0.5:1.5:0.5	170	286.64	7.53	74.4	**75.00**
			285.96	7.51	75.6	
X3	0.5:0.5:1.5:0.5	195	349.44	7.43	51.3	**51.00**
			349.90	7.44	50.7	
X4	0.5:0.5:1.5:0.5	220	413.80	7.23	33.4	**34.00**
			415.00	7.25	34.6	
X5	0.5:0.5:1.5:0.5	245	484.24	7.06	29.4	**29.00**
			483.48	7.06	28.6	
Y1	0.5:0.75:1.5:0.5	135	228.44	7.48	30.2	**31.00**
			228.91	7.50	31.8	
Y2	0.5:0.75:1.5:0.5	170	286.98	7.54	44.6	**44.20**
			287.65	7.56	43.8	
Y3	0.5:0.75:1.5:0.5	195	348.52	7.41	50.9	**50.70**
			349.44	7.43	50.5	
Y4	0.5:0.75:1.5:0.5	220	415.60	7.26	39.9	**40.10**
			414.40	7.24	40.3	
Y5	0.5:0.75:1.5:0.5	245	486.52	7.09	29.7	**29.90**
			485.00	7.07	30.1	

Table 7. Comparison of the Mechanical Properties of lightweight composite slab and plywood

S/N	Mechanical Property at Mix Ratio 0.5:0.5:1.5:0.5 0.5:0.75:1.5:0.5	Produced lightweight composite slab	Plywood [1, 3, 4, 5, 8, 9, 11]	Percentage Increase in mechanical property for Produced lightweight composite slab (%)
	WOOD MATERIALS			
1	Mean Compression strength (N/m²)	75.55	55	37.4
2	Average Tensile strength	91.52	70.01	24.5
3	Mean Density (kg/m³)	1290.87	770	67.6
4	Average Brinell Hardness Number (kgf)	61.50	45	36.7
5	Average Flexural strength (N/mm²)	7.34	5.87	20
6	Average deflection (mm)	47.14	40.07	15

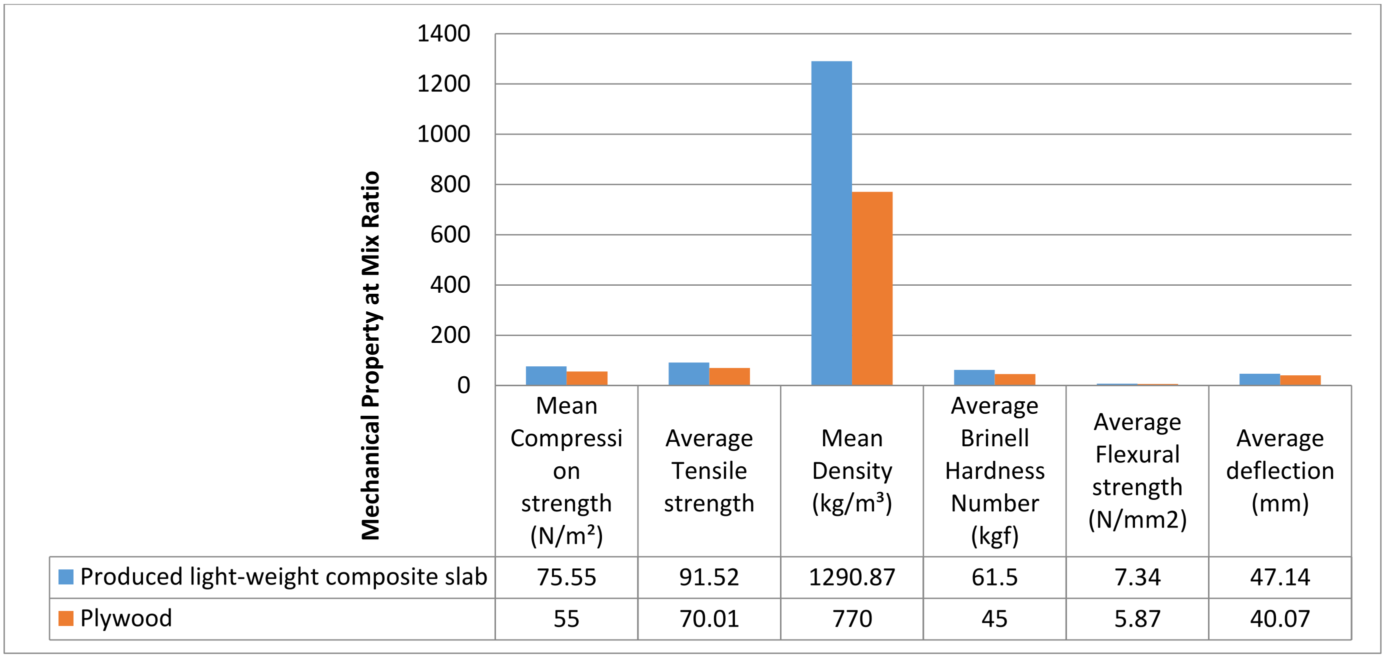

Figure 8. Mechanical Property of lightweight composite slab and plywood

3.1 Discussion of Results

The mean compressive strength of the developed lightweight slab was 74.6MPa and 76.5MPa for mix ratio 0.5:0.5:1.5:0.5 and 0.5:0.75:1.5:0.5 respectively (Table 1). The average compressive strength for both mix ratios was 75.55MPa (Table 7). The average value of the two mix ratios obtained is about 37.4% greater than the average compressive value of the timber veneer species (Mahogany, and wood specie) with about average of 55MPa for structural purposes [1, 3, 4, 5, 8, 9, 11]. The mean tensile strength of the developed lightweight slab was 89.50MPa and 93.53MPa for mix ratio 0.5:0.5:1.5:0.5 and 0.5:0.75:1.5:0.5 respectively (Table 2). The average tensile strength for both mix ratios was 91.52MPa (Table 7). The average value of the two mix ratios obtained is about 24.5% greater than the average tensile strength value of the timber veneer species (Mahogany wood specie) with about average of 70.01MPa for structural purposes [8, 9, 11]. The average density of slab density were 1246.92 Kg/m³ and 1334.81 Kg/m³ for mix ratio 0.5:0.5:1.5:0.5 and 0.5:0.75:1.5:0.5 respectively (Table 3). The average density for both mix ratios is 1290.87 kg/m³ (Table 7). The average value of the two mix ratios obtained is about 67.6% greater than the average density value of the timber veneer species (Obeche wood specie) with about average of 770kg/m³ [11]. The mean hardness of the developed light-weight slab was 59.5kgf and 63.5kgf for mix ratio 0.5:0.5:1.5:0.5 and 0.5:0.75:1.5:0.5 respectively (Table 4). The average mean hardness for both mix ratios was 61.5kgf (Table 7). The average value of the two mix ratios obtained is about 37.6% greater than the average hardness value of the timber veneer species (Iroko wood specie) with about average of 45kgf for structural purposes [8, 9, 11]. The mean flexural strength of slab for both mix ratio 0.5:0.5: 1.5:0.5 and 0.5:0.75:1.5:0.5 is in accordance with the allowable limit of the timber veneer and that of light weight element. The highest bending strength were recorded on 170mm thick slab for both mix ratios while the least bending strength were recorded on 245mm thick slab for both mix ratios. From Table 6, the mean deflection of slab ranged from 28.9mm to 86.5mm for mix ratio 0.5: 0.5 : 1.5:0.5 and 29.85mm to 50.7mm for mix ratio 0.5: 0.75:1.5:0.5. The highest deflection were recorded on 135mm thick slab for mix ratio 0.5:0.5:1.5:0.5 and on 195mm thick slab for 0.5:0.75:1.5:0.5 while the lowest deflection were recorded on 245 mm thick slab for both blend ratios. The results obtained shows that the developed lightweight composite slab had better mechanical properties than ordinary timber veneer.

4. Conclusion

With the help of Guinea grass, wood sawdust, crack filler, and wood adhesive, the mechanical qualities of wood have been improved. The lightweight composite slabs made with mixture ratios of 0.5:0.5:1.5:0.5 and 0.5:0.75:1.5:0.5 (WA: CF: SD: GG), respectively, demonstrate how the addition of guinea grass, wood sawdust, crack filler, and wood glue enhanced the mechanical qualities of slabs made from plywood. The findings demonstrate the significance of the compressive strength, tensile strength, density, hardness, flexural strength, and average deflection of the laminate composite.

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