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Mechanical Strength of Particleboard Produced from Fonio Husk with Gum Arabic Resin Adhesive as Binder

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Abstract
Fonio ("Acha") husk passing through a maximum 4mm sieve aperture was blended with an adhesive liquid resin of gum Arabic to form Fonio Husk Particleboard (FHP) samples. The resin binder was a product of crushed balls of gum Arabic that was mixed with water at ratio 4:3 by weight. The resin was introduced at percentage levels of 20%, 25%, 30%, 35%, 40% and 45% by weight. After pressing, heat treatments and curing, the particleboard samples were tested for mechanical strengths. The compressive strength ranged from 0.057N/mm^2 at 20% level to 0.369N/mm^2 at 45% level. Tensile strength increased steadily with increase in resin levels peaking at 0.792 N/mm^2 for 45% level. The flexural strength followed the same trend peaking at 45% level with 3.697 N/mm^2. Some of the values met the minimum values prescribed by British, American and European Standards. The boards may not be used as load bearing materials but will be better suited as internal wall partitions and ceiling materials.

I. Introduction

The Construction industry is one of the fastest growing sectors in Nigeria and globally too. Rapid construction activity and growing demand of houses has led to the short fall of traditional building materials. Bricks, cement, sand and wood are now becoming more expensive. Demand for good quality of building materials to replace the traditional materials and the need for cost effective and durable materials for the low cost housing has necessitated the researchers to develop variety of new and innovative building materials (CIRAD, 2010).

Wood or wood based composite boards with lightweight & high strength are still a preferred option for construction. The growing shortage of wood has led to the development of suitable alternative materials. Fonio husk, which is a post harvest agricultural waste, can be converted into particle board and then considered as a potential substitute for wood & wood based boards. Previous works on particle board made from post harvest agro-wastes like rice husks (Ndububa, 2012), (Bamisaye, 2007), maize cobs (Ndububa et. al., 2006) showed the boards as possessing appreciable mechanical strengths that met International standards. In the case of Bamisaye (2007), Aluminium Chloride was introduced as a chemical additive.

Others from saw dust and wood shavings also showed high performance in flexure, tension and compression with gum Arabic as resin binder (Ndububa, 2013)

Particleboard is a panel product manufactured from lignocellulosic materials primarily in the form of discrete particles combined with a synthetic resin or other suitable binder and bonded together under heat and pressure. In essence, particleboard is a composite material. Most of the time particleboard pertains to panels manufactured from a mixture of wood particle or otherwise from particles other than wafers and flakes.

Conventional Particle board is manufactured by mixing wood particles or flakes together with a resin and forming the mix into a sheet. There are several types of resins that are commonly used. Amino formaldehyde based resins are the best with respect to cost and ease of use. Urea melamine resins are used to offer water resistance with increased melamine offering enhanced resistance. Phenol formaldehyde is typically used where the panel is used in external application due to the increased water resistance offered by phenolic resins and also the colour of the resin resulting in a darker panel. In addition, panel production involves various other chemicals. These include wax, dyes, wetting agents and release agents. They make the final product water resistant, fire proof, insect proof or give it some other quality. Once the resin has been mixed with the particles, the liquid mixture is made into a sheet. The sheets formed are first cold-compressed to reduce their thickness. Later, they are compressed again under pressures between two and three mega Pascal and temperatures between 140^{o}c and 220^{o}c. This process sets and hardens the glue with consideration to the size, density and consistency of the board. The boards produced lies within the densities of 590kg/m^3 to 900kg/m^3. They are then cooled, trimmed and sanded. These boards can then be sold as raw board or surface improved through the addition of a wood veneer or laminated surface.

Fonio is the name given to cultivated grains in the Digitaria genius. It is called "Acha" by Hausa speaking people of Northern Nigeria. The grains are quite small and look like millet in appearance. It is commonly found in West Africa and presents itself in two forms namely; White Fonio (Digitaria Exilis) and Black Fonio (Digitaria Iburua). Among these two varieties, the white fonio is the most important and popular due to its uses and ease of cultivation. De-husking of the fonio seed is done traditionally by pounding the harvested fruit in a mortar with sand and then separating the grains, sand and husk by winnowing and further pounding. Fonio husks are the hard protecting coverings of the grains.

Fonio has the potential just like any other common cereal to improve nutrition. It is used to prepare porridge and in bakery. It is also used in brewery, drug manufacturing and the husk can be used for fuel generation.

Gum Arabic is a natural gum made of hardened sap taken from two species of the acacia tree; Acacia Senegal and Acacia Seyal. The tree grows in the Arabia, West Asia, the Sahel and much of West Africa. Gum Arabic is a complex mixture of polysaccharides and glycoproteins that is used primarily in the food industry as a stabilizer. Gum Arabic is used in printing, paint production, glue, cosmetics and various industrial applications, including viscosity control in inks and in textile industries.

Gum Arabic is available in brownish crystals or granules which are soluble in water. It is mostly sticky with a slightly sweet smell when used or observed in fresh State. It is unique among the natural hydro colloids (water soluble glues) because of its organic reactivity in water which is quite uncommon in most glues due to their very high viscosities.

II. Materials and Methods

2.1 Preparation of Materials

The Fonio ("Acha") husk or chaff was locally sourced from farms around Kuru, near Jos in Plateau State of Nigeria. It was reduced it into finer particles using locally made grinding machine before passing through British Standard sieves (BSI, 1990) with mesh sizes 4mm 2mm and 0.8mm apertures. The husk was then dried in the sun for 24hours so as to reduce the moisture content. Congealed lumps of solid Gum Arabic were also broken and grinded. The ground gum was measured out at 20%, 25%, 30%, 35%, 40% and 45% levels before diluting with water to form liquid resin adhesives in a gum/water ratio of 4:3 by weight.

2.2 Mixing, Blending and Forming

The liquid resin and the Acha straw were mixed and blended together manually in the laboratory. The blended mix was poured into a (100mm × 100mm × 25mm) thick steel formwork and was tampered using tamping rod so as to give a well blended uniform mix. The top of the formwork was covered by another metal plate and was cold pressed by applying a heavy weight on it for a period of 20mins. The mix after cold pressing for 20mins was then placed in the oven at a temperature of 150˚C. After the 24hrs period the particle board was brought out and kept under room temperature to cure for a week in accordance with European Standards (EN 312, 2003)

2.3 Compressive Strength Test

The compressive strength test was carried out in accordance with the specifications of ASTM, D-1037 (1978), EN 310 (1993) and EN 319 (1993). The specimen were cast into cubical sizes of 25x25x25 mm before being placed on "Perrier Maurice" compression machine with 1500 KN capacity. Three samples were tested for each replacement percent level and the average value was determined. The samples were placed on the machine platen and loaded at 5 bars per second until crushed. The compressive strength T_c was calculated (Neville, 2003) from

$$T_c = \frac{W_c}{bt}$$

Where W_c in (N) is the failure load, b and t are the breadth and the thickness of the samples in (mm) respectively.

2.4 Tensile Strength Test

The Tensile strength test was carried out in accordance with the specifications of ASTM, D-1037 (1978). The specimens were cut into sizes 150 x 50 x25mm for the test. The sample was placed on the machine and anchored at both ends. As the machine was pumped manually, both tensioned ends were stretched till it failed. Failure occurred by splitting. The tensile strength was calculated using the formulae

$$\delta t = \frac{Wt}{b \times t}$$

Where, $\delta t =$ Tensile stress (N/mm^2),
Wt = Failure tensile load (N)
b = Breadth of the specimen (mm) and t = Thickness of the specimen (mm)

2.5 Flexural Strength Test

Samples for flexural test were 150 x 50 x 25 mm in size. Centre point loading was applied on a "Perrier Maurice" Bending machine. Tests were conducted in accordance with EN 310 (1993). The Modulus of Rupture was taken as a measure of the

Flexural Strength as given by Neville (2003) and calculated from the formula:

$$T_b = \frac{3WL}{2bt^2}$$

Where T_b is Modulus of Rupture in (N/mm^2), W is load at failure in (N), L, b and t are respectively the length, breadth and thickness of the samples in (mm).

2.6 Permeability Test

The falling head permeability test was adopted. Water was allowed to run through specimens and observations made by monitoring the rate of fall of water in the manometer tubes. Coefficient of permeability was determined (Terzaghi and Peck, 1967) from the equation

$$K = \frac{al}{A(t_2 - t_1)} \log_e \left(\frac{h_1}{h_2}\right)$$

Where **a** is the area of standpipe in mm^2, **A** is the area of core cutter of the cell in (mm^2), t_2-t_1 is the time taken in running the test in (s), h_1/h_2 is the height ratio and l is the sample length in (m).

III. Results and Discussions

The results of the Compressive, Tensile and Flexural strengths tests along with densities are presented in Table 1 and Figures 1, 2 and 3. The Permeability test result is presented in Table 2.

The permeability of FHP Arabic proportion was 5.6 x 10^{-6} m/s at 20% level and 5.0 x 10^{-9} at 45% as shown in Table 2. The average modulus of rupture (i.e. flexural strength) of the FHP ranged from 0.030 N/mm^2 to 3.697 N/mm^2 for gum Arabic contents of 20 to 45%. The static bending requirement for general purpose boards according to EN 312 – 2 (1996) is 11.5 N/mm^2. It is apparent that none of the samples met this specification. Also average values of test results ranged from 0.363 N/mm^2 to 0.792 N/mm^2 for the tensile strength. The minimum requirement of tensile strength for general-purpose boards according to EN 312 – 2 (1996) is 0.24 N/mm^2. The values for all of the % levels are higher. This shows that when used as partition boards, FHP will be able to bear as much axial load as the conventional particleboard and more.

The range of values of the compressive strength test results is from 0.057 N/mm^2 to 0.363 N/mm^2. The minimum acceptable compressive strength for sandcrete blocks in Nigeria according to Nigerian Standards Organization is 2.5 N/mm^2 (NSO, 1975). This shows that FHPs cannot serve for load bearing purposes in constructions. The range of values for density is from 213 kg/m^3 to 580 kg/m^3. According to British Department of Environment (1973), 1600kg/m^3 is considered the maximum value for lightweight masonry. The FHP therefore easily passes for a very lightweight building material. The general trend from the Tables and Figures show that mechanical strength increased with increase in gum Arabic content.

IV. Conclusion

This paper shows that particleboard produced from Fonio husk, and bonded with gum Arabic as the resin adhesive possesses some mechanical properties, particularly, of tension for applications as partition boards. This performance characteristic is however enhanced as the gum Arabic resin content of the total composite particleboard material by weight is increased. Further investigations on other performance characteristics like dimensional stability, water absorption capacity, impregnation of additives and durability parameters is recommended.

Table 1: Compressive, Tensile and Flexural Strengths of Fonio Husk Particleboard (FHP)

Gum Arabic content %	**Compressive strength N/mm^2**	**Tensile strength N/mm^2**	**Flexural strength N/mm^2**	**Density kg/m^3**
20	0.057	0.363	0.030	213
25	0.110	0.472	0.864	262
30	0.127	0.560	1.128	322
35	0.176	0.688	1.848	403
40	0.259	0.717	2.904	507
45	0.363	0.792	3.697	580

Table 2: Permeability of FHP

Gum Arabic content %	**Permeability**
20%	5.6×10^{-6} m/s
45%	5.0×10^{-9} m/s

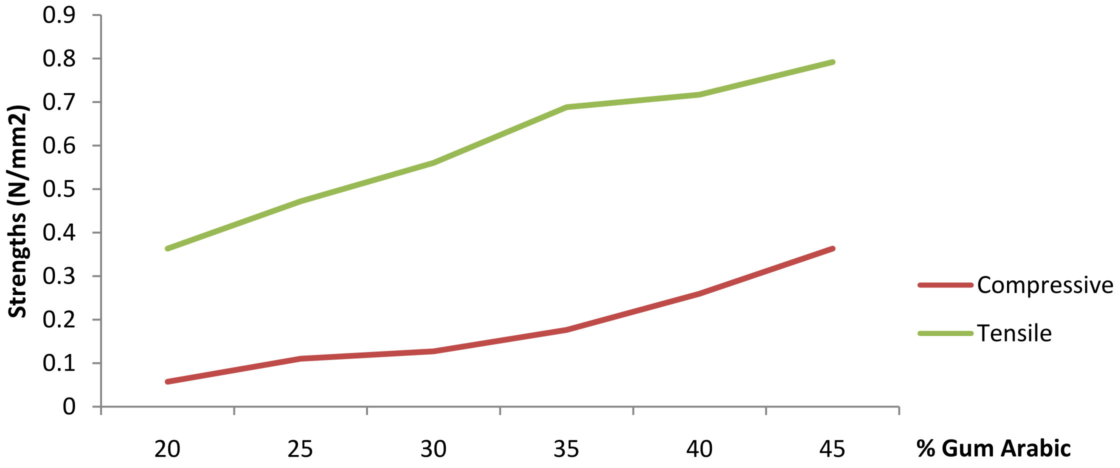

Fig. 1: Compressive and Tensile Strengths of FHP

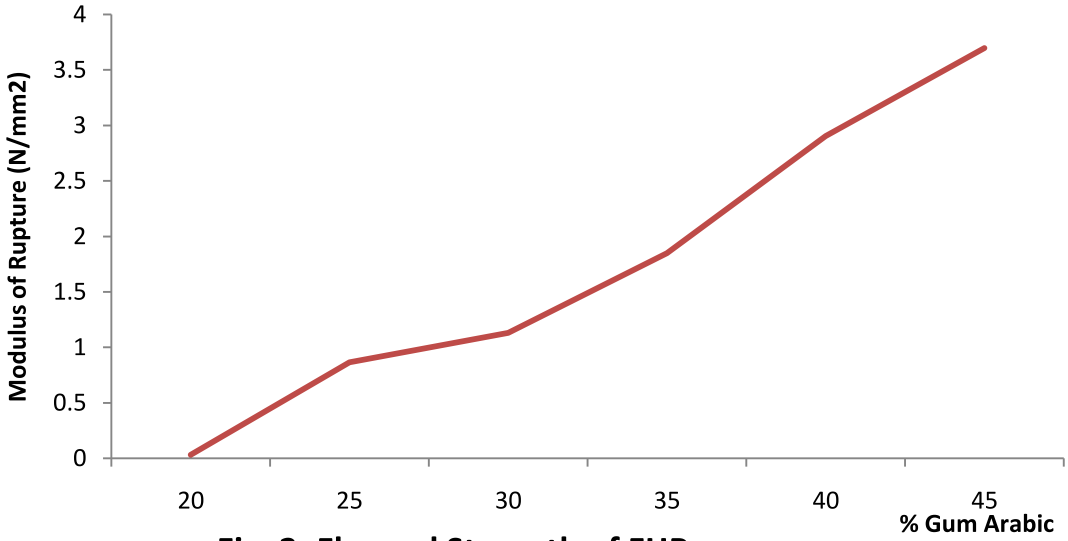

Fig. 2: Flexural Strength of FHP

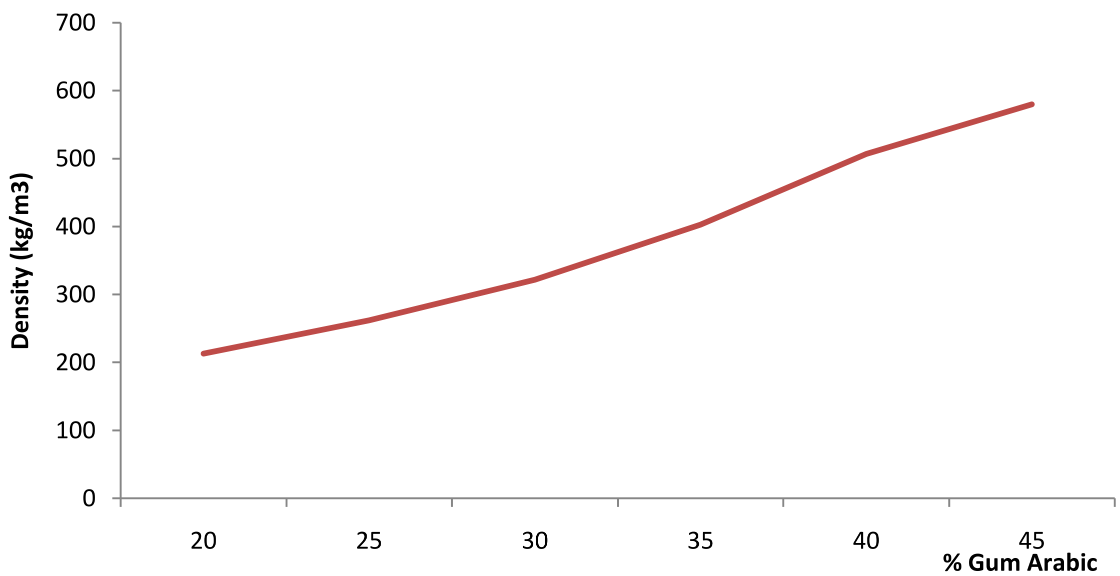

Fig. 3: Density of FHP

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