Full Paper

PERFORMANCE CHARACTERISTICS OF GUM ARABIC BONDED PARTICLEBOARD MADE FROM SAWDUST AND WOOD SHAVINGS

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ABSTRACT

Sawdust and sieved wood shavings' specimens in a 1:1 mix proportion were combined with gum arabic (acacia leguminosae) as adhesive resin to produce particleboard samples. The Sawdust and Wood Shavings Particleboard (SWSP) samples were subjected to flexural, tensile, compressive, water absorption and permeability tests to evaluate the physical and mechanical properties required in building and structural materials. Increase in the gum arabic content from 12% to 20% by weight of the SWSP improved the flexural strength (measured as modulus of rupture) from 10.42 to 46.87 N/mm^2. The tensile strength (internal bond), density and compressive strength also increased from 0.32 to 2.28 N/mm^2, 692.13 to 864.44 kg/m^3 and 1.74 to 9.02 N/mm^2 respectively. The results showed that SWSP exceeded the recommendation of the European standards for flexural and tensile strengths when the proportion of gum arabic was between 14 and 20%. The compressive strengths at 16% resin and above exceeded 2.5 N/mm^2 (the minimum acceptable compressive strength of sandcrete blocks according to Nigerian Standards Organization). The coefficient of permeability values range from $1.48x10^{-6}$ to $5.4x10^{-6}$ m/s. The maximum density of 864.44 kg/m^3 places SWSP as a lightweight building material. However the water absorption capacity value of 30.1% for 20% resin soaked for 12 minutes is far higher than the average specified value of 3.96% by European standards. SWSP may be useful as internal partition wall material and as internal ceiling board.

Keywords: Particleboard, sawdust, gum arabic, wood shavings, strength.

1. INTRODUCTION

Fibreboards include hardboards, Medium Density Fibre (MDF) boards and particleboards. Particleboard is an engineered panel product in which particles of wood are bonded together to form a panel. Most conventional particleboards are produced from wood-based materials, which are formed by using a synthetic resin adhesive. Particleboards are used as ceiling boards and partitions in the building industry. The boards are used extensively in Nigeria, but are usually imported and are expensive. There is therefore the need to explore the possibility of making producing the board locally, with the intent of reducing its unit cost. Industrial manufacturing process of particleboards involves the drying and screening of the wood/fibre particles or flakes. An appropriate adhesive is then sprayed through nozzles on to the particles. The wood particle and adhesive are then mixed and formed under pressure. Common industrial and relatively expensive adhesives are urea formaldehyde resin, melamine formaldehyde resin and phenol formaldehyde resin. These resins are sometimes mixed with other additives before being applied to the particles in other to make the final product waterproof, fireproof, insectproof or to give it some other desirable qualities. Once mixing is done, the mixture is made into a sheet. The sheet is compressed under high temperature (1400°C - 2200°C) and pressure (2 – 3 MPa) to reduce the thickness, set and harden the glue (resin). The boards are air cooled, then trimmed and polished to be sold either in an untreated form or covered in a wood veneer. Other types of particleboards made from synthetic fibres, cement bonds and gypsum plasters are relatively costly (Japhet, 2007).

Sawdust and wood shavings are left as wastes in the open around sawmills and carpentry workshops, and therefore constitute nuisance and environmental hazard. Only limited quantities are used as fuel, poultry bedding and then re-used as organic fertilizer (Barks, 2005). They are usually disposed of by incineration where no use is found for them. However they are considered potential building/structural materials because of certain properties which include light weight (low density), absorption of impact, resistance to thermal penetration and resistance to abrasion (Japhet, 2007).

Gum arabic is the hardened sap of the acacia Senegal tree (*acacia leguminosae*) which is found on the swath of arid lands extending from Senegal on the west coast of Africa all the way to Pakistan and India. The gum has strong/weak binding and stabilizing properties and has found application as additives and thickners in foods and beverages, pharmaceuticals and cosmetics (Ndububa et al, 2006).

Non–wood fibres, particularly those derivable from agricultural wastes have also been used to produce particleboards. Wang and Sun (2002) had identified agricultural residues as renewable resources which can be used as raw materials for producing particleboard. Some of the residues include wheat straws (Mosesson, 1980), rice husks (Vasisth and Chandramouli, 1975), coir (Ndububa, 2000), groundnut shells (Jain et al, 1967), bamboo (Rowell and Norimoto, 1988), tea leaf waste (Yalinkiling et al., 1998), bagasse (Mitlin, 1968), sunflower stalks (Khristova et al., 1998), and palm fruit fibre (Ndububa et al., 2001).

Previous research showed that smaller particles decreased the static bending and modulus of elasticity (Mottet, 1967) of particleboard; low particle moisture content decreased the mechanical properties (Kolman et al, 1975) and particle dusts between voids increased the shelling ratio, thereby improving the physical and mechanical properties of particleboard (Gokay, 2003). Also, increase in percent ratio of gum arabic in ground maize cob matrix improved the mechanical properties of the particleboard produced from the mixture (Ndububa et al., 2006).

Due to the high cost of conventional resins and woods used in the production of particleboards, there is the need to explore cheaper alternative materials. The major objective of this study as reported in this paper is to explore the viability of locally sourced and natural gum arabic as an adhesive binder for the production of particleboard from readily available waste products, such as sawdust and wood shavings.

2. MATERIALS AND METHODS

Sawdust and wood shavings were collected from 'Muda Lawal' timber market area of Bauchi, while the gum arabic was obtained from a neighbouring state of Yobe, both in Northern Nigeria. Gum arabic content was varied from 12 - 20% at intervals of 2% by weight for each tests. For each proportion of gum arabic, fifteen samples were produced in the laboratory and the sawdust/wood shaving ratio was kept at 1:1 by volume.

2.1. Preparation of Materials

The dry wood shavings were crushed with mortar and reduced into smaller particles. Wood shavings and dry sawdust sample were sieved using British Standard meshes of 3, 1.5 and 0.8 mm apertures (BSI, 1990) to remove oversize and undersize particles. Congealed gum arabic was broken up and ground before diluting with water to form a liquid resin adhesive in a gum/water ratio of 4:1 by weight. The water was expected to be evaporated during heat treatment.

2.1.1. Mixing (Blending) and Forming

The liquid resin and the sawdust/wood shaving matrix samples were blended manually with a stirring rod for a period of 15 minutes when it was formed, in the laboratory. The blended mix was then transferred into a 100 x 100 x 50 mm mat formwork made with steel material. Tamping was done to give a "formed mat" which was covered up with a steel metal and placed in a "Memmert" Universal" oven (series u – ul 1992 model, France). The temperature of the gum arabic/sawdust/wood shaving matrix was raised to 150°C over a period of 20 minutes, enough to evaporate the water content and dry the samples. The liquid resin content was varied from 12 to 20% of particleboard weight for sets of experimental samples.

2.1.2. Heat Treatment and Compaction

Once the water content in the resin had evaporated, the boards were pressed with the "Perrier Maurice" compression machine (Perrier Maurice/Sodeteg, 1981, France) at 2.6–3.0 N/mm^2 pressure for 7 minutes, reducing the thickness of the particleboard samples to an average of 12 mm. After pressing and in accordance with European standardization requirements (EN 312 –2, 1996), the particleboards were placed again in the oven and conditioned for two days at an equilibrium and curing temperature of 26 $\pm$ 2°C with an average humidity of 68%.

2.2. Characterisation of Experimental Particleboard

The experimental particleboards were characterized in terms of the flexural, tensile and compressive strengths, density, water absorption capacity and permeability, in order to characterize its suitability for use in the building industry.

2.2.1. Flexural Strength (Modulus of Rupture) Test

Samples for flexural test were 100 x 100 x 12 mm in size. Centre point loading was applied on a "Perrier Maurice" Bending machine (Perrier Maurice/Sodeteg, 1981, France). 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 Equation 1.

$$T_b = \frac{3WL}{2bt^2} \quad (1)$$

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.

2.2.2. Splitting Tensile Strength Test

Splitting tensile strength tests were conducted in accordance with EN 310 (1993). The specimen were trimmed using saw blade to give a cylindrical shape with 12 mm diameter and a length of 100 mm. Failure occurs by splitting of the cylinder along the loaded plane. The splitting tensile strength T is obtained (Neville, 2003) from the expression

$$T = \frac{2P}{\pi DL} \quad (2)$$

Where, P is the maximum applied load in N, L and D are the lengths and diameter in mm of the cylindrical samples.

2.2.3. Compressive Strength Test

The compressive strength test was carried out in accordance with the recommendation of EN 310 (1993) and EN 319 (1993). The specimen were cast into cubical sizes of 12x12x12 mm before being placed in a "Perrier Maurice" compression machine of 1500 kN capacity. The samples were placed on the machine platen and loaded at 5 bars per second until crushed. The machine indicator stops at failure load, which was then read off from the indicator. The compressive strength T_c was calculated (Neville, 2003) from

$$T_c = \frac{W_c}{bt} \quad (3)$$

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

2.2.4. Density

The weights of the test samples subjected to compressive strength were measured on a "Mettler PL 2000" electronic balance (Sodeteg 1981, France). The values obtained were divided by the compressed volume (12 x 12 x 12 mm) to determine their compressed densities (Neville, 1995).

2.2.5. Water Absorption

Samples of SWSP of known weights (initial weight) were immersed in water at room temperature. They were brought out and re-weighed at 2 minutes intervals until they reached saturation points when the weights ceased to change (ASTM D-1037, 1978).

Water Absorption Capacity (WAC) at any time is taken as

$$WAC = \frac{\text{Weight at given time - Initial Weight}}{\text{Initial Weight}} x100\% \quad (4)$$

2.2.6. 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. Coefficient of permeability was determined (Terzaghi and Peck, 1967) from Equation (5)

$$K = \frac{al}{A(t_2 - t_1)} \log_e \left(\frac{h_1}{h_2}\right) \quad (5)$$

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.

3. RESULTS AND DISCUSSION

Fig. 1 and Fig. 2 show the respective values of the flexural, tensile and compressive strengths for different proportions of SWSP. The density values are shown in Fig. 3. Trends in the physical properties of water absorption capacity and permeability are shown in

Figs 4 and 5. The average modulus of rupture (that is, the flexural strength) of the SWSP ranged from 10.4 to 46.9 N/mm^2 for gum arabic contents of 12 to 20%. The static bending requirement for general purpose boards according to EN 312 – 2 (1996) is 11.5 N/mm^2. The specimen with gum arabic content above 14% had higher flexural strength than the general purpose requirements. Also average values of test results ranged from 0.32 N/mm^2 to 2.28 N/mm^2 for the splitting tensile strength. The minimum requirement of tensile strength for general-purpose boards according to EN 312 – 2 (1996) is 0.24 N/mm^2. Again the tested SWSP specimens had higher strengths than the requirement for general purpose boards. These show that when used as ceiling boards, SWSP will be able to bear more transverse load than the conventional particleboard with less tendency to sag.

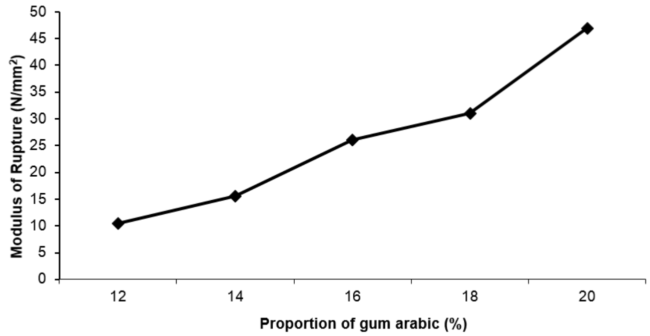

Fig.1: Flexural strength of SWSP with different proportions of gum arabic binder

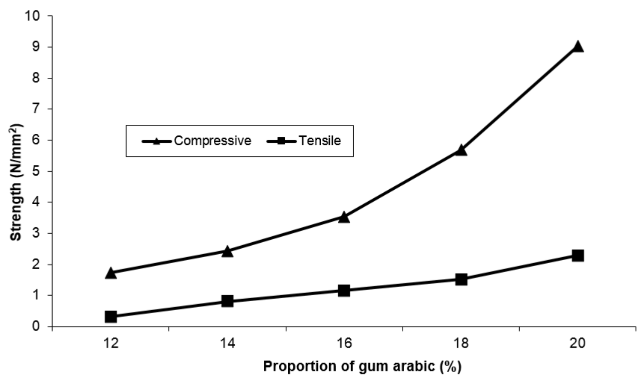

Fig. 2: Tensile and compressive strengths of SWSP with different proportions of gum arabic binder

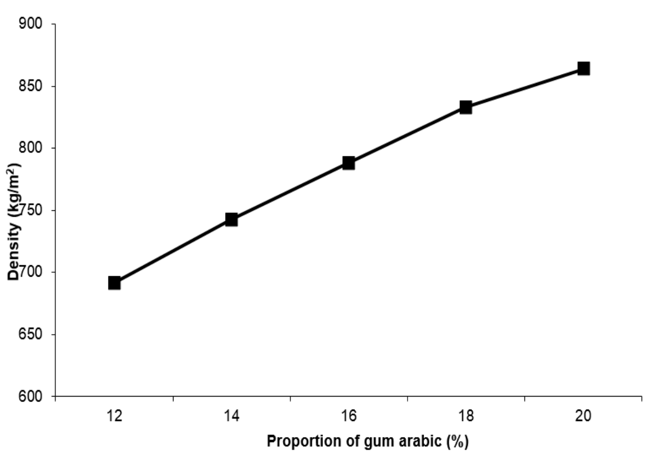

Fig. 3: Density of SWSP with different proportions of gum arabic binder

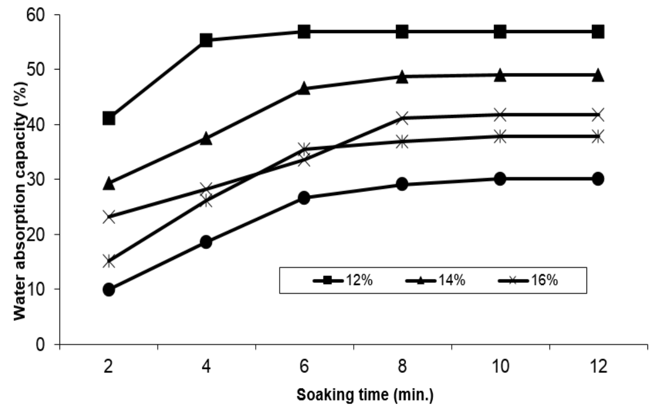

Fig.4: Water absorption trends for different proportions of gum arabic content

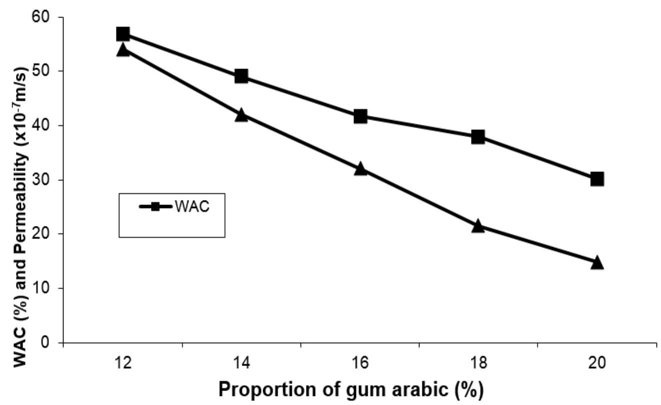

Fig.5: Water absorption capacity and Permeability of SWSP for different proportions of gum arabic

The range of values of the compressive strength test results is from 1.74 N/mm^2 to 9.0 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 SWSPs may be used as internal partition wall materials in non waterlogged locations. The range of values for compressed density is from 692 to 864 kg/m^3. According to British Department of Environment (1973), 1600 kg/m^3 is considered the maximum value for lightweight masonry. The SWSP therefore easily passes for a lightweight building material. The general trend from the tables and figures is that mechanical strength increased with increase in gum arabic content.

While the mechanical strength results show that SWSP is a viable building material, the high water absorption capacity is a disadvantage in its use. The EN 312-2 (1996) specification for average water absorption capacity of a standard particleboard is 0.66% soaked for a minimum of 2 minutes and 3.96% soaked for a maximum of 12 minutes, but none of the SWSP samples met this requirement. The coefficients of permeability of SWSP are given in Table 2, falling within the range of 10^{-5} – 10^{-7} m/s, described as "low degree of coefficient of permeability" for soils (Terzaghi and Peck, 1967). It is believed that if developed and mass produced, Sawdust and Wood Shavings Particleboard (SWSP) bonded with gum arabic will serve as a credible alternative building material to imported particleboards produced from more expensive synthetic binders and fibres. Most of the results are found to have met the minimum standards as set up by different standardization bodies

Table 1: Flexural, tensile and compressive strength of experimental sawdust/wood shavings particleboard (SWSP)

Gum Arabic content %	Flexural strength N/mm²	Tensile strength N/mm²	Compressive strength N/mm²	Density kg/m³
12	10.42	0.32	1.74	692
14	15.62	0.81	2.43	743
16	26.01	1.17	3.54	788
18	31.05	1.53	5.68	833
20	46.87	2.28	9.02	864

4. CONCLUSION

This paper presents a report on the production of particleboard from a combination of sawdust and wood shavings, bonded with gum arabic as the resin adhesive. The particleboard possesses the required mechanical properties of flexure, tension and compression, for applications as ceiling boards and moisture-protected partition walls. The performance characteristic is however enhanced as the gum arabic resin content of the total composite particleboard material by weight is increased. However, the relatively high water absorption capacity and permeability of the SWSP diminish the performance.

Further investigations on other performance characteristics of the SWSP in respect of its dimensional stability, nailability and durability is recommended.

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Table 2: Water absorption and permeability of experimental sawdust/wood shavings particleboard (SWSP)

Gum Arabic content, %	Initial sample mass, g	Water Absorption Capacity for specified soaking time (min.)						Permeability X 10⁻⁷m/s
		2	4	6	8	10	12	
12	89.7	41.1	55.4	56.9	56.9	56.9	56.9 *(140.8)**	54.0
14	110.6	29.3	37.6	46.6	48.8	49.0	49.0 *(164.8)*	42.0
16	128.8	23.2	28.2	33.6	41.2	41.8	41.8 *(182.7)*	32.0
18	135.2	15.2	26.2	35.5	37.0	37.9	37.9 *(186.3)*	21.5
20	150.0	10.0	18.7	26.7	29.1	30.1	30.1%*(195.2)*	14.8

** Final sample weights (in grammes) at saturation points are given in parentheses*