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ENGINEERING CHARACTERIZATION OF GUM ARABIC BONDED PARTICLE BOARD MADE FROM RICE HUSK AND SAWDUST

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ABSTRACT

The Particle board (PB) was developed using Rice Husk (RH) and Sawdust (SD) with Gum Arabic (GA) resin as binder. The aim of the research work was to explore the engineering viability of GA bonded particle board made from agro-industrial wastes for sustainable environment. It was also to investigate aalternative to the high-in-demand conventional particle board made from wood and urea melamine or amino-formaldehyde which is known to be carcinogenic. The RH/GA/SD materials used to produce samples were cheap and locally sourced. For the experiment, the rice husk (RH) content was kept constant although at 65%but the sawdust (SD) and gum arabic (GA) were varied at percentage levels of 5/30%, 10/25%, 15/20%, 20/15%, and 25/10%. After characterization the density of the Pb samples ranged from 447.71 Kg/m^3 to 698.84Kg/m^3. The compressive, split tensile and flexural strengths ranged from 2.24 to 23.31N/mm^2, 1.52 to 3.04 N/mm^2 and 1.776 to 4.752N/mm^2 respectively. Modulus of elasticity ranged from 33.20 to 158.4N/mm^2. The results showed that all the mechanical parameters tested met the requirement of the standards, except for moisture intrusion. The maximum value of water absorption was 7.62% for 2 minutes' immersion in water as against 0.66% and 3.45% in 12 minutes recommended by European standards. The produced particle board is considered structurally viable in that at its ultimate strength it can serve as load-bearing in spite of relatively low density. To mitigate against water absorption, use of wax, veneer and paints can be introduced.

Keywords: *Rice husk, Gum Arabic, Saw dust, Particle board, Waste*

INTRODUCTION

There is an increasing demand for wood in the construction industry as a result of population growth. This has resulted in higher costs and deforestation which is detrimental to climate change. Conventional particle boards are generally produced from wood material and synthetic resin adhesives as binders. The common binders include resins from amino-formaldehyde and urea melamine which are expensive and can cause health challenges if the emissions are inhaled (Chaiklieng *et al*., 2021).

Waste generation is a normal process in post-harvest agricultural activity and industrialization which results in environmental degradation. The quest for environmental sustainability demands systematic waste management approaches, one of which is waste recycling. Rice husk (RH) and sawdust (SD), though bio-degradable are a nuisance to the environment as the major means of their disposal is by incineration which may release greenhouse gases to the atmosphere. Nigeria as well as several other countries within the sub-Saharan region are agrarian, and rice is a staple food (Ndububa, 2012). It is noted that a metric ton of rice results in the dumping of about 35% of the husk per year and lumbering for wood for industrial purposes results in the production of heaps of sawdust. Review articles have reported the difficulties encountered in the efficient use of RH because of their intrinsic properties, which include hard surface, poor nutritive value, high silicon content, low bulk density, and difficulty to decompose with bacteria (Soltani *et al*., 2015). Treatment of the husk by onsite burning to produce steam or electricity, open dumping, or land-filling had led to serious environmental pollution producing smog, dust, and a greenhouse effect (Kuan *et al*., 2012). To reduce pollution from RH and similar wastes, recycling can be introduced as a sustainable system in which they can be converted for use in the production of new materials. Previous research efforts also show that the potential replacement of wood-based raw materials with agricultural residual wastes to produce particle boards is promising. In addition to RH, other examples are fonio husk (Ndububa *et al*., 2015) and maize cob (Ndububa & Oke, 2006), which were produced with Gum Arabic (GA) as binder. Findings from them showed that while they met the minimum mechanical requirements, they, however, did not meet the requirement for water absorption. The use of wastes as particle board materials will reduce the pressure on wood and by extension discourage deforestation.

Gum Arabic (Acacia Senegal) is a native to semi-desert region of Sub-Sahara Africa as well as Middle East/South Asian countries. Gum Arabic is used as a food additive and in cosmetics. It is produced in northern Nigeria where wild and reserve forest reserve cultivation is put at a production capacity of 490,695.9 tons per annum with the States of Bornu, Yobe, and Jigawa having 66% of this capacity (Mustapha, 2018).

This study was aimed at investigating the engineering viability of gum Arabic bonded particleboard made from rice husk and sawdust

MATERIALS AND METHODS

Materials

The materials used were rice husk, sawdust, Gum-Arabic, and water. All the materials were sourced locally. RH was obtained from a rice mill at Dakin-Gari in the rice-growing state of Kebbi, and the SD was from saw mills at Dei-Dei in Abuja, all in Nigeria. Clear drinking water from Abuja Water Board was used for the formulation of the GA resin. The chemical composition of GA shows that it has up to 56.94% of calcium oxide (CaO) (Derrick *et al*., 2021) which is slightly higher than the 40% average for cement. This could be a reason for its binding property as it also has other chemicals obtained in cement like magnesium and potassium oxides

Materials Preparations

The composite materials from different sources were transported to the laboratory of the Nigerian Building and Road Research Institute, Jabi – Abuja where the experiments largely took place.

Rice husk

This was processed by washing with water under normal temperature. The RH was placed inside a big bowl filled with water and allowed to soak for 1 – 5 minutes to make the dust accompanying the husk settle down, thereafter the rice husk was subjected to hand stirring to ensure proper dissolution of deleterious materials in the water. The process continued with every change in water until the water became clean. It was then air-dried for three days. Figure 1 shows the prepared RH sample

Gum Arabic

The Gum Arabic was broken into small crystalline particles with pounding mortar. Figure 2 shows the GA before and after pounding

Gum Arabic resin

The GA resin was prepared by first boiling water to a temperature of (60±5) ºC. At this temperature, the water was removed from the water heater and poured into a mixing bowl. Then GA was mixed with the water at a gum/water ratio of 4: 1.5 by weight. A spatula was used to gradually turn the gum/water ratio to form a resin.

Figure 1: Prepared rice husk for experiment
Source: Nigerian Building and Road Research Institute Laboratory

Figure 2: Gum Arabic before and after pounding
Source: Nigerian Building and Road Research Institute Laboratory

Preliminary tests and mix ratios

Bulk density, specific gravity, and sieve analysis tests on the individual component materials were carried out in accordance with British Standard for sieve analysis tests a mechanical shaker at a frequency of 50Hz for 20 minutes was used (British Standard, 1991: 1989: 1998). After the shaking period, the materials retained on each sieve were weighed together and recorded. The fineness modulus was calculated. Combinations of RH/SD/GA were made with a constant RH value of 65% while SD and GA varied at 5/30%, 10/25%, 15/20%, 20/15%, and 25/10%, and then labelled as Pb1, Pb2, Pb3, Pb4, and Pb5 respectively.

The production procedure of samples

RH and SD were poured into the GA resin in a mixing bowl at different mix ratios. The manual mixing, blending and forming were conducted by European standards (European Standard, 2003; 1993). The mixture was blended into homogeneity and placed in 100 mm x 100 mm x 50 mm size steel formwork. It was tampered with a rod before covering and cold pressed in a compression machine at 0.6 N/mm^2 – 0.8 N/mm^2 Pressure until the thickness reduced from 50 mm to (25±3) mm. This took about 20 minutes. Based on heat treatment, which was also expounded by *Cai et al*. (2006), the mixture was then fired in an oven at a temperature of 150˚C for (20 ± 2) minutes to evaporate the water content, allowing a good flow of GA and turn the particle board sample to a plastic state. Hot compaction was done by placing the already hot sample in the compression machine and gradually pressing at the same rate as cold pressing until the thickness is limited to 18 – 25 mm. The sample was then placed back in the oven and conditioned for two days at a temperature of (25 ± 2) ^{o}C and average humidity of (65 ± 5) %.

Figure 3: Measuring and cutting to the size of samples
Source: Nigerian Building and Road Research Institute Laboratory

Compressive Strength Test

This test was carried out in accordance with European standards (European Standard, 2003; 2001 and 2009). Samples were cut into cube shapes and crushed in a universal testing machine at a crushing rate of 6KN/s. The compressive strength is expressed as

$$f_c = \frac{F_{max}}{ab} \quad (1)$$

Where, F_{max} is the crushing load and a, b are the length and breadth of the test sample.

Figure 4: Crushing of a sample
Source: Nigerian Building and Road Research Institute Laboratory

Density Test

The density of sample is the mass per unit volume. This was measured in accordance with European standards (European Standard, 2003; 1995 and 1993). The weights of the compressed samples were obtained from a digital electronic weighing machine and the values were divided by compressed volumes of the samples to obtain density which is expressed as;

$$D = \frac{M}{V} \quad (2)$$

Where, D, is the density of the sample, M, is mass, and V, is the volume

Flexural Strength Test

Centre point loading was applied in accordance with ASTM (Muhammed, 2018) using Flexural strength test machine (ELE International) with model No 36-0720/01. The modulus of rupture (MOR) which is the measure of the flexural strength, when fractured within the central one-third of the beam sample is as given by Neville (2011) to be

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

Where, T_b is flexural strength, w is the load at failure, c, b, t are the length, breadth and thickness of sample.

Axial tensile test.

The sample was subjected to axial tensile stress to determine its resistance to pull tension. The tensile strength perpendicular to the plane of the board is determined by the maximum axial tensile load with the surface area of the test sample as expressed in equation (4).

$$f_t = \frac{F_{max}}{ab} \quad (4)$$

Where, F_{max} is the axial tensile rupture load, a and b are the length and width of sample.

Split Tensile Strength Test

The test was carried out in accordance with American standards (ANSI, 1999), (ASTM, 2017). The specimen was trimmed to give a cylindrical shape of required diameter and a length of 100 mm. Failure occurred by splitting of the cylinder along the loaded plane. The split tensile strength will be computed from equation (5).

$$T = \frac{2P}{\pi dl} \quad (5)$$

Where, T, is splitting tensile strength, P, is maximum applied load, l, is length and d, is diameter

Modulus of elasticity

The modulus of elasticity is the resistance of materials to bending. It was carried out to ascertain the particle board strength when subjected to bending. The test was carried out in accordance with the provision of British Standard and European Standard.

Water Absorption and swelling thickness

European standard (317, 1993) was used to measure water absorption and swelling. The dry sample was weighed to determine initial weight before immersion in water, then the sample was brought out and re-weighed at intervals of 30 seconds until saturation point. Water absorption was calculated from equations (6):

$$Water\ absorption = \frac{Weight\ at\ saturation - Initial\ weight}{Initial\ weight}\ x\ 100\% \quad (6)$$

Thickness swelling (G_t) is a measure of the dimensional stability in a moisture environment. It is the degree of variation in size after immersion in water or humid condition and is determined by measuring the increase in thickness of the test sample after complete immersion in water its determination is as shown in equation (7)

$$G_t = \frac{t_1 - t_2}{t_1} x 100\% \quad (7)$$

Where, t_1 is the initial thickness of the sample before immersion, t_2 is the final thickness of the sample after immersion.

RESULTS AND DISCUSSIONS

Preliminary Materials Tests Results

Bulk density

From the results shown in Table 1, the average compacted bulk density was 262 Kg/m^3 Uncompacted values range from 100 – 160 Kg/m^3 (Yanping & Yang, 2019). The value is reasonable though the variations of values may be attributed to location/cultivation region, climatic condition, soil type, and rice species. The Table also presents the result of GA bulk density which was 624 Kg/m^3. The established values range from 502 ± 20 to 790 ± 20Kg/m^3 (Rosland *et al.*, 2020). The sample is within the range. The bulk density for the SD used was 199 Kg/m^3. The value ranged from 349.9 and 1031.7 Kg/m^3 from previous works (Ikenyiri *et al*., 2019) depending on the type of wood from which SD was derived. The sample used in the present work is lighter probably due to its level of dryness. The specific gravity values are also presented in Table 1, showing that the materials were all lighter than water and any composite from them will make for light-weight material.

Table 1: Results of Preliminary Material Tests

Material	Bulk density (Kg/m^3)	Specific gravity	Fineness modulus
RH	262	0.26	4.55
GA	624	0.62	4.80
SD	199	0.20	4.04

Source: Nigerian Building and Road Research Institute Laboratory

Particle size distribution

Figure 5 shows the RH particle size distribution graph. The grading curve shows that the husk particles fall within the sand region which is good for blending with GA resin. Figure 6 shows the grading curve of the ground GA used which is not much different from that of RH. SD sieve analysis result as shown in Figure 7 is not much different from the previous two except that it is finer.

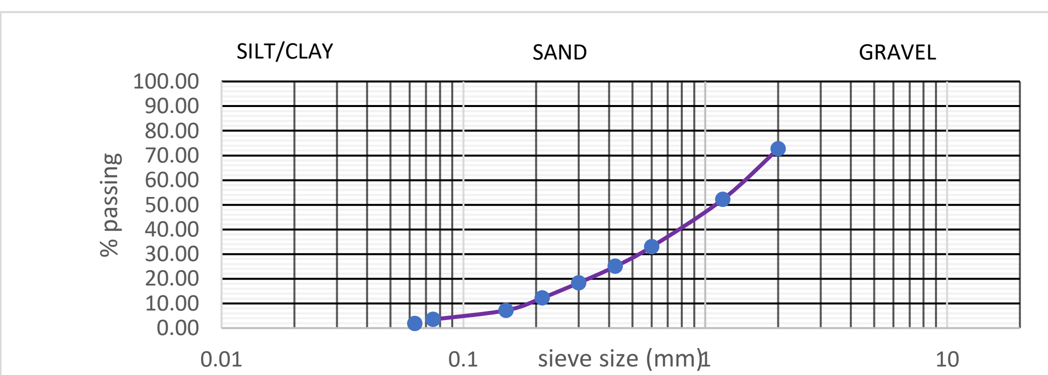

Figure 5: RH particle size distribution graph

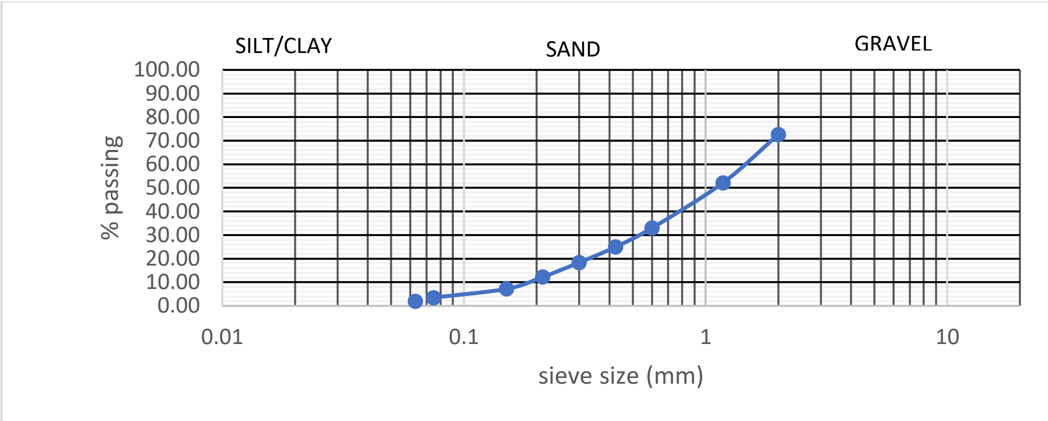

Figure 6: GA particle size distribution

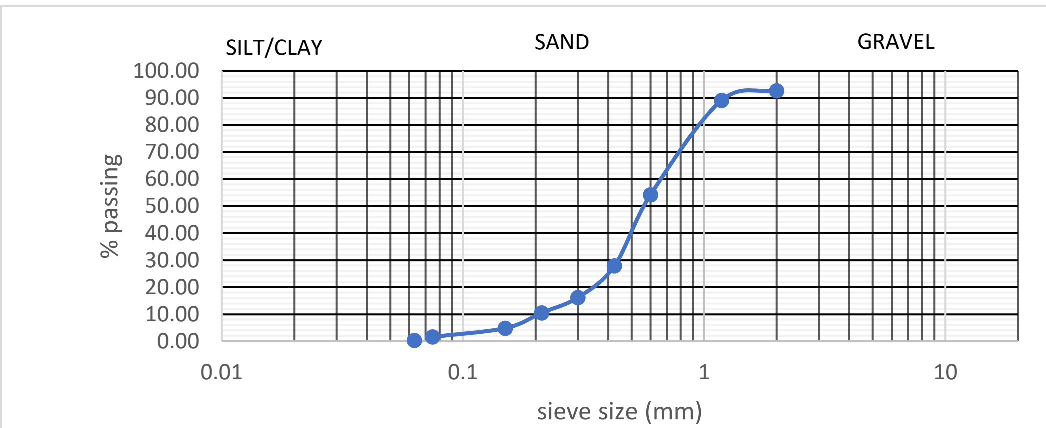

Figure 7: SD particle size distribution

Compressive Strength

The compressive strength for the samples was determined from equation (1) and the results are shown in the second column of Table 2. The results indicate that the compressive strength ranged from 2.24N/mm² at 5/30% to 23.31N/mm² at 30/5%, and there was an increase in compressive strength with increasing percentage of GA and decreasing percentage of SD. This establishes GA as not only a good binder but also a strength provider in particle boards. Previous works provided values that ranged from 0.363N/mm² in fonio husk particle board (Ndububa *et al.*, 2015) and 3.13 N/mm² (Ndububa, 2013) in wood shaving/sawdust particle board. However, Derrick *et al*. (2021) obtained a strength of 22.54 N/mm² with a 50% GA content from particle board made from macadamia nutshell. This value is close to the 23.31 N/mm² of PB 1. Apart from PB 5, other samples met the minimum compressive strength of 2.5 – 3.45 N/mm² allowable for sandcrete blocks (NSO, 1975), (NIS, 2004). These results imply that the particle boards, particularly the PB 1 sample are capable of load bearing. The higher values may be due to the washing operation carried out on the RH to remove deleterious materials, the particle size and water gum/ratio.

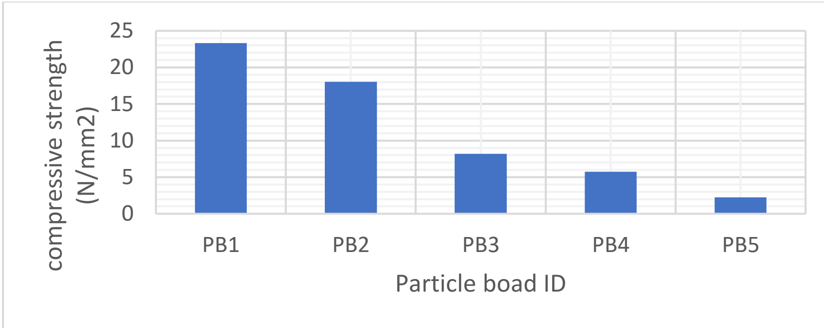

Figure 8: Variations of compressive of produced particle boards with particle board type

Density

The third column in Table 2 shows the density values as calculated from equation (2), which appear to decrease with a decrease in GA content from 698.84Kg/m³ for PB 1 to 447.71 kg/m³ for Pb 5. The increase in density with an increase in GA is in tandem with previous reports on fonio husk and sawdust/wood shavings (Ndububa *et al.*, 2015), (Ndububa, 2013). The closeness in values and the declining values with the increase of SD shows that SD moderated the values in a decreasing manner and thereby contributing to the light-weight property of the board; a similar work with RH alone with GA produced a density range of 546.2 to 809.5 kg/m³ (Ndububa, 2012). A report previously cited had a maximum density of 1219.20 kg/m³ with macadamia nutshell and 50% GA binder. That passed as a high-density board (HDB). The specification requirement according to BSEN (European Standard, 1999 & 2019) for soft boards and medium-density boards (MDB) is 560 - 900 kg/m³. Except for PB 1 which falls within this range, other samples fall very slightly below this range except pb5 at 447.71 kg/m³.

Flexural strength

The test results shown in Table 2 presented modulus of rupture (MOR) values as computed from equation (3) that decreased with the reduction of GA content and increase of SD content, from 4.75 to 1.78 N/mm². Figure 9 shows the variation chart. However, despite this decrease in flexural strength with an increase in SD, the produced particleboards met the relevant European standards [29] for soft boards of thickness greater than 10 but less than 19mm which the MOR value must not be less than 0.8 N/mm².

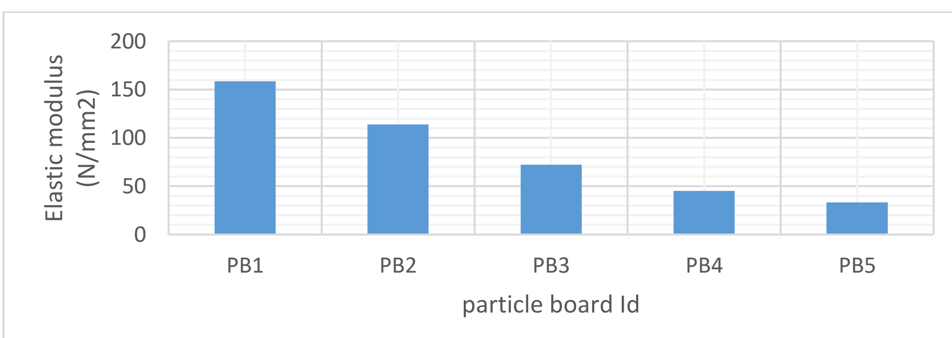

Figure 9: Variations of modulus of rupture of particle board samples

Tensile strength

The axial tensile strength values as shown in Table 2 and Figure 10 presented decreased as SD increased and GA decreased from 0.13 to 0.0413 N/mm². The brittleness may be attributed to the presence of SD which is a very brittle material. These results are lower than the range of results obtained by the previous researchers on fonio husk (0.363 to 0.792 N/mm²) and rice husk (0.18 to 0.34 N/mm²) using gum Arabic binder. The results are also lower than the European requirement for tensile strength which is 0.24 N/mm².

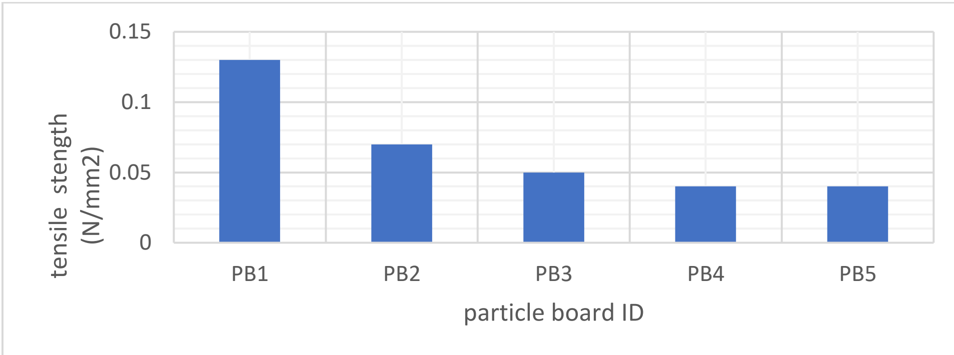

Figure 10: Variations of tensile strength of produced particle boards with particle board type

Split Tensile Strength

Samples test results are shown in Table 2 and Figure 11. It shows that the split tensile strengths ranged from 3.04 to 1.52 N/mm². The strength increased as the SD was reduced and G.A was increased. The trend is not different from those of compressive, flexural and axial or direct tensile strength test results. Again, the incorporation of SD reduced strength though it served as a cheap filler in all of the samples.

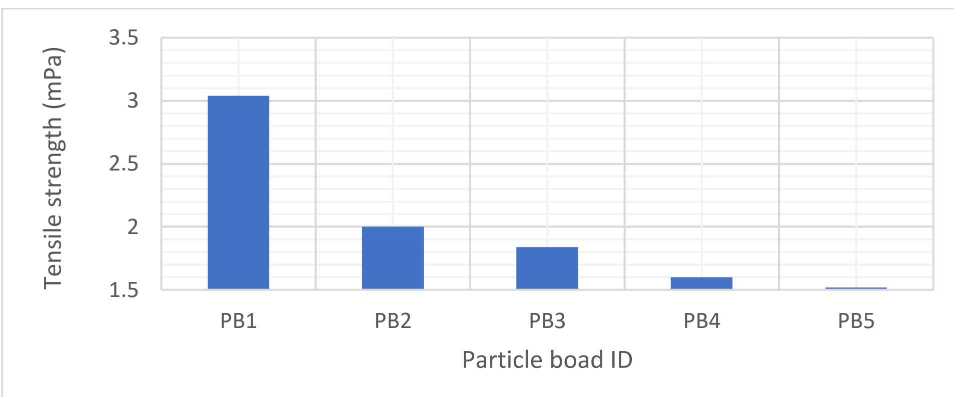

Figure 11: Variations of split tensile strength of particle board samples

Modulus of Elasticity (MOE)

The modulus of elasticity (MOE) results are presented in Table 2 and Figure 12. The results show that MOE declined from 158.40 to 33.20 N/mm^2. The minimum requirement of European code is 100 N/mm^2 (European Standard, 1997), so, this was met by only PB 1 and PB 2 samples. The general trend is not different from those that were earlier discussed.

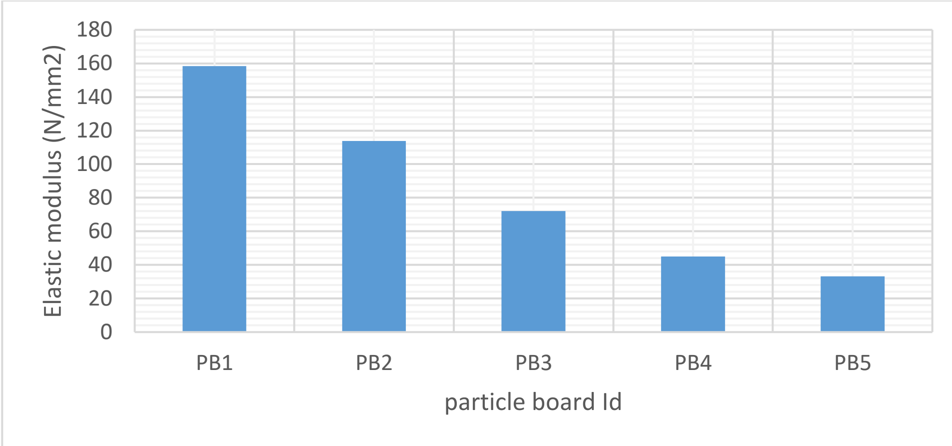

Figure 12: Variations of modulus of elasticity of particle board samples

Water absorption

Table 2 and Figure 13 show the water absorption trends. The minimum value was 7.62% for Pb1 and maximum at 70.08% for Pb2 after 2 minutes of soaking. While the minimum water absorption is 0.66% for 2 minutes soaking and 3.45% for 12 minutes according to European standards EN (312 2, 1996), none of the samples met that. However, from a previous research result the water absorption ranged from 7.9 - 35% and 9.45% in the case of Derrick *et al*. (2021) while the maximum prescribed value is 8% according to ANSI (ANSI, 1999) The reason could be the hygroscopic nature of the constituent materials. It was observed that prolonged immersion in water resulted in loss of materials due to gradual dissolution. The use of the particle board in wet environments will therefore require some water-proof coating. More research efforts are needed on introducing water-resisting materials to the matrix. Possibly needed is an additive material that can form a floating film to coat the individual particles of the composite particle board as well as probably act as a binder.

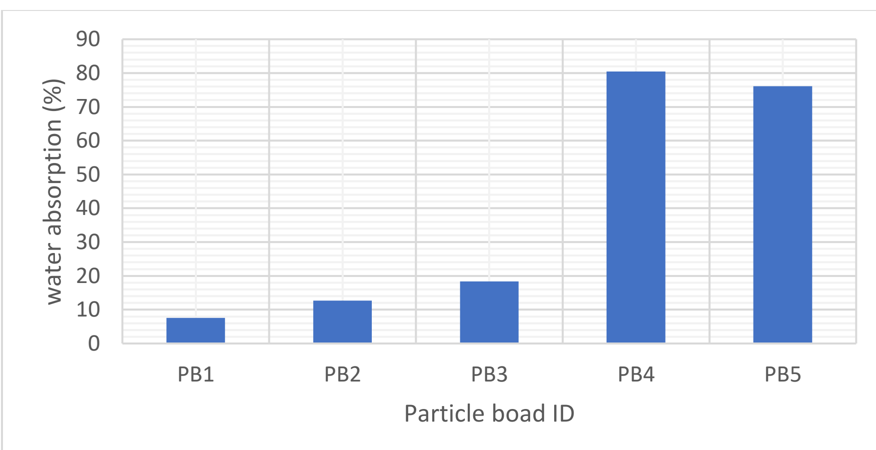

Figure 13: Water absorption of particle board samples

Swelling in thickness

The last column in Table 2 and Figure 14 shows the swelling in thickness (ST) values. European standard BS EN 316 prescribe a maximum value of 10% for wood-based boards while the American standard ANSI prescribes 3% for composite panels after 24 hours of immersion. Derrick et al. (2021) achieved 6.22%. Only Pb1 and Pb2 samples fall within 10% at 7.6% and 7.65% respectively but for 2 minutes immersion in water. The particle board samples can therefore not be said to have met the minimum standards in ST and so will require some form of water-proof covers before they are deployed in moist environment.

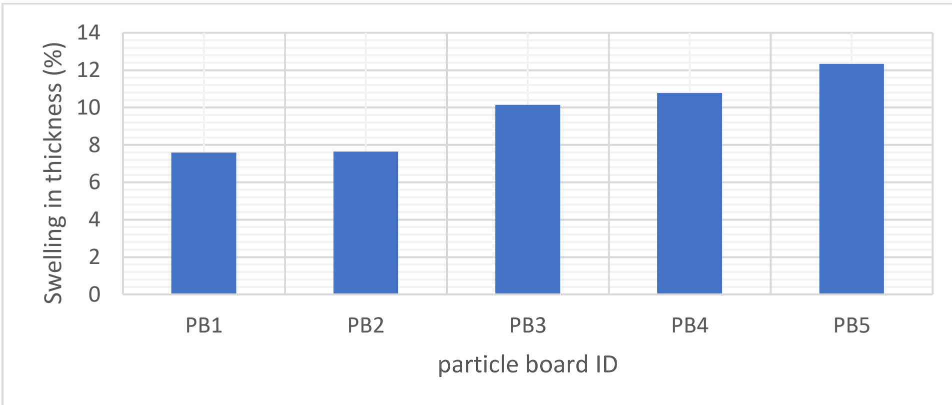

Figure 14: Swelling in thickness for the particle board samples

Table 2: Test results of particle board samples

Sample	Compressive strength (N/mm^2)	Density (Kg/m^3)	Flexural strength (N/mm^2)	Axial Tensile strength (N/mm^2)	Split Tensile strength (N/mm^2)	Modulus of Elasticity (N/mm^2)	Water Absorption (%)	Swelling Thickness (%)
Pb1	23.31	698.84	4.75	0.13	3.04	158.40	7.62	7.60
Pb2	18.03	559.16	3.98	0.07	2.00	113.83	12.67	7.65
Pb3	8.31	556.30	2.69	0.05	1.84	72.16	18.38	10.14
Pb4	5.76	546.00	2.23	0.04	1.60	45.09	80.44	10.77
Pb5	2.24	447.71	1.78	0.04	1.52	33.20	70.08	12.33

Source: Nigerian Building and Road Research Institute Laboratory

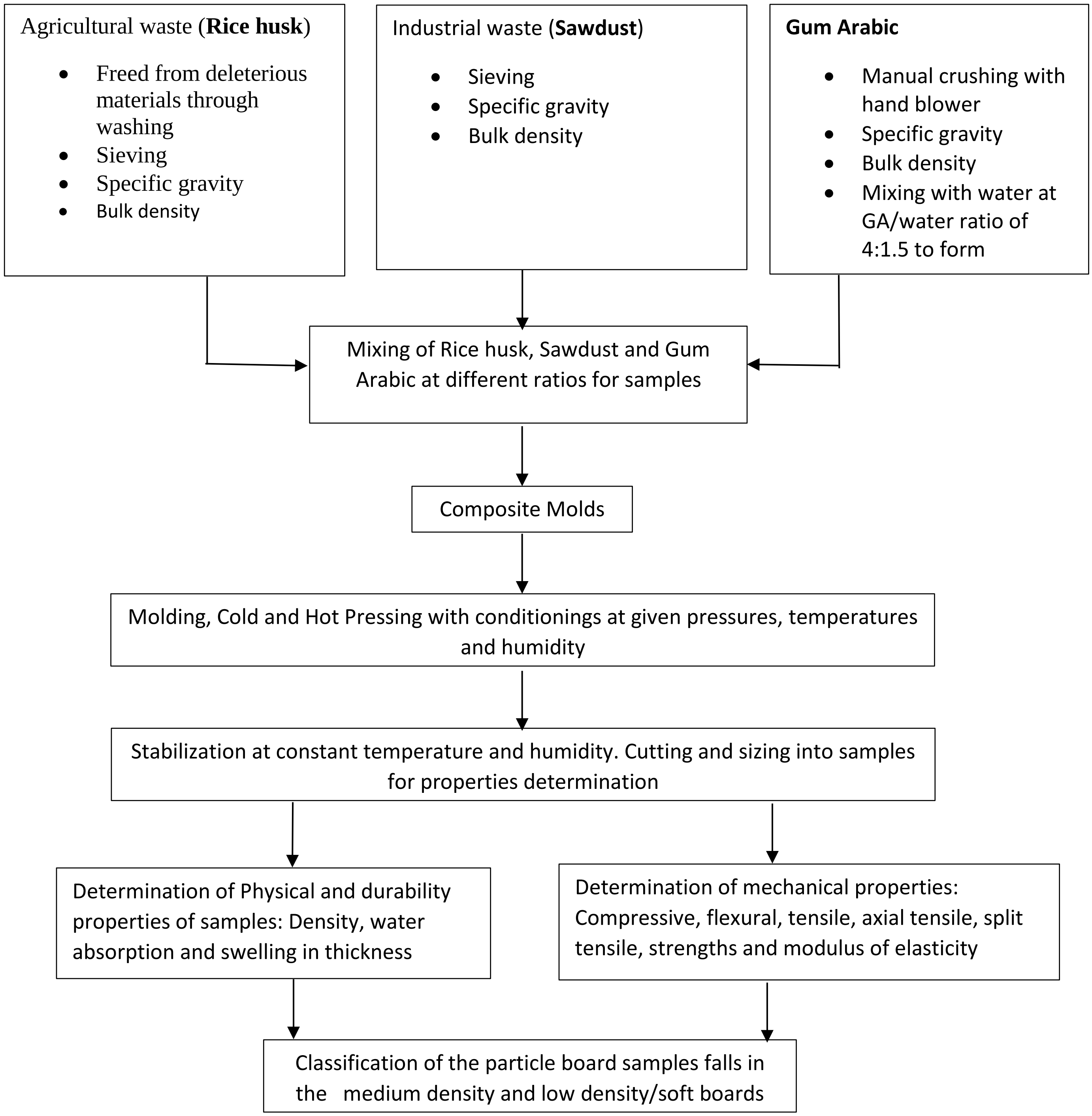

Figure 15: Flowchart of particle board samples production and tests

Conclusion

Gum Arabic bonded particle boards produced from combined rice husk and sawdust was investigated as a potential building material. The boards may be classified as both medium-density and low-density boards depending on the

GA/SD contents since the densities were above and below 560Kg/m^3 respectively. It is worth noting that in spite of the low density, the particle boards exhibited substantial mechanical properties which include compressive, flexural and split tensile strengths that exceeded the minimum values prescribed by relevant standards consulted. The component filler materials (RH and SD) must have contributed immensely to the flexural strength as it outperformed one with macadamia seed, though with 50% GA content. The compressive strength for 65/30/5%, RH/GA/SD% particle board was high enough to serve as a load-bearing building material. On a final note, a particle/fibre board that is eco-friendly and largely meets prescribed mechanical strengths based on BS EN 316 and ANSI A208 was produced with rice husk/sawdust fillers and Gum Arabic as binder. The boards could be applied as ceiling boards, partitions (load-bearing and non-load-bearing), furniture and decorations.

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