

Development of Particleboard from Groundnut Shell Based Composite

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Abstract

In this study, some characteristics of Epoxy resin-bonded groundnut shell particleboards was investigated. The groundnut shell particleboards were fabricated in three epoxy resin adhesive treatment levels 20%, 30% and 40% with three groundnut shell particle sizes 500 μ m, 1000 μ m, and 1500 μ m. Each groundnut shell particle size was blended with adhesive at treatment level 20%, 30% and 40% to produce particleboard samples A, B, C, D, E, F, G, H, and I. The physical and mechanical properties of the fabricated particleboards were investigated. The average densities of the boards were determined to be 789.12kg/m³ to 429.38kg/m³ representing samples C and H respectively. The effect of groundnut shell particle size and adhesive treatment levels had much influence on the tensile strength, Modulus of elasticity (MOE), Modulus of rupture (MOR) and the dimensional stability of the boards produced. Results from tests indicated the optimal values for tensile strength, MOE, MOR, water absorption rate (WA) and thickness swelling (TS) as 6.36 N/mm², 2511MPa, 14.616 MPa, 37.38% and 18.69% respectively. The results showed a potential of developing an Epoxy resin-bonded Groundnut shell particleboard for general-purpose applications.

Keywords: Groundnut shell, Epoxy resin, Particleboard. Physical properties, Mechanical Properties.

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I. Introduction

Increasing global demand for wood and wood-based products from the forest industry due to increasing population and advanced technology is and will continue to cause significant pressure on the current forest resources [FOA]. Continuous depletion of these forests due to excessive demand for wood is causing serious global ecological problems such as loss of diversity, soil erosion, climate change, disruption of water cycle, flooding and desertification. In the quest to finding alternative suitable materials as a replacement to wood, researchers have investigated the possibility of utilizing agricultural post-harvest waste such as rice husk, maize cobs, fonio husk, groundnut shell to develop composite boards as alternative to wood and engineered woods. Results from their findings indicates that high quality wood based composite boards possessing appreciable mechanical and chemical properties that met international standards could be produced from many post-harvest agro waste materials [1, 2, 3, 4, 5, and 6]. Particleboards are generally termed as engineered wood-based panels. They may be a blend of wood-based particles with either synthetic or natural (bio-adhesives) binders; or may be binderless [7]. In binderless particleboards, the particles are bound together with the simultaneous application of pressure and temperature in the absence of any adhesive as binder [8]. Investigation into the properties of some binderless particleboards suggested their limited applications; mostly restricted to practical applications in medical radiation centers [8]. Marashdeh et al (2011) investigated the properties of *Rhizophora Spp* binderless particleboards. Results from their work indicated that an acceptable mass attenuation coefficient very close to that of water; which is suitable standard phantom material in medical radiation detection could be achieved. However, the internal bonding (IB) strength was found to be very low, suggesting the particleboards were easily disintegrated by water over a short period. They generally have poor water absorption (WA) and thickness swelling (TS) [6]. Hassan B.B. et'al (2019) produced particleboard composites from common agricultural waste materials ie sawdust, corncob and rice husk blended with polyester resin. The study investigated suitability of the boards produced in terms of flexural strength, compressive strength, density and dimensional stability. The flexural strength, compressive strength, density, water absorption and thickness swelling values ranges between 4.86 MPa and 14.78 MPa, 1.16MPa and 4.41 MPa, 800 kg/m³ and 860 kg/m³, 5.44% and 47.97%, 1.26% and 13.24%, respectively. Areil et'al (2017) investigated the physical and mechanical properties of particleboard samples produced from a composite of Pili nut and saw dust blended with HDPE adhesive at a treatment level of 50%. Results from test conducted on the particleboards shows a densities ranging from 1220.01 kg/ m³ to 1204.09 kg/ m³, an average MOR value ranging between 61.28MPa to 110MPa and a thickness swelling ranging from 0 – 2.78%. All the samples satisfied the minimum standard of Philippines Standard Association (PHILSA) for

particleboards. Ady frenly et'al (2021) developed and investigated the mechanical properties of isocyanate-bonded corncob particleboard samples. The boards were produced from a blend of 60 μ m, 65 μ m, 70 μ m and 75 μ m corncob particle sizes at binder treatment levels of 25%, 30%, 35% and 40%. Results from this work produced a particleboard with optimum MOR, MOE and tensile strength of 87.56 kgf /cm², 24483, 32 kgf /cm² and 4.41 kgf /cm² respectively. The mechanical properties of the boards from this investigation were in accordance with the minimum standards SNI. 03 -2105 -2006. In his quest to utilize maize cobs to develop particleboards, Dagne, (2021) investigated the mechanical properties and the dimensional stability of particleboard samples from a blend of modified starch (starch cross-linked with wood adhesive; top bond) as alternative source of adhesive with maize cob. The blends were hot pressed into particleboard samples and their effectiveness in terms of density, internal bond strength and water absorption rate were investigated. Results from this work recommended the particleboard investigated for indoor applications, building and furniture applications. The densities were varied between 6840 kg/m³ and 9083.33 kg/m³, with an optimum water absorption rate of 11.43% and a low internal bonding (IB) strength of 0.132 N/mm². Eyide et'al (2023) investigated the optimization of mechanical properties of bonded particleboards produced from agricultural waste wood chips. The work investigated the modulus of rupture (MOR) and the modulus of elasticity (MOE) of particleboards produced under stacking time (14 -21 days), resin loading (386-463 g) and amount of agro residue (154-185 g) conditions using Box-Behnken design. in the design of experiment (DOE), analysis of variance (ANOVA) results showed that MOE and MOR were influenced by the stacking time, amount of resin and agro residue used. The optimum MOE and MOR values were determined using response surface methodology (RSM) at 1114.09N/mm² and 9.34 N/mm² respectively under the chosen production conditions. All the particleboards produced these optimised condition satisfied the ANSI/A208.1-1999 specification for general purpose particleboards.

The use of binders in the manufacture of wood based or engineered woods such as particleboard is evolving within the woo-based industry. Binders may be natural (bio-adhesive) or synthetic binders [11, 4, 13]. Enhanced water resistance, internal bonding strength, cost and ease of use are major considerations in the selection of amino formaldehyde based and urea-melamine resins in particleboard production. Darker particleboards; mostly for external applications, phenol formaldehyde based resins which are typically darker in color are utilized [14].

Nigeria is one of the largest producers of groundnut in Africa, with an estimated production of 2.699 million metric tons in 2008 [15]. In Nigeria, groundnut crop is almost entirely grown in the northern parts of the country, hence groundnut shell is found in large quantities as agricultural farm wastes in parts such as Katsina, Sokoto, Kebbi, Kaduna, Kano, Borno and Yobe States [16]. It is grown as an annual crop in the tropical and subtropical regions and the warmer areas of the temperate regions of the world, principally for its edible oil and protein rich kernels or seeds, borne in pods, which develop and mature below the soil surface [16]. Groundnut shell fibre is one of the many natural fibers simply refereed as non-synthetic fibers. Characterization of groundnut shell fibre shows an average length of 35mm and 0.25mm diameter, average tenacity of 1.06g/den, average strain of fibre as 7.45% and average modulus of 25.3g/den [17].

II. Materials and Method

2.1 Materials

The materials used in this research are:

Groundnut shell

Epoxy resin: (Bisphenol-A-CO-Epichlorohydrine) and hardener (Tetraethylenepentamine).

Mold

2.2 Method

2.2.1 Preparation

Groundnut shells were procured from Dawanau market in Kano State, washed in distilled water to remove sand and other impurities and further leached using sodium hydroxide (NaOH) in order to further remove remnant impurities. The shell was then sun dried for 48 hours and then grounded using a grinding machine. The groundnut shell powder was screened using British Standard (BS) sieve with mesh sizes 500 μ m, 1000 μ m and 1500 μ m aperture [Plate III]. The measureable effects of grain size in terms of hardness, yield strength, tensile strength, fatigue strength, machinability at room temperatures were some of the considerations for the choice of groundnut shell particle sizes.



Plate I: Groundnut Shell



Plate II: Leached Groundnut Shell



Plate III: Sieved Groundnut shell particles

2.3 Blending and Compaction

The groundnut shell particles grain sizes 500 μ m, 1000 μ m and 1500 μ m were measured at the ratio of 80%, 70% and 60% by weight of the particleboard respectively. Separately, the resin and the hardener were thoroughly mixed at the ratio of 10:1 for five minutes [19]. The mixture of the resin and the hardener representing 20%, 30% and 40% by weight of the particleboard were measured. Groundnut shell particles of 500 μ m were blended with the resin at 80:20, 70:30 and 60:40 respectively representing sample A, B and C, other particle sizes were blended in the same proportions with the resin as shown on table 1. Each blend was then poured unto a waxed mold of dimension 500mm X 500mm X 10mm and hot pressed for 15 minutes using a workshop press at 80 °C with an applied pressure of 2.5kN/mm². The boards produced were removed from the mold and allowed to cool at room temperature in a desiccator containing anhydrous calcium chloride for a 24hrs.

Table 1: Randomized Composition for particleboard samples

Sample	Groundnut Shell Particle Size (μ m)	% by Weight Groundnut Shell Particle	% by Weight Resin
A	500	80	20
B	500	70	30
C	500	60	40
D	1000	40	60
E	1000	80	20
F	1000	70	30
G	1500	70	30
H	1500	80	20
I	1500	60	40

III. Tests

3.1 Density

Density of each sample was determined in accordance with ASTM D-1037. Each test piece conditioned, weighed using calibrated weighing machine, length, width and thickness were measured using a digital Vernier caliper and recorded as W, l, b and t respectively. The volume for each sample was determined and recorded.

$$\rho = \frac{W}{\text{Volume}} \quad (1)$$

Where ρ is density (kg/m³), Volume = air dried volume lbt (m³), W = air dried weight (kg)

3.2 Tensile Strength Test

This test was carried out in accordance with International Standard method of determining tensile strength ASTM D-1037. Twenty seven (27) samples were produced for the test with each test replicated twice. Each board sample

size was 250 mm long, 50 mm wide and 10mm thick . The test pieces were ensured to have clean and uniform cut edges. Samples with dents, uneven cut and any other deformity were discarded. The test pieces were conditioned. Immediately on removal from the desiccator, the thickness of each piece was measured with a Vernier caliper in about four places within 50 mm on both sides of the center. The smallest dimension was taken as the thickness. After measurement each test piece was gripped between the jaws of a universal tensile testing machine, the distance between the jaws being not less than 100 mm. Load was applied, stretching the test sample until it fails. The maximum load at failure was recorded as the breaking load. The rate of transverse of the moving jaw was 3 ± 1 mm per minute. In cases where the test piece breaks at the jaws, the reading was not taken into consideration [22].

$$\text{The tensile strength} = \frac{\text{Breaking load}}{\text{Crossectional Area of test piece}} \quad (2)$$



Plate VIII: Samples used for tensile strength test



Plate IV: Load application for Tensile Strength Test

3.3 Flexural strength test

This test was carried out at the Material Science Laboratory, Bayero University Kano using a Universal Testing Machine in accordance with ASTM-D1037-23. The size of each test piece was 250mm length, 75mm width. Thickness (d) of each sample was measured (10mm) and recorded. Each particleboard sample was placed on the two supports ensuring the load nose was aligned with the center of the sample. The three-point bending fixture was selected and samples were stretched at a speed of 50mm/min until failure occurs. Readings were obtained from the plots generated by the universal testing machine and was used to determine the modulus of rupture (MOR) and the modulus of elasticity (MOE) of the particleboards fabricated. Each sample test was replicated thrice and an average taken.

$$\text{MOR} = \frac{3Pl}{2bd^3} \quad (3)$$

$$\text{MOE} = \frac{PL^3}{4\delta bd^2} \quad (4)$$

Where P is rupture or breaking load (N), l, b and d are length, width and thickness of sample respectively in (m) and δ is the deflection.

3.4 Water absorption (WA) and Thickness swelling (TS) Tests

This test was carried out to determine the dimensional stability of the fabricated particleboards through WA and TS analyses. The tests were carried out in accordance with ASTM D-1037. The test pieces were cleanly cut to size 50 mm x 50 mm and conditioned. Each test piece was weighed in air to the nearest milligram (W_0) and its thickness (T_0) determined and recorded as well. The nine (27) test pieces were immersed in distilled water at room temperature for 24hrs. The weight (W) and thickness (T) were measured at intervals of 2, 4, 6, 8, 12, 15, 18, 20 and 24hrs of immersion time [18]. The WA and TS were calculated by equations 5 and 6 respectively.

$$\text{WA} (0/0) = \frac{W-W_0}{W} \times 100 \quad (5)$$

$$\text{TS} (0/0) = \frac{T-T_0}{T} \quad (6)$$

Where W_0 and T_0 are the initial weight and thickness of the samples respectively. W and T are weight and thickness of samples at time intervals of immersion respectively.

IV. Results and discussion

4.1 Density test.

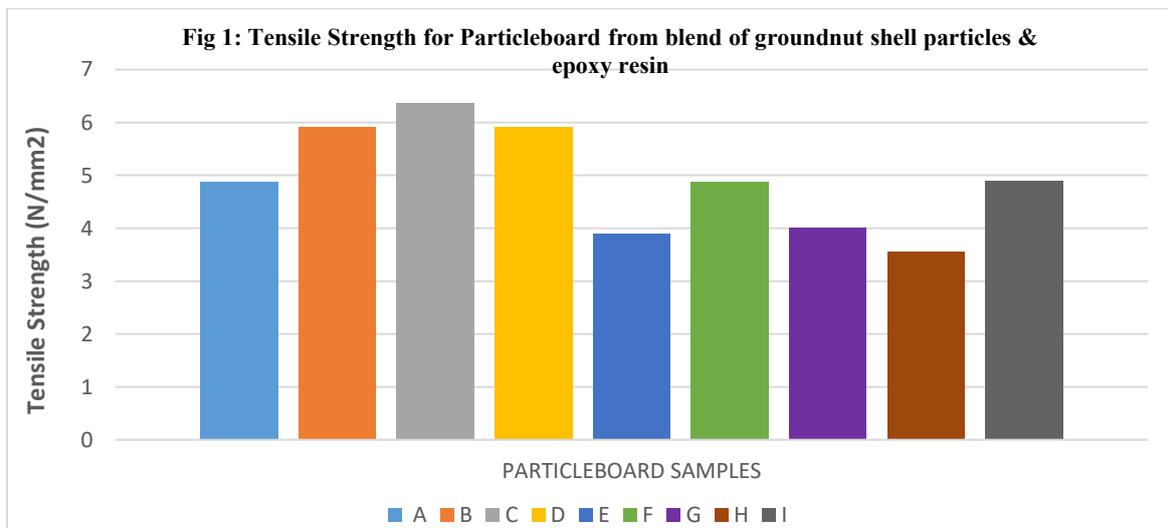
Table 2 shows the average density of the fabricated particleboards samples. Samples A, B, C shows higher average densities with sample C having the highest density of 789.12kg/m³. Samples E, G, H showed lower average densities with sample H having the lowest density of 429.38kg/m³ which may be due to increase in void content and poor particle packing due to increase in particles size. Results indicated that densities of fabricated particleboards increases with increase in loading level of the binder. It also decreases with increase in size of groundnut shell particles, which indicates the significant effect of both particle size and binder loading levels on the particle boards fabricated. Comparing the density results obtained with international standard IS3087, all boards produced with the exception of samples E and H met this requirement. Results obtained from this work is also in agreement with the range of values obtained from the works of [1], [2], [18] and [20].

Table 2 shows randomized results from density tests.

Sample	Groundnut Shell Particle Size (µm)	% by Weight		Density (kg/m ³)	Density (kg/m ³)		
		Groundnut particles	Shell		Max	Min	Average
A	500	80	20	635.00	589.94	612.47	
B	500	70	30	675.35	643.41	660.88	
C	500	60	40	795.97	782.27	789.12	
D	1000	40	60	712.83	655.39	684.11	
E	1000	80	20	501.64	463.44	482.54	
F	1000	70	30	585.14	492.12	538.63	
G	1500	70	30	521.31	477.75	499.53	
H	1500	80	20	402.86	455.9	429.38	
I	1500	60	40	539.05	483.87	511.46	

4.2 Tensile Strength

Figure 1 shows the tensile strength of each particleboard sample. The maximum tensile strength values ranges between 3.56 N/mm² and 6.36 N/mm² representing board samples C and H. The finer the particle sizes, the better the tensile strength as less voids are left during bonding with the binder; hence denser packing. Particleboard samples with larger particles sizes have lower tensile stress that may be due to weaker bonding due to voids created by air spaces in the material and the likely stress concentration at particle points on the board samples. Tensile strength values from particleboard samples also indicated the effect of adhesive treatment level on the tensile strength. Higher adhesive level resulted in increase in tensile strength due to greater homogeneous internal bonding of the board samples.



4.3 Flexural Strength: MOR and MOE

Figure 3 and Figure 4 shows results from the flexural strength of the fabricated particleboards indicating the static bending properties of the boards. From figure 3, the maximum modulus of rupture of the fabricated particleboards ranges between 8.484 MPa to 14.616 MPa representing samples I and B respectively. Sample test results also indicated the effect of particle size and that of adhesive treatment level on the modulus of rupture of the fabricated particleboards. Results indicated an increase in modulus of rupture with increase in binder loading

level, however at binder level above 30%; sample results indicated a decrease in modulus of rupture. According to the European Standard EN 312, the minimum static bending requirement for general purpose boards is 11.5 N/mm² (11.5MPa), hence from the results obtained; samples A,B,C,E, F and G were closely within standard values, while samples H, J and I failed to meet the required minimum MOR standard. Sample A, B, C, E and F with greater MOR values satisfy recommendation for general-purpose applications.

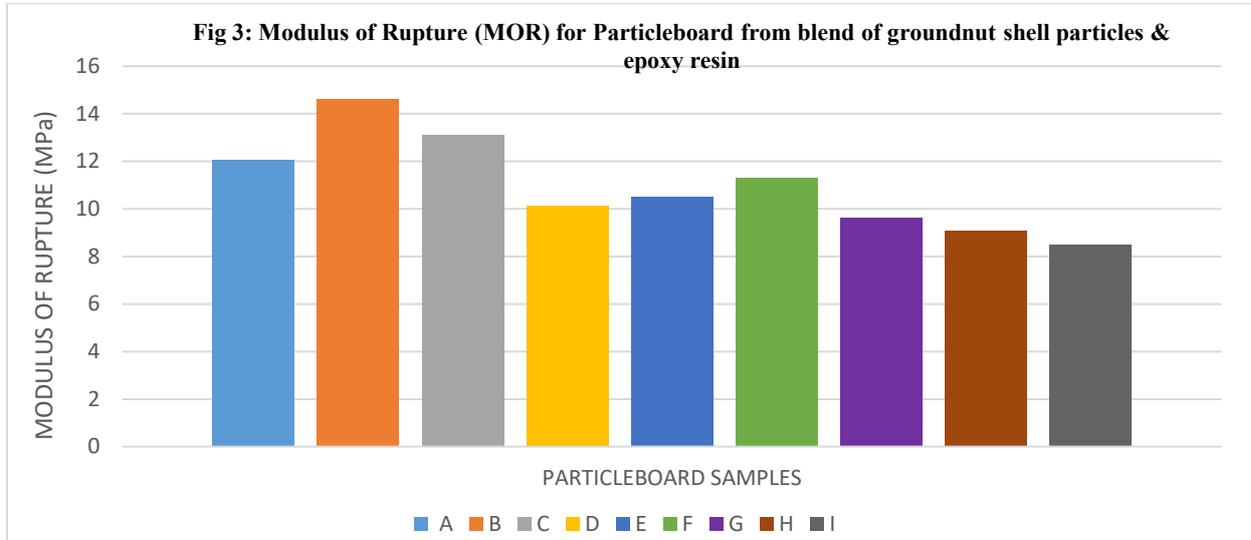


Figure 4 highlights the results for the Modulus of the elasticity (MOE) of the fabricated particleboard. It ranges between 813MPa to 2511MPa representing board samples I and B respectively. Results also indicated the significant effect of particle size on the value of MOE and the effect of binder level as well for the fabricated particleboard samples. Values of the MOE decreases with increase in particle size up to 1000µm. However, beyond 1000µm and at a binder level above 30%, the MOE values starts to decreases significantly. This may be due to reduced inter-particle contact area, poor resin distribution and increased void content; leading to inefficient stress transfer within the particleboard structure.

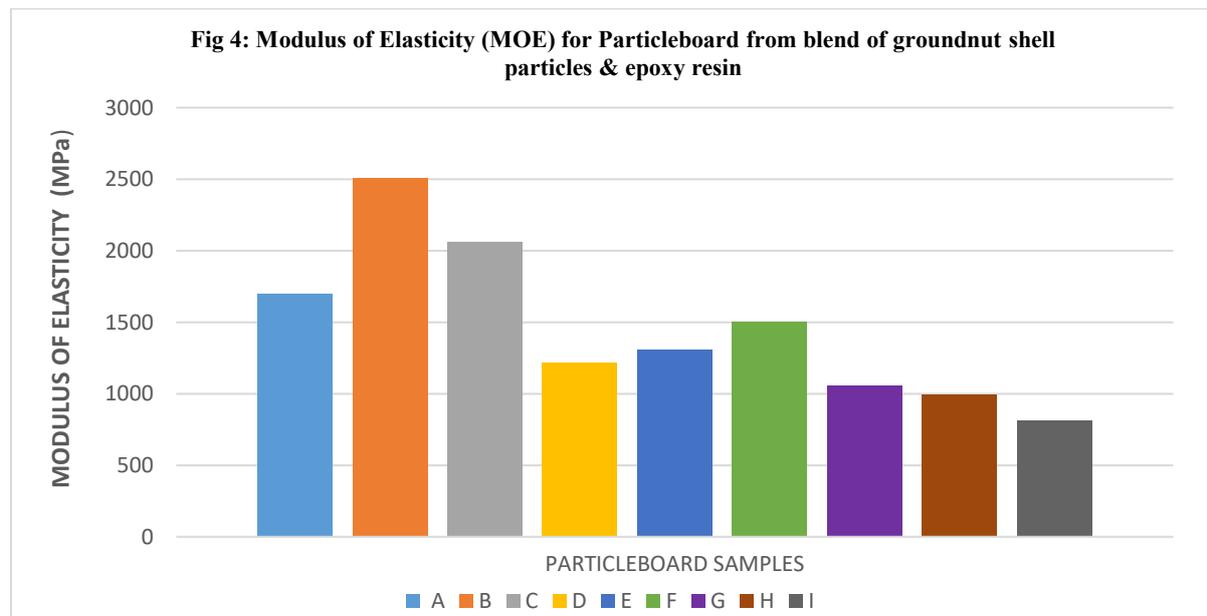


Table 3: Results from randomized flexural test

Samples	Max. Load (N)	Max. Deflection (mm)	Modulus of Elasticity (MPa)	Modulus of Rupture (MPa)
A	130.68	3.993	1696	12.063
B	259.11	4.280	2511	14.616
C	161.35	4.071	2065	13.135

D	121.83	4.682	1221	10.147
E	128.49	5.115	1309	10.542
F	143.91	4.963	1504	11.323
G	118.69	5.791	1056	9.615
H	114.07	5.953	995	9.107
I	95.50	6.116	813	8.484

4.5 Water absorption and Thickness Swelling.

Water absorption and thickness swelling tests indicated the dimensional stability of the fabricated particleboard samples. Fig. 5 shows the water absorption rate of each particleboard sample. The result shows increase in water absorption rate of the board samples with time. The increase was high during the first two (2) hours of immersion in water for all samples. Water absorption rate increases with increase in particle size of the boards as well as decrease in resin level for same board particle size. Sample C has the least water absorption rate while sample H has the highest absorption rate, which indicates the influence of particle size and binder loading level. The WA rate of particleboards with the same particle size increases with decrease in adhesive treatment level.

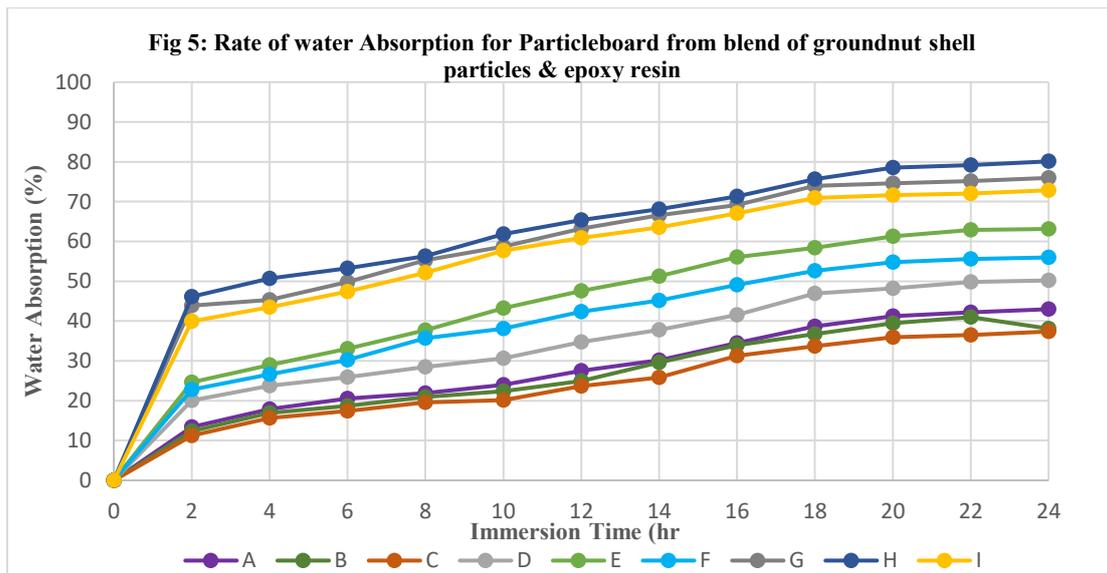
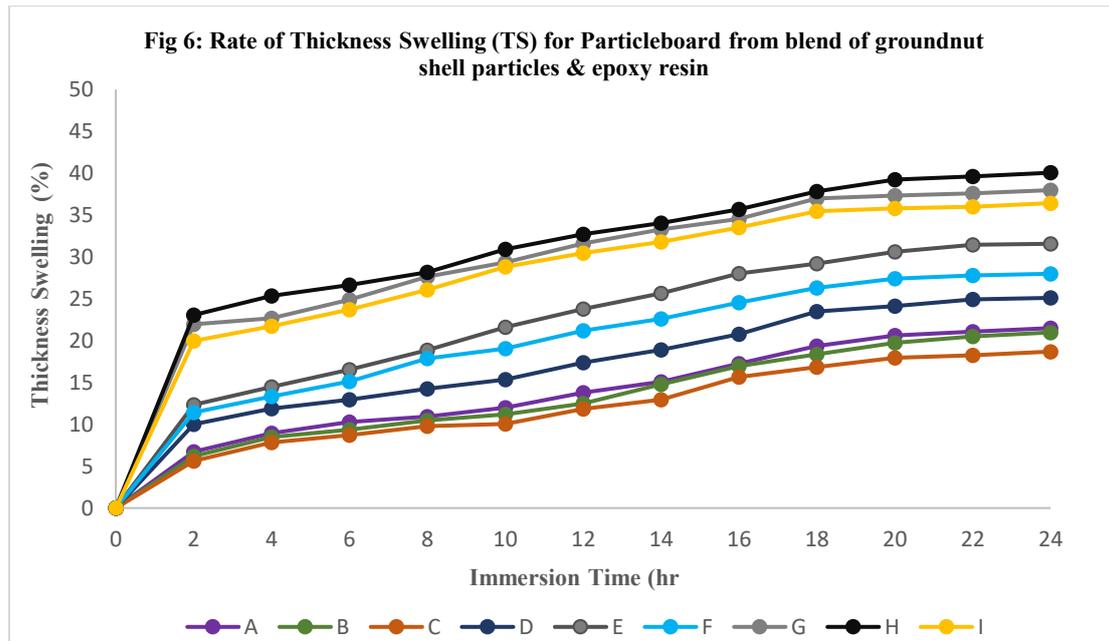


Figure 6 shows the thickness absorption rate of the particleboard samples. Particleboard sample C has the least thickness-swelling rate, while board sample has the highest thickness swelling. As observed from WA values of the fabricated particleboard samples, the TS rate increases with increase in particle size. The TS rate of particleboards with the same particle size increases with decrease in adhesive treatment level as well.



V. Conclusion

In this study, the characteristics of the fabricated epoxy resin-bonded Groundnut shell particleboards in three adhesive treatment levels (20%, 30% and 40%) and three groundnut shell particle sizes (500 μm , 1500 μm , and 1500 μm) were investigated. Their density, flexural strength, tensile strength, water absorption (WA), and thickness swelling (TS) were evaluated. The Density, MOE, MOR and Tensile strength values increased with the smaller groundnut shell particle size and higher epoxy resin treatment level. In addition, the WA value decreased with the reduced Groundnut shell particle size and increased epoxy resin adhesive treatment level. Similarly, the TS value decreased with the smaller *Rhizophora* spp. particle size. The TS value, however, increased with the higher epoxy adhesive treatment level for all groundnut shell particle sizes and decrease in adhesive treatment levels, which showed the hydrophilic property of the epoxy resin adhesive. The board samples passed the EN standards for flexural strength, tensile strength and density and dimensional stability, hence this indicates the potential developing particleboard from groundnut shell composite especially for loading bearing and general-purpose applications.

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