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OPTIMIZATION OF THE MIXING RATIO FOR PARTICLEBOARD PRODUCTION FROM GROUNDNUT SHELL AND RICE HUSK

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The aim of this work is to optimize the mixing ratio for production of particleboard (PB) from groundnut shell and rice husk. This research is focused on optimization approach for turning the agricultural waste into quality value-added composite PB for sustainable development. Box-Behnken design was used to optimize the effect of three process variables: groundnut husk (0–100 g); rice husk (0–100 g) and resin (1.5–2.5 g). The best process levels for PB production predicted by the software were validated. The PB samples produced were analysed using scanning electron microscope. The best results were obtained at levels: groundnut husk – 50 g; rice husk –100 g; resin – 3.50 g with rupture modulus of 3.50 N·mm^{-2} and elasticity modulus of 932.4 N·mm^{-2}, the predicted optimal levels of 65.99 g; 86.34 g and 1.69 g were validated. The validation results gave rupture modulus of 3.49 N·mm^{-2}, and elasticity modulus of 932.10 N·mm^{-2}. It can be concluded that PB produced at the optimized conditions satisfied the American National Standard ANSI/A208.1-999 specification for general purpose particleboards for sustainable development.

Keywords: Box-Behnken design; ANOVA; regression; elasticity modulus; rupture modulus

The reserves of indigenous plant species have declined due to the rise in wood consumption, leading to a search for new lignocellulosic products that can successfully meet the demand. The 95% of lignocellulosic components used in PB manufacturing is wood. Abdulkareem and Adeniyi (2017) noted that the wood alternatives, such as agricultural residues and non-wood crops, have started to play an essential role in this field (Idris et al., 2011; Ezenwa et al., 2019). Prominent agricultural residues include cereal straw; bagasse sugar cane; cornstalks and cobs; stalks of cotton; seeds of sunflower (Fiorelli et al., 2016); rice husk (Madu et al., 2018; Akinyemi et al., 2020); rice straw (Matías et al., 2019); cassava peels (Villamizar et al., 2012); coir pith (Ahmed et al., 2016); red iron wood (Akinyemi et al., 2019a); sawdust (Akinyemi et al., 2019b; Atuanya et al., 2016); and palm kernel shells (Akinyemi et al., 2016). PB is widely used for flooring, wall bracing, ceiling, furniture, partitioning and cladding purposes (Olorunmaiye and Ohijeagbon, 2015; Chibudike et al., 2011). However, the panel/board industry has encountered continuous growth in developing countries, such as Nigeria, over the previous few years and the demand for panels/boards rapidly increased, what placed a lot of pressure on forest resources, resulting in deforestation and its corresponding negative effects on the environment, as well as increased timber prices (Sotannde et al., 2012). For this very reason, major focus has been put on the development of composite materials from agricultural waste as an alternative particleboard to timber-based products. The composite materials are held together by synthetic resins and other additives, which may be added to enhance the final composite material properties. Several resin types are widely used, the cheapest is urea formaldehyde and phenol formaldehyde resins (Akindapo et al., 2015).

One of the major causes of environmental pollution is the rapid depletion of forest raw resources. Furthermore, to reduce forest exploitation, it is vital to explore alternative sources of raw materials. It is thus crucial to explore the suitability of agricultural residues for PB production, since it would be more eco-friendly and promote the waste to prosperity concept in construction sector. This would protect the environment and promote eco-friendly techniques (Bektas et al., 2015). Numerous authors have dealt with the issue of PB production from agricultural wastes: Mendes et al. (2009) investigated coffee husks and hull fibres; Sarkar et al. (2012) and Madu et al. (2018) observed rice husk and saw-dust; Suleiman et al. (2013) researched the rice husk PBs reinforced with Gum Arabic and formaldehyde; Amenaghawon et al. (2016) studied corn cobs and cassava leaves. However, there is a scarcity of information on the impacts of control variables, such as the amounts of agro-residue composites and urea formaldehyde resin, on the mechanical PB properties (Amenaghawon et al., 2016). The research presented hence investigates the use of groundnut shell and rice husk as a composite material for PB production using optimization approach.

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Material and methods

The materials used included groundnut shell; rice husk (collected from Landmark University, Commercial farm); and binder (urea formaldehyde).

Experimental design

The experimental design was conducted by means of Box-Behnken design in the 6.0.8 Design Expert software in order to determine the interaction effect of three variables (groundnut shell content, rice husk content and urea formaldehyde content). The range and levels of independent variables are shown in Table 1. The matrix for the three variables was varied at 3 levels (-1, 0 and +1) as shown in Table 2. The Box-Behnken design has been established to be suitable for the quadratic response surfaces and this design generated a second-degree polynomial model (Amenaghawon et al., 2014), in which Y_i is a dependent variable or predicted response; X_i and X_j are independent variables; b_0 is an offset term; b_i and b_{ij} are the single and interaction effect coefficients; and e_i is the error term. The Design Expert software was used for the regression and graphical analysis of experimental data. The responses analysed were elasticity modulus (*MOE*) and rupture modulus (*MOR*). Design Matrix for the PB production from groundnut shell and rice husk is shown in Table 2.

Production of particleboards

Waste materials were cleaned, washed, air dried to reduce its moisture content and milled to reduce the particle size. The groundnut shell and rice husk were separated using standard sieve sizes into two different group sizes (0.85 mm and 1.7 mm). PB after moulding is shown in Figs. 1 and 2.

Digital weighing balance was used for weighing of variables via the interactions generated by the experimental design. Subsequently, materials were thoroughly mixed with binder in a mixing bowl. Polythene nylon was used to cover the resulting homogeneous mixture. Cold and hot compression was performed on the boards using a hydraulic press and pressing was retained for 24 h prior to release of the compacting pressure. The boards were dried at temperature of approx. 80 °C. PBs were then subjected to mechanical and physical tests.

Table 1 Coded and actual levels of the variables

Independent variables		**Coded and actual levels**		
	symbols	**-1**	**0**	**+1**
Amount of groundnut shell (g)	X_1	0	50	100
Amount of rice husk (g)	X_2	0	50	100
Resin loading (g)	X_3	1.5	2.0	2.5

Table 2 Design matrix for the PB production from groundnut shell and rice husk

Std	**Run**	**Coded variables**			**Groundnut actual**	**Rice husk**	**Resin loading**
		X_1	X_2	X_3	X_1	X_2	X_3
16	1	1	-1	0	100	0	2.0
7	2	0	1	-1	50	100	1.5
9	3	0	0	0	50	50	2.0
12	4	0	1	1	50	100	2.5
4	5	0	-1	-1	50	0	1.5
11	6	1	0	1	100	50	2.5
8	7	-1	0	-1	0	50	1.5
14	8	-1	0	1	0	50	2.5
5	9	-1	-1	0	0	0	2.0
17	10	1	0	-1	100	50	1.5
10	11	0	0	0	50	50	2.0
1	12	0	0	0	50	50	2.0
15	13	0	-1	1	50	0	2.5
13	14	0	0	0	50	50	2.0
6	15	1	1	0	100	100	2.0
3	16	-1	1	0	0	100	2.0
2	17	0	0	0	50	50	2.0

Fig. 1 Particleboards after moulding

Particleboard testing

Laboratory test

The elasticity modulus (*MOE*) and rupture modulus (*MOR*) of samples showed a rate of 10 mm·min^{-1} when observed by universal testing machine Testometric M500-50AT. The experiments were performed at ambient room temperature (25 ±1 °C), with each sample at a slack of 80 mm-·min^{-1} depending on the varying PB density and width. The *MOE* and *MOR* were calculated as follows:

$$MOR = \frac{3PL}{2bh^2} \quad \left(\mathrm{N \cdot mm^{-2}}\right) \tag{1}$$

$$MOR = \frac{PL^3}{4bh^3Y} \quad \left(\mathrm{N \cdot mm^{-2}}\right) \tag{2}$$

where:
P – maximum load or maximum force
L – span
b – width
h – height
Y – deflect

Thermal conductivity test was performed using hot-disk transient plane source, and SEM analysis was performed using a JEOL model machine.

Results and discussion

Statistical analysis

Box-Behnken designs for responses obtained for *MOR* and *MOE* are shown in Table 3. The Eqs. 3 and 4 are models obtained from the response via the regression analysis in terms of coded terms:

Fig. 2 Particleboards during flexural strength test

$$MOR = 3.01 + 0.50X_1 + 1.01X_2 + 1.85X_3 + 0.036X_1X_2 - \\ - 0.18X_1X_3 - 0.24X_2X_3 + 0.33X_1^2 - 0.16X_2^2 - 1.24X_2^3 \quad (\mathrm{N \cdot mm^{-2}}) \tag{3}$$

$$MOE = 891.5 - 3.93X_1 + 123.29X_2 + 9.06X_3 - \\ - 2.19X_1X_2 + 1.19X_1X_3 - 132.33X_2X_3 - 16.84X_1^2 - \\ - 68.31X_2^2 - 67.23X_2^3 \quad (\mathrm{N \cdot mm^{-2}}) \tag{4}$$

Furthermore, Table 4 shows the ANOVA for *MOR* and Table 5 shows ANOVA for *MOE*.

Tables 4 and 5 revealed that the models for *MOR* and *MOE* were statistically significant with p values of 0.0004 and 0.0057, respectively. However, the models showed that the terms representing the amounts of groundnut shell, rice husk and resin loading were significant by indicating that all variables influenced the *MOR* and *MOE* of the boards produced. The F values of 19.67 for *MOR* and 8.13 for *MOE* showed that the models generated were significant. Statistical information for ANOVA showed that models describing the *MOR* and *MOE* have high coefficient of determination (R^2) as shown in Table 6. Moreover, Table 6 indicates that the models were able to adequately represent the relationship between the selected factors (content of variables) and responses (*MOR* and *MOE*); R^2 of 0.96 and 0.91 for the *MOR* and *MOE*, respectively, suggests that the models were able to explain 96% and 91% of the variability observed in the *MOR* and *MOE* values, respectively. The results observed showed a high reliability as recommended by Montgomery (2005). The adequate precision for both models indicate that these models can be used to navigate the design space (Cao et al., 2009).

Results of 3D surface plots

The impacts of resin loading and groundnut shell content on the *MOR* of PBs are given in Fig. 3. Observed trends showed that the *MOR* increased concurrently with enhanced quantities of resin and groundnut shell. This complies with observation of other researchers – Murakami et al. (1999) reported that the mechanical and physical properties of PBs can be increased. The amount of vacuum present in boards was assessed by the resin loading as reported by Sekaluvu et al. (2014). Optimal volumes of groundnut shell and rice husk were used to produce the boards with high *MOR* values, suggesting that the mechanical properties can be improved by application of higher resin contents. Made of a hygroscopic material, the board will tend to absorb the moisture when placed in a humid environment. The moisture content of tested board is 3%. The boards produced are not

Table 3 Box-Behnken design for response (*MOR* and *MOE*)

Run	Factors						Response			
	coded values			actual values			*MOR* ($N \cdot mm^2$)		*MOE* ($N \cdot mm^2$)	
	X_1	X_2	X_3	X_1	X_2	X_3	actual	predicted	actual	predicted
1	1	-1	0	100	0	2.0	2.28	2.25	576.5	599.0
2	0	1	-1	50	100	1.5	3.50	3.69	932.4	946.0
3	0	0	0	50	50	2.0	2.45	3.19	732.4	822.3
4	0	1	1	50	100	2.5	2.14	2.10	360.8	429.5
5	0	-1	-1	50	0	1.5	0.43	0.47	492.5	423.8
6	1	0	1	100	50	2.5	1.74	1.96	680.2	671.3
7	-1	0	-1	0	50	1.5	2.99	2.77	764.7	773.6
8	-1	0	1	0	50	2.5	2.36	2.38	678.0	631.8
9	-1	-1	0	0	0	2.0	2.13	2.31	494.2	554.0
10	1	0	-1	100	50	1.5	3.38	3.86	760.1	806.3
11	0	0	0	50	50	2.0	3.38	3.19	845.0	822.3
12	0	0	0	50	50	2.0	3.38	3.19	844.3	822.3
13	0	-1	1	50	0	2.5	0.47	0.27	677.1	663.5
14	0	0	0	50	50	2.0	3.38	3.19	845.0	822.3
15	1	1	0	100	100	2.0	5.10	4.92	794.0	734.2
16	-1	1	0	0	100	2.0	4.66	4.69	729.6	707.1
17	0	0	0	50	50	2.0	3.38	3.19	845.0	822.3

Table 4 ANOVA results for model representing *MOR*

Sources	Sum of squares	*Df*	Mean squares	*F*-value	*P*-value
Model	23.65	9	2.63	19.67	0.0004
X_1	1.07	1	1.07	8.00	0.0255
X_2	4.31	1	4.31	32.26	0.0008
X_3	3.07	1	3.07	22.98	0.0020
X_1X_2	0.021	1	0.021	0.16	0.7034
X_1X_3	0.26	1	0.26	1.91	0.2096
X_2X_3	0.49	1	0.49	3.67	0.0970
X_1^2	1.86	1	1.86	13.96	0.0073
X_2^2	0.42	1	0.42	3.17	0.1184
X_3^2	6.50	1	6.50	48.61	0.0002
Residual	0.94	7	0.13	–	–
Lack of fit	0.24	3	0.081	0.47	0.7200
Pure error	0.69	4	0.17	–	–
Cor total	24.59	16	–	–	–

Table 5 ANOVA results for model representing *MOE*

Sources	Sum of squares	*Df*	Mean squares	*F*-value	*P*-value
Model	3.397	9	37,745.94	8.13	0.0057
X_1	65.38	1	65.38	0.014	0.9089
X_2	64,224.00	1	64,224.00	13.83	0.0075
X_3	73.29	1	73.29	0.016	0.9036
X_1X_2	80.10	1	80.10	0.017	0.8992
X_1X_3	11.56	1	11.56	2.189E-003	0.9616
X_2X_3	1.430E + 005	1	1.430E + 005	30.77	0.0009
X_1^2	4,970.26	1	4,970.26	1.07	0.3354
X_2^2	81,829.27	1	81,829.27	17.62	0.0041
X_3^2	19,032.46	1	19,032.46	4.10	0.0826
Residual	32,517.55	7	4,645.36	–	–
Lack of fit	22,405.68	3	7,468.56	2.95	0.1613
Pure error	10,111.87	4	2,527.97	–	–
Cor total	3.722E + 005	16	–	–	–

Table 6 Statistical information for ANOVA

Parameter	Value	
	MOR	*MOE*
R-squared	0.96	0.91
Mean	2.77	708.93
Standard deviation	0.37	68.16
C.V %	13.18	9.61
Adeq. precision	16.57	9.99

suitable for environments with higher relative humidity; however, these can be used as insulation boards. Fig. 4 shows the importance of resin loading and rice husk volume on the *MOR*. On the contrary, Fig. 5 shows that there was an increase in *MOE* with usage of small contents of rice husk. The resin loading did not influence the *MOR* of boards significantly. However, Fig. 6 shows the effects of the rice husk and groundnut shell contents on the *MOE*. Fig. 7 shows the impacts of resin loading and groundnut shell content on the *MOE*; Fig. 8 shows the effect of resin loading and rice husk content on the *MOE*. Furthermore, there is a correlation of the obtained results with observations made by Sekaluvu et al. (2014), who reported that high-quality bond can result from good contact between resin and agro-residue particles in PBs with *MOE* values. This is because the increased resin loads improve the bond contact between particles, leading

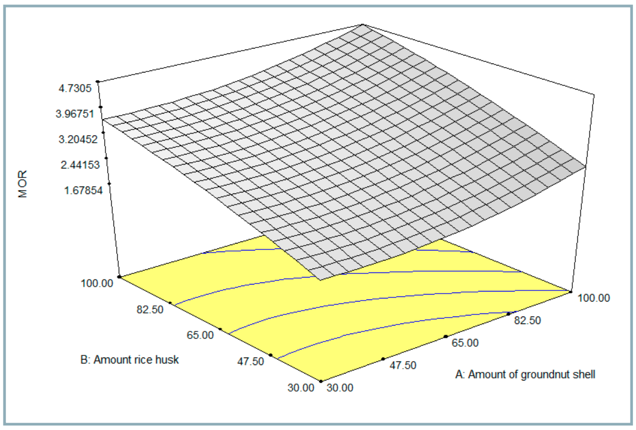

Fig. 3 Effects of rice husk and groundnut shell contents on *MOR*

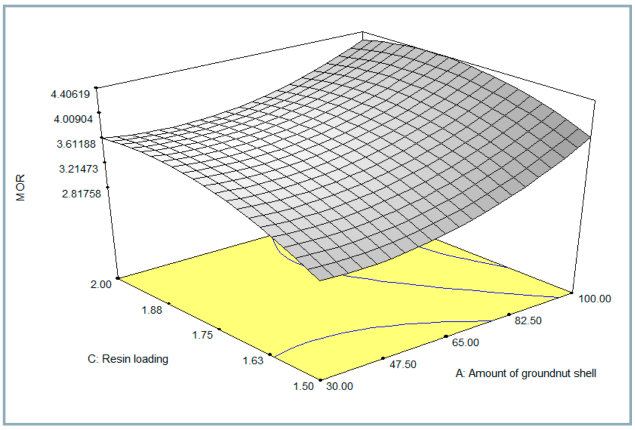

Fig. 4 Effects of resin loading and groundnut shell content on *MOR*

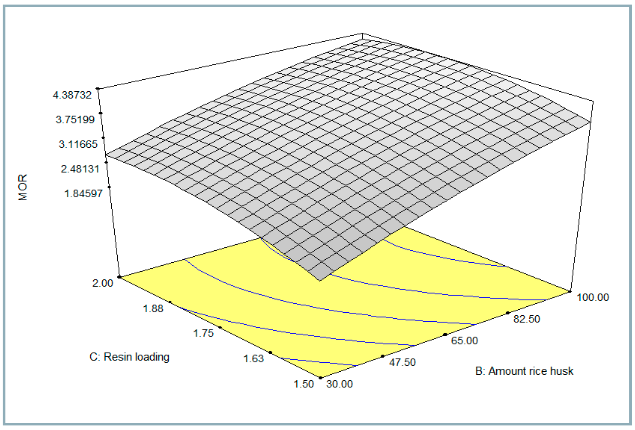

Fig. 5 Effects of resin loading and rice husk content on *MOR*

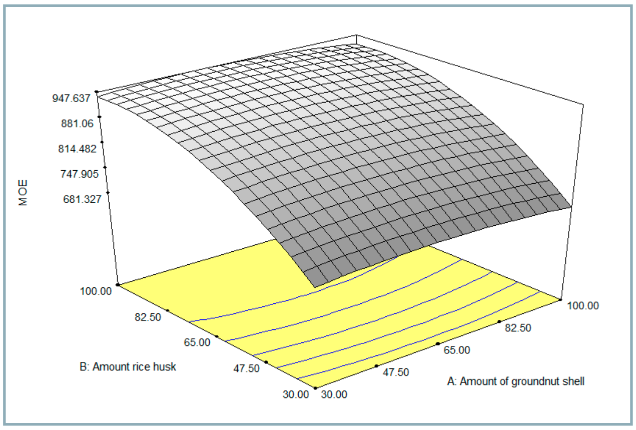

Fig. 7 Effect of resin loading and amount of groundnut shell on *MOE*

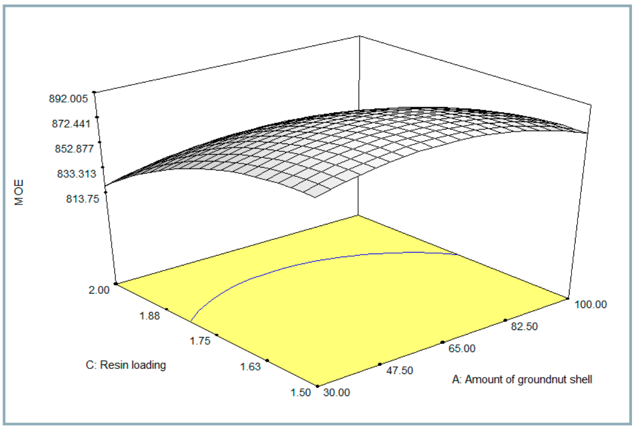

Fig. 6 Effect of amount of rice husk and amount of groundnut shell on *MOE*

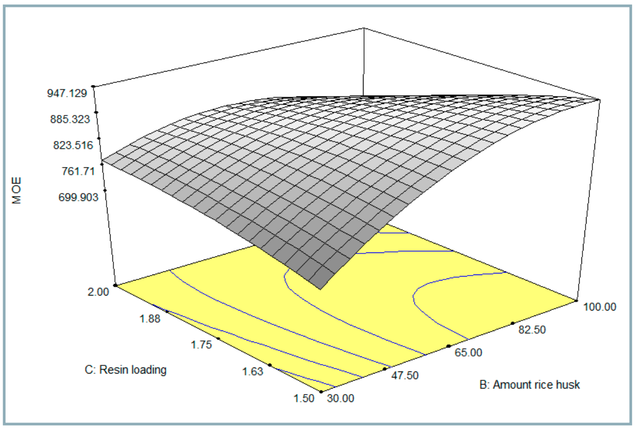

Fig. 8 Effect of resin loading and amount of rice husk on *MOE*

to enhanced surface contact (Babatunde and Olufemi, 2011). Since both *MOR* and *MOE* are mechanical features, it is expected that the trend observed for both is related. The requirements for PBs made of agro-residues include high values of *MOR* and *MOE*. Derkyi et al. (2008) reported that resin with higher viscosity improved the board bonding strength.

Validation of optimal predicted levels

The optimal level variables predicted by the software are shown in Table 7, demonstrating a strong correlation between experimental and predicted results. The results indicate that the maximum *MOR* and *MOE* values of 3.50 N·mm^{-2} and 932.40 N·mm^{-2}, respectively, were close to those of 3.49 N·mm^{-2} and 932.10 N·mm^{-2}.

Results of surface characterization of PBs via SEM

The optimal and validated particleboards were subjected to SEM and the results observed indicate that the surface of boards showed fibrous network structures, which were covered and bonded by the resin. The boards with higher resin loading showed lower voids, because the resin cured more effectively in the void spaces (Fig. 9). The lower density board (Fig. 10) had higher voids and spaces, which led to high moisture absorptivity. The board density is found to increase with increasing resin loading.

Table 7 Validated optimal variables

Solution	Amount of groundnut shell	Amount of rice husk	Resin loading	*MOR*	*MOE*	Desirability
1	65.99	86.34	1.69	3.49	932.10	1.000

Table 8 Thermal conductivity results

Room temperature 25 ±1 °C	Thermal conductivity (W·mK^{-1})
G3 (optimal)	0.172
G6 (validated)	0.178

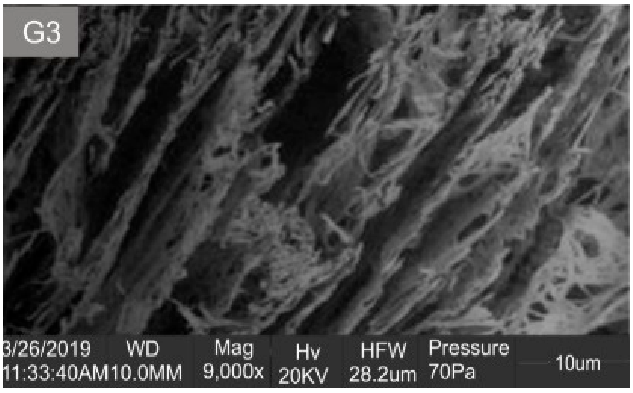

Fig. 9 Optimal particleboard

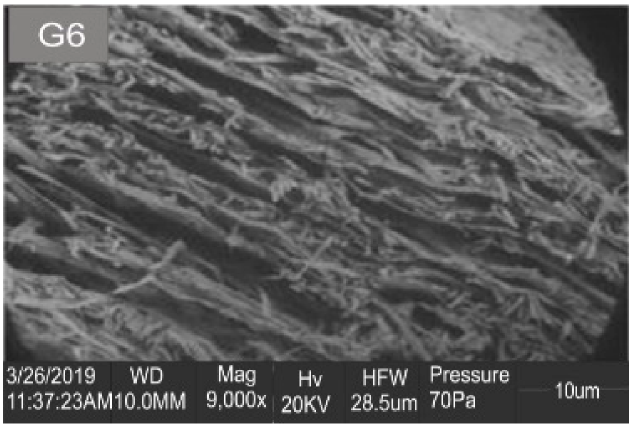

Fig. 10 Validated particleboard

Thermal properties analysis

Thermal conductivity results are given in Table 8. These suggest that the PBs do not conduct electricity, what makes them usable as material for switch boards in electrical circuits. The thermal conductivity tests were conducted in accordance with the American Society for Testing Materials (ASTM C177-97).

Conclusion

Design of experiment for response surface methodology has been demonstrated to be useful in optimizing the board production process. Mechanical properties of boards, such as *MOR* and *MOE*, were influenced by the amount of agro-residues and resin used. The quadratic statistical models developed to represent *MOR* and *MOE* showed a good fit with the experimental data with R^2 values of 0.96 and 0.91, respectively. The predicted optimum conditions (65.99 g for groundnut shell; 86.34 g for rice husk; and 1.69 g for resin loading) were validated to show a *MOR* and *MOE* of 3.50 N·mm^{-2} and 932.40 N·mm^{-2}, respectively. The particleboards produced at the optimized conditions satisfied the American National Standard ANSI/A208.1-1999 specification for general purpose particleboards. This study dealt with particleboards produced from groundnut shell and rice husk using urea formaldehyde as binder. Based on the results, it can be concluded that optimization of the amounts of agricultural waste products and resin was successful in terms of the production of particleboards, which are environmentally friendly and easy to manufacture.

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