Acta Tecnología - International Scientific Journal about Technologies
Volume: 6 2020 Issue: 3 Pages: 59-67 ISSN 2453-675X

doi:10.22306/atec.v6i3.78 *Received: 26 Apr. 2020; Revised: 11 June 2020; Accepted: 19 Sep. 2020*

OPTIMIZATION AND MATERIAL CHARACTERIZATION OF GROUNDNUT SHELL AND RICE HUSK FOR PRODUCTION OF PARTICLEBOARD

Olawale Olamide
Chemical Engineering Department, Landmark University, Km 4 Ipetu, Omu-Aran Road, PMB 1001, Ipetu Road, Omu-Aran, Kwara State, Nigeria, olawale.olamide@lmu.edu.ng (corresponding author)
Akinyemi Banjo
Agriculture and Biosystems Engineering, Landmark University, Km 4 Ipetu, Omu-Aran Road, PMB 1001, Ipetu Road, Omu-Aran, Kwara State, Nigeria, akinyemi.banjo@lmu.edu.ng
Attabo Favourite Omojo
Chemical Engineering Department, Landmark University, Km 4 Ipetu, Omu-Aran Road, PMB 1001, Ipetu Road, Omu-Aran, Kwara State, Nigeria, attabo.favouriteomojo@lmu.edu.ng

Keywords: particle board, urea formaldehyde, groundnut shell, rice husk, optimization
Abstract: The aim of this work is to the produce particle board (PB) from groundnut shell and rice husk using optimization approach. This research is tailored towards the quest for economical and eco-friendly materials by converting a waste into wealth. Box Behnken Design was used to optimize the effect of three variables: Groundnut husk (0-100g); Rice husk (0-100g) and resin (1.5-2.5g) respectively. The optimal process levels predicted by the software for the PB were validated. The PB produced was analysed using Scanning Electron Microscope. The best levels from the interactions of the variables were: groundnut husk:50g; rice husk:100g and resin:3.50 with MOR of 3.50 N/mm^2 and MOE of 932.4 N/mm^2 while the predicted optimal levels of 65.99g; 86.34g and 1.69 was validated .The result of the Validation gave MOR of 3.49 N/mm^2 and MOE of 932.10 N/mm^2 . It can be concluded that particle board produced at the optimized conditions satisfied the American National Standard ANSI/A208.1-999 specification for general purpose particle boards.

1 Introduction

The demand for wood in the forest industry has escalated, but the production of industrial wood from the natural forest continues to deteriorate, and increasing concerns for waste minimization have however led to account of the use of agricultural waste in the manufacturing of some construction products. Due to the increase in wood consumption, the reserves of indigenous species of plants have been declining, resulting in a quest for fresh lignocellulose products that can fulfil the requirement effectively. Any lignocellulose material can be used as a raw material for the manufacture of particleboards. Besides wood, agricultural residues such as: cereal straw, sugar cane bagasse, cornstalks and corn cobs, cotton stalks, rice husks, sunflower stalks and hulls among others can be used [1]. A particle board is an engineering wood product produced under pressure using wood chips, sawmill shavings or even sawdust (fibreboard products) with an adhesive binder [2]. However, in developing nations such as Nigeria, the panel / board sector has witnessed constant development in past few years and has recently estimated demand for wood and wood produced panels / boards to be 4.704 and 0.688 million m^3 respectively. This has put a lot of pressure on forest assets leading to deforestation and its associated negative environmental effects as well as higher timber prices [3]. It was reported that the worldwide demand of particleboard panels was 56.2 Mm^3 in 1998 as reported by Food and Agricultural Organization (FAO)of the nation's [4]. The demand for particleboards in the sectors of housing construction and furniture manufacturing has continued to increase [5-6]. Particleboard is a composite panel product made up of wood particles such as sawdust, wood chips, sawmill shavings or other agricultural waste related to synthetic resin or other suitable additive under heat and pressure [7]. It is widely used as flooring material, wall bracing, ceiling boarding, furnishings, partitioning, cladding and so on. Composite materials are manufactured by mixing two or more materials to enhance the original's characteristics. There is a chance that two or more lignocellulose materials would be coupled for more valuable products without affecting the particle board's properties. In latest years, the manufacturing of composite materials from agricultural wastes as an alternative particleboard to timber-based products has become a major study area [8]. Several of these lignocellulose components have been used to effectively create inorganic-bonded boards, particle boards and fibre boards to some extent.

The composite material's particles are held together by synthetic resins and other additives may be added to enhance the properties of the final composite material. Several resin kinds are widely used with the cheapest and easiest to use being urea formaldehyde and phenol formaldehyde resin [9]. One of the major causes of

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environmental pollution is the rapid depletion as a raw material of forest resources. To reduce forest consumption, it is vital to explore alternative sources of raw materials. It is therefore crucial to explore the suitability for panel (wood) manufacturing of agricultural residues. The use of agricultural waste as a particulate board is eco-friendlier and can aid to promote the concept of waste to prosperity in the construction sector. This will also help to protect the environment and promote environmentally friendly techniques [10]. As sources of environmentally friendly, non-toxic and cheap particle boards, agricultural waste residues have continued to gain attention. Several research reports of the use of agricultural residues for particleboard development exist, such include [11] who explored the manufacturing of coffee husk and hull fibre particle boards using portion-produced thermosetting resins. However, [12] evaluated the impact of adhesive type and loading on the quality of the produced particle board. They reported that the finest particleboard was generated at a load of 6% using urea formaldehyde. Furthermore [13] studied the characteristics of wheat straw and its particleboard manufacturing potential while [8] examined the factors affecting the manufacturing of maize cobs particle boards.

Limited studies however exist on the use of multiple agricultural residues as constituent material in production of composite particleboards. Some of the studies that considered optimization approach for mechanical features of particle boards using Response Surface Methodology are [14-15] considering board density, resin loading and agro-residue quantity as variables. The outcome obtained showed that the mechanical features (MOE and MOR) were affected by the volume of resin and agro-residue used but did have any significant effect on the MOE and MOR of the boards produced. In the same vein, [16] studied the impact of process parameters on the tensile characteristics of groundnut shell-vinyl ester composites using experiment design analysis. Three process parameters were considered namely: particle size, filler processing, and alkaline particle therapy. Tensile characteristics were predicted using surface response methodology and the findings showed that the tensile strength and tensile modulus increase with increase in filler loading up to 50-wt% and beyond 5% NaOH treatment of particles. To the best of the authors' knowledge, limited studies have attempted to optimize the characteristics of the particleboard produced from these agrarian residues. While studies on the mechanical conduct of agricultural waste based particleboards have been recorded in the literature, restricted research has been reported on the impact of control variables such as the amount of agro-residue composite and urea formaldehyde resin on the mechanical properties of the particle boards. Hence, this research investigated the use of groundnut shell and rice husk as a composite for the production of particle board using optimization approach.

2 Materials and Methods

2.1 Materials

The materials used for this research were groundnut shell (GS) and Rice Husk (RH) which were collected from Landmark University commercial farm and lastly the binder (Urea Formaldehyde Resin) was also sourced locally.

2.2 Experimental Design

The experimental settings were designed using Response Surface Methodology (RSM). It was conducted using Box-Behnken design in the software Design Expert (6.0.8). This was used to determine the effect of the interactions of the three variables, which are: GS, RH and resin loading on the mechanical properties of the particle boards produced. The range and levels of the independent variables are as shown in Table 1. The matrix for the three variables were varied at 3 levels (-1, 0 and +1) as shown in Table 2.

Table 1 Coded and actual levels of the factors for three factor Box-Behnken design for particle board production

Independent Variables	Independent Variables			
	Symbols	-1	0	+1
Independent Variables	X_1	0	50	100
Independent Variables	X_2	0	50	100
Independent Variables	X_3	1.5	2.0	2.5

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Table 2 Design Matrix for the Production of Particle Board from Groundnut Shell and Rice Husk

	Coded variables				Groundnut husk	Rice husk	Resin
					Actual Variables		
Std	Run	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

The Box-Behnken design has been established to be suitable for the quadratic response surfaces and this design generated a second-degree polynomial model [16].

As shown as:

$$Y_i = b_0 + \sum b_i X_j + \sum b_{ij} X_i X_j + \sum b_{ii} X_i^2 + e_i \;\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where Y_i is the dependent variable or predicted response, X_i and X_j are the independent variables, b_0 is the 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 regression and graphical analysis of the experimental data. The optimum values of the variables tested were obtained by numerical optimization based on the criterion of desirability [17]. The responses analysed were MOE and MOR respectively. Design matrix for the production of PB from GS and RH is shown in Table 2.

2.3 Production of Particle Boards

The groundnut shell was washed to remove debris and other foreign materials present in it. It was further air dried at 23 °C for 2 days after washing to reduce moisture content and further milled for size reduction. The GS and RH were sieved and separated into two different sizes (0.85 mm and 1.7 mm) using standard sieve sizes. Required composition and weight as determined by the experimental design was measured and poured into a mixing bowl. Based on the optimization protocol, the needed resin dosage was added and the mix was manually mixed homogenously for about 3 minutes until the required uniformity was attained.

Thereafter, the mixture was transferred to 80 x 120 x 300 mm wooden mould with the interior covered with polyethene material. Standard tamping rod was used to compact the PB before the cover was placed and put under a cold press at 3.8 MPa for 24 hours and later hot pressed for 6 hours. The particle board produced after moulding is as shown in Plate 1. Samples of 10 x 60 x 150 mm needed for physical and mechanical tests were cut from the PB and 3 replications were performed for proper analysis.

2.4 Mechanical Test

Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) were conducted in accordance with [18-19] for Testing Materials methods for evaluating properties of wood base fibre and particle panel material using Universal Testing Machine. Both properties were calculated from the following equations:

$$MOR = \frac{3PL}{2bh^2} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$MOE = \frac{PL^3}{4bh^3Y} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where: P = maximum load or maximum force, L = span, b = width, h = thickness and Y = deflection.

2.5 Characterization of Particle Board and thermal conductivity

The scanning electron microscope (SEM) was used to observe the morphology of the particle board. SEM was used to examine the microstructural morphology occurring at the surface of the boards and chemical composition of the boards following wetting and drying. Furthermore, Electron Dispersive Spectroscopy (EDS) was used to determine the elemental composition of the particle board

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produced. A Hot Disk Thermal Constants Analyzer, which uses the transient plane source method, was employed to measure the thermal conductivity of the various samples. All tests were conducted under ambient environmental conditions (20–22 °C).

3 Results and Discussion

Box-Behnken design for Response (MOR and MOE) is as shown in Table 3.

Table 3 Box-Behnken design for Response (MOR and MOE) production of particle boards

Run	Coded Factors			Actual Values			MOR(N/mm^2) Response		MOE(N/mm^2) Response	
	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

The equations (3) and (4) were obtained from the response via the regression analysis in terms of coded terms. The response generated in terms of coded and predicted values for both MOR and MOE is as shown below:

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

$$MOE = 891.5 - 3.93X_1 + 123.29X_2 + 9.06X_3 - 2.19X_1X_2 + 1.19X_1X_3 - 132.33X_2X_3 - 16.84X_1^2 - 68.31X_2^2 - 67.23X_3^2 \quad (4)$$

Table 4 showed the ANOVA for MOR while Table 5 showed ANOVA for MOE respectively. Furthermore, Table 4 and 5; revealed that the models for MOR and MOE were statistically significant with p values of 0.0004 and 0.0057 respectively as shown in Tables (4) and (5). However, the models showed that the terms: representing the amount of GS and RH and the resin loading were significant showing that all variables influenced the MOR and MOE of the boards produced.

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_{12}	1.86	1	1.86	13.96	0.0073
X_{22}	0.42	1	0.42	3.17	0.1184
X_{32}	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			

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Table 5 ANOVA results for model representing MOE

Sources	*Sum of Squares*	*DF*	*Mean Square*	*F Value*	*P value*
Model	3.397	9	37745.94	8.13	0.0057
X_1	65.38	1	65.38	0.014	0.9089
X_2	64224.00	1	64224.00	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
X1X3	11.56	1	11.56	2.189	0.9616
X_2X_3	1.43	1	1.430	30.77	0.0009
X_{12}	4970.26	1	4970.26	1.07	0.3354
X_{22}	81829.27	1	81829.27	17.62	0.0041
X_{32}	19032.46	1	19032.46	4.10	0.0826
Residual	32517.55	7	4645.36		
Lack of Fit	22405.68	3	7468.56	2.95	0.1613
Pure Error	10111.87	4	2527.97		
Cor Total	3.72	16			

F Value of 19.67 for MOR and 8.13 for MOE showed that models generated were significant. Statistical information for ANOVA showed that the models describing MOR and MOE has high coefficient of determination (R^2) as shown in Table 6. This showed that the models were able to adequately represent the relationship between the chosen factors (amount of GS, amount of RH and resin loading) and the responses (MOR AND MOE). R^2 values of 0.96 and 0.91 means that the models were able to explain 96% and 91% of the variability observed in the values of MOR and MOE respectively. The values obtained showed a high reliability as recommended by Montgomery [17]. The adequate precision for both models indicated that the models can be used to navigate design space [20].

Table 6 Statistical information for ANOVA

Parameter	**MOR value**	**MOE value**
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

3.1 Results of 3D Surface Plots

Figure 1 showed the effect of resin loading and the amount of groundnut shell on the MOR of the particle boards. The trend observed showed that MOR increased with increase in the amount of the resin and the amount of groundnut shell simultaneously.

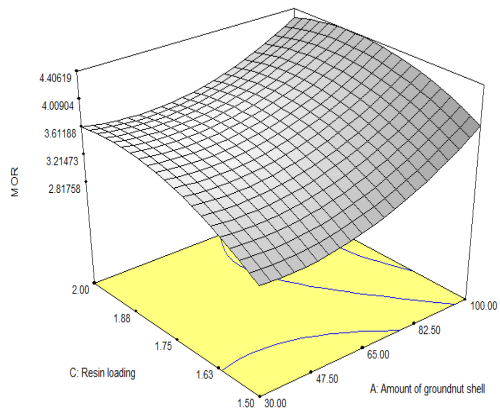

Figure 1 Effect of amount of Rice husk and amount of groundnut shell on MOR

This showed that there was appropriate adhesion between the amounts of groundnut shell. Previous reports have shown that to produce particle boards with high MOR, more of the resin has to be used. According to report by [21]; the mechanical and physical properties of particle boards could be enhanced by increasing the amount of resin used. The resin loading has been reported to determine the amount of voids present in the boards produced [8]. However, when low amounts of resin are used, the resin is mixed up with the agro residue particles leaving some voids present. However, when the resin loading is increased, some of it is mixed up with the agro residue particles to form the finish while the remainder fills up the voids that would otherwise be present in the finished product. Intermediate amounts of both groundnut shell and rice husk was needed to produce particle boards with high MOR values meaning that more resin could be used to produce the boards therefore resulting in the improvement of the mechanical properties. The effect of resin loading and amount of rice husk on the MOR is shown in Figure 2. Furthermore, Figure 3 showed that high MOE values were obtained when low levels of rice husk were used. The resin

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Volume: 6 2020 Issue: 3 Pages: 59-67 ISSN 2453-675X

loading did not significantly influence the MOR of the boards.

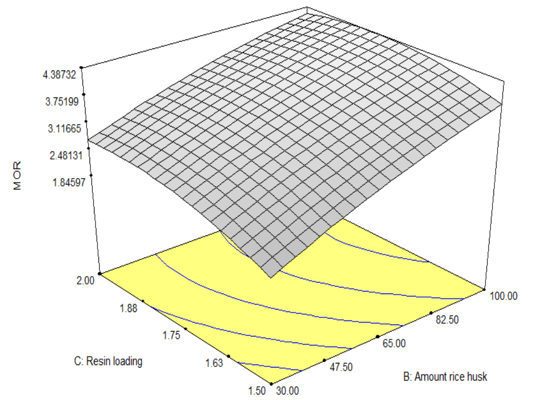

Figure 2 Effect of resin loading and amount of groundnut shell on MOR

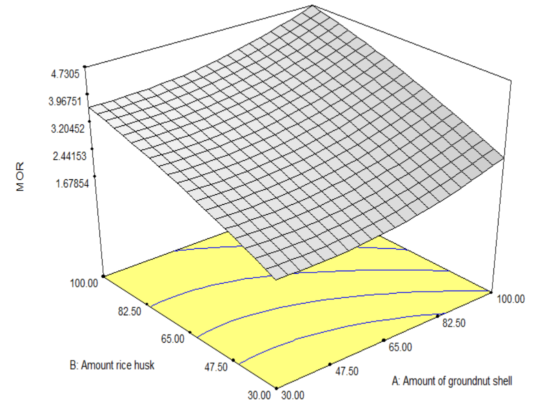

Figure 3 Effect of resin loading and amount of rice husk on MOR

The MOE of the boards was observed to increase with increase in the amount of rice husk as shown in Figure 4. The MOE of the boards was observed to increase with increase in resin loading as shown in Figure 5. Good bond quality resulting from adequate contact between the resin and the agro residue particles has been cited as a reason for high MOE values ([8]. This is because high resin loadings increase the bond contact between the particles which in turn results in improved surface contact [22]. Since MOR and MOE are both mechanical properties, the trend observed for both would be expected to be similar. Both measures of mechanical strength of particle boards have been reported to be influenced by particle geometry and amount of resin. The requirement for agro residue-based particle boards is high MOR and MOE. Figures 5 and Figure 6 showed that high MOE values were obtained when low levels of agro residue were used. Since a fixed ratio of agro residue to resin was utilized in producing the boards, a low level of agro residue translates to a high loading of resin. Therefore, reducing the amount of agro residue means increasing the amount of resin used which consequently increases the MOE of the boards. [23] reported that the increase in content of resin viscosity helps in enhancing the bonding strength.

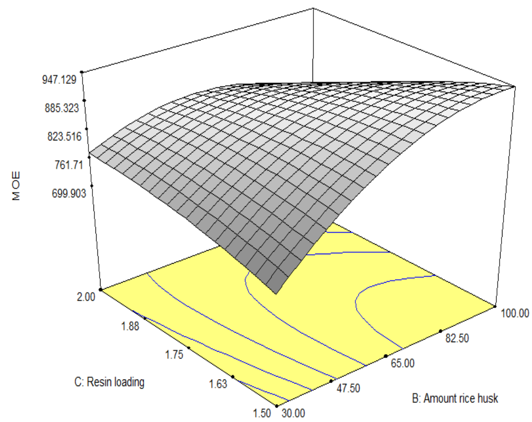

Figure 4 Effect of amount of rice husk and amount of groundnut shell on MOE

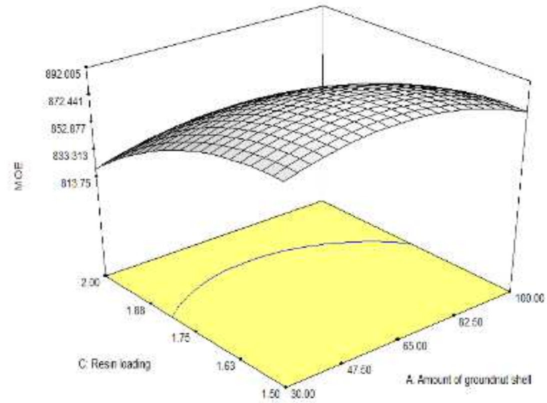

Figure 5 Effect of resin loading and amount of groundnut shell on MOE

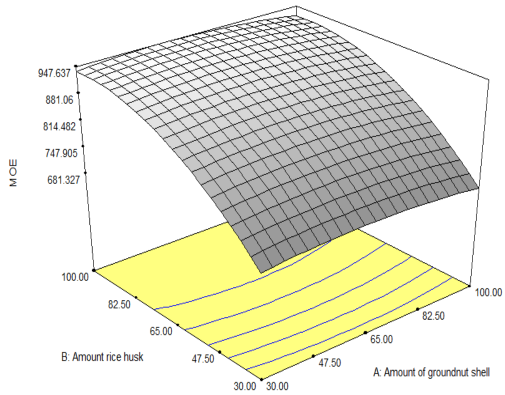

Figure 6 Effect of resin loading and amount of rice husk on MOE

3.2 Validation of Optimal Predicted Levels

The optimal variables predicted by the software which was validated as given in Table 7. The result showed that the maximum MOR and MOE values of 3.50 N/mm^2 and

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Volume: 6 2020 Issue: 3 Pages: 59-67 ISSN 2453-675X

932.40N/mm^2 respectively obtained were close to the predicted values of 3.49 N/mm^2 and 932.10 N/mm^2 respectively which confirmed result by [22]; of 0.50 to 1.40 N/mm^2 for binder-less particleboard made from oil palm trunk. The excellent correlation between the predicted and measured values of these experiments shows the validity of the statistical model. Good correlation between experimental and the predicted results confirmed adequacy of the model predicted.

Table 7 Optimal variables validated

S/N	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

3.3 *Scanning Electron Microscopy (SEM) and EDS Analysis*

The particle board from both the best process level and validated were subjected to SEM and the results observed showed that the surface of the boards showed fibrous network structures which were covered and bonded by the resin. The boards with the higher resin loading had lower voids because the resin is cured more effectively in the void spaces in Figure 7. The lower density board in Figure 8 has higher voids and spaces which results in high moisture absorptivity. The density of the board is found to increase with increasing resin loading.

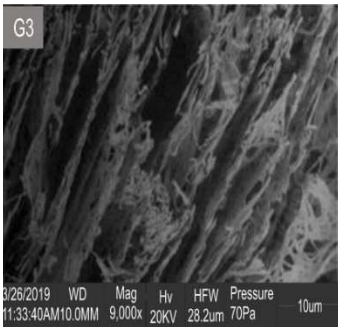

Figure 7 Particleboard from best process level

The Energy Dispersive X-ray Spectroscopy (EDS) was carried out to study the percentage of elements. The variation of percentage of elements suggests inhomogeneity in molecular composition such as organic or inorganic composition. The table below (Table 8) shows the variations of the percentage of elements.

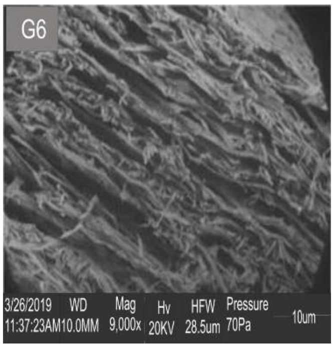

Figure 8 Validated particleboard

Table 8 Energy Dispersive X-ray Spectroscopy results

Samples	C	0	K	Si	Ca	Mg	Na	Al
G3	3.20	51.30	8.51	34.65	1.23	3.50		0.10
G6		52.39	3.02	24.04	8.92	1.02	8.60	1.45

3.4 *Thermal Properties Analysis*

The result of the thermal conductivity is as shown in Table 9. The heat flow transfers through solid substance and void, while the thermal conductivity of air within the voids is much lower than that of solid substance, therefor a lower thermal conductivity of the whole material. Thus, the lower density boards conduct less heat than the higher density boards. From Table 9, the higher the density of the board, the higher the thermal conductivity of the boards but due to a close difference between their densities, the values of the thermal conductivity were slightly different. Furthermore, densities of 367, 375 kg/m^3, then the values of the thermal conductivity are 0.172, 0.178 W/mK respectively.

Table 9 Thermal Conductivity results

Parameter	Thermal Conductivity (W/mK)
G3(Particleboard from best process level)	0.172
G6 (Validated)	0.178

4 Conclusion

Design of experiment for response surface methodology has been demonstrated to be useful in optimizing the board production process. Mechanical properties of the boards such as MOR and MOE were influenced by the amount of agro residue and resin used.

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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 of; 65.99 g of groundnut shell, 86.34 g of rice husk and 1.69 g of resin loading was validated to give a MOR and MOE of 3.50 N/mm^2 and 932.40 N/mm^2. The particle board produced at the optimized conditions satisfied the American National Standard ANSI/A208.1-1999 specification for general purpose particle boards. This study showed that particle boards were produced from groundnut shell and rice husk using urea formaldehyde as binder. It can be concluded that optimizing the agricultural waste products and the resin was successful for the production of particle boards.

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Review process

Single-blind peer review process.

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