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Optimal Design for Rice Husk-Saw Dust Reinforced Polyester Ceiling Board

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ABSTRACT**:** *Optimal design for producing rice husk-saw dust reinforced polyester composite for ceiling board application was determined in this study as a response to the quest for an economical and eco friendly indigenous source of building materials in Nigeria through waste to wealth initiative. Central composite response surface design and modeling was applied in the empirical analysis and quantification of the influence of the composing materials on the mechanical properties of the products. The properties of the ceiling board evaluated include toughness, hardness, tensile, compressive and flexural strength. The optimal product design was determined using desirability function analysis with ISO specifications on these five mechanical properties of ceiling board as target responses. Result revealed 3:5:6:1 as the composing ratio of rice husk, saw dust, polyester resin and methyl ketone peroxide for standard ceiling board production. This product design yields a ceiling board with toughness, hardness, tensile, compressive and flexural strengthof 3.75, 182, 19.6MPa, 8.8MPa and 5.8MPa respectively. The cost of producing 1.4m^{2}ceiling board based on this optimal design is one thousand three hundred and thirty one naira forty kobo (₦1331.40). This amounts to31.44% savings when compared to prevailing market price of one thousand seven hundred and fifty naira (₦1750).*

KEY WORDS: *Ceiling board, polyester composite, product design, rice husk, saw dust*

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I INTRODUCTION

Ceiling board can be defined as panel sheets covering the upper layer of an internal section of a building which improves it aesthetics and reduces sound and heat transmission in the house [1]. Ceiling boards are made from gypsum, acoustic, asbestos and agricultural wastes such as maize husks, coconut coir, bamboo fibers, saw dust and rice husks etc. The national quest for locally sourced economic and eco friendly building materials has led to on ending assessment on the viability of these agricultural wastes for roof sheet and ceiling board production in the past decade. [2] showed that reinforced wood fibers possesses the required mechanical properties for this application to substitute high cost materials while [3] and [4] revealed low density merit of natural fiber composites over conventional composites. [5] established that the rice husk, starch and wood glue combination provides results which have high potential to be used in the production of particleboard while [6]showed suitability composite ceiling board materials made from waste paper and rice husk for low-cost construction work due to its good flexural strength, water absorption and density. [7] also revealed that ceiling board produced from rice husk reinforced gum Arabic and formaldehyde top bond resins composite compares favorably with density boards obtained from markets. According to [1] composite ceiling boards made from saw dust, paper and starch were successfully nailed with firm grips.

However, [8] showed that the flexural strength of agro waste composite ceiling board produced from rice husk-maize-husk-saw dust ranges from 0.05MPa and 0.1MPa indicating a fragile board. Although, other works on the suitability of other agricultural/natural fiber reinforced materials for ceiling board production cannot be over emphasized. [9] showed that particle boards with the admixture of rice husk-sawdust have a higher tensile strength than commercial ceiling boards. In addition, [10] showed that cement bonded rice husk-saw dust composite ceiling board are good and [11], indicated that a composite ceiling board produced from rice husk-saw dust using cascamite glue as a binder has a good tensile strength. But, the contrary view of [12] that composite ceiling board produced from rice husk-maize-husk-saw dust reinforced phenol formaldehyde resin has poor water adsorption and not sustainable. Hence the position of [13] and [14] indicates that polyester composite is the best value for a balance between performance and structural capabilities due to dimensional stability/fabrication ability, affordable cost, high corrosion resistant and fire retardants call for a comprehensive analysis to determine the optimal design of rice husk-saw dust reinforced polyester composite for ceiling board application.

Most industrial/scientific search of this nature lends themselves response surface methodology because the tool uses special experimental designs with small number of experimental runs to test the effects of several variables on all the responses involved at a time, thereby, eliminating time consumption and high cost of one-factor-at-a-time experimental approach [15]. In addition the technique is an outstanding tool for optimizing multiple outputs that are under the influence of several variables and the outputs are interrelated in a way that improving one will cause deterioration of another [16].Thus the objective of this work is to develop an optimal formulation for producing rice husk-saw dust reinforced polyester composite for ceiling board application.

II METHODOLOGY

Rice husk (RH) was obtained from mill in Abakaliki, Ebonyi State. The finely milled rice husk was collected in large quantity and unwanted materials such as stones, soil particles etc were carefully removed manually from the sample rice husk, after which it was put in a stainless pot containing water and placed on a stove. It was boiled at a temperature of 95℃ for 40 minutes before pouring on a filter bed and sun dried for seven days. The purpose of this is to improve adhesion properties of the fiber surfaces without significantly damaging their composition and properties. Saw dust was obtained from timber market, Mary-land in Enugu. It was dried in an open environment at room temperature and was later sieved through 1.18mm sieve to get rid of unwanted materials. The polyester resin (DG774TSY-A) was bought at Ariaria Market, Aba in Abia State, Nigeria. The accelerator (methyl ketone peroxide) and mould release wax were bought at Kenyetta market. Wooden materials were cut and formed into dimensions 500mm by 500mm by 5mm which served as mould for the production of rice husk- saw dust ceiling board. The formulation of this composite was used to produce 1kg of ceiling board composite. It was poured in a mixer and 0.09kg of water, 0.007kg of methyl ketone peroxide and 0.003kg of wax were then added to the composite to give the desired quality of ceiling board. The mixture was stirred at a rate of 300rpm for 20 minutes and was then cast into the designed mould. The mould composite was pressed using manual compaction with hydraulic press

The experimental investigation of the influence of different formulation of this composite on its mechanical properties and determination of its optimal product design involves experimental design, model fitting, model selection, model validation and optimization in accordance with [16]. The tests were conducted at the Engineering Laboratory of Standard Organization of Nigeria, Enugu. Universal testing machine was used in performing the tensile test. The cured polyester-rice husk- saw dust composites were cut into tensile test samples in accordance with the ASTM standard D638 and was subjected to test. Tinus Olsen Universal Testing Machine was used to carry out compressive strength test. Compressive test specimen was loaded to fracture by applying uniaxial compressive force. The maximum compressive force that crushed the specimen was read. The toughness test was performed according to the standard charpy v-notched method. Impact specimen was notched at the center to a depth of about 3mm where an area of stress concentration was observed. Flexural strength test involved placing of each of the specimens on the flexural testing machine. The three point flexing and loading arrangement was used in which fracture occurred at the middle. An automatic electric powered Rockwell hardness testing machine was used to determine the hardness value of the polyester composite fiber.

MINITAB 17 version 1 was used to generate and randomize a two coded levels (+1 and -1) full factorial design layout in which "+1"and "-1" indicate the high and low level of the factors respectively with "0" as the midpoint of the factors. Thereafter, the actual high and low levels of the operational factors been investigated were determined from experimental tests and the factor limits. Optimization of the developed models was performed using both the graphical/analytical desirability optimization tools of version 17.1 of MINITAB to ensure accuracy of the results. The optimization graphs were generated per factor pair per response with exploration data tips using version 17.1 of MINITAB software. The data tips of the graph are the optimization tool used for exploring the critical (optimal) factor levels that yields maximum possible values of the tensile strength, toughness, hardness, flexural strength and compressive strength in the plots. The optimal coded factor level obtained graphically was further subjected to another analytical confirmation. The coded solution (optimum coded factor levels) obtained were then compared with the ones obtained graphically before the actual optimal settings of the parameters for composite ceiling board production were derived from the following transformation (17)

$$X = \frac{[2x-(x_{max}+x_{min})]}{[x_{max}-x_{min}]} \quad (1)$$

The mechanical properties of composite ceiling boards produced using the optimal setting were compared with the predictions and ISO specifications for standard ceiling board using Analysis of Variance. The comparative cost analysis of $1.4m^2$rice husk-saw dust reinforced polyester composite boards produced using the optimal product design was based on the prevailing average wages and market prices in Enugu State of Nigeria between January and March, 2018.

III RESULTS AND DISCUSSION

The percentage composition limits of rice husk, saw dust, polyester resin and methyl ketone peroxide required for producing a ceiling board whose mechanical properties conform to ISO specifications were determined as shown in Table 1 while Table 2 constitutes the results of the multi objectives analysis of combined effects of different factor setting on the responses.

Table 1: Factor Limits for Producing Rice Husk-Saw Dust Based Ceiling Board

S/N	Factor Description	Factor Symbols		Factor Values (%)	
		Coded	Actual	High (+1)	Low (-1)
1	Rice Husk	x_1	*RH*	25	15
2	Saw Dust	x_2	*SD*	40	20
3	Polyester Resin	X_3	*PR*	50	30
4	Methyl ketone peroxide	X_4	*MR*	8	6

Table 2: Multi Factors-Objectives Analysis of Rice Husk-Saw Dust Based Ceiling Board

Experimental runs		Coded Factor Setting				Responses				
Std Order	*Run Order*	x_1	x_2	x_3	x_4	*Ts (MPa)*	*To (J)*	*H*	*F, (MPa)*	*Cs (MPa)*
1	1	-1	-1	-1	-1	16.58	3.45	169	5.39	7.9
2	2	1	-1	-1	-1	17.98	3.58	165	5.56	8.19
3	3	-1	1	-1	-1	18.00	3.29	149	5.31	8.45
4	4	1	1	-1	-1	17.10	3.00	133	4.12	9.80
5	5	-1	-1	1	-1	13.40	3.30	125	4.8	8.0
6	6	1	-1	1	-1	14.50	3.10	105	4.78	9.52
7	7	-1	1	1	-1	16.50	3.00	154	4.43	7.05
8	8	1	1	1	-1	17.68	2.30	101	3.89	9.15
9	9	-1	-1	-1	1	19.60	3.10	123	3.50	8.10
10	10	1	-1	-1	1	20.10	2.80	126	4.2	7.60
11	11	-1	1	-1	1	19.5	2.9	134	4.1	8.9
12	12	1	1	-1	1	17.20	3.0	142	4.4	6.8
13	13	-1	-1	1	1	15.90	2.7	138	3.8	7.5
14	14	1	-1	1	1	16.80	3.2	156	3.7	7.1
15	15	-1	1	1	1	18.20	3.4	164	3.5	6.9
16	16	1	1	1	1	16.90	3.1	148	4.2	7.8
17	17	-2	0	0	0	17.80	3.3	152	4.8	7.2
18	18	2	0	0	0	15.90	3.15	164	3.7	8.0
19	19	0	-2	0	0	18.90	3.4	153	3.6	8.2
20	20	0	2	0	0	17.60	3.20	155	3.4	7.4
21	21	0	0	-2	0	16.40	3.5	162	3.2	7.9
22	22	0	0	2	0	18.30	3.1	143	3.5	8.1
23	23	0	0	0	-2	12.50	3.4	152	3.4	7.8
24	24	0	0	0	2	14.70	3.2	151	4.5	7.9
25	25	0	0	0	0	19.10	3.3	149	4.8	8.3
26	26	0	0	0	0	20.20	3.8	163	4.10	8.1
27	27	0	0	0	0	19.80	3.70	188	6.15	8.67
28	28	0	0	0	0	20.40	3.80	188	6.16	8.67
29	29	0	0	0	0	19.40	3.70	189	6.18	8.7
30	30	0	0	0	0	20.40	3.80	188	6.20	8.8
31	31	0	0	0	0	19.50	3.9	189	6.19	8.8

Statistical analysis (Table 3) and confirmatory test plots (Fig. 1) of the empirical models (equations 2 to 6) developed from this experimental records revealed that the value of R-square associated with each of these functions is over 0. 97. Thus, the developed models are adequate for prediction and optimization of the responses because their prediction capabilities are above 95%acceptable confidence bound.

$$Ts = -88.23 + 1.508 x_1 + 0.4107 x_2 + 0.1078 x_3 + 23.781 x_4 - 0.00903 x_1*x_2 + 0.00397 x_1*x_3 - 0.0625 x_1*x_4 + 0.006950 x_2*x_3 - 0.04662 x2*x_4 - 0.00637 x_3*x_4 - 0.02462x_1^2 - 0.002780 x_2^2 - 0.005030 x_3^2 - 1.4405 x_4^2 \quad (2)$$

$$T = -0.758 + 0.2342 x_1 + 0.0294 x_2 + 0.0256 x_3 + 0.36 x_4 - 0.00035 x_1*x_2 - 0.00005x_1*x_3 + 0.00575 x_1*x_4 + 0.00005 x_2*x_3 + 0.011875x_2x_4 + 0.015625x_3x_4 - 0.006415x_1^2 - 0.001704 x_2^2 - 0.001704 x_3^2 - 0.10664 x_4^2 \quad (3)$$

$$H = -45.5 + 8.807\, x_1 + 2.446\, x_2 - 1.943\, x_3 + 41.76\, x_4 - 0.09264\, x_1{*}x_2 - 0.07736 x_1{*}x_3 + 1.3236\, x_1{*}x_4 + 0.04257\, x_2{*}x_3 + 0.4493 x_2 x_4 + 1.3257 x_3 x_4 - 0.31666 x_1^2 - 0.08917\, x_2^2 - 0.09292\, x_3^2 - 9.542\, x_4^2 \quad (4)$$

$$Fs\ (MPa) = -14.89 + 0.289\, x_1 + 0.189 x_2 + 0.315\, x_3 + 2.84\, x_4 - 0.000587\, x_1{*}x_2 - 0.001188 x_1{*}x_3 + 0.02712 x_1{*}x_4 - 0.000819\, x_2{*}x_3 + 0.0173 x_2 x_4 + 0.01556 x_3 x_4 - 0.010595 x_1^2 - 0.004511\, x_2^2 - 0.004899\, x_3^2 - 0.3399\, x_4^2 \quad (5)$$

$$Cs = -17.24 + 0.7326\, x_1 + 0.18298 x_2 + 0.08803\, x_3 + 4.265\, x_4 - 0.001674\, x_1{*}x_2 - 0.006349 x_1{*}x_3 + 0.09199 x_1{*}x_4 - 0.002113\, x_2{*}x_3 + 0.004619 x_2 x_4 + 0.009244 x_3 x_4 - 0.008829 x_1^2 - 0.001706\, x_2^2 - 0.001207\, x_3^2 - 0.15822\, x_4^2 \quad (6)$$

Table 3: Coefficients of determination/error standard deviation of the developed response models

Responses	S	R-sq	R-sq(adj)	R-sq(pred)
Tensile strength	0.318406	0.9847	0.9713	0.9789
Toughness	0.0102716	0.9994	0.9989	0.9990
Hardness	0.833435	0.9991	0.9983	0.9988
Flexural strength	0.042165	0.9984	0.9969	0.9978
Compressive strength	0.0375469	0.9981	0.9965	0.9974

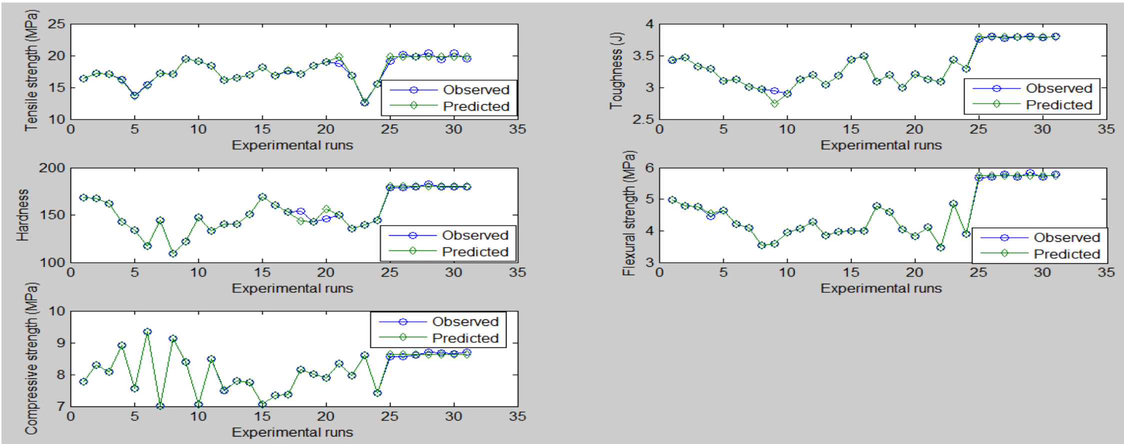

Fig. 1: Confirmatory test plots of the developed response models

The optimization plot of the developed models (Fig. 2) revealed optimal composite setting of 20.3%, 30%, 37.3% and 6.7%of rice husk, saw dust, polyester resin and methyl ketone peroxide respectively as the composite and individual function desirability to approximate one. This plot also showed the hardness, flexural strength, compressive strength, toughness and tensile strength associated with this optimal product design as 180.2, 5.79MPa, 8.72MPa, 3.78 and 19.68MPa respectively. Experimental evaluation (Table 4) showed prediction error of 0.41-0.99% between this optimization results and the measured mechanical properties of the ceiling board developed using this product design.

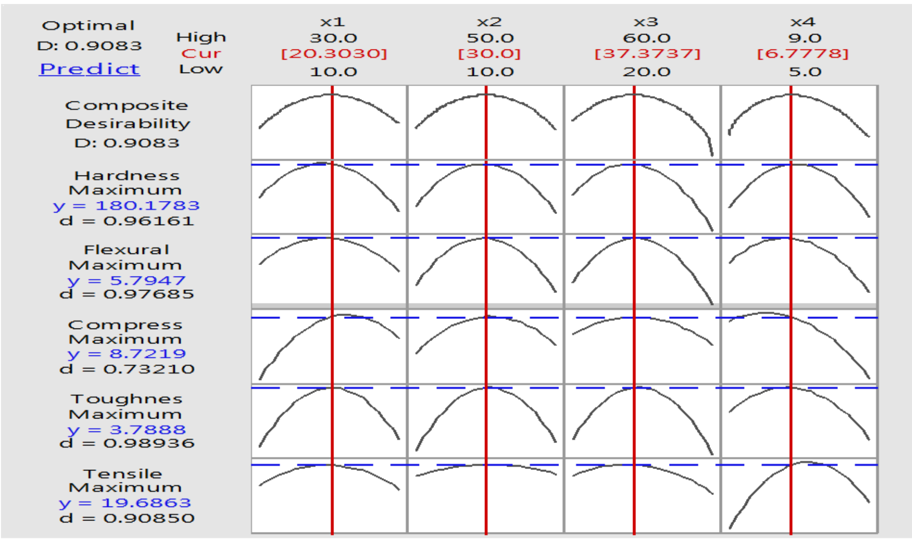

Fig. 2: Desirability function analysis of rice husk-saw dust based ceiling board

Table 4: Experimental confirmation of optimization result

S/N	Response	Predicted	Actual	Percentage error
1	Tensile strength (MPa)	19.68	19.60	±0.41
2	Hardness	180.2	182.00	±0.99
3	Toughness	3.78	3.75	±0.8
4	Flexural strength (MPa)	5.79	5.80	±0.17
5	Compressive strength (MPa)	8.72	8.80	±0.92

In addition, analysis of variance (Table 5), revealed no difference at both 0.05 and 0.01 significance levels between the properties of the test ceiling boards and ISO specification on hardness (180-209), flexural strength (5.7 - 6.2), compressive strength (8.4-10.5), toughness (3.7-4.0) and tensile strength (18.4 - 21.5)of standard ceiling board. Further analysis shown in Table 6 indicated one thousand three hundred and thirty one naira forty kobo (₦1331.40) as the cost of producing 1.4m^2 ceiling board based on this optimal design against prevailing average market price of one thousand seven hundred and fifty naira (₦1750) for ceiling board from other sources. This amounts to31.44% savings, hence, rice husk-saw dust reinforced polyester composite developed using the optimal formulation derived in this study is suitable for ceiling board production contrary to the views of [18] and [8].

Table 5: Analysis of variance for optimal rice husk-saw dust ceiling board and ISO specifications

Source of variation	Df	Adj SS	Adj MS	F-value	P-value	A	F-critical
Factors	1	1.2	1.23	0.00	0.989	0.05	5.32
Error	8	49788.2	6223.53			0.01	11.30
Total	9	49789.5					

Table 6: Cost Analysis of optimal 1.4m^2- rice husk-saw dust ceiling board

S/N	Description	Quantity (kg)	Unit Price ₦K	Amount ₦ K
1.	Saw dust	2.10	5.00	10.50
2.	Rice husk	1.26	5.00	6.30
3.	Polyester resin	2.52	225.00	567.00
4	Methylketone peroxide	0.42	300.00	126.00
5	Wax	0.18	120.00	21.60
4.	Labour cost		LS	600.00
	Total			**1331.40**

IV CONCLUSION

This study revealed 3:5:6:1 as the composing ratio of rice husk, saw dust, polyester resin and methyl ketone peroxide for standard ceiling board production. This product design yields a ceiling board with toughness, hardness, tensile, compressive and flexural strength of 3.72, 180.2, 19.68MPa, 8.72MPa and 5.79MPa respectively which conforms to the ISO specifications. The cost of producing 1.4m^2 ceiling board based on this optimal design is one thousand three hundred and thirty one naira forty kobo (₦1331.40). This amounts to31.44% savings when compared to prevailing market price of one thousand seven hundred and fifty naira (₦1750). Hence, rice husk-saw dust reinforced polyester composite is suitable for ceiling board production when developed using the optimal formulation derived in this study.

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