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OPTIMIZATION OF AVOCADO WOOD FLOUR POLYMER COMPOSITE

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Abstract

This research was aimed at optimizing the properties of avocado wood flour/high density polyethylene composite (AW/HDPE). The effect of particle size (P_1) and filler weight (P_2) on the tensile strength (Z_{TS}), flexural strength (Z_{FS}), impact strength (Z_{IM}) and water absorption (Z_W) properties of the composite was examined. The avocado wood flour (AW) was compounded into fine particles (100-20 mesh) at 5-25 % wt with high density polyethylene (HDPE) by injection molding. The optimization process was done using a quadratic function of central composite design to forecast the optimum size and filler weight on the properties of the composite. The optimum input variables were 80 mesh and 21.62 % for P_1 and P_2. The optimum output variables were 25.652 MPa, 55.168 MPa, 47.397 KJ/m^2 and 2.782 % for Z_{TS},$Z_{FS,}$ Z_{IM} and Z_W, respectively. The error between the experiment and response surface methodology (RSM) model at optimum is less than 1%, which indicated a good prediction of the model. This shows that RSM model is appropriate for the optimization of avocado wood flour polymer composite. Natural filler should be considered as a suitable substitute to conventional non-metal compound use as filler in the production of avocado wood flour polymer composite for furniture application.

Keywords:optimization, natural filler, avocado wood flour/high density polyethylene, properties, central composite design

1. Introduction

The continuous demand of cheap raw material as filler and the reduction of environment challenges have led to more production of different lignocelluloses polymer composite (Supri and Lim, 2009; Chanda et al, 2015). In the past, non metal based compounds were basically employed as additives in the composites manufacturing process. These compounds include: calcium oxide, titanium dioxide, calcium carbonate, zinc oxide, magnesium oxide, etc. These conventional substances negatively influenced the final outputs and production machines (Abdulkhalili and Razman, 2000; Yang et al, 2006; Government et al, 2017). The research of using natural filler was adopted to provide solution to these problems. The major essence of using natural fillers as an additional material in filling polymer is to improve on the properties of the composites (George et al, 2001; Yang et al, 2004).

There are many positive effects of the natural filler as an additive over the non-metal based compounds. These include low cost and density, appropriate strength, superior thermal insulation properties, renewable materials and recycling potential without affecting the environmental damage, and together with the biodegradable capability (Weinberg et al, 2003). They are applied in the field of life such as construction materials since early times and provide the reward of aesthetically agreeable, renewable, recyclable and biodegradable (Zadorecki and Michell, 1989). They are mostly lignocelluloses material, which is comprised of helically wound cellulose micro fibrils in a matrix of lignin and hemicelluloses (Lundquist et al, 2003).

There is need to source for new natural fillers that will compete with the one invoke due to the popularity in use for the manufacturing of organic filler polymer composites. These materials have received worldwide attention due to frequently order of these products (Bledzki and Spencer, 2008). This is why researchers in world at large are making effort to source for new fillers for production of composites at optimum conditions. The characteristics of natural filler are influence by the nature of filler and size, polymer matrix and surface modification (Bogoeva-Gaceva et al, 2007; Netral et al, 2012). Therefore, it is necessary to optimize the properties of the filler with the correlation of particle size and filler weight in this study.

Many researches on natural filler polymer composite have been carried out on the experimental determination of the mechanical properties and water absorption resistance (Kord, 2011; Lee et al, 2009; Zabihzabeth, 2010; Netral, 2012; Obasi, 2012; Obasi, 2013, Obasi, 2015). The connections between the properties and composition of operating conditions of the composite are essential to be tackled (Chanda et al, 2015). The optimization of process parameters and the properties of composite have been given limited attention in previous works. In order to meet up the design of satisfactory performance of the composite, these parameters must be considered. This is to reduce the material and processing cost, improving the properties of the composites during production. Therefore, the optimal significant input and output variables are paramount.

The objective of this study was to investigate the influence of particle size and filler weight on the properties of the composite and maximize the filler weight and size that will produce the optimum properties of the composite using central composite design (CCD) of experiment.

2.0 Material and methods

2.1 Preparation of avocado wood filler

The avocado wood was obtained from Federal Housing Trans Ekulu Enugu State of Nigeria. The wood was sun-dried for 336 hours, crushed, ground, and sieved to mesh size of 100-20 mesh.

2.2 Composite preparation

The wood filler at 5, 10, 15, 20 and 25 % by weight was mixed with high density polyethylene (HDPE). The mixture was compounded by the application of injection molding machine. The composite produced was subjected to mechanical and water absorption tests.

2.3 Testing of tensile strength of composites

The tensile strength was tested at the Civil Engineering Workshop, University of Nigeria, Nsukka, Enugu State of Nigeria using universal tensometer (BSS1610 model no 8889). The equipment has a cross-head speed between 10-100 cm/s. The dimensions of tensile test sample size for ASTM D638 (ASTM, 1990) used were 3.2 mm x 19 mm x 160 mm. The samples were introduced into the griping chucks of the tensometer and placed firmly. A continuous load was applied to the sample until fracture occurs. The ultimate tensile strength was calculated using Eq. (2.1).

$$\sigma_T = \frac{f_m}{A} \qquad (2.1)$$

Where σ_T is the tensile strength, $f_m$is the maximum tensile force and A is the cross-sectional area of the material.

2.4 Testing of flexural strength of composite

The equipment used for this was universal tensometer. The dimension of flexural test sample size for ASTM D790 (ASTM, 1990) used was 3.2mm x 19mm x 300mm. The test sample was placed and fixed firmly on 3-point support span. A continuous load was applied on the centre of the sample until fracture and constant deflection occurred. The flexural strength was obtained. The flexural strength was evaluated using Eq. (2.2).

$$\sigma = \frac{3FL}{2bd^2} \qquad (2.2)$$

Where σ is the flexural strength, F is the load (force) at the fracture, d is the thickness, L is the length of the support span and b is the width of the sample.

2.5 Testing of impact strength

The equipment used for this test was Charpy impact tester machine (LOS model no.17562/1963)located at the University of Nigeria, Nsukka, Mechanical Engineering Department Workshop, Enugu State. The dimension of impact testing specimen size for ASTM D610-02M (ASTM, 1990) used was 3.2 mm × 19 mm×80mm. The pendulum from the impact tester was released and allowed to strike through the specimen. The impact strength was calculated using Eq. (2.3)

$$IS = \frac{E}{A} \quad (2.3)$$

Where IS is the impact strength, E is the energy at break and A is the cross-sectional area of the specimen.

2.6 Water absorption test

The test was carried out at Divine Chemical and Analytical Laboratory, Nsukka, Enugu state. The composite sample was cut to dimension of 3.2mm x 19mm x19mm. The samples were conditioned by drying in an oven at 50^0C for 30 minutes, cooled and weighed (Lulianelli et al, 2010). The sample was immersed in water for 12 weeks at room temperature using ASTM D570 (ASTM, 1990) and weighed againafter the left over water on the surface was removed. The percentage of water absorption was calculated using Eq. (2.4).

$$M = \frac{B_2 - B_1}{B_1} \times \frac{100}{1} \quad (2.4)$$

Where M is the percentage of water absorbed, B_1 initial weight and B_2 the weight after immersing in water.

2.7 Modeling of the experimental results

2.7.1 Modeling and optimization

Modeling and optimization of the experimental data were done using Response Surface Methodology (RSM). A central composite design (CCD) was applied using the software design expert version 7.0. Theface cantered experimental plan was used. A CCD is made face cantered when the choice of α = 1 (Mongtomery, 2001). A total of 13 experiments were conducted for each response. Each response of the composites was optimized using a second degree polynomial equation as given by Eq. (2.5).

$$Z_i = C_0 + \sum_{i=1}^{n} C_i P_i + \sum_{i=0}^{n} P_{ii} P_i^2 + \sum_{i=1}^{n} \sum_{i=i+1}^{n} C_{ij} P_i P_j + \varepsilon \quad (2.5)$$

Where Z_i is the predicted response, C_o is the constant coefficient, C_i the linear coefficients, $B_{ii}$is the quadratic coefficients, Cij is the interactive coefficients, P_i and $P_j$are the coded values of the variables, n is the number of independent test variables and ε is the random error. The factors (particle size (P_1) and filler weight (P_2)), levels, and the range of the experimental design table are presented in Table 1.

Table 1: The factors, range and levels of the parameters analysis in the CCD design.

Parameters	Factors	Range and levels				
		Lowest	Low	Center	High	Highest
		-α	-1	0	+1	+α
Particle size	P_1 (mesh)	20	20	60	100	100
Filler content	P_2 (%)	5	5	15	25	25

3.0 Results and Discussions

3.1 Generation of regression model

Experiments were carried out to investigate the effect of connecting various factors of variables by applying central composite design of experiment. Table 2 presents the design matrix and response for the avocado wood flour polyethylene composite. The experiment was carried to evaluate the mechanical and water absorption properties of avocado wood flour polyethylene untreated composite model for Z_{TS}, Z_{FS}, Z_{IM} and Z_W. The outputs factors of mechanical and water absorption properties were associated with two input factors (mesh particle size and filler weight) using quadratic function of Eq. (2.5). The regression models that were developed to predict the tensile strength (Z_{TS}), flexural strength (Z_{FS}), impact strength (Z_{IS}) and water absorption (Z_W) of AW/HDPE composite were stated in Eq. (3.1), Eq. (3.2), Eq. (3.3) and Eq.(3.4).

$$Z_{TS} = 24.60920 + 0.061890P_1 - 0.024318P_2 - 3.93361E\text{-}004P_1^2 - 2.05847E\text{-}003P_2^2 \quad (3.1)$$

$$Z_{FS} = 42.41458 + 0.14335P_1 + 0.34476P_2 - 1.09809E\text{-}003P_1^2 - 6.45171E\text{-}003P_2^2 \quad (3.2)$$

$$Z_{IM} = 47.41112 + 0.068672P_1 + 0.0653612P_2 - 5.11990E\text{-}004P_1^2 - 7.56900E\text{-}003P_2^2 \quad (3.3)$$

Z_W=2.47437-0.015212P_1+0.010799P_2+1.10532E-0041P_1^2+1.42595E-003P_2^2(3.4)

Equations 3.1-3.4 show the final empirical equation in terms of actual factors after excluding the non-significant terms for the tensile strength (Z_{TS}), flexural strength (Z_{FS}), impact strength (Z_{IS} and water absorption (Z_W) properties, respectively of avocado wood flour/high density polyethylene untreated composite.

Table 2: Design matrix for AW/HDPE composite in coded unit.

	Factors		Responses			
	Particle Size (mesh)	Filler weight (%)	Z_{TS} (MPa)	Z_{FS} (MPa)	Z_{IM} (KJ/m^2)	Z_W (%)
Run	P_1	P_2				
1	0	1	24.7	51.7	45.84	3.26
2	-1	0	24.3	47.44	47.39	2.83
3	1	-1	26.6	46.95	49.29	2.16
4	1	1	25.12	49.62	45.77	3.12
5	1	0	26.01	48.73	48	2.5
6	0	0	26.13	50.6	48.9	2.4
7	0	0	26.13	50.6	48.9	2.4
8	0	0	26.13	50.6	48.9	2.4
9	0	0	26.13	50.6	48.9	2.4
10	-1	-1	25.48	46.31	48.71	2.3
11	0	-1	26.97	48.04	49.75	1.96
12	0	0	26.13	50.6	48.9	2.4
13	1	1	23.9	49.23	45.28	3.34

Where Z_{TS} is the tensile strength, Z_{FS} is the flexural strength, Z_{IM} is the impact strength and Z_w is the water absorption.

3.2 ANOVA for response surface quadratic model for Z_{TS}, Z_{FS}, Z_{IM} and Z_W of AW/HDPE composite

It was observed that the models depict a high F-value in Table 3 (F values = 273.05, 80.42, 286.89 and 617.99) for tensile strength (Z_{TS}), flexural strength (Z_{FS}), impact strength (Z_{IM}) and water absorption (Z_W), respectively. The probability values were low (P values = 0.0001, 0.0001, 0.0001 and 0.0001) for tensile strength, flexural strength, impact strength and water absorption, respectively. The coefficients of particle size (P_1), filler weight (P_2), and the corresponding square terms ((P_1)^2 and (P_2)^2) were less than 0.05 for their probability values. The interactive term (P_1P_2) shows no significant effect on the four responses. The fitting of the models was checked by the determination coefficient values (R^2 values = 99.49%, 98.29%, 99.51% and 99.77%), for tensile strength, elongation, tensile modulus, flexural strength, flexural modulus, hardness, impact strength, and water absorption, respectively. These results were in accordance with previous researchers (Soury et al, 2009; Hadi, 2011; Patpen et al, 2015). The value of R^2 and adjusted R^2 are not significantly different as shown in Table 3. These close values of R^2 and adjusted R^2 confirm the significance of the models (Khuri et al, 1987). These indicate good precision and reliability of the experiment (Kuchi, 2000).

Table 3: ANOVA for the four responses of avocado wood flour-high density polyethylene composite: Z_{TS}, Z_{FS},Z_{IM} and Z_W.

Z_{TS} Tensile Strength	Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	
	Model	9.966668	5	1.993334	273.0523	< 0.0001	Significant
	P_1-Particle Size	2.816597	1	2.816597	385.8252	< 0.0001	
	P_2-Filler Content	4.886902	1	4.886902	669.4214	< 0.0001	
	P_1 P_2	0.0025	1	0.0025	0.342457	0.5768	
	P_1^2	2.042211	1	2.042211	279.7477	< 0.0001	
	P_2^2	0.218457	1	0.218457	29.92491	0.0009	
	Residual	0.051101	7	0.0073			
	Lack of Fit	0.051101	3	0.017034			
	Pure Error	0	4	0			
	Cor Total	10.01777	12				
	R-Squared	0.994899					
	Adj R-Squared	0.991255					
	Pred R-Squared	0.962311					

Z_{FS} Flexural Strength	Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	
	Model	33.56657	5	6.71331	80.4233	< 0.0001	Significant
	P_1-Particle Size	0.984579	1	0.98457	11.7949	0.0109	
	P_2-Filler Content	14.50593	1	14.5059	173.776	< 0.0001	
	P_1 P_2	0.015625	1	0.01562	0.18718	0.6783	
	P_1^2	15.91444	1	15.9144	190.65	< 0.0001	
	P_2^2	2.14599	1	2.14599	25.7082	0.0014	
	Residual	0.584323	7	0.08347			
	Lack of Fit	0.584323	3	0.19477			
	Pure Error	0	4	0			
	Cor Total	34.15089	12				
	R-Squared	0.98289					
	Adj R-Squared	0.970669					
	Pred R-Squared	0.877486					

Z_{IM} Impact Strength	Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	
	Model	26.53859	5	5.30771	286.891	< 0.0001	Significant
	P_1-Particle Size	0.470996	1	0.47099	25.4581	0.0015	
	P_2-Filler Content	19.65221	1	19.6522	1062.23	< 0.0001	
	P_1 P_2	0.002025	1	0.00202	0.10945	0.7504	
	P_1^2	3.459724	1	3.45972	187.004	< 0.0001	
	P_2^2	2.953627	1	2.95362	159.648	< 0.0001	
	Residual	0.129506	7	0.01850			
	Lack of Fit	0.129506	3	0.04316			
	Pure Error	0	4	0			
	Cor Total	26.66809	12				
	R-Squared	0.995144					
	Adj R-Squared	0.991675					
	Pred R-Squared	0.964686					

Z_W Water absorption	Source	Sum of Squares	df	Mean Square	F Value	p-value Prob>F	
	Model	2.19637	5	0.43929	617.996	< 0.0001	Significant
	P_1-Particle Size	0.08399	1	0.083969	118.1332	< 0.0001	
	P_2-Filler Content	1.8447	1	1.8447	2595.251	< 0.0001	
	P_1 P_2	0.0016	1	0.0016	2.25099	0.1772	
	P_1^2	0.161248	1	0.161248	226.8551	< 0.0001	
	P_2^2	0.104831	1	0.104831	147.4828	< 0.0001	
	Residual	0.004976	7	0.000711			
	Lack of Fit	0.004976	3	0.001659			
	Pure Error	0	4	0			
	Cor Total	2.201323	12				
	R-Squared	0.99774					
	Adj R-Squared	0.996125					
	Pred R-Squared	0.983481					

3.3 D surface plots for the mechanical and water absorption properties of AW/HDPE composite showing different effect interactions for: Z_{TS}, Z_{FS}, Z_{IM} and Z_W.

Figure 1(a-d) presents the surface plot of the mechanical and water absorption properties of AW/HDPE composite as a function of particle size and filler content. It was observed in Figure 1 that the optimum tensile strength (Z_{TS}), flexural strength (Z_{FS}), impact strength (Z_{IM}) and water absorption properties (Z_w) were at mesh particle size of 100 to 20 mesh and filler content of 5 to 25 %.

From Fig.1 (a), the maximum tensile strength was obtained at lower filler content. This is due to higher filler content of AW in the HDPE matrix causes poor filler-matrix interaction leading to decrease in tensile strength. The maximum tensile strength was recorded at lower particle size. At lower filler size, the AW will have more dispersion in HDPE than higher filler size. The same trend was reported by previous works (Lee et al, 2009; Brent et al, 2014).

It was observed in Fig 1(b) that the optimum flexural strength was displayed at high filler weight and lower size particle. These observations could be concluded that lower size particle was able to resist bending during addition of AW into HDPE matrix. This outcome was discussed elsewhere (Mayers, 1991; Zaini et al, 1995: Stark and Berger, 1997ab; Gallager et al, 2013).

The impact strength of AW/HDPE composite at optimum was observed at 80 mesh size in Fig. 1 (c). It was observed that an increase in the filler content of AW decreases the impact strength of AW/HDPE composite. This may be attributed to tiny size of AW in HDPE stands larger energy to inhibit crack failure (Joseph et al, 2002; Lou et al, 2007). However, smaller size filler enlarges the impact strength of AW/HDPE composite. The trend was discussed by previous researchers (LeBaron et al, 1999: Gallager et al, 2013).

The ultimate water absorption was observed at high filler content in Fig. 1(d). The reason for this result was concluded that the addition of AW in the matrix increases more pore spaces in the composite. Thus, the hydrophilic nature of AW in the matrix decreases with increase in the weight of the filler. The highest water absorption resistance was recorded at minute filler size. The results were comparable to previous researchers (Zabihzabel, 2010; Kord, 2011; Lopez et al, 2006). This inference was ascertained due to high particles leads to large pores space for the composite to absorb water.

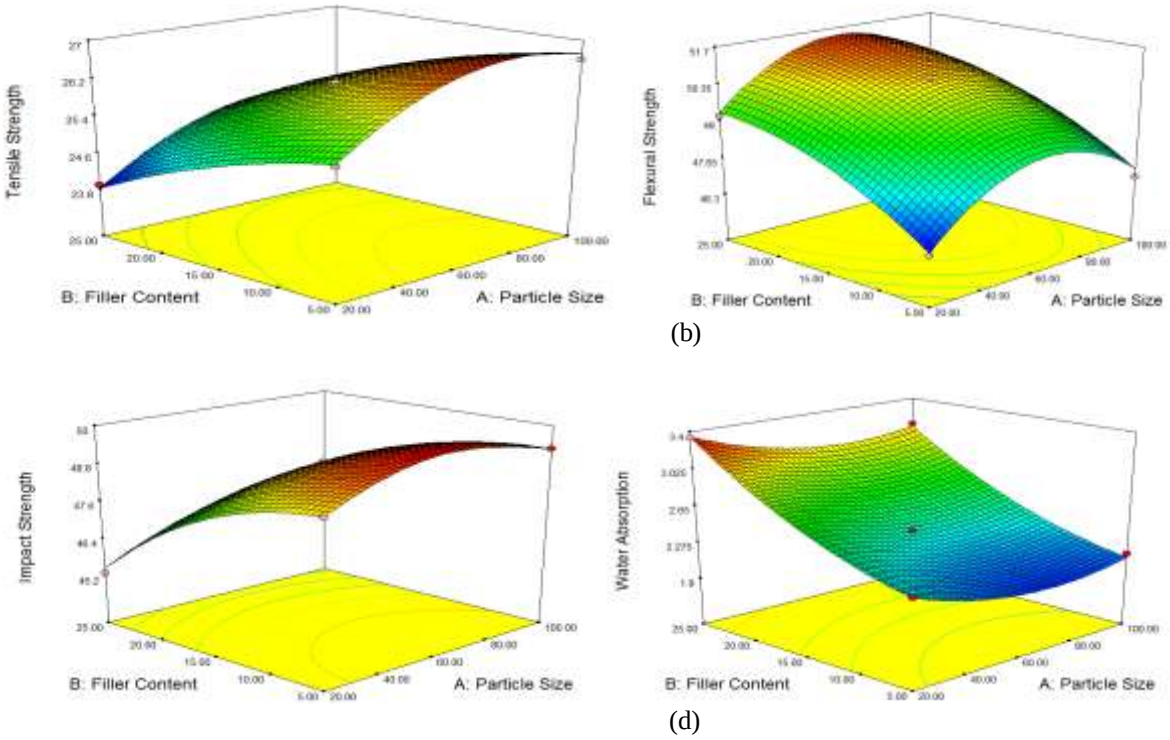


Figure 1: 3D Surface plots for the mechanical and water absorption properties of AW/HDPE composite: (a) Z_{TS} (b) Z_{FS} (c)Z_{IM} (d) Z_W as a function of particle size and filler content.

3.4 Model adequacy determination

Figure 2 (a-d) presents the predicted versus actual plots for the mechanical and water absorption properties of AW/HDPE composite. It was observed from the plots that predicted and the actual points were correlated with the straight line. This means that there is good correlation between the actual and predicted results. This trend was reported by other researchers (Mayers et al, 2004; Onyekwere et al, 2016). This confirmed that the models for the tensile strength, flexural strength, impact strength and water absorption were fit to predict the experimental values. From this investigation, these models were appropriate in predicting the properties of AW/HDPE composite.

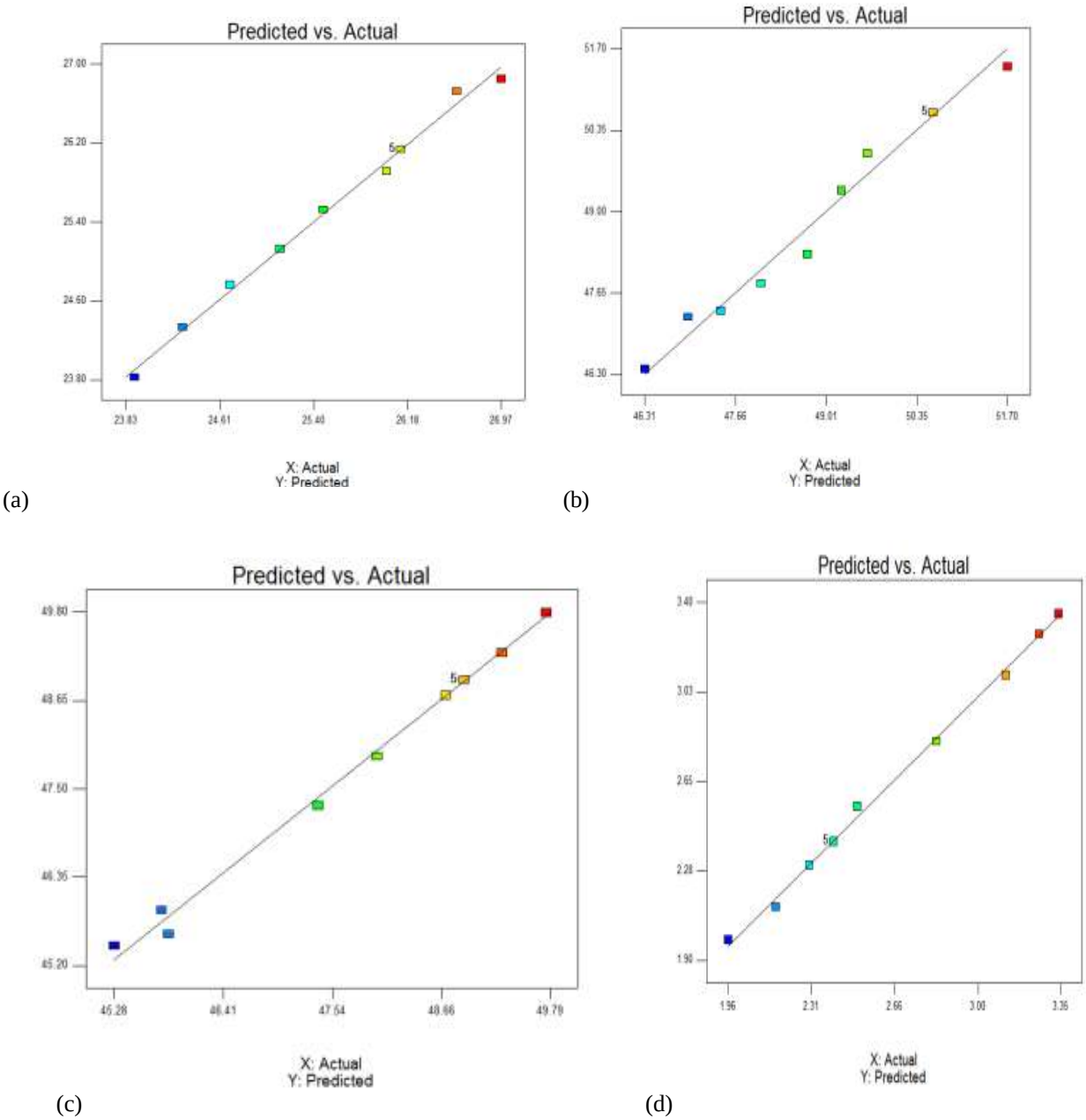


Figure 2: Predicted versus actual plots for mechanical and water absorption properties of AW/HDPE composite for: (a) Z_{TS} (b)Z_{FS} (c) Z_{IM} (d) Z_W.

3.5 Optimization

3.5.1 Model validation

Table 4 presents the analysis of the model at optimum values for mechanical and water absorption properties of AW/HDPE composite. The observation from the experimental analysis at optimum condition shows that there is agreement with the response surface models. The relative percentage deviation errors between the predicted and experimental response show that it is less than 1%. This depicts that the response surface model is an indication for good prediction of the experimental result.

Table 4: Analysis of the model predicted using optimum values for mechanical and water absorption properties of untreated avocado wood flour/high density polyethylene composites

Response	Particle Size (mesh)	Filler Weight (%)	Predicted Value of Response	Experimental Value of Response	Relative percentage deviation Error (%)
Z_{TS} (MPa)	80	21.62	25.65232	25.599	0.208307
Z_{FS} (MPa)	80	21.62	51.1682	50.987	0.35538
Z_{IM} (KJ/m^2)	80	21.62	47.46243	47.3974	0.137192
Z_W (%)	80	21.62	2.774477	2.782	0.27043

4.0. Conclusion

Central composite design was successfully employed in optimizing the two major factors in the study, particle size and filler weight on the mechanical properties and water absorption properties of avocado wood flour-high density polyethylene composites. The results presented have shown that particle size and filler weight affected the mechanical properties of the composites. From the optimization process, maximum mechanical and water absorption properties were 25.652 MPa, 55.168 MPa, 47.397 KJ/m^2 and 2.782 % for Z_{TS},$Z_{FS,}$ Z_{IM} and Z_W, respectively at optimum condition of particle size 0f 80 mesh and filler weight of 21.62 %. The confirmation experiments indicated good experimental and model results, showing response surface methodology was successfully employed for optimization of avocado wood flour polymer composite.

5.0 Recommendation

The AW/HDPE composite produced can be recommended as alternative material to medium-density-fiber board for furniture and furnishing applications.

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