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Prediction of the Tensile Strength of an Experimental Design Reinforce Polyvinyl Chloride Composite using Response Surface Methodology

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Abstract

In this study, a five factor Box-Behnken Design (BBD) was applied to plan and perform experiments for the production of composite polyvinyl chloride (PVC) material. The Box-Behnken Design combined with Response Surface Methodology (RSM) was utilized to optimise the production variables, physical and tensile strength of composite PVC. Design Expert® software version 7.0.0, (Stat-ease, Inc. Minneapolis, USA) was used for the experimental design. The Design Expert® software utilizes the concept of randomization to generate the experimental design. This was achieved by scheduling the experiments in a random manner in order to minimise the effects of unexplained variability in the response. The design involved five different variables; three of which are the composite constituents (PVC, raffia palm and plantain peduncle) and the remaining two are the production variables (temperature and pressure). An assessment of the results showed that the quadratic model was suitable for modelling the responses considered in this study. The R^2 value was close to one while the standard deviation was equally small. The result of the experimental and RSM predicted results for tensile strength showed that for all responses considered, there was close similarity between the experimental results and those predicted by the quadratic model. The results of the parity plots obtained shown that there was a good fit between the model predictions and the experimental results, thus, validated. Besides, increasing the proportion of PVC resulted in a steep and significant increase in the tensile strength of the composite. Thus, the tensile strength was improved as a result of the synergistic effect of the PVC and the fiber. However, increasing the level of rattan and plantain peduncle did not result in an increase in the tensile strength of the composite and this was as a result of the low lignin content of these fiber materials. Similarly, increasing the temperature and pressure resulted in a decrease in the tensile strength of the composite pipes.

Keywords: Tensile Strength, Response Surface Method, Reinforce PVC, Composite, Experimental Design.

1. Introduction

Plastics are generally used for an extensive range of commercial and industrial piping applications [1-4]. The most common types are polyvinyl chloride (PVC), polyethylene (PE), polypropylene (PP), acrylonitrile–butadiene–styrene (ABS), polybutylene (PB) and glass–fibre reinforced polyester (GRP or FRP) [5-6]. However, because of the ability of thermoplastics to be reheated, remelted, and remolded, they were selected for this present study. The aforementioned attributes have the potential to give thermoplastics an essentially endless shelf life as well as making them easily repairable and recyclable. Besides, PVC water pipes preserve drinking water quality due to their high degree of inertness and resistance to corrosion. PVC pipes are therefore free from bio-film contamination that can be a breeding ground for bacteria. PVC water pipes also prevent unnecessary water waste from source to consumer. In the study area, one major usage of plastics is for water storage and water transportation. Similarly, PVC has outstanding chemical resistance to wide range of corrosive fluids and offer more strength and rigidity than most of the other plastics [7-9]. For instance, the tensile stress of PVC is 40-60 MPa, its modulus of elasticity is 2-7 GPa and with has a density of 1380-1410 kg/m^3 [10-12]. PVC possesses unique responsive to functional additives which permit the generation of rigid and flexible products, useful in designed engineering application [10]. Nevertheless, for some specific uses and mechanical properties, the application of PVC might be inadequate. Thus, various approaches have been developed to improve on the properties of PVC [13-16]. The properties of PVC are modified using fillers and fibres to suit improved mechanical properties such as tensile strength and high modulus requirements [17]. Research has shown that fibre reinforce plastics have mechanical properties compared to the conventional materials and find applications in diverse field, ranging from different applications in the industry [18]. There are three principal ways in which the reinforcing material can be achieved: as grainy material (or particulates), as fibre (in the form of individual fibres embedded in the matrix) and as layers

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(fibres woven into mats which are laid on top of one another to create a laminate [19-21].Reinforced composites comprise of a high strength additive included with the virgin resin and it include Kevlar fibre, glass, etc. These fibers may be random, oriented, or in a mat format but, in some cases, fine metal shavings are used. Reinforced composite materials are widely acknowledged considering their eco-friendliness and sustainable features as compared with conventional synthetic fiber-based composites [22-28]. Besides, the possibility of adaptation of fiber reinforced composite is much easier as compared with other materials. Thus, this makes these materials to be applied in diversified and voluminous areas as noticed in building materials, aerospace industry, mattress industry, crude oil industry, and automotive industry [29]. However, natural reinforcements (NR) are usually applied and this is due to the advantages they possess over synthetic reinforcements resulting from the natural alignment of the carbon–carbon bonds and also their significant strength, stiffness [30, 54-60], low density, low cost and biodegradability they offer. Also, natural reinforcements provide specific properties, better structure insulating properties, and low energy consumption during their growth or processing [30-31].

Above and beyond, the mechanical properties of NF reinforced polymer matrix composites (PMCs) depend on a number of factors, such as volume fraction of the fibers, fiber–matrix adhesion, stress transfer at the interface, and orientation of the fibers [31, 61-64]. The tensile properties of PMCs depend on the interfacial strength achieved between the fibers and polymer matrix since fibers have much higher strength and stiffness values than those of the matrices [32]. Previous research work suggests that as the fiber content in the composite increase, there was a corresponding increase in both the strength and modulus [33]. Also, [34-35] studied the influence of flax fiber addition on the mechanical properties of high-density polyethylene (HDPE). They reported that flax fiber reinforced HDPE containing 30 wt. % fibers gave the highest flexural strength and modulus, which are 51% and 128% respectively over that of pure HDPE.

A composite is an exact blending of two or more materials to create a new material that is stronger, lighter (less comparable weight) and easier to work with than alternative individual material such as plastics and metal [36]. Composite materials are grouped according to structural design, (i.e. type of reinforcing element and its disposition in the matrix); material type (i.e. type of matrix and reinforcements and their properties); processing technology (i.e., production process) [37]. Composite primarily consists of matrix and reinforcement and in addition may contain a third component known as ‘filler’. The filler is mixed with the matrix during fabrication and may not necessarily improve the mechanical properties but rather some aspects of desired considerations. According to Dan-asabe*et al.* [38], a banana particulate reinforced polyvinyl chloride (PVC) composite will result to an optimum density of 1.24 g/cm3, Young’s Modulus of 1.3 GPa and tensile strength of 42 MPa. Also, David *et al.*[39] developed kenaf reinforced propylene (PP) composite having maximum value of elastic moduli of 1.89 GPa and 2.64 GPa recorded at 2 mm/min and 10 mm/min extension rates respectively for a 60% weight of kenaffbre content. Mirza *et al.* [40] on the other hand, developed a jute fibre reinforced polypropylene (PP) composite using injection molding and determined that tensile strength and Modulus were enhanced as compared to the pure polypropylene. Nuher*et al.* [41] suggested that a palm fibre reinforced acrylonitrile butadiene styrene (ABS) composite will result to an increased density and water absorption. The PVC is a widely used plastic [42] and also one of the most valuable products of the chemical industry and the second-largest thermoplastic commodity produced worldwide after polyethylene [44]. Polyvinyl chloride (PVC) is readily available in Nigeria and is a better resistant to chemical attack [45] and weighs lesser than most metals. Nevertheless, because of the residential and commercial requirements in the study area, PVC-U pipes, which are used mainly for transportation of drinking water, soil and waste, sewage, underground drainage, and industrial applications, were selected for this investigation. Besides, the ability of PVC U-pipes to withstand a maximum amount of tensile stress without failure is a major determining factor in their selection for usage. Tensile stress occurs while the material is being pulled or stretched and is the point at which the material goes from elastic to plastic deformation. Therefore, a study to evaluate and predict the tensile strength of an experimentally designed reinforced PVC composite PVC U-pipe using response surface methodology is urgently needed.

Furthermore, a five-factor Box-Behnken Design (BBD) was used to plan and execute the experiments for the production of composite PVC material. Box-Behnken designs are usually used to generate higher-order response surfaces using fewer required runs than a normal factorial technique. This and the central composite techniques essentially suppress selected runs in an attempt to maintain the higher-order surface definition. The Box-Behnken design uses twelve middle edge nodes and three center nodes to fit a second-order equation. The central composite plus Box-Behnken becomes a full factorial with three extra samples taken at the center. Box-Behnken designs place points on the midpoints of the edges of the cubical design region, as well as points at the center. Box-Behnken design is still considered to be more proficient and powerful than other designs such as the three-level full factorial design, central composite design (CCD), and Doehlert design, despite its limitations resulting from poor coverage of the corner of nonlinear design space.

2. Materials and Methods

The raffia palm and plantain peduncle used in this study were collected from Okada, Ovie North East Local Government Area of Edo State. The natural fibers obtained from raffia palm and plantain peduncle were processed to remove the pulp that holds them together. The resulting raw fibers were subsequently cleaned with 2% detergent to remove oily substances and other impurities from the fiber surface. After cleaning, the fibers were dried in an oven at 70^{o}C for one day and subsequently air-cooled to room temperature. The PVC powder was collected from Forsten PVC Company, Benin-Lagos Expressway, Nigeria.

To improve fiber-matrix adhesion, chemical treatments were carried out to alter their surface chemistry via alkaline (NaOH) treatments. Two aqueous solutions of NaOH with different concentrations (5% and 10% by weight) were prepared by dissolving sodium hydroxide pellets in distilled water. The ground fibers were immersed in the 5% w/v and 10% w/v aqueous NaOH solutions at room temperature for selected durations of time (5 h, 10 h, and 20 h) with a solution-to-fiber ratio of 10 ml to 1 g. Correspondingly, ground fiber was immersed in a 10% w/v aqueous NaOH solution at 60 °C for 5 h with a solution-to-fiber ratio of 10 ml to 1 g. After the immersion, the fibers were initially washed in laboratory water and finally in distilled water to ensure that no NaOH was left. Subsequently, the fibers were dried at 60^{o}C for a duration of one (1) day. After thorough mixing of the ground fibers with the PVC powder, the blend was fed into a parallel twin-screw extruder (model SHJ-35) machine (Figure 2), where uniformly mixed extrudates were produced. The tensile test analysis was conducted using an Instron TM (model 5500R) machine according to the ASTM D638 standard. The test was conducted at ambient temperature (25ºC) and 20% relative humidity. The test specimens were cut into a dog-bone shape of 160 mm by 22 mm by 3.5 mm using a hydraulic cutter. The specimens were tested for each composite formulation with a load cell of 8 kN and a crosshead speed of 5 mm/min. An extensometer with a 50-mm gauge length was attached to the test specimens.

The Box-Behnken Design (BBD) was used to plan and execute the experiments for the production of composite PVC material. The Box-Behnken Design was coupled with response surface methodology (RSM) to optimise the production variables, physical and tensile strength of composite PVC. The Box-Behnken Design, BBD for the response surface methodology, RSM, is specially designed to fit a second-order model, which is the primary interest in most RSM studies. To fit a second-order regression model (quadratic model), the BBD only needs three levels for each factor. The BBD set a mid-level between the original low and high-level of the factors, avoiding the extreme axial (star) points. Moreover, the BBD uses face points, often more practical, rather than the corner points. The addition of the mid-level point allows the efficient estimation of the coefficients of a second-order model. The quadratic (second order) model is shown in Equation 1.

$$Y = b_o + \sum_{i=1}^{N} b_i X_i + \sum_{i,j=1}^{N} b_{ij} X_i X_j + \sum_{i=1}^{N} b_{ii} X_i^2 + \sum_{i=1}^{N} e_i \qquad (1)$$

The quadratic model is easily the most commonly used model for RSM and this is because it is very flexible, and the unknown model parameters can easily be estimated using the least squares method algorithm in the Design Expert software. For the quadratic models, the method of ridge analysis was used for optimising the tensile strength. The condition of optimality of the second order model is that the Hessian matrix obtained from the model (after incorporating the Lagrange multipliers) with respect to the independent variables must be positive definite for a minimisation problem and negative definite for a maximisation problem. RSM is used for the experimental design and empirical modelling of processes and has the capacity for determining mathematical relationships between experimental factors and process responses. The RSM has the ability to reduce the number of experimental runs required to obtain acceptable results. Beyond that, it can be used to identify the optimum combination of process factors for the process under consideration [46].The Box-Behnken Design was chosen in this study for the experimental design because it has been found to be very adequate for fitting quadratic response surfaces which are usually encountered in most production processes [47-48, 69-70]. The experimental design was implemented in Design Expert® software version 7.0.0, (Stat-ease, Inc. Minneapolis, USA). Design-Expert was selected in this study because, unlike other statistical software, it makes it easy to see what, if anything, emerges as statistically significant and how to model the results most precisely. Besides, the feature of automated model-reduction tools, paired with in-line diagnostic graphs, provides a streamlined analysis process. The design involved five variables, three of which are the composite constituents (PVC, raffia palm and plantain peduncle) and the remaining two production variables (temperature and pressure). The range and levels of these variables are shown in Table 1. The Design Expert® software utilizes the concept of randomization to generate the experimental design. This is usually done by scheduling the experiments in a random manner in order to minimise the effects of unexplained variability in the response [49]. The values of the independent variables were calculated using Equation (2).

$$x_i = \frac{X_i - X_o}{\Delta X_i} \qquad (2)$$

where,

x_i and X_i = Coded and actual values of the independent variable respectively

X_o = Actual value of the independent variable at the centre point, and

ΔX_i = Step change in X_i.

a. Plantain peduncles fibre b. Raffia palm fibre c. PVC Powder

Figure 1. Raw materials used

a. Twin-screw extrusion machine b. Instron™ tensile machine

Figure 2. Equipment used

The data in Table 1 was used to generate the experimental design matrix as shown in Table 2 and this was used to plan and execute the experiments for the production of the composite PVC. The melting temperature of PVC is in the range of 100 - 260°C. Thus, the experimental design temperature was set to be in that range.

$$\begin{aligned} \textit{Tensile strength} = & -10.85 + 0.19X_1 + 0.78X_2 + 0.079X_3 - 0.0067X_4 + 0.0036X_5 - 0.0010X_1X_2 \\ & - 0.00016X_1X_4 + 0.000045X_1X_5 - 0.00080X_2X_3 + 0.00078X_2X_4 + 0.0017X_2X_5 \\ & + 0.00050X_3X_4 - 0.00065X_3X_5 + 0.000038X_4X_5 - 0.00072X_1^2 - 0.029X_2^2 - 0.010X_3^2 \\ & - 0.0000097X_4^2 - 0.00025X_5^2 \end{aligned} \tag{3}$$

Table 1. Coded and Actual Levels of the Factors for Box-Behnken Design

Factors	Unit	Symbols	Coded and Actual Levels		
			-1	0	1
PVC	%	X_1	50	60	70
Raffia Palm	%	X_2	15	17.5	20
Plantain Peduncle	%	X_3	5	7.5	10
Temperature	ºC	X_4	110	200	290
Pressure	MPa	X_5	55	82.5	110

Table 2. Experimental Design Matrix for Five Factors BBD for Producing Composite PVC

Run	Factors				
	PVC	Raffia Palm	Plantain Peduncle	Temperature	Pressure
1	70	15	7.5	200	82.5
2	60	17.5	10	200	82.5
3	50	17.5	7.5	200	82.5
4	70	17.5	10	200	82.5
5	60	17.5	7.5	200	82.5
6	60	15	10	200	82.5
7	60	17.5	10	200	110
8	60	17.5	7.5	200	82.5
9	60	17.5	7.5	200	82.5
10	60	15	7.5	200	110
11	60	15	5	200	82.5
12	60	20	7.5	110	82.5
13	60	17.5	5	200	82.5
14	50	17.5	7.5	200	55
15	60	17.5	7.5	110	55
16	60	17.5	10	200	55
17	70	17.5	7.5	200	55
18	60	17.5	10	110	82.5
19	60	17.5	7.5	200	110
20	70	20	7.5	200	82.5
21	60	17.5	5	200	110
22	60	17.5	7.5	200	55
23	70	17.5	7.5	110	82.5
24	70	17.5	7.5	200	110
25	60	20	5	200	82.5
26	60	20	7.5	200	82.5
27	60	15	7.5	110	82.5
28	60	17.5	7.5	200	82.5
29	60	17.5	5	200	55
30	50	15	7.5	200	82.5
31	60	20	10	200	82.5
32	70	17.5	7.5	200	82.5
33	60	17.5	7.5	110	110
34	60	15	7.5	200	82.5
35	50	20	7.5	200	82.5
36	50	17.5	5	200	82.5
37	50	17.5	7.5	110	82.5
38	60	20	7.5	200	110
39	60	20	7.5	200	55
40	50	17.5	7.5	200	110
41	70	17.5	5	200	82.5
42	60	15	7.5	200	55
43	60	17.5	7.5	200	82.5
44	60	17.5	5	110	82.5
45	60	17.5	7.5	200	82.5
46	50	17.5	10	200	82.5

The predictive ability of the developed models for the responses was evaluated by comparing the predicted results by the models with those of the actual experiments. Also, the level of fit between the two was evaluated by using the coefficient of determination (R^2 value), adjusted coefficient of determination (adjusted R^2 value), predicted coefficient of determination (predicted R^2 value), standard deviation, coefficient of variation and adequate precision [50]. Generally, it is desirable that the R^2 value be as close to unity as possible while the standard deviation should be as small as possible [51, 66-68]. A low coefficient of variation is also desired while the adequate precision should be greater than 4 for the model to be useful in navigating the design space. The R^2 value is a measure of the amount of variation around the mean explained by the model. The Adjusted R^2 is a measure of the amount of variation around the mean explained by the model, adjusted for the number of terms in the model. The adjusted R^2 decreases as the number of terms in the model increases if those additional terms do not add value to the model. Both the R^2 and related Adjusted R^2 values should be close to one [67]. A value of 1 represents the ideal case at which 100 percent of the variation in the observed values can be explained by the chosen model [68]. The Predicted R^2 estimates the amount of variation in new data explained by the model. It can be negative, but this is very bad and suggests that the model consisting of only the intercept is a better predictor of the response than this model. The closer to 1, the better the predicted R^2 [52]. The standard deviation was used to express the deviation of the individual response values from the mean. A small value of standard deviation is generally desired and the PRESS statistic, indicates how well the model fits the data. The PRESS for the chosen model should be small relative to the other models under consideration [67, 68].

3. Results and Discussion

Tables 1 shows the model summary of fit test results of tensile strength. Evaluation of the results showed that the quadratic model was appropriate for modelling the responses considered in this study. The quadratic model displayed a good coefficient of determination (R^2) as well as low standard deviation and predicted residual error sum of squares (PRESS). In this case, the R^2 value was close to one while the standard deviation was equally small which is an indication that the developed model is accurate. The PRESS statistic gives a measure of how a particular model fits each design point and a small value is desirable and this was the case in this study.

Table 1. Summary of model fit results for tensile strength

Source	Standard deviation	R^2	Adjusted R^2	Predicted R^2	PRESS
Quadratic	0.06	0.9861	0.9749	0.9679	0.2

The lack of fit test results presented in Tables 2, for tensile strength of the quadratic model showed a non-significant lack of fit. This further confirmed that the quadratic model can predicts the tensile strength of the Experimental Design Reinforce PVC Composite using Response Surface Methodology. The lack of fit test is the variation of the data around the fitted model. If the model does not fit the data well, this will be significant.

For a statistical model, the F value of a model term is used for comparing the term's variance with the residual variance. It is mathematically expressed as the ratio of the mean square for that term to the mean square for the residual. The F value assesses the significance of additional terms to a model. Small F values are usually indicative of non-significance of the terms. The P value (Prob>F) is the probability value that is associated with the F Value for a particular term model. It is the probability of getting an F Value of this size if the term did not have an effect on the response. In general, a term that has a probability value less than 0.05 would be considered a significant effect, otherwise, it is generally regarded as not significant but this was not the case in this study because the value was determined to be 0.9997. Also, the lack of fit p value is the probability associated with the lack of fit calculation for a model. Generally, a good model should have an insignificant probability value, or p>0.10. Therefore, the model is a good one.These findings agree with the research work of [58-72]. According to them, the decision to reject the null hypothesis can be provided by the p-value. When the p-value is less than 0.05, it simply confirms the rejection of the null hypothesis, thereby stating that the factor is significant. Also, the amount of F-value is directly proportional to the relative significance of the concerned factor with respect to others. Thus, if the values of Prob>F are less than 0.05, then the corresponding factors are significant.

Table 2. Lack of fit test results for tensile strength

Source	Sum of square	degree of freedom	Mean square	F-value	p value
Quadratic	0.030	20	1.50E-03	0.13	0.9997

Similarly, adequate precision was evaluated using equation (3). This is a signal to noise ratio. It compares the range of the predicted values at the design points to the average prediction error. Ratios greater than 4 indicate adequate model discrimination.

$$\left[\frac{\max(\hat{Y})-\min(\hat{Y})}{\sqrt{\bar{V}(\hat{Y})}}\right]>4 \qquad \bar{V}(\hat{Y})=\frac{1}{n}\sum_{i=1}^{n}V(\hat{Y})=\frac{p\sigma^2}{n} \quad (4)$$

where,

p = number of model parameters (including intercept (b_0) and any block coefficients)

σ^2 = residual MS from ANOVA table

n = number of experiments

For the results presented in Table 3, it can be seen that the R_i^2 value was in the range 0.0000 to 0.1636. This is acceptable as these values are close to the ideal value of R_i^2 i.e. 0.0000. The R_i^2 shows the level of collinearity between model terms. Low R_i^2 values are desirable. High values usually mean that the design lacks orthogonality and the model terms exhibit collinearity, a situation which is not desirable. According to[71-76], the ideal case for a design is that the R_i^2 values of all the model terms should be equal to zero in which case we have a purely orthogonal design. High R_i^2 values are not desirable because it is usually an indication that the model terms are correlated with each other and this could result in a bad model.

Table 3 shows the result of the experimental and RSM predicted values for tensile strength. A total of 46 experimental results were obtained for each response. The predictive model (Equation 2) which was obtained by fitting the general quadratic model to the experimental results was then used to predict their corresponding responses. It can be seen that for all responses considered, the values obtained for the experimental results and those predicted by the quadratic model are very close and this is an indication of the validity of the statistical model developed [53].

Table 3. Estimated standard error of design model terms

Term	Standard error	VIF	R_i^2	Power at 5 % alpha level for effect of		
				0.5 Std. dev.	1 Std. dev.	2 Std. dev.
X_1	0.25	1	0	16.1 %	48.5 %	97%
X_2	0.25	1	0	16.1 %	48.5 %	97 %
X_3	0.25	1	0	16.1 %	48.5 %	97 %
X_4	0.25	1	0	16.1 %	48.5 %	97 %
X_5	0.25	1	0	16.1 %	48.5 %	97 %
X_1X_2	0.5	1	0	7.7 %	16.1 %	48.5 %
X_1X_3	0.5	1	0	7.7 %	16.1 %	48.5 %
X_1X_4	0.5	1	0	7.7 %	16.1 %	48.5 %
X_1X_5	0.5	1	0	7.7 %	16.1 %	48.5 %
X_2X_3	0.5	1	0	7.7 %	16.1 %	48.5 %
X_2X_4	0.5	1	0	7.7 %	16.1 %	48.5 %
X_2X_5	0.5	1	0	7.7 %	16.1 %	48.5 %
X_3X_4	0.5	1	0	7.7 %	16.1 %	48.5 %
X_3X_5	0.5	1	0	7.7 %	16.1 %	48.5 %
X_4X_5	0.5	1	0	7.7 %	16.1 %	48.5 %
X_1^2	0.34	1.2	0.1636	29.5 %	81 %	99.9 %
X_2^2	0.34	1.2	0.1636	29.5 %	81 %	99.9 %
X_3^2	0.34	1.2	0.1636	29.5 %	81%	99.9 %
X_4^2	0.34	1.2	0.1636	29.5 %	81 %	99.9 %
X_5^2	0.34	1.2	0.1636	29.5 %	81 %	99.9 %

Table 4. Experimental and RSM predicted results for tensile strength

Run	Factors					Response	
	PVC (%)	Rattan (%)	Plantain peduncle (%)	Temp. (°C)	Pressure (MPa)	Actual experiment (MPa)	RSM prediction (MPa)
1	70	15.0	7.5	200	82.5	3.06	3.04
2	60	17.5	10.0	290	82.5	2.57	2.55
3	50	17.5	7.5	290	82.5	2.13	2.12
4	70	17.5	10.0	200	82.5	2.97	2.98
5	60	17.5	7.5	200	82.5	2.50	2.66
6	60	15.0	10.0	200	82.5	2.37	2.35
7	60	17.5	10.0	200	110	2.16	2.18
8	60	17.5	7.5	200	82.5	2.70	2.66
9	60	17.5	7.5	200	82.5	2.70	2.66
10	60	15.0	7.5	200	110	2.16	2.15
11	60	15.0	5.0	200	82.5	2.58	2.57
12	60	20.0	7.5	110	82.5	2.21	2.15
13	60	17.5	5.0	290	82.5	2.57	2.55
14	50	17.5	7.5	200	55	1.93	1.92
15	60	17.5	7.5	110	55	2.54	2.53
16	60	17.5	10.0	200	55	2.40	2.42
17	70	17.5	7.5	200	55	3.02	3.03
18	60	17.5	10.0	110	82.5	2.27	2.26
19	60	17.5	7.5	290	110	2.46	2.45
20	70	20.0	7.5	200	82.5	2.89	2.90
21	60	17.5	5.0	200	110	2.48	2.49
22	60	17.5	7.5	290	55	2.42	2.41
23	70	17.5	7.5	110	82.5	3.17	3.19
24	70	17.5	7.5	200	110	2.89	2.90
25	60	20.0	5.0	200	82.5	2.47	2.48
26	60	20.0	7.5	290	82.5	2.53	2.56
27	60	15.0	7.5	110	82.5	2.58	2.59
28	60	17.5	7.5	200	82.5	2.70	2.66
29	60	17.5	5.0	200	55	2.54	2.55
30	50	15.0	7.5	200	82.5	1.90	1.86
31	60	20.0	10.0	200	82.5	2.24	2.25
32	70	17.5	7.5	290	82.5	3.02	2.96
33	60	17.5	7.5	110	110	2.20	2.19
34	60	15.0	7.5	290	82.5	2.20	2.30
35	50	20.0	7.5	200	82.5	1.83	1.82
36	50	17.5	5.0	200	82.5	2.08	2.07
37	50	17.5	7.5	110	82.5	1.70	1.77
38	60	20.0	7.5	200	110	2.27	2.28
39	60	20.0	7.5	200	55	2.19	2.20
40	50	17.5	7.5	200	110	1.75	1.75
41	70	17.5	5.0	200	82.5	3.19	3.20
42	60	15.0	7.5	200	55	2.54	2.53
43	60	17.5	7.5	200	82.5	2.80	2.66
44	60	17.5	5.0	110	82.5	2.72	2.71
45	60	17.5	7.5	200	82.5	2.57	2.66
46	50	17.5	10.0	200	82.5	1.85	1.85

The predicted results by the RSM models for the responses were validated by comparing them with the actual experimental results. This was done by producing parity plots and the result is shown in Figure 3. The essence of producing the parity plots is to evaluate the level of fit between the model predictions and the experimental results. A good fit result is obtained since the data points for the plot clustered around the 45^o diagonal line [54]. This means that there is little deviation between the model predictions and the experimental results. The results presented in Figures 3 indeed show that there was a good fit between the model predictions and the experimental results.

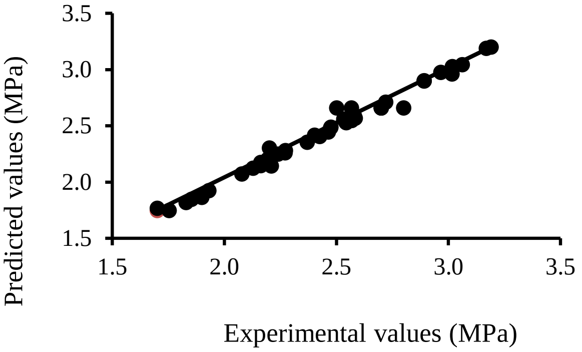

Figure 3. Parity plot for model representing tensile strength

The tensile strength of the composite PVC produced was positively influenced by the composition of PVC and rattan as shown by the 3D and contour plots (Figures 4 and 5).

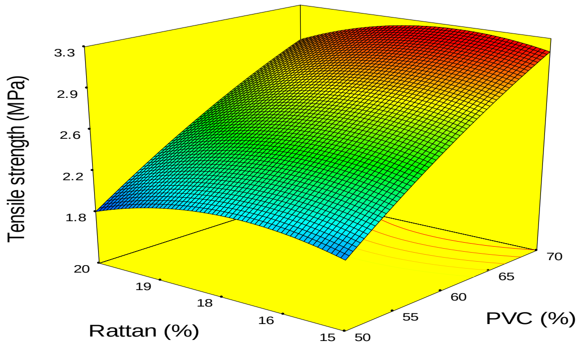

Figure 4. Response surface plot showing the effect of PVC and rattan composition on tensile strength

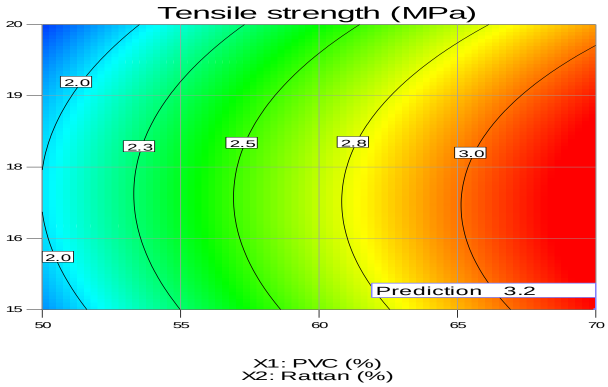

Figure 5. Contour plot showing the effect of PVC and rattan composition on tensile strength

The relationship between input variables and tensile strength shows that increasing the proportion of PVC resulted in a steep and significant increase in the tensile strength of the composite and this observation occurs both at low and high levels of rattan. This finding could be attributed to the mechanical strength which the PVC particles provide to the composite. Similar findings were also reported by researchers in the past. For instance, Dinh*et al.*[55] produced polypropylene composites reinforced with wheat and flax straw fibres and evaluated their mechanical properties. Their findings show that the tensile strength improved as a result of the synergistic effect of the polymer and the fibres. It was reported by [56], that the coupling of the polymer material with the fibre conferred superior properties on the produced composite material thus, resulting to an increase in strength. This behavior was attributed to the flow and film formation of the PVC in the composite structure [56]. Figure 6 and 7 show that increasing the level of rattan and plantain peduncle did not result in an increase in the tensile strength of the composite.

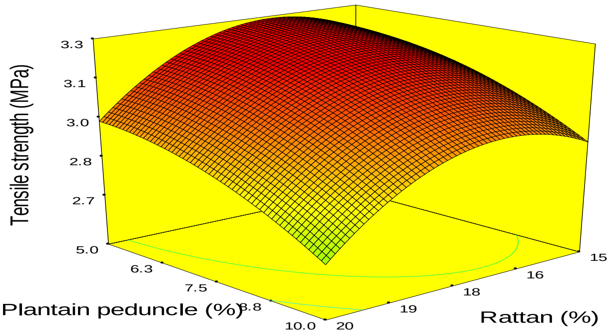

Figure 6. Response surface plot showing the effect of rattan and plantain peduncle composition on tensile strength

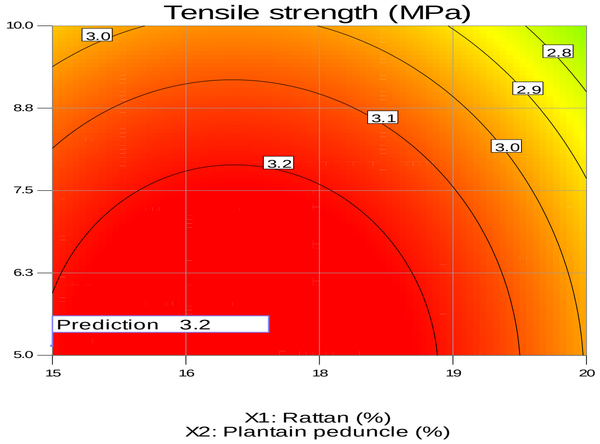

Figure 7. Contour plot showing the effect of rattan and plantain peduncle composition on tensile strength

This could be as a result of the low lignin content of these fibre materials [57]. According to Feldman *et al.*[51], the existence of proton donor–proton acceptor interactions between PVC and lignin chains results in the enhancement of the mechanical properties like tensile strength. Thus, the low lignin content of these fibre materials could have worked against its properties. Figures 8 and 9 show that increasing the temperature and pressure resulted in a decrease in the tensile strength of the composite pipes produced.

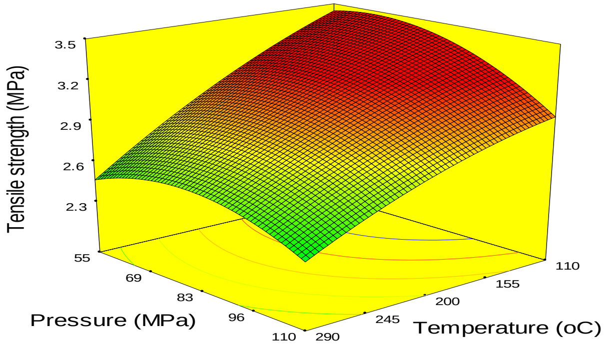

Figure 8. Response surface plot showing the effect of temperature and pressure on tensile strength

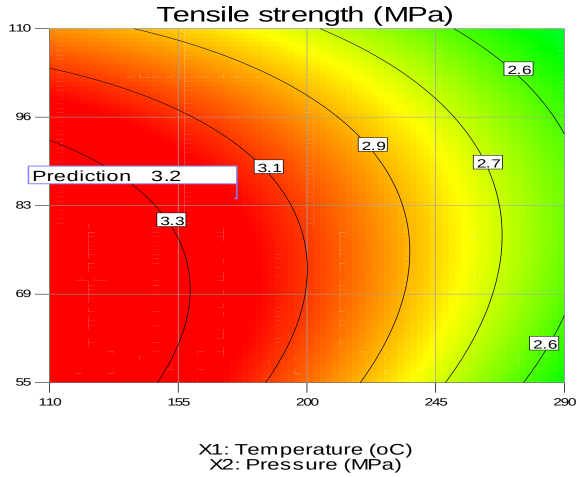

Figure 9: Contour plot showing the effect of temperature and pressure on tensile strength

According to Hebel *et al.* [49], varying both temperature and pressure at the same time significantly alters the mechanical properties of the composite. They attributed this to variations of the viscosity of the polymer material at higher temperatures and therefore variations of the fiber wetting and/or different binder-network structures are formed under different temperature/pressure conditions. Furthermore, operating at elevated temperatures could result in the carbonization of the fibers – especially at elevated pressures – which consequently leads to a modification of the intrinsic fiber matrix and a loss of tensile strength.

4. Conclusion

In this study, the prediction of the tensile strength of an experimental design reinforce PVC composite using response surface methodology was successfully carried out. The predictive capacity of the developed models for the responses was assessed by comparing the results predicted by the models with those of the actual experiments. The level of fit between the two was assessed by using the coefficient of determination (R^2 value), adjusted coefficient of determination (adjusted R^2 value), predicted coefficient of determination (predicted R^2 value), standard deviation, coefficient of variation and adequate precision. An evaluation of the results showed that the quadratic model was suitable for modelling the responses considered in this study. The quadratic model displayed a good coefficient of determination (R^2 value of 0.9861, predicted R^2 value of 0.9679, and adjusted R^2 value of 0.9749) as well as the low standard deviation value of 0.06, and predicted residual error sum of squares (PRESS) value of 0.2. The lack of fit test results for tensile strength of the quadratic model showed a non-significant lack of fit. This further confirmed that the quadratic model can predict the tensile strength of the Experimental Design Reinforce PVC Composite using Response Surface Methodology. The results predicted by the RSM models for the responses were validated by comparing them with the actual experimental results. This was done by producing parity plots and the result obtained showed that there was a good fit between the model predictions and the experimental results. Moreover, the tensile strength of the composite PVC produced was positively influenced by the composition of PVC and rattan. With respect to the relationship between input variables and tensile strength, it shows that increasing the proportion of PVC resulted in a steep and significant increase in the tensile strength of the composite. Nevertheless, some potential limitations of the response surface method were observed. The experimental data are fitted to a polynomial model at the second level, and this might restrict the behavior of responses so that it cannot explain all systems containing curvature. Thus, as the number of independent variables increases, it is expected that the number of experiments will also increase, which exhibits low prediction capability outside the experimental domain. Therefore, for future studies, the number of applied states can be considered to better understand the logic of optimization of the production of composite PVC materials. Besides, both independent and dependent parameters can be varied to enhance optimization of composite PVC materials.

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