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Investigation of Low Density Polyethylene Polymeric Composite Using Split-Split Plot Experimental Designs

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Abstract

This study focused on the investigation of polymeric composite of low density polyethylene and clay using split-split plot experimental designs. The effects of process parameters such as percentage by volume of material, material type, barrel temperature and their interactions on the mechanical properties of the produced low density polyethylene-clay composite using split-split plot design was examined. The mechanical properties investigated in this study include; proof stress, percentage elongation, tensile strength and flexural strength. The values obtained from the evaluation of the mechanical properties were imputed into the analytical design of the split-split plot to obtain its numerical designs. Interactive model for the process parameters were also developed for this study. The sum of squares (SS) and the mean of square (MS) were calculated from the numerical designs of split-split plot to obtain the Fisher's ratio (F_{cal}) values. The results of the calculated Fisher's ratio at significant value of 0.05 for the process parameters and their interactions ranges from -80.11 to 29.95, and were presented on analysis of variance (ANOVA) table. The results obtained shows that these process parameters contribute significantly to the production of low density polyethylene-clay composite for domestic and industrial applications.

1. Introduction

A qualitative analysis of the influence of process parameters such as barrel temperature, percentage by volume of material and material type on the mechanical properties of injection moulded part will be helpful in gaining better insight into low density polyethylene-clay composite processing methods [1]. Moreover, inadequate investigation of the effects of the interaction of process parameters in the production of low density polyethylene-clay composites had resulted to most failure in the manufacture of these composite. The utilization of process control and process monitoring are rarely fully implemented for the production of injection moulded products. This may be due to a poor scientific understanding of the moulding process based on the complexities of the process containing multiple variables affecting the final part.

Split plot designs initially developed by Fisher in 1925 were use in agricultural experiments, and are basically the modified form of randomized block designs. These designs are used in situations where complete randomization of runs within block is not possible. These designs are used widely in industrial experiments, experiments where one set of factors may require a large amount of experimental materials (Whole Plot factors), while another set of factors might be applied to smaller

experimental materials (Sub Plot factors) [2]. Olodu and Osarenmwinda [3] examined the effect of process parameters such as temperature in the production of polypropylene-grass composite using split-split plot experimental design, their results shows that temperature contributes significantly to the production of composites in polymeric industries. Aviles and Pinheiro [4] examined the experiments that have complete randomization order of runs which was not feasible or might be too expensive to use when performed. They concluded from their study that the use of split-plot designs and models are feasible, efficient and cheap. Goldsmith and Gaylor [2] carried out extensive investigation on optimal designs for estimating variance components in a completely random nested classification. Loeza-Serrano and Donev [5] constructed D-Optimal design for variance components estimation in a three stage crossed and nested classification. For experiments that include both crossed and nested factor in the same model, no assumption of a complete random model has been made. Ankenman et al; Aviles and Pinheiro [6,4] investigations indicates that experiments involving complete randomization of order of runs which is not feasible or too expensive to use is performed using split plot models. Chunping *et al* [7] carried out a study aimed to model fundamental bonding characteristics and performance of wood composite. In their work, mathematical model and a computer simulation model were developed to predict the variation of inter-element (strand) contact during mat consolidation. The mathematical predictions and the computer simulations agree well with each other. Their results showed that the relationship between the inter-element contact and the mat density was highly nonlinear and was significantly affected by the wood density and the element thickness.
This study therefore focused on investigation of low density polyethylene polymeric composite using split-split plot experimental designs.

2. Methodology

2.1 Preparation and Processing of Clay

The clay obtained was first air dried in the sun and later transferred to an oven and dried at 105^0C. It was continuously monitored until a moisture content of about $2\pm 0.2\%$ was obtained [8]. The clay was ground to granules using crushing machine. The ground clay was screened to a particle size of 100μm diameters using vibrating sieve machine.

2.2 Mixing, Compounding and Production of Composites

Low density polyethylene (LDPE) was mixed with ground clay in the proportion of 20:80, 30:70, 40:60, 50:50, 60:40, 70:30 and 80:20 percentages by volume respectively. The prepared Low density polyethylene-clay composite was blended in a cylindrical container until a homogenous mixture was obtained in the composite. The homogenous mixture of the composite was feed into the hopper of injection moulding machine and were produced at various barrel temperature ranging from 210^oC to 310^oC respectively at an interval of 10^oC [9].

2.3 Evaluation of Low Density Polyethylene-Clay Composite for Mechanical Strength

The produced low density polyethylene-clay composite was evaluated for mechanical strength (tensile strength, proof stress, percentage elongation and flexural strength) using Equations (1) to (4) respectively [10].

$$\text{Tensile strength} = \frac{\text{Maximum Load}}{\text{Original Cross} - \text{Sectional Area}} \quad (1)$$

The original cross-sectional area of the specimen is $18.9mm^2$.

$$\text{Proof stress} = \frac{\text{Force at yield}}{\text{Cross – Sectional Area}} \quad (2)$$

The cross-sectional area of specimen =18.9 mm^2

$$\text{Hence, proof stress} = \frac{\text{Force at yield}}{18.9}\ \text{N}/mm^2$$

$$\text{Percentage (\%) Elongation} = \frac{\text{Extension}}{\text{Gauge Length}} \times 100\% \quad (3)$$

$$\text{Flexural Strength} = \quad EI = \frac{\mathbf{PL^3}}{\mathbf{48y}} \quad (4)$$

Where y is the deflection in mm, P= Load, L= Length of test specimen

2.4 The Split-Split Plot Designs

The split-split plot design which is an experimental design was used to investigate the interaction between material type, percentage by volume of material and barrel temperature on the mechanical properties of the produced low density polyethylene-clay composite. In simple terms, a split-split plot experiment is a blocked experiment, where the blocks themselves serve as experimental units for a subset of the factors [11]. Analytical and numerical designs using split-split plot design was carryout to investigate the effect of process parameters in the developed low density polyethylene-clay composite.

2.5 The F-test

The F-test was used for comparing the factors of the total deviation (using Equation 5). The statistical significance was tested by comparing the F test statistic.

$$F = \frac{Variance\ between\ treatments}{Variance\ within\ treatments} \quad (5)$$

$$F = \frac{MS_{Treatments}}{MS_{Error}} = \frac{SS_{Treatments/(I-1)}}{SS_{Error}/(nT-1)}$$

2.6 The Interactive Model Developed for Low Density Polyethylene-Clay Composite

Equation 6 shows the interactive model developed and is depicted as:

$$X_{ijkl} = \mu + \gamma_i + \beta_j + \delta_l + y_k + \gamma\beta_{ij} + \gamma y_{ik} + \beta y_{jk} + \gamma\delta_{il} + \beta\delta_{jl} + y\delta_{lk} + \gamma\beta y_{ijk} + \gamma\beta\delta_{ijl} + \gamma y\delta_{ikl} + \beta y\delta_{jkl} + \gamma\beta\delta y_{ijkl} + \varepsilon_{ijkl} \quad (6)$$

Where:

μ= Mean response; γ_I= Block variable (mechanical properties); β_j= Block variable (barrel temperature); δ_l= Treatment Variable (percentage by volume of material); y_k= Treatment Variable (type of material); $\gamma\beta_{ij}$ = Block interaction (mechanical properties and barrel temperature interaction); γy_{ik} = Block and Treatment interaction (mechanical properties and type of material interaction);βy_{jk}= Treatment Interaction (barrel temperature and type of material interaction); $\gamma\delta_{il}$ = Block and Treatment interaction (mechanical properties and percentage by volume of material interaction); $\beta\delta_{jl}$ = Block and Treatment interaction (barrel temperature and percentage by volume of material interaction); $y\delta_{lk}$ = Treatment Interaction (percentage by volume of material and type of material interaction); $\gamma\beta y_{ijk}$ = Block and Treatment interaction (mechanical properties, barrel temperature and type of material interaction); $\gamma\beta\delta_{ijl}$ = Block and Treatment interaction (mechanical properties, barrel temperature and Percentage by volume of material interaction); $y\gamma\delta_{ikl}$ = Block and Treatment interaction (mechanical properties, type of material and Percentage by volume of material interaction); $\beta y\delta_{jkl}$ = Block and Treatment interaction (barrel temperature, type of material and Percentage by volume of material interaction); $\gamma\beta\delta y_{ijkl}$= Block and Treatment interaction (mechanical properties, barrel temperature, type of material and percentage by volume of material interaction); X_{ijkl} = Response Variable; ε_{ijkl}= Error term.

2.7 Statistical Computations for Low Density Polyethylene-Clay Composite

Equations 7 to 22 was used to calculate for the sum of squares for the process parameters and their interactions which were used to investigate the effects of process parameters using Split-Split Plot experimental design analysis, the obtained results were presented on ANOVA Table.

A) Total Sum of Squares (SS_T)

$$SS_T = \sum_{i=1}^{I=4}\sum_{j=1}^{J=11}\sum_{k=1}^{K=2}\sum_{l=1}^{L=7} X_{ijkl}^2 - \frac{X^2_{....}}{IJLK} \quad (7)$$

Where I =4, J=11, K=2, L=7

B) Sum of squares for materials (SS_A)

$$SS_A = \sum_{k=1}^{K=2} \frac{X^2_{..K.}}{IJL} - \frac{X^2_{....}}{IJLK} \quad (8)$$

C) Sum of squares for the percentage by volume of materials (SS_B)

$$SS_B = \sum_{l=1}^{L=7} \frac{X^2_{...l}}{IJK} - \frac{X^2_{....}}{IJLK} \quad (9)$$

D) Sum of squares for mechanical strength (SS_C)

$$SS_C = \sum_{i=1}^{I=4} \frac{X^2_{i...}}{JKL} - \frac{X^2_{....}}{IJLK} \quad (10)$$

E) Sum of squares for temperature (SS_D)

$$SS_D = \sum_{j=1}^{J=11} \frac{X^2_{.j..}}{IKL} - \frac{X^2_{....}}{IJLK} \quad (11)$$

F) (Material type) X (percentage by volume of material) Interaction (SS_{AB})

$$SS_{AB} = \sum_{k=1}^{K=2}\sum_{l=1}^{L=7} \frac{X^2_{..kl}}{IJ} - \sum_{k=1}^{K=2} \frac{X^2_{..k.}}{IJK} - \sum_{l=1}^{L=7} \frac{X^2_{...l}}{IJK} + \frac{X^2_{....}}{IJLK} \quad (12)$$

G) (Material type) X (Mechanical Strength) Interaction (SS_{AC})

$$SS_{AC} = \sum_{i=1}^{I=4}\sum_{k=1}^{K=2} \frac{X^2_{i.k.}}{JL} - \sum_{i=1}^{I=4} \frac{X^2_{i...}}{JKL} - \sum_{k=1}^{K=2} \frac{X^2_{..k.}}{IJL} + \frac{X^2_{....}}{IJLK} \quad (13)$$

H) (Material type) X (Temperature) Interaction (SS_{AD})

$$SS_{AD} = \sum_{k=1}^{K=2}\sum_{j=1}^{J=11} \frac{X^2_{.jk.}}{IL} - \sum_{k=1}^{K=2} \frac{X^2_{..k.}}{IJL} - \sum_{j=1}^{J=11} \frac{X^2_{.j..}}{IKL} + \frac{X^2_{....}}{IJLK} \quad (14)$$

I) (Percentage by Volume of material) X (Mechanical Strength) Interaction (SS_{BC})

$$SS_{BC} = \sum_{i=1}^{I=4}\sum_{l=1}^{L=7}\frac{X^2_{i\,.\,.\,l}}{JK} - \sum_{i=1}^{I=4}\frac{X^2_{i\,.\,.\,.}}{JKL} - \sum_{l=1}^{L=7}\frac{X^2_{.\,.\,.\,l}}{IJK} + \frac{X^2_{.\,.\,.}}{IJLK} \quad (15)$$

J) (Percentage by volume of material) X (Temperature) Interaction (SS_{BD})

$$SS_{BD} = \sum_{j=1}^{J=11}\sum_{l=1}^{L=7}\frac{X^2_{.\,j\,.\,l}}{IK} - \sum_{j=1}^{J=11}\frac{X^2_{.\,j\,.\,.}}{IKL} - \sum_{l=1}^{L=7}\frac{X^2_{.\,.\,.\,l}}{IJK} + \frac{X^2_{.\,.\,.}}{IJLK} \quad (16)$$

K) (Mechanical Strength) X (Temperature) Interaction (SS_{CD})

$$SS_{CD} = \sum_{i=1}^{I=4}\sum_{j=1}^{J=11}\frac{X^2_{i\,j\,.\,.}}{KL} - \sum_{i=1}^{I=4}\frac{X^2_{i\,.\,.\,.}}{JKL} - \sum_{j=1}^{J=11}\frac{X^2_{.\,j\,.\,.}}{IKL} + \frac{X^2_{.\,.\,.}}{IJLK} \quad (17)$$

L) (Material type) X (Percentage by volume of material) X (Mechanical Strength) Interaction (SS_{ABC})

$$SS_{ABC} = \sum_{i=1}^{I=4}\sum_{k=1}^{K=2}\sum_{l=1}^{L=7}\frac{X^2_{i\,.\,k\,l}}{J} - \sum_{i=1}^{I=4}\sum_{k=1}^{K=2}\frac{X^2_{i\,.\,k\,.}}{JL} - \sum_{k=1}^{K=2}\sum_{l=1}^{L=7}\frac{X^2_{.\,.\,k\,l}}{IJ} + \sum_{k=1}^{K=2}\frac{X^2_{.\,.\,k\,.}}{IJL} \quad (18)$$

M) (Material type) X (Percentage by volume of material) X (Temperature) Interaction (SS_{ABD})

$$SS_{ABD} = \sum_{j=1}^{J=11}\sum_{k=1}^{K=2}\sum_{l=1}^{L=7}\frac{X^2_{.\,j\,k\,l}}{I} - \sum_{j=1}^{J=11}\sum_{k=1}^{K=2}\frac{X^2_{.\,j\,k\,.}}{IL} - \sum_{k=1}^{K=2}\sum_{l=1}^{L=7}\frac{X^2_{.\,.\,k\,l}}{IJ} + \sum_{k=1}^{K=2}\frac{X^2_{.\,.\,k\,.}}{IJL} \quad (19)$$

N) (Material type) X (Mechanical strength) X (Temperature) Interaction (SS_{ACD})

$$SS_{ACD} = \sum_{i=1}^{I=4}\sum_{j=1}^{J=11}\sum_{k=1}^{K=4}\frac{X^2_{i\,j\,k\,.}}{L} - \sum_{i=1}^{I=4}\sum_{j=1}^{J=11}\frac{X^2_{i\,j\,.\,.}}{KL} - \sum_{j=1}^{J=11}\sum_{k=1}^{K=7}\frac{X^2_{.\,j\,k\,.}}{IL} + \sum_{j=1}^{J=11}\frac{X^2_{.\,j\,.\,.}}{IKL} \quad (20)$$

O) (Percentage by volume of material) X (Mechanical strength) X (Temperature)

Interaction (SS_{BCD})

$$SS_{ACD} = \sum_{i=1}^{I=4}\sum_{j=1}^{J=11}\sum_{l=1}^{L=7}\frac{X^2_{i\,j\,.\,l}}{K} - \sum_{i=1}^{I=4}\sum_{j=1}^{J=11}\frac{X^2_{i\,j\,.\,.}}{KL} - \sum_{j=1}^{J=11}\sum_{l=1}^{L=7}\frac{X^2_{.\,j\,.\,l}}{IK} + \sum_{j=1}^{J=11}\frac{X^2_{.\,j\,.\,.}}{IKL} \quad (21)$$

P) Error Sums of Squares $SS_E = SS_T - SS_A - SS_B - SS_C - SS_D - SS_{AB} - SS_{AC} - SS_{AD} - SS_{BC} - SS_{CD} - SS_{ABC} - SS_{ABD} - SS_{ACD}$. (22)

2.8 Hypothesis Statements for Low Density Polyethylene-Clay Composite

The null hypothesis with its alternative was formulated for the low density polyethylene-clay composite as follows:
***Null Hypothesis*(H_o):** The percentage by volume of material, material type, barrel temperature and their interactions contributes significantly to the mechanical properties of the composite produced at α-value of 0.05.
***Alternate Hypothesis* (H_1):** The percentage by volume of material, material type, barrel temperature and their interactions does not contributes significantly to the mechanical properties of the composite produced at α-value of 0.05.

3. Results and Discussion

Table 1 shows Analysis of Variance (ANOVA) result for the effects of process parameters and their interactions on produced low density polyethylene-clay composite.

Table 1: Analysis of Variance (ANOVA) Result Table for Effects of Process Parameters on Low Density Polyethylene-Clay composite

Sources of Variation	Sum of Squares (SS)	Degree of freedom	Mean of Squares (MS)	Fisher's Ratio F_{cal} α=0.05	Fisher's Ratio F_{Tablel}	Decision
SS_A	0.00	K-1=1	0.00	$\frac{MS_A}{MS_B} = 0.00$	5.99	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis.
SS_B	161.35	L-1=6	26.39	$\frac{MS_B}{MS_{AB}} = 0.00$	4.28	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis.
SS_C	105622.38	I-1=3	35207.46	$\frac{MS_C}{MS_{AC}} = 0.00$	9.28	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis.
SS_D	24.13	J-1=10	2.41	$\frac{MS_D}{MS_{AD}} = 0.00$	2.98	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis.
SS_{AB}	0.00	(K-1)(L-1) =6	0.00	$\frac{MS_{AB}}{MS_C} = 0.00$	8.94	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis.
SS_{AC}	0.00	(K-1)(I-1) =3	0.00	$\frac{MS_{AC}}{MS_{BC}} = 0.00$	3.16	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis.
SS_{AD}	-0.00	(K-1)(J-1) =10	0.00	$\frac{MS_{AD}}{MS_{BD}} = 0.00$	1.99	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis.
SS_{BC}	1299.40	(L-1)(I-1) =18	72.19	$\frac{MS_{BC}}{MS_{ABC}} = 1.00$	2.01	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis.
SS_{BD}	0.70	(L-1)(J-1) =60	0.01	$\frac{MS_{BD}}{MS_{ABD}} = 1.00$	0.51	$F_{cal} > F_{Table}$, there is enough evidence to reject null hypothesis
SS_{CD}	261.38	(I-1)(J-1) =30	8.71	$\frac{MS_{CD}}{MS_{ACD}} = 0.00$	1.37	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis.
SS_{ABC}	1299.40	(K-1)(L-1)(I-1) =18	72.19	$\frac{MS_{ABC}}{MS_D} = 29.95$	2.98	$F_{cal} > F_{Table}$, There is enough evidence to reject null hypothesis
SS_{ABD}	0.70	(K-1)(L-1)(I-1) =60	0.01	$\frac{MS_{ABD}}{MS_{CD}} = 0.001$	0.17	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis.
SS_{ACD}	0.00	(K-1)(I-1)(J-1) =30	0.00	$\frac{MS_{ACD}}{MS_{BCD}} = 0.00$	1.93	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis.
SS_{BCD}	103965.01	(L-1)(I-1)(J-1) = 180	577.58	$\frac{MS_{BCD}}{MS_E} = -80.11$	6.57	$F_{cal} < F_{Table}$, no enough evidence to reject null hypothesis.
SS_E	-1297.53	(I-1)(J-1)(K-1)(L-1) = 180	-7.21			
SS_T	107371.21	IJKL-1=615				

3.1 Interpretation of the Results

Table 1 shows that the fourteen null hypothesis H_o^1, H_o^2, H_o^3, H_o^4, H_o^5, H_o^6, H_o^7, H_o^8, H_o^9, H_o^{10}, H_o^{11}, H_o^{12}, H_o^{13}, H_o^{14} are respectively not rejected at α-value of 0.05, suggesting that there appears to be no differential treatment and block effects. Also interaction appears to exist between treatment and block effects.

(a)Examination of Treatment Effect of Materials (Low Density Polyethylene-Clay Composite) (SS_A)

$F_{cal}=0.00<F_{Table}=5.99$, the F_{cal} is less than the F_{Table} in the statistical Table (Table 1); our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^1 treatment at α-value of 0.05. Our conclusion therefore is that the materials (low density polyethylene and clay) parameters contribute significantly to the mechanical property of the composite produced in industries.

(b) Examination of Treatment Effect of Percentage by Volume of Materials (SS_B)

Since $F_{cal}=0.00<F_{Table}=4.28$, the F_{cal} is less than the F_{Table} in the statistical Table (Table 1); our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^2 treatment at α-value of 0.05. Our conclusion therefore is that the percentage by volume of materials parameter contributes significantly to the mechanical property of the produced low density polyethylene-clay composite.

(c) Examination of Treatment Effect of Mechanical Strength (SS_C)

Since $F_{cal}=0.00<F_{Table}=9.28$, the F_{cal} is less than the F_{Table} in the statistical table (Table 1); our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^3 at α-value of 0.05. Our conclusion therefore is that the mechanical strength parameters contribute significantly to the strength of the produced low density polyethylene-clay composite.

(d) Examination of Treatment Effect of Temperature (SS_D)

Since $F_{cal}=0.00<F_{Table}=2.98$, the F_{cal} is less than the F_{Table} in the statistical table (Table1); our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^4 of block effect α-value of 0.05. Our conclusion therefore is that the temperature parameters contribute significantly to the mechanical property of the produced low density polyethylene-clay composite.

(e) Examination of Treatment Effect of (Material Type) X (Percentage by Volume of Material) Interaction (SS_{AB})

Since $F_{cal}=0.00<F_{Table}=8.94$, the F_{cal} is less than the F_{Table} in the statistical table (Table 1); our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^5 of interaction effect of material type and percentage by volume of material interaction at α-value of 0.05. Our conclusion therefore is that the material type and percentage by volume of material interaction parameters contribute significantly to the mechanical property of the produced low density polyethylene-clay composite.

(f) Examination of Treatment Effect of (Material Type) X (Mechanical Strength) Interaction (SS_{AC})

Since $F_{cal}=0.00<F_{Table}=3.16$, the F_{cal} is less than the F_{Table} in the statistical table (Table 1): our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^6 interaction at α-value of 0.05. Our conclusion therefore is that the materials (low density polyethylene and clay)

and Mechanical Strength interaction parameters contribute significantly to the strength of the produced low density polyethylene-clay composite.

(g) Examination of Treatment Effect of (Material Type) X (Temperature) Interaction (SS_{AD})

Since $F_{cal}=0.00<F_{Table}=1.99$, the F_{cal} is less than the F_{Table} in the statistical table (Table 1); our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^7 interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect of material type and blocks effect (temperature) interaction parameters contribute significantly to the mechanical property of the produced low density polyethylene-clay composite.

(h) Examination of Treatment Effect of (Percentage by Volume of Material) X (Mechanical Strength) Interaction (SS_{BC})

Since $F_{cal}=1.00<F_{Table}=2.01$, the F_{cal} is less than the F_{Table} in the statistical table (Table 1); our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^8 interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect of (percentage by volume of material) and block effect (mechanical strength) interaction parameters contribute significantly to produced low density polyethylene-clay composite.

(i) Examination of Treatment Effect of (Percentage by Volume of Material) X (Temperature) Interaction (SS_{BD})

Since $F_{cal}=1.00>F_{Table}=0.51$, the F_{cal} is greater than the F_{Table} in the statistical table (Table 1); our experimental data furnish enough proof for us to reject the null hypothesis H_o^9 interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect (percentage by volume of material) and block effect (temperature) interaction parameters does not contribute significantly to the mechanical property of the produced low density polyethylene-clay composite.

(j) Examination of Treatment Effect of (Mechanical Strength) X (Temperature) Interaction (SS_{CD})

Since $F_{cal}=0.00<F_{Table}=1.37$, the F_{cal} is less than the F_{Table} in the statistical table (Table 1), our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^{10} interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect (mechanical strength) and block effect (temperature) interaction parameters contribute significantly to the strength of produced Low density Polyethylene-Clay Composite.

(k) Examination of Treatment Effect of (Material Type) X (Percentage by Volume of Material) X (Mechanical Strength) Interaction (SS_{ABC})

Since $F_{cal}=29.95>F_{Table}=2.98$, the F_{cal} is greater than the F_{Table} in the statistical table (Table 1); our experimental data furnish enough proof for us to reject the null hypothesis H_o^{11} interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect of material type, percentage by volume of material and block effect (mechanical strength) interaction parameters does not contribute significantly to the strength of the produced low density polyethylene-clay composite.

(l) Examination of Treatment Effect of (Material type) X (Percentage by Volume of Material) X (Temperature) Interaction (SS_{ABD})

Since $F_{cal}=0.001<F_{Table}=0.17$, the F_{cal} is less than the F_{Table} in the statistical table (Table 1); our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^{12} interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect of material type, percentage by volume of material and block effect (temperature) interaction parameters contribute significantly to the mechanical property of the produced low density polyethylene-clay composite.

(m) Examination of Treatment Effect of (Material Type) X (Mechanical Strength) X (Temperature) Interaction (SS_{ACD})

Since $F_{cal}=0.00<F_{Table}=1.93$, the F_{cal} is less than the F_{Table} in the statistical table (Table 1); our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^{13} interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect of material type, and block effect of both mechanical strength and temperature interaction parameters contribute significantly to the strength of the produced low density polyethylene-clay composite.

(n) Examination of Treatment Effect of (Percentage by Volume of Material) X (Mechanical Strength) X (Temperature) Interaction (SS_{BCD})

Since $F_{cal}=-80.11<F_{Table}=6.57$, the F_{cal} is less than the F_{Table} in the statistical table (Table); our experimental data do not furnish enough evidence for us to reject the null hypothesis H_o^{14} interaction at α-value of 0.05. Our conclusion therefore is that the treatment effect of percentage by volume of material, and block effect of both mechanical strength and temperature interaction parameters contribute significantly to the strength of the produced low density polyethylene-clay composite.

Furthermore, Olodu and Osarenmwinda [3] examined the effect of process parameters such as temperature in the production of polypropylene-grass composite using split-split plot experimental design, their results shows that temperature contributes significantly to the production of composites in polymeric industries. Hence, $F_{cal} < F_{Table}$, there was no enough evidence to reject null hypothesis. This result compared favourably with the result obtained in this study. Aviles and Pinheiro [4] examined the experiments that have complete randomization order of runs which was not feasible or might be too expensive to use when performed. They concluded from their study that the use of split-plot designs and models are feasible, efficient and cheap. Loeza-Serrano and Donev [5] constructed D-Optimal design for variance components estimation in a three stage crossed and nested classification. For experiments that include both crossed and nested factor in the same model, no assumption of a complete random model has been made. These results compared favourably with the results obtained in this study.

4. Conclusion

The results of the calculated Fisher's ratio at significant value of 0.05 for the process parameters and their interactions ranged from -80.11 to 29.95. The results obtained from the interactive model developed using the split-split plot design indicates that there was strong interaction between barrel temperature, type of material and percentage by volume of material on mechanical properties (Tensile Strength, Proof Stress, Percentage Elongation and Flexural Strength) for the produced low density polyethylene-clay composite. Hence, these process parameters contribute significantly to the produced low density polyethylene-clay composite. Decisions made based on the hypothesis statements shows that there were no enough evidence to reject the null hypothesis at α-value of 0.05 for low density polyethylene-clay composite. The developed interactive model will also be useful to researcher, industrialist and small scale manufacturer to ease the production of composites in polymeric industries.

References

[1] Olodu D.D and Osarenmwinda J.O., (2019). Empirical Modelling of Developed Polyvinyl Chloride-Grass Composite. *Journal of Energy Technology and Environment*, Vol. 1, issue 1, pp. 29-37.

[2] Goldsmith, C.H and Gaylor, D.W.,(1970). Three Stage Nested Designs for Estimating Variance Components. *Journal of Technometrics, Vol.* 12, pp. 487-498.

[3] Olodu, D.D and Osarenmwinda, J.O., (2018). Effects of Process Parameters in the Production of High Density Polyethylene-Grass Composite. *Journal of Applied Sciences and Environmental management*, Vol. 22, issue 9, pp. 1479-1483.
[4] Avilles, A.I and Pinheiro, J.C., (2015). Optimal Design for Mixed Effects Models with two Random Nested Factors. *Journal of Statistical Sinica*, Vol. 13, pp. 385-401.
[5] Loeza, S and Donev, A.N., (2014). Construction of Experimental Design to estimate Variance Components. *Journal of Computational Statistics and Data Analysis.* Vol. 71, pp. 1168–1177.
[6] Ankenman, B.E; Liu, H; Karr, AF and Picka, J.D.,(2001). A Class of Experimental Designs for Estimating a Response Surface and Variance Components. *Journal of Technometrics, Vol.* 44, pp. 45-54.
[7] Chunping, D; Changing. Y; and Cheng, Z., (2007). Theoretical Modeling of Bonding Characteristics and Performance of Wood Composites of Inter-element Contact. *Journal of Wood and Fiber Science*, Vol. 39, pp. 48-55.
[8] Adeyemi, S.O. and Adeyemi, M.B.,(2016). Temperature Effect on Extrusion Moulded Plastic. *International Journal of Materials and Product Technology*,Vol. 5, issue 6, pp. 300-311.
[9] Olodu, D.D.,(2017). Modelling and Development of Injection Moulded Plastic-Grass Composites. *PhD Thesis, Department of Production Engineering, Faculty of Engineering,University of Benin, Nigeria.*
[10] Osaremwinda, J.O. and Olodu, D.D. (2015). Effects of Barrel Temperature on the Mechanical Properties of Injection Moulded Product. .*Nigeria Journal of Technology (NIJOTECH)*, Vol. 34, issue 2, pp. 292-296.
[11] Goos, P. and Vandebroek, M., (2003). D-optimal Split-Plot Designs with Given Numbers and Sizes of Whole Plots. *Journal of Technometrics*, Vol. 45, pp.235-245.