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Multi Response Optimization of the Functional Properties of Rubber Seed – Shear Butter Based Core Oil Using D-Optimal Mixture Design

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Abstract

In this study, rubber seed/shea butter oil was used to formulate core oil. The formulated core oil was characterised. D-optimal mixture design was used for multi response optimisation of the functional properties of rubber seed-shea butter coil oil. Desirable values for some responses might be obtained from a factor combination while for others responses not so desirable values. Through multiple response optimisations, a factor setting that gives the desirable values for all responses was obtained. The selected optimum mixture setting for the formulated core oil is 65.937% Rubber seed and 34.063% Shea butter oil at desirability of 0.924. Under the optimum condition the functional properties of the core oil was found to be 39.57KN/M2, 626.85KN/M2, 36.63KN/M2, 593.906KN/M2, 412.605 and 167.309s for Green Compressive Strength, Dry Compressive Strength, Green Tensile Strength, Dry Tensile Strength, Permeability and Collapsibility respectively. The optimum conditions were validated with less than 0.2% error. The functional properties of the formulated core oil was compared to the functional properties of linseed core oil. It was found that rubber seed-shea butter core oil can be used for producing cores suitable for Aluminium casting.

Keywords: Core oil, Rubber seed oil, Shea butter, Aluminum casting

1. Introduction

A core is used to produce internal cavities and re-entrant angles in casting and moulding processes. The core is normally a disposable item that is destroyed to get it out of the piece. They are most commonly used in sand casting, but are also used in die casting. The oils used to produce cores in foundry practice for casting purpose are known as core oil. As a result of increased demand for environmentally friendly core oils, there is a growing interest in binders that would offer substantial advantages in terms of cost, occupational health, safety and other environmental issues [1, 2].

The need for development of environmentally friendly binder systems based around organic, inorganic or hybrid derivatives that would offer substantial advantages in terms of cost, occupational health safety and other environmental issues was emphasised by Ibitoye and Afonja [3]. They argued that the processes that would be involved in the use of such binders should be simpler for easy adoptions by foundries in developing economies like Nigeria, to enable the industry contribute its quota to national growth. They further stated that locally developed organic vegetable oil binders obtained from plant trees would be known for clean and non-toxicity. Most core oils used in developing countries like Nigeria are imported, which contributes to high cost of casting products. Rubber seed (*Heveabrasilienesis*) and Shea butter (*Vitellariaparadoxa*) oils are available and aboundant in Nigeria. If well researched and produced in large quantity, they may replace existing imported core oils for Aluminium casting and will make cast Aluminium products cheaper.

In this study, a statistically designed mixture experiment was used to identify the best factor settings for optimizing functional properties of rubber seed – shea butter core oil mixture. A factor combination may give a desirable value for some responses while for others, not so desirable values in an experiment. Through multiple optimisations it will be possible to obtain a factor setting that will give desirable values for all responses.

D-optimal mixture design was used to obtain the desired characteristics. They are especially useful for solving the problem of searching the optimal proportions of the mixture components [2, 4–7]. It has been reported that D-optimal mixture design has the advantage of reducing the number of experimental runs needed to evaluate multiple variables. It is also able to identify statistical interactions, which is able to overcome the shortcomings of the traditional formulation method [6, 8].

The responses obtained from the optimum parameter setting of the formulated rubber seed-shear butter core oil was compared to an oil that is already in use in core making – Linseed oil, which serves as the control.

2. Experimental

Materials

Raw rubber oil (RSO) was obtained from Rubber Seed Research Institute Benin City, Edo state, Nigeria, with chemical composition: 19.0% saturated acids made up of - Palmitic acid (10.6 %) and Stearic acid (8.4 %) and 81.0% unsaturated acids made up of Oleic acid (24.6 %), Linoleic acid (39.4 %) and Linolenic acid (17.0 %).

Shea butter oil (SBO) was obtained from Idumuje Unor, Aniocha south local government area of Delta state, Nigeria, with chemical composition: Oleic acid 60%, Stearic acid 30%, Linenoleic acid 7%, Palmitic acid 2%, Linoleic acid 0.6% and Arachidic acid 0.4% as its major active ingredients.

The clay was collected from clay depot in Ebu Oshomili north local government area of Delta state, Nigeria while the silica sand was collected from Federal Institute of Industrial Research Oshodi Lagos state (FIIRO).

Characterisation of the Core Oils

The core oils were characterised to determine the specific gravity, flash point, iodine value, pH value and refractive index.

Test Specimen Preparation

The experimental raw materials were core oil, water, silica sand - washed and oven dried at 110°C to remove water. The silica sand was classified with BS sieve of size range 40 - 72 mesh. Mixes were comprised of 6% clay, 5% water and 3% cereal binder (alkama). The proportion of sand in each of the mixture was: 85.5, 85, 84.5, 84, 83.5 and 83% for 0.5, 1, 1.5, 2, 2.5 and 3% core oil binders, respectively.

Using a digital scale, measured quantities of silica sand, clay, cereal binder and water were mixed in a roller mill for 10 min and moulded into test core as shown in Figure 1(a) and 1(b), which were oven baked at 200°C for 1hr, and then oven cooled to room temperature before the tests for compression strength, tensile strength, permeability and collapsibility. Specimen for green compression, permeability and collapsibility was cylindrical in shape, 2 inches diameter, 2 inches height and weighed 130g after compacting with a standard rammer with 3 blows each of 6.5kg from a height of 50mm in a standard ram. The tensile strength test specimen was in accordance with standard foundry practice shaped like figure number eight dimensioned while compression strength, permeability and collapsibility specimen were made into 50mm diameter by 50mm height cylindrical shape according to American Foundry Society (AFS) [9] as shown in Figure 1b. Each of the mixture weighed 800g and then was further subdivided into five portions of 160 g each.

All test specimens were prepared by subjecting a weighed quantity of sand core mixes to three blows adjusted to produce a close tolerance specimens which was expelled from the tube on a striping post. Freshly prepared unbaked specimens were used for green properties testing such as green tensile, green compressive, permeability and collapsibility. The whole of the procedure was repeated, 3 times, for mixes containing varying amount of rubber seed oil.

a) 

b) 

Fig. 1. Moulded Rubber seed – Shea Butter Oil Core Test specimens: (A) Tensile specimens (B) Compression strength, Permeability and collapsibility Test specimens

Core Specimen Testing
The tests were conducted according to AFS procedures [9]. The tensile strength specimens were oven baked at 200°C for 1 hour and then oven cooled to room temperature before the tests. A steadily increasing tensile force was applied on specimen by turning the hand wheel of the universal sand strength machine until failure occurred. A magnetic rider on the scale recorded the position at which the specimen fractured, and the strength of the sand was read direct from the scale. The test procedure for green tensile strength (GTS) was similar except that the specimens were not baked.
To determine the compressive strength, the compressive strength specimens were oven baked at 200°C for 1 hour and then oven cooled to room temperature before the tests. A steadily increasing compressive force was applied on specimen by turning the hand wheel of the universal sand strength machine until failure occurred. A magnetic rider on the scale recorded the position at which the specimen collapsed, and the strength of the sand was read direct from the scale. Similarly the specimens for green compressive strength (GCS) was not oven baked, and was tested but in green state in the lower hole of the machine.
The permeability specimens were made and tested in the green state with the perm meter. In the permeability tests, a steady and standard air pressure of $9.8x10^2 N/m^2$was passed through specimen in sample tube placed in the meter, the time it took for $2000cm^3$ of air to pass the sample tube was then recorded. Permeability was calculated using equation 1[10].

$$P = \frac{3007}{T(\text{sec})} \qquad (1)$$

Where:
P – permeability
T – time

The baked collapsibility was determined by loading standard AFS specimens into the collapsibility testing machine with an in-built furnace, in which the specimen was heated to 600°C and soaked at that temperature. The time it took for the specimen to collapse was recorded.

3. Experimental design

Two numeric factors and one categorical factor D-optimal mixture design was employed to determine the effect of rubber seed oil and shear butter oil blend on response variables at various percentage oil in sand. The independent variables for the mixture and their levels are listed in Table 1.

Table 1.
Factors and their Levels

Factor Variables	Level of Variables (%)	
	Low	High
A Rubber seed Oil	0	100
B Shear Butter Oil	0	100
C % Oil in Sand (Categorical Factor)	0.5	3.0

Design expert 7.0.0 software was used to generate the design matrix comprising of 42runs. The response functions measured are shown in Table 2. The experiments were carried out in a randomized order according to D-optimal model design to minimize the effect of unknown bias or unexplained variability on the actual response owing to extraneous factors.

Statistical Analysis
D-optimal mixture design, analysis of variance (ANOVA) and regression analysis was used to obtain regression model to predict the effect of variation of component compositions on the responses and to ascertain the optimal setting of the factor variables for optimum responses. Model fitting was carried out using statistical parameters which include, multiple correlation coefficient (R^2), adjusted multiple correlation coefficient (adjusted R^2), lack of fit test and regression (P value and F value). A second order polynomial equation was fitted for each factor as follows

$$Y= \beta 0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2 \qquad (2)$$

Where y is the estimated response; β_0, β_1, β_2, β_{11}, β_{22} and β_{12} are constant parameters; x_1 and x_2 are the values of the mixture components. The variance of each factor was partitioned into linear, quadratic and interactive terms. The suitable polynomial equations for the design, such as linear, quadratic, or special cubic was chosen according to the fittest model.

Optimisation of Multiple Quality Characteristics
A factor combination may give a desirable value for some responses while for others, not so desirable values in an experiment. Through multiple optimisations it will be possible to obtain a factor setting that will give desirable values for all responses. For multiple quality characteristics, Derringer and Suich [11] developed a suitable optimization method using desirability function. The transformation of individual responses, y_i into individual desirability function d_i could be three possible ways where d_i is between 0 and 1. If response value equals to target, the value of d_i is 1. If the value of y_i is not acceptable, the value of d_i is 0. For the case of multiple quality characteristics, the d_i values with maximal D value will be selected. Where $D = (d_1.d_2...d_m)^{1/m}$, m is the number of response variables. For quality characteristics with various specifications, the transformation of y_i into d_i could be three possible ways, which are;

i. The larger the better
ii. The smaller the better
iii. The nominal the best

In this research of core oil formulation, the responses were set at various quality characteristics as shown in Table 2.

Table 2.
Responses and their Quality Characteristics for Optimisation

S/N	Response	Quality Characteristics
1	Green Compressive Strength	The Bigger the Better
2	Dry Compressive Strength	The Bigger the Better
3	Green Tensile Strength	The Bigger the Better
4	Dry Tensile Strength	The Bigger the Better
5	Permeability	The Nominal the Best
6	Collapsibility	The Nominal the Best

Desirability was used as the criteria for selecting factor settings used for optimisation. Design expert software was employed for the optimisation.

4. Results and discussion

Physic - Chemical Properties of the Formulated Core Oil
Table 1 shows the physical and chemical properties of the pure and blended oils. It is observed that rubber seed oil has higher iodine value and flash point than shea butter oil. The flash point and iodine values of the blend are between those of the pure oils. Linseed oil – the control, shows the highest Iodine value and flash point. Iodine value expresses the degree of unsaturation of oil; the higher the iodine numbers the higher the rate of absorption of air at room temperature. The absorption of oxygen causes core oils in sand to polymerise after application to form tough, adherent, impervious and resistance films [12]. Hybrid mixture effect was observed in the formulated core oil.

Table 3.
Physic-Chemical Properties of Rubber seed and Shea butter oil Formulation

Formulation	Linseed Oil	0% RSO - 100% SBO	25%RSO– 75% SBO	50% RSO - 50% SBO	75% RSO - 25% SBO	100%RSO– 0% SBO
Refractive Index	1.48	1.60	1.57	1.53	1.50	1.46
Iodine Value	170	85	101	117	134	145
Flash Point	226	120	145	169	194	218
Specific Gravity	0.931	0.935	0.934	0.933	0.932	0.930
pH value	5.8	6.1	5.7	5.4	4.9	4.5

Model Selection and Verification of the Functional Properties
Models were selected based on the highest order polynomial where the additional terms are significant for both Mixture and Process and the model is not aliased. Focus was on the model maximizing the "AdjustedR-Squared" and the "Predicted R-Squared". Therefore, combined quadratic and main effect model was employed for Green compressive strength, green tensile strength, permeability and collapsibility analysis while combined cubic and main effect model, and combined linear and main effect were employed for dry compressive strength and dry tensile strengths respectively.

Model fitting and evaluation of coefficient terms were done using analysis of variance and regression analysis. The results are shown in Tables 4 to 10. The ANOVA shows that the regression model for all the functional properties were highly significant; $P < 0.0001$. This probability value shows that there is only 0.01% chance that model this magnitude could occur due to noise.

The lack-of-fit for all functional properties, were significant. This implies that the model requires further analysis. The goodness-of-fit of the models were further inspected using the R^2 values. The R^2 values are shown in Table 11. The values show that 99% for green compressive strength, 99% for dry compressive strength, 98% for green tensile strength, 99% for dry tensile strength, 96% for permeability and 99% for collapsibility of the total variability of the response data around its mean was explained by the model. The difference between the predicted and adjusted R-square was also considered. A rule of thumb is that the adjusted and predicted R-square should be within 0.2 of each other [13]. Table 11 Shows reasonable agreement between adjusted R-square and predicted R-square (within 0.2 of each other). Adequate precision was used to measure the signal to noise ratio. A ratio greater than 4 indicates an adequate signal and shows that the model can be used to navigate the design space [14]. All The adequate precision for the responses are greater than 4 as shown in Table 11.

Table 4.
Analysis of Variance for Quadratic green compressive strength

Source	Sum of Square	Df	Mean Square	F Value	P-Value
Model	1335.15	17	78.54	163.02	< 0.0001
Linear Mixture	*5.61*	1	5.61	11.65	0.0023
AB	*33.53*	*1*	*33.53*	*69.59*	*<0.0001*
AC	*340.31*	*5*	*68.08*	*141.28*	*< 0.0001*
BC	*342.73*	*5*	*68.55*	*142.28*	*<0.0001*
ABC	3.81	*5*	*0.76*	*1.58*	*0.2035*
Residual	11.56	24	0.48		
Lack of Fit	8.94	*12*	0.74	*3.42*	*0.0217*
Pure Error	2.62	*12*	*0.22*		
Cor Total	1346.71	41			

Table 5.
Analysis of Variance for dry compressive strength

Source	Sum of Square	df	Mean Square	F Value	P-Value
Model	14317.23	23	622.49	2171.62	< 0.0001
Linear Mixture	*265.90*	1	265.90	927.63	<0.0001
AB	*1.90*	*1*	*1.90*	*6.63*	*0.0191*
AC	*3132.39*	*5*	*626.48*	*2185.54*	*< 0.0001*
BC	*4296.16*	*5*	*859.23*	*2997.53*	*<0.0001*
ABC	7.36	*5*	*1.47*	*5.14*	*0.0042*
Residual	5.16	18	0.29		
Lack of Fit	3.34	*6*	0.56	*3.68*	*0.0261*
Pure Error	1.82	*12*	*0.15*		
Cor Total	14322.39	41			

Table 6.
Analysis of Variance for combined Quadratic x main effect green tensile strength

Source	Sum of Square	df	Mean Square	F Value	P-Value
Model	1164.48	17	68.50	127.05	< 0.0001
Linear Mixture	*4.09*	1	4.09	7.59	0.0110
AB	*42.61*	*1*	*42.61*	*79.04*	< 0.0001
AC	*282.50*	*5*	*56.50*	*104.79*	*< 0.0001*
BC	*301.54*	*5*	*60.31*	*111.86*	*<0.0001*
ABC	9.56	*5*	*1.91*	*3.55*	*0.0153*
Residual	12.94	24	0.54		
Lack of Fit	12.81	*12*	1.07	*102.79*	< 0.0001
Pure Error	0.12	*12*	*0.010*		
Cor Total	1177.42	41			

Table 7.
Analysis of Variance for combined Linear x main effect for dry tensile strength

Source	Sum of Square	df	Mean Square	F Value	P-Value
Model	18286.26	11	1662.39	643.80	< 0.0001
Linear Mixture	*755.30*	1	755.30	292.51	< 0.0001
AC	*4823.93*	*5*	*964.79*	*373.64*	*< 0.0001*
BC	*4507.24*	*5*	*901.45*	*349.11*	*<0.0001*
Residual	77.46	30	2.58		
Lack of Fit	77.36	*18*	4.30	*505.31*	< 0.0001
Pure Error	0.10	*12*	*8.506E-003*		
Cor Total	18363.72	41			

Table 8.
Analysis of Variance for combined Quadratic x main effect permeability

Source	Sum of Square	df	Mean Square	F Value	P-Value
Model	2642.01	17	155.35	34.16	< 0.0001
Linear Mixture	*0.96*	1	0.96	0.21	0.6494
AB	389.85	1	393.85	86.60	< 0.0001
AC	*558.73*	*5*	*111.75*	*24.57*	*< 0.0001*
BC	*611.92*	*5*	*122.38*	*26.91*	*<0.0001*
ABC	30.64	5	6.13	1.35	0.2787
Residual	109.15	24	4.55		
Lack of Fit	108.45	*12*	9.04	*154.38*	< 0.0001
Pure Error	0.70	*12*	*0.059*		
Cor Total	2750.16	41			

Table 9.
Analysis of Variance for combined Quadratic x main effect permeability

Source	Sum of Square	df	Mean Square	F Value	P-Value
Model	2642.01	17	155.35	34.16	< 0.0001
Linear Mixture	*0.96*	1	0.96	0.21	0.6494
AB	389.85	1	393.85	86.60	< 0.0001
AC	*558.73*	*5*	*111.75*	*24.57*	*< 0.0001*
BC	*611.92*	*5*	*122.38*	*26.91*	*<0.0001*
ABC	30.64	5	6.13	1.35	0.2787
Residual	109.15	24	4.55		
Lack of Fit	108.45	*12*	9.04	*154.38*	< 0.0001
Pure Error	0.70	*12*	*0.059*		
Cor Total	2750.16	41			

Table 10.
Analysis of Variance for combined Quadratic x main effect collapsibility

Source	Sum of Square	df	Mean Square	F Value	P-Value
Model	71242.31	17	4190.72	10156.37	< 0.0001
Linear Mixture	*12.77*	1	12.77	30.95	< 0.0001
AB	376.70	1	376.70	912.95	< 0.0001
AC	*18549.21*	*5*	*3709.84*	*8990.94*	*< 0.0001*
BC	*18710.89*	*5*	*3742.17*	*9069.29*	*<0.0001*
ABC	61.68	5	12.34	29.90	< 0.0001
Residual	9.90	24	0.41		
Lack of Fit	9.62	*12*	0.80	*34.55*	< 0.0001
Pure Error	0.28	*12*	*0.023*		
Cor Total	71252.21	41			

Table 11.
Model Summary

Response	R-Squared	Adj.R-Squared	Pred.R-Squared	Adeq. Prediction
Green Compressive Strength	0.9914	0.9853	0.9512	43.258
Dry Compressive Strength	0.9996	0.9992	0.9769	154.681
Green Tensile Strength	0.9890	0.9812	0.9310	38.092
Dry Tensile Strength	0.9958	0.9942	0.9909	97.795
Permeability	0.9603	0.9322	0.8000	22.201
Collapsibility	0.9999	0.9998	0.9988	295.530

From Tables 4 to 10 it is evident that both the linear mixture and all interactions in the models are significant for all responses except for green compressive strength and permeability where the interactions between shear butter oil, rubber seed oil and percentage oil in sand are not significant.

The model equations for the functional properties of rubber seed oil/shear butter oil in core are shown in equations 3 to 8. Only the equation for 3% oil in sand, which has the optimum properties are shown.

$$Green\ Compressive\ Strength = 0.37628A + 0.37496B + 9.03536E^{-004}AB \quad (3)$$

$$Dry\ Compressive\ Strength = 6.17109A + 6.33109B + 1.51652E^{-004}AB + 1.03556E^{-006}A^2B^2 \quad (4)$$

$$Green\ Tensile\ Strength = 0.30998A + 0.31670B + 1.86574E^{-003}AB \quad (5)$$

$$Dry\ Tensile\ Strength = 5.79874A + 6.01154B \quad (6)$$

$$Permeability = 4.18478A + 4.18742B - 2.69217E^{-003}AB \quad (7)$$

$$Collapsibility = 1.74954A + 1.72954B - 2.81693E^{-003}AB \quad (8)$$

Residual Analysis
Residuals are the difference between the actual and predicted values. They play important role in judging model adequacy [14]. To check whether the residuals followed a normal distribution, a normal probability curve of the residuals was constructed. If the residual plots approximately along a straight line, then the normality assumption is satisfied. Figures 2 to 7 shows a normal plot of residuals for the responses. These figures show that there is no apparent problem with normality as the residuals plot approximately along a straight line.

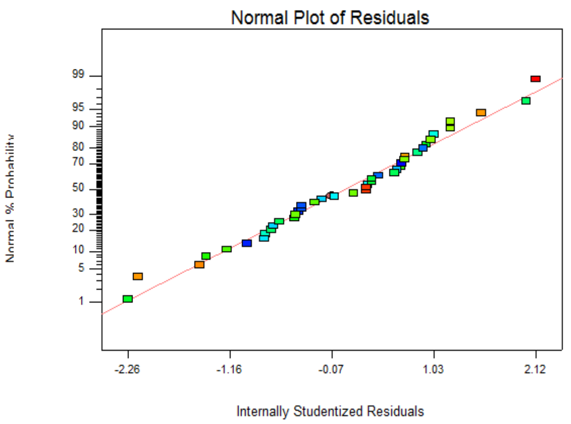

Fig. 2. Normal Plot of Residuals for Green Compressive Strength

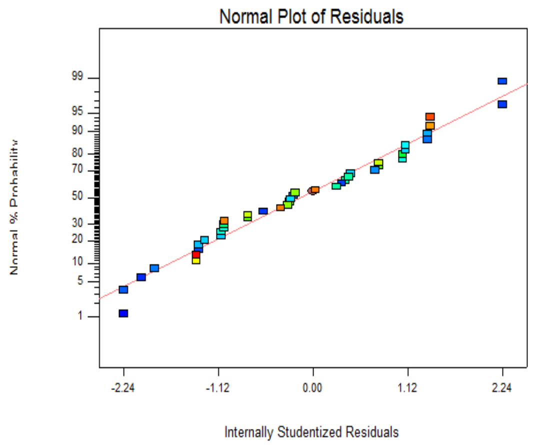

Fig. 3. Normal Plot of Residuals for Dry compressive strength

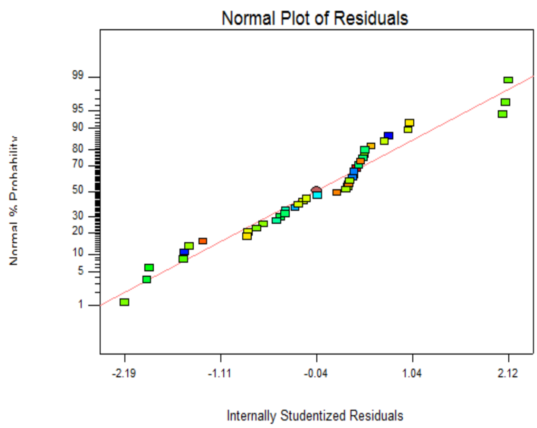

Fig. 2. Normal Plot of Residuals for dry tensile strength

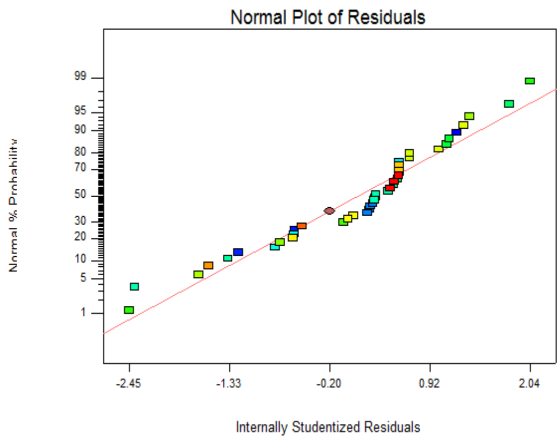

Fig. 5. Normal Plot of Residuals for green tensile strength

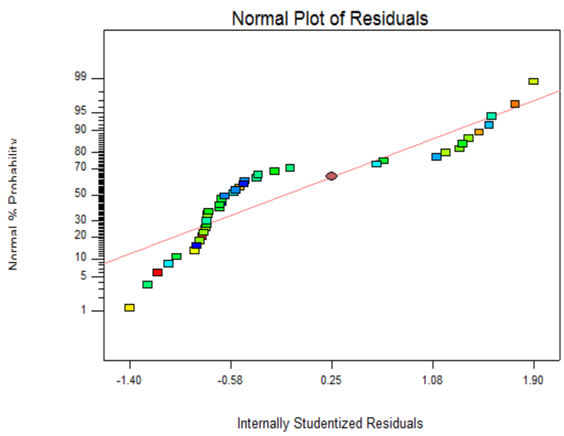

Fig. 6. Normal Plot of Residuals for permeability

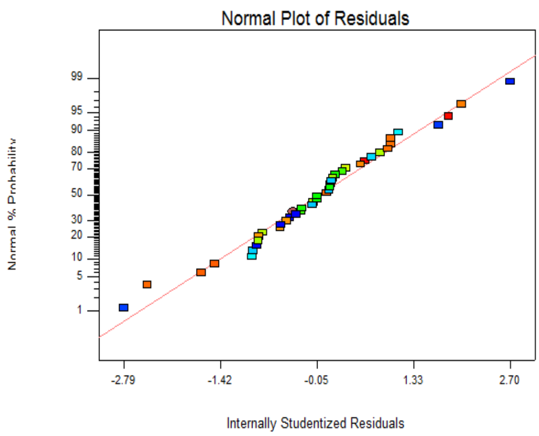

Fig. 7. Normal Plot of Residuals for collapsibility

The actual response value versus the predicted response value graph was used to determine if the model is a satisfactory fit to the data. The condition is that the data point should be approximately split evenly by the 45 degree line [14]. Figures 8 to 13 show the plot of predicted versus actual values for the tensile responses. The plots show that the data points were, approximately, evenly split by the 45 degree line. This shows that the models are satisfactory fit to the data. All the values were well predicted by the data.

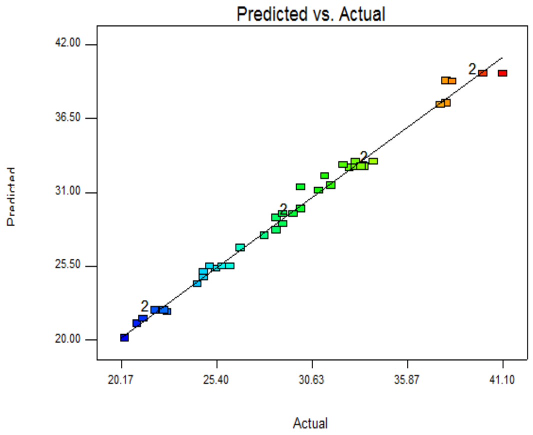

Fig. 8. Predicted vs Actual Response for Green Compressive Strength

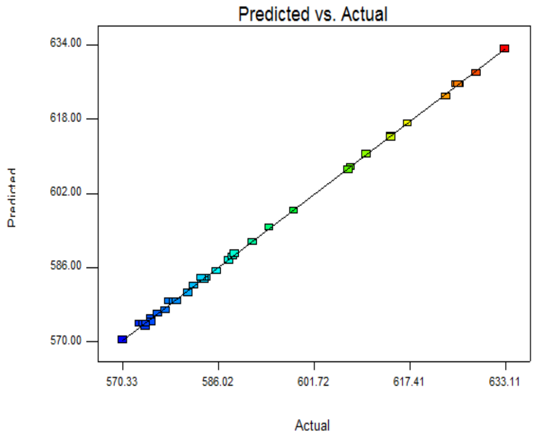

Fig. 9. Predicted vs Actual Response for Dry Compressive Strength

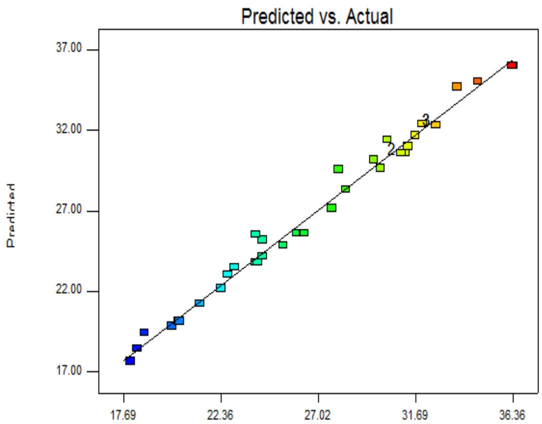

Fig. 10. Predicted vs Actual Response for Green Tensile Strength

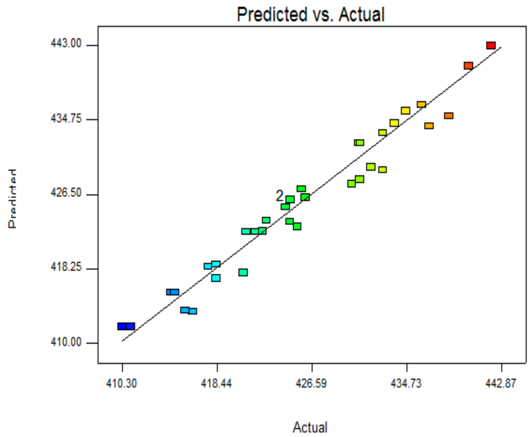

Fig. 3. Predicted vs Actual Response for Permeability

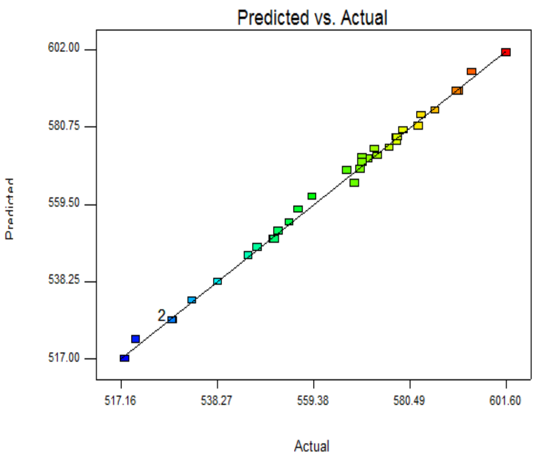

Fig. 12. Predicted vs Actual Response for Dry Tensile Strength

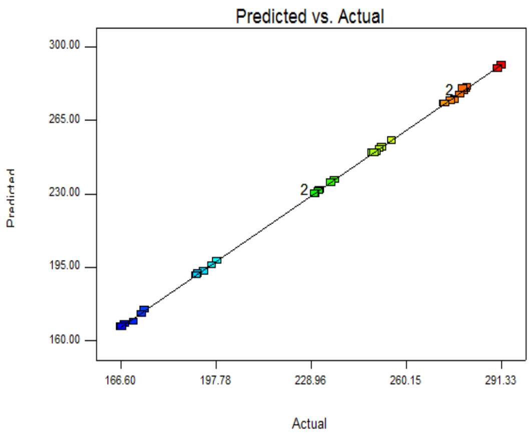

Fig. 13. Predicted vs Actual Response for Collapsibility

From the above analysis, it can be concluded that this model is suitable for predicting the functional properties of rubber seed/shear butter core oil within the limits of the experiment.

Model Graphs

Two component mixture graphs shown in figures 14 to 49, shows the factor and mixture effects of the core oils on their functional properties.

Figures 14 to 19 and figures 26 to 31 show that the mixture of Rubber seed oil and Shear butter oil improves the green compressive and green tensile strength of the core. The maximum green strength was observed at 50% of each oil. A good mixture effect was observed. This could be attributed to the effective bonding mechanism of the formulated RSO-SBO binder which promotes formulation of binder film which surrounds the core sand particles. The binder film surrounding each particle of the core sand, resulting from the mixture, is sufficiently thinner such that the inter – particles distance between neighbouring particle closes up leading to strong bonds within the matrix of the core sand.

It could also be that the mixture absorbs more oxygen than individual components, which gives rise to more impervious and resistant film, causing green sand core to polymerise and form improved strength green sand core [12, 15].

Figures 20 to 25 and Figures 32 to 37 shows the main effects and mixture effects on Dry compressive strength and Dry tensile Strength respectively. It was observed that pure rubber seed oil resulted in cores with the highest dry strengths while pure shear butter oil resulted in cores with the lowest dry strengths. The strengths of the mixture were observed to be in between that of the two oils.

Table 1 shows that flash points of rubber seed oil and shear butter oil are 218^{0}C and 120^{0}C respectively. In the preparation of the core, the baking temperature of 200^{0}C is below the flash point of rubber seed core oil and above the flash point of shear butter core oil - which causes burning of some molecules of shear butter oil and reduction of strength of its core. However, the results of the dry strengths of the formulated 50% rubber seed – shea butter oil falls within the range required for casting aluminium alloy [12, 16].

Figures 38 to 43 show the main effect and mixture effect of Permeability. It was observed that pure core oils have better permeability which indicates that gases and vapour can easily permeate the pores of the core made with these oils individually than those made with the mixture. However, cores produced with the mixture have acceptable permeability value for Aluminium casting [16, 17].

The main and mixture effect of the core oils on collapsibility are shown in Figures 44 to 49. It is observed that the mixture resulted in faster collapsibility time of the core.

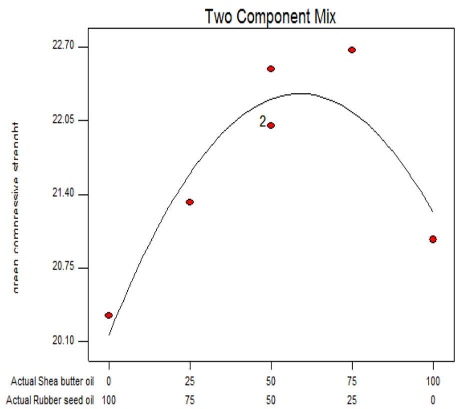

Fig. 14. 0.5% Oil in Sand: Green Compressive Strength

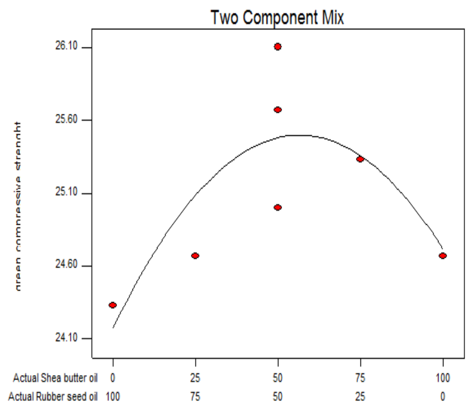

Fig. 15. 1% Oil in Sand: Green Compressive Strength

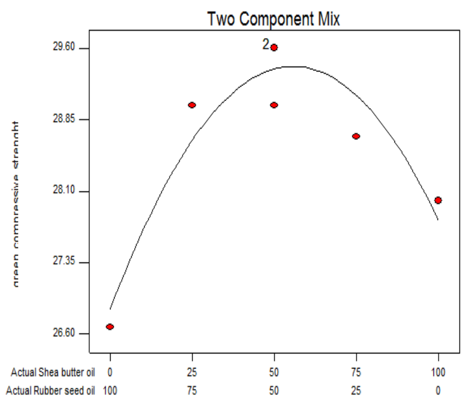

Fig. 16. 1.5% Oil in Sand: Green Compressive Strength

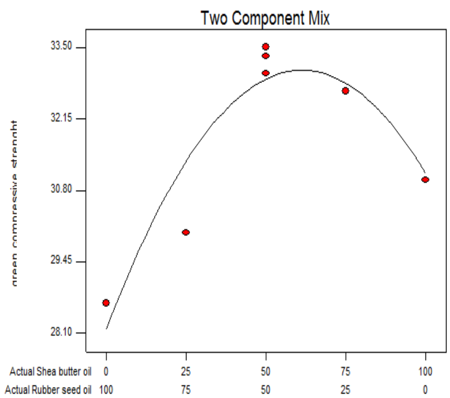

Fig. 17. 2% Oil in Sand: Green Compressive Strength

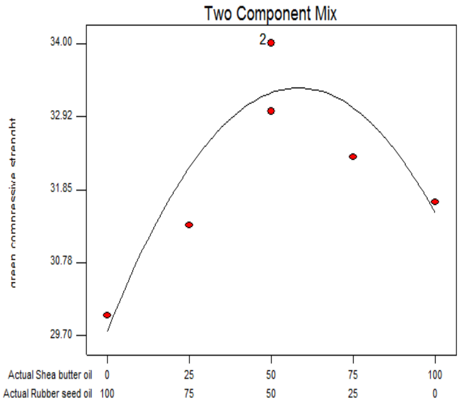

Fig. 18. 2.5% Oil in Sand: Green Compressive Strength

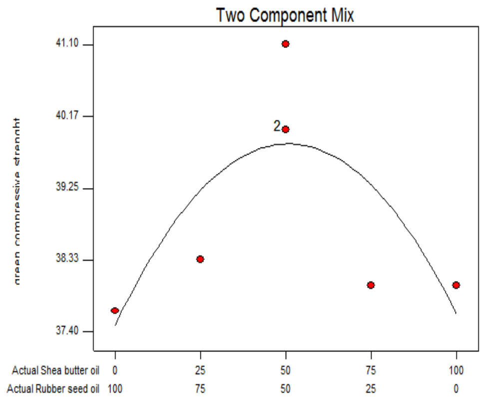

Fig. 19. 3.0% Oil in Sand: Green Compressive Strength

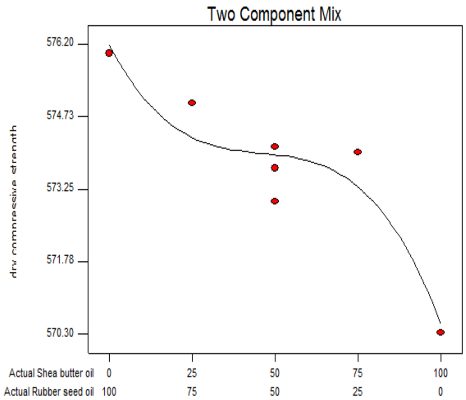

Fig. 20. 0.5% Oil in Sand: Dry Compressive Strength

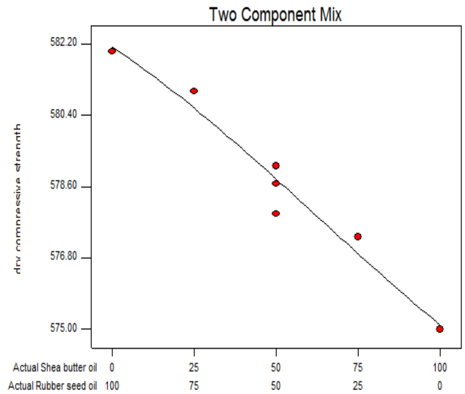

Fig. 21. 1% Oil in Sand: Dry Compressive Strength

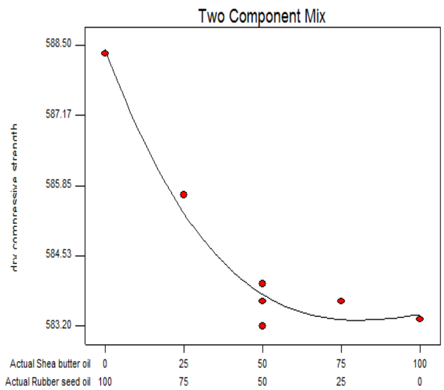

Fig. 22. 1.5% Oil in Sand: Dry Compressive Strength

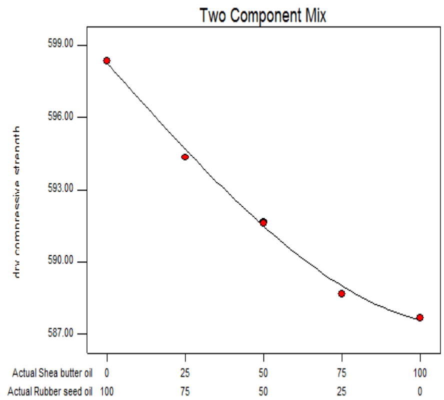

Fig. 23. 2% Oil in Sand: Dry Compressive strength

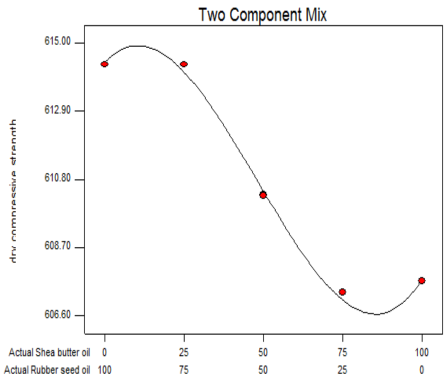

Fig. 24. 2.5% Oil in Sand: Dry Compressive Strength

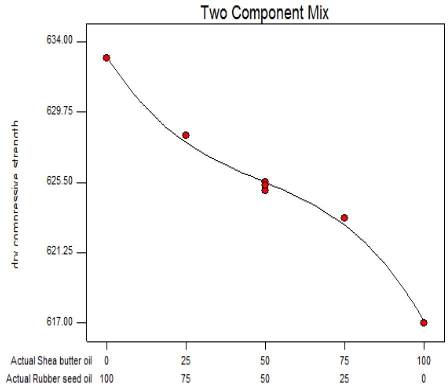

Fig. 25. 3% Oil in Sand: Dry Compressive Strength

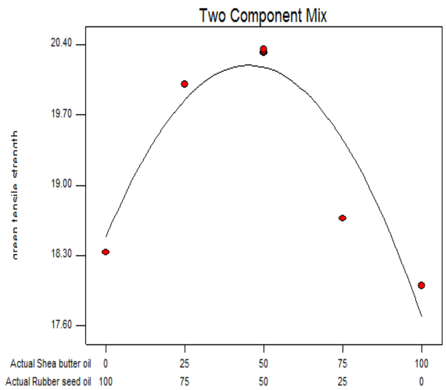

Fig. 26. 0.5% Oil in Sand: Green Tensile Strength

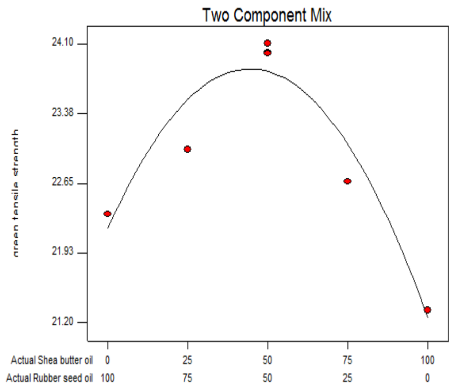

Fig. 27. 1% Oil in Sand: Green Tensile Strength

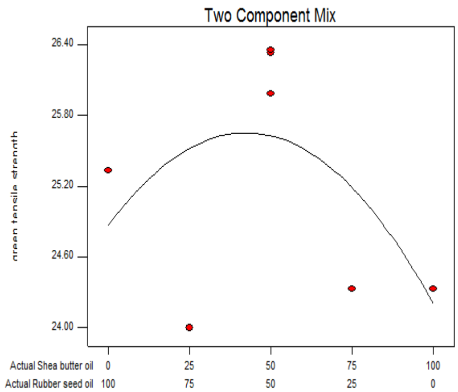

Fig. 28. 1.5% Oil in Sand: Green Tensile Strength

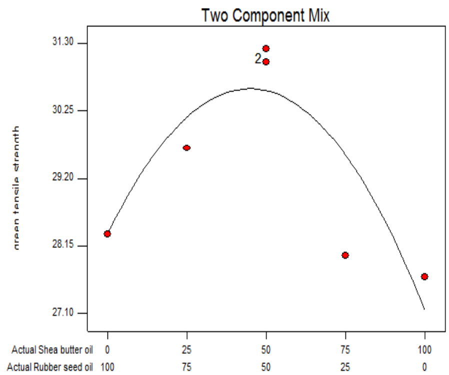

Fig. 29. 2.0% Oil in Sand: Green Tensile Strength

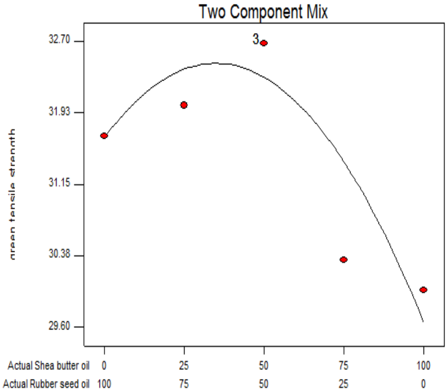

Fig. 30. 2.5% Oil in Sand: Green Tensile Strength

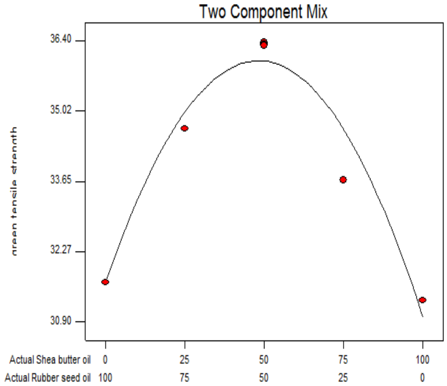

Fig. 31. 3% Oil in Sand: Green Tensile Strength

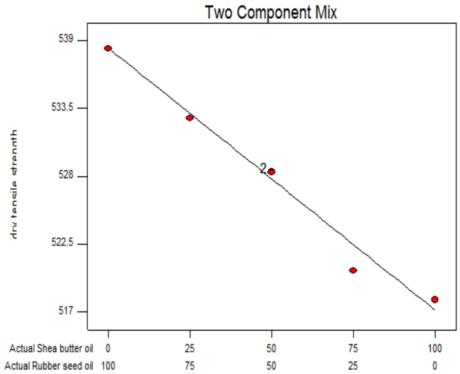

Fig. 32. 0.5% Oil in Sand: Dry Tensile Strength

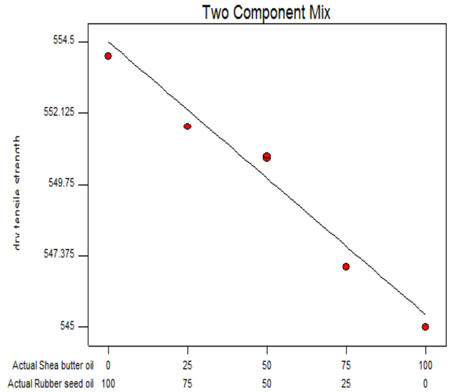

Fig. 33. 1% Oil in Sand: Dry Tensile Strength

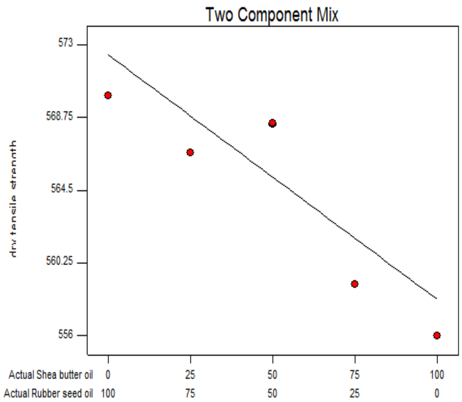

Fig. 34. 1.5% Oil in Sand: Dry Tensile Strength

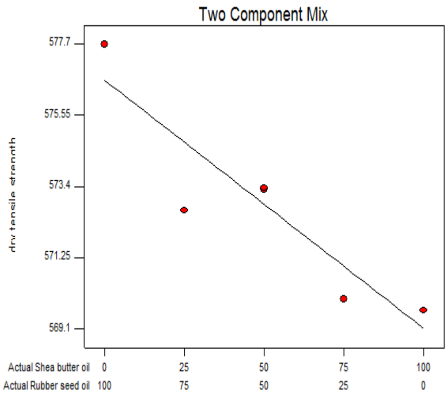

Fig. 35. 2% Oil in Sand: Dry Tensile Strength

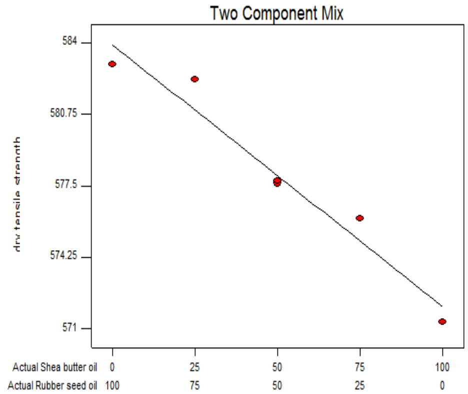

Fig. 36. 2.5% Oil in Sand: Dry Tensile Strength

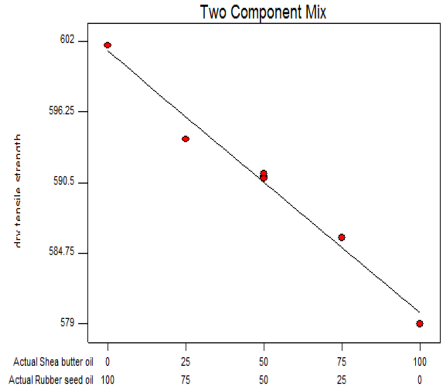

Fig. 37. 3% Oil in Sand: Dry Tensile Strength

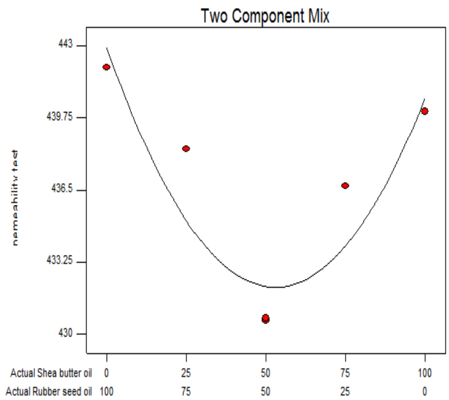

Fig. 38. 0.5% Oil in Sand: Permeability

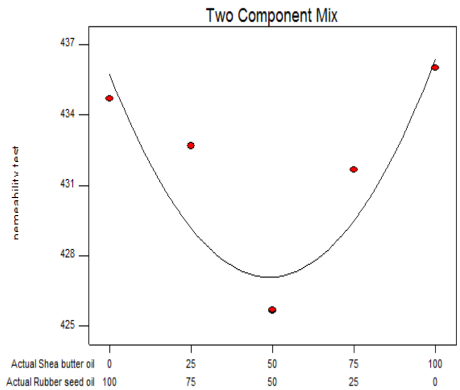

Fig. 39. 1% Oil in Sand: Permeability

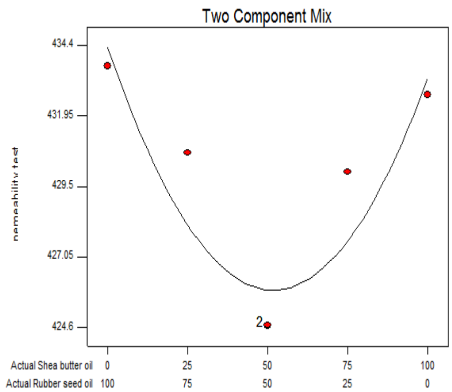

Fig. 40. 1.5% Oil in Sand: Permeability

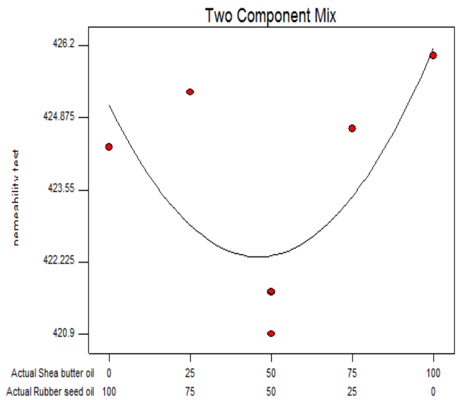

Fig. 41. 2.0% Oil in Sand: Permeability

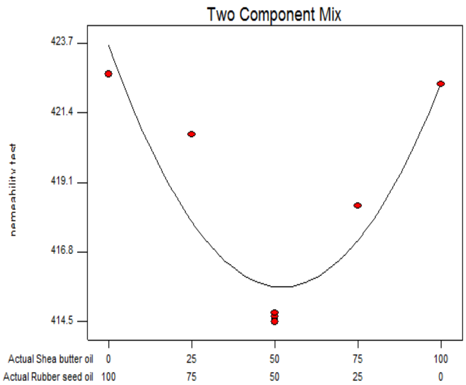

Fig. 42. 2.5% Oil in Sand: Permeability

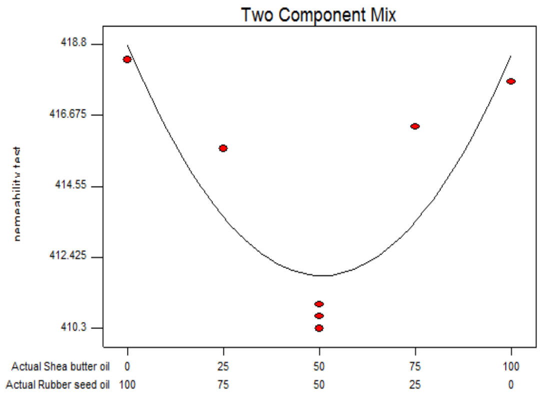

Fig. 43. 3.0% Oil in Sand: Permeability

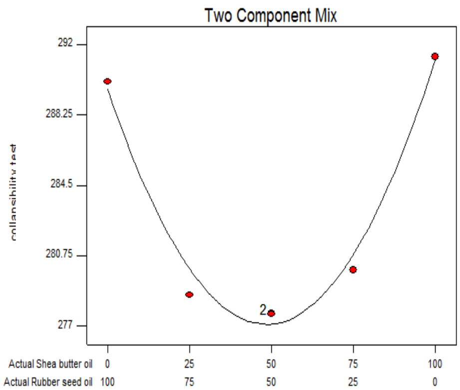

Fig. 44. 0.5% Oil in Sand: Collapsibility

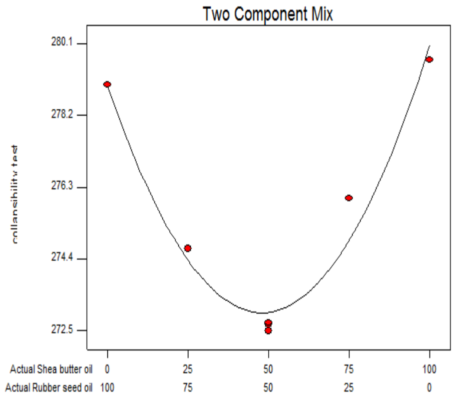

Fig. 45. 1% Oil in Sand: Collapsibility

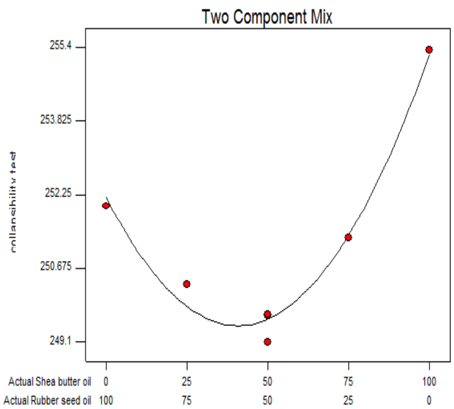

Fig. 46. 1.5% Oil in Sand: Collapsibility

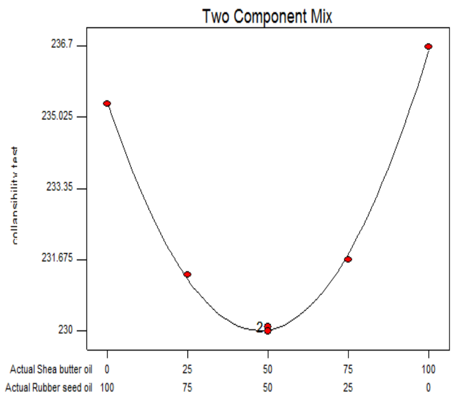

Fig. 47. 2.0% Oil in Sand: Collapsibility

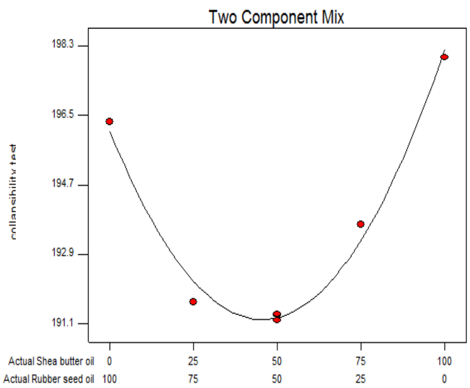

Fig. 48. 2.5% Oil in Sand: Collapsibility

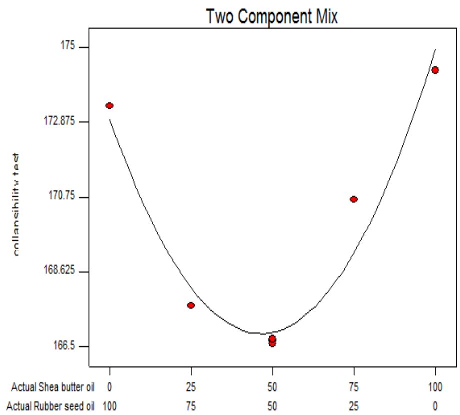

Fig. 49. 3.0% Oil in Sand: Collapsibility

5. Optimisation

Numerical optimisation was used to explore the design space to determine factor settings that met the design goal. The quality characteristics for the optimisation are specified in Table 2. Desirability was used as the criteria for selecting factor settings used for the optimisation. The collapsibility was set in range of 150 s to 300s. According to Dietert [18], collapsibility within the range of 60 – 120 s are considered as fast with the consequence of the production of cracks and warpage in castings whereas those greater than 480 s are regarded to be slow, thus, resulting in metal penetration in castings.

The factor settings that give the optimum responses in this study, as obtained using D-Optimal Mixture design model in Design Expert 7 Statistical Software, are: 34.063 % shear butter oil and 65.937% rubber seed oil in 3% oil in sand. The corresponding responses at the optimal parameter settings are: 39.57 green compressive strength, 626.85 dry compressive strength, 35.63 green tensile strength, 593.906 dry tensile strength, 412.605 permeability and 167.309 sec. Collapsibility at desirability of 0.924. The optimum setting of the formulated core oil is shown in Table 12. In Table 13, the core oil functional properties of Linseed oil are shown. Comparison of Table 12 and 13 shows that the functional properties of the formulated core oil at the optimal setting is close to that of linseed oil – which is already in use as core oil.

Table 12.
Optimal Factor Settings and Functional Properties at Optimum Settings for Rubber Seed-Shear butter core oil at desirability of 0.924. (Percentage oil in Sand is 3)

Factors/Factor Percentage		Responses					
Factors	Percentage of Factor	Green Compressive Strength (KN/M^2)	Dry Compressive Strength (KN/M^2)	Green Tensile Strength (KN/M^2)	Dry Tensile Strength (KN/M^2)	Permeability	Collapsibility (seconds)
Rubber Seed	65.937	39.57	626.85	36.63	593.906	412.605	167.309
Shear Butter	34.063						

Table 13.
Functional Properties of Linseed Oil at 3% oil in Sand

Functional Properties of Linseed Oil					
Green Compressive Strength	Dry Compressive Strength	Green Tensile Strength	Dry Tensile Strength	Permeability	Collapsibility
38.00	634.00	35.00	604.67	421.67	170.00

Validation

Experiment was carried out using the optimal factor settings of Rubber seed-shea butter oil formulation. Table 14 shows the comparison of the experimental value to the pridicted value. The closeness of the predicted value to the experimental values shows that the model can be reliably use for prediction within the experimental limit.

Table 14.
Predicted Versus Experimental Value

Optimal Factor Setting		Predicted Value						Experimental Value					
Rubber Seed (%)	Shear Butter (%)	Green Compressive Strength	Dry Compressive Strength	Green Tensile Strength	Dry Tensile Strength	Permeability	Collapsibility	Green Compressive Strength	Dry Compressive Strength	Green Tensile Strength	Dry Tensile Strength	Permeability	Collapsibility
65.937	34.063	39.57	626.85	36.63	593.906	412.605	167.309	41.2	625.5	38.3	590.1	418.4	171.5

6. Conclusion

This work was carried out to determine the optimum parameter settings to produce rubber seed – shea butter core oil with desirable functional properties for Aluminum casting. The optimal parameter settings was determined to be 65.937% Rubber seed and 34.063% Shea butter oil at desirability of 0.924 . The fuctional properties at the optimum parameter settings was found to be within the range of core oil properties for Aluminum casting. This study has proved that rubber seed-shea butter based core oil – which is aboundant in developing countries like Nigeria, has fovourable properties for Aluminum casting.

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