JOURNAL OF ENGINEERING
AND
APPLIED SCIENCES

Journal of Engineering and Applied Sciences 12 (2018), 18-34

EVALUATION OF OPTIMUM TENSILE PROPERTIES OF UKAM PLANT FIBRE REINFORCED CASHEW NUT SHELL LIQUID (CNSL) COMPOSITE.

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Abstract

This study focuses on the evaluation of optimum tensile properties which include tensile strength, modulus of elasticity, modulus of resilience and modulus of toughness of ukam plant fibre reinforced cashew nut shell liquid utilizing Taguchi Robust Design. Three factors considered include fibre volume fraction, aspect ratio and fibre orientation. Minitab release 16 software and a program written in Microsoft Excel Visual Basic code windows were used for the optimization analysis. Simpsons 1/3 rule was used to solve the area under the stress-strain curve to obtain the modulus of toughness. The expected optimum tensile strength was evaluated as 21.92982MPa.The expected optimum modulus of elasticity was evaluated as 1.857519GPa. The expected optimum modulus of resilience was obtained as 113.0502x10^{-3} J/m^3. While the expected optimum modulus of toughness was evaluated as 0.2308497J/m^{3}.The analysis shows that fibre volume fraction is the most significant factor in the optimization of all the tensile properties of the bio composite material evaluated.

Keywords: Ukam plant fibre, cashew nut shell liquid, Taguchi robust design, tensile properties, Simpson 1/3 rule

1. Introduction

Fibres produced by plants, animals or through geological processes are basically known as natural fibres. Due to their low cost, fairly good mechanical properties, high specific strength, non-abrasive, eco-friendly and biodegradability characteristics, they are exploited as replacement for the conventional fibre, such as glass, aramid and carbon (Ku *et al,* 2011). Research carried out by (Malkapuram *et al,* 2008) shows that some advantages of Natural Fibres include its low density, good specific tensile properties, recyclability and biodegradability over carbon fibres. The current quest by the nations of the world for environmentally safe, eco-friendly, biodegradable, global warming free, green sourced fibres or materials over synthetic ones has to be met through dedicated research on opportunity scopes and optimum properties of natural fibres. Ukam plant fibre is an example of such natural fibre which is extracted from the stem of Ukam plant. Ukam plant fibres have been used as cordage crop to produce twine, rope, sack cloth, building material, absorbent and animal feeds. Cashew nut shell liquid is also a natural bio-resins. It is a reddish brown viscous liquid extracted from the honey comb structure of the shell of cashew kernel. It is alkylphenolic oil contained in the spongy mesocarp of cashew nut. The main constituents of cashew nut shell liquid are cardonol, anarcardic acid, cardol, 2-methyl cardol and small amount of polymeric material (Mwaikambo and Anseli, 2001).In this research, the tensile properties of ukam plant fibre reinforced cashew nut shell liquid will be analysed.

2.0 Material and methods

2.1 Design of Experiment

Telford defined Design of experiment as series of tests in which purposeful changes are made to the input variables of a system or process and the effects on response variables measured (Telford, 2007). Design of experiment helps draw valid and definite conclusion from measured data with minimum use of resources. Taguchi Robust design involves reducing the variation in a process through robust design of experiments. The experimental design method developed by Dr. Genichi Taguchi was described in his early books (Taguchi, 1987). Taguchi robust design had been utilized effectively by researchers on different types of composite materials which include wood and non-wood natural fibres. Taguchi robust design was used for the experiment conducted in this paper. Three factors and three levels were used to conduct the experiment as shown in the table 1 below:

Table 1: Processing Factors and Levels Considered in Taguchi Robust Design of Experiment

S/N	Processing Factors	Level		
		1	2	3
1	A: Fibre Orientation (deg)	0	45	90
2	B: Fibre Volume Fraction (%)	10	30	50
3	C: Fibre Aspect Ratio l_f/d_f (mm/mm)	8	80	160

Since three parameters and three levels were considered, L9 orthogonal array was selected as shown in table 2

Table2: L9 Orthogonal Array Showing the Arrangement of Parameters and Levels Utilized for the experiment.

Experiment Runs	A: Fibre Orientation (deg)	B: Fibre Volume Fraction (%)	C: Aspect Ratio	Response		
				Trial 1	Trial 2	Trial 3
1	0	10	8	$T_{1,1}$	$T_{1,2}$	$T_{1,3}$
2	0	30	80	$T_{2,1}$	$T_{2,2}$	$T_{2,3}$
3	0	50	160	$T_{3,1}$	$T_{3,2}$	$T_{3,3}$
4	45	10	80	$T_{4,1}$	$T_{4,2}$	$T_{4,3}$
5	45	30	160	$T_{5,1}$	$T_{5,2}$	$T_{5,3}$
6	45	50	8	$T_{6,1}$	$T_{6,2}$	$T_{6,3}$
7	90	10	160	$T_{7,1}$	$T_{7,2}$	$T_{7,3}$
8	90	30	8	$T_{8,1}$	$T_{8,2}$	$T_{8,3}$
9	90	50	80	$T_{9,1}$	$T_{9,2}$	$T_{9,3}$

2.1.1 Analyzing Experiment Data

The signal to noise ratio, SN number is used to determine the effect each variable has on the output. Optimization requires maximizing the performance characteristics, so the signal to noise ratio, SN number utilized in this research is based on larger is better SN ratios as shown in equation 1

$$SN_i = -10\log\left[\frac{1}{N_i}\sum_{i=1}^{Ni}\frac{1}{y_i^2}\right] \quad (1)$$

The mean squared deviation, MSD is given by

$$MSD_i = \left[\frac{1}{N_i}\sum_{i=1}^{Ni}\frac{1}{y_i^2}\right] \quad (2)$$

$$\therefore SN_i - 10\log MSD_i \quad (3)$$

The mean response is

$$Mmsi = \overline{y} = \left(\frac{1}{n} \sum_{i=1}^{n} y_i \right) \quad (4)$$

Standard deviation, S

$$s = \sqrt{\sum_{i=1}^{n} \frac{\left(y_i - \overline{y}_i\right)^2}{n-1}} \quad (5)$$

Where

y_i is the value of the performance characteristics.

Also Degree of Freedom $(DOF)_R$ is

$$(DOF)_R = P * (L - 1) \quad (6)$$

Where P = number of parameters

L = number of levels

For 3 parameters and 3 levels utilized in this dissertation

$(DOF)_R = 3(3 - 1) = 6$

Program written in Microsoft excel visual basic code windows was used to execute equation 1 to 6 for the optimization. The same result is obtained with Minitab release 16 software.

2.1.2 Tensile Test

A tensile test determines the behaviour of material under tension loading. It is a fundamental mechanical test where a carefully prepared specimen is loaded in a controlled manner while measuring the applied load and the elongation of the specimen over some distance.

The tensile Replicate samples of 160 x 19 x 3.2mm each were cut from the Specimen of the Ukam Plant Fibre Reinforced cashew nut shell liquid Resin composite prepared using hand lay up technique. The samples were uniaxially pulled by Hounsfield Monsanto universal tensometer with serial number 8889 in accordance with ASTM D638 standards. The magnification of 4:1 and 9806.65N (1000KgF) beam Force was used at crosshead speed of 1.66667×10^{-5} m/s (1mm/min). Each specimen was loaded to Failure. The force applied and extension was recorded. The key mechanical properties determined from the tensile test include:

a) Modulus of Elasticity, E
b) Yield stress, σ_y
c) Ultimate tensile strength, σ_{ult}
d) Strain at failure, ε_f
e) Modulus of Resilience, u_R
f) Modulus of Toughness, u_T

3.0 Results and Discussions

Evaluation of Modulus of Elasticity, E of Ukam Plant Fibre Reinforced Cashew Nut Shell Liquid Composite

The modulus of Elasticity, E obtained from the slope of Regression model of linear region of stress-strain relationship for each experimental runs is shown in Table 3. Modulus of Elasticity, E is the ratio of applied stress to the strain of the composite. It is a measure of stiffness of the composite. Observations made from the bar chart (Fig.1) showed that the maximum modulus of Elasticity is captured at the third runs of experiment carried out with the factor settings of fibre orientation of 0 degree, Fibre volume fraction of 50% and Aspect ratio of 160.The least modulus is observed at the first runs of experiment. The maximum modulus of Elasticity response is observed at the first trial of third experimental run as 2.105GPa.

Table 3: The modulus of Elasticity, E of Ukam plant fibre Reinforced CNSL composite.

Experiment Runs	Fibre Orientation (Deg)	Fibre volume fraction (%)	Aspect Ratio	Modulus of Elasticity, E (GPa)		
				Trial 1	Trial 2	Trial 3
1	0	10	8	1.113	1.052	1.110
2	0	30	80	1.776	1.719	1.777
3	0	50	160	2.105	1.914	1.966
4	45	10	8	1.468	1.259	1.403
5	45	30	80	1.494	1.423	1.460
6	45	50	160	1.287	1.302	1.265
7	90	10	8	1.165	1.026	0.992
8	90	30	80	1.449	1.403	1.299
9	90	50	160	1.447	1.465	1.410

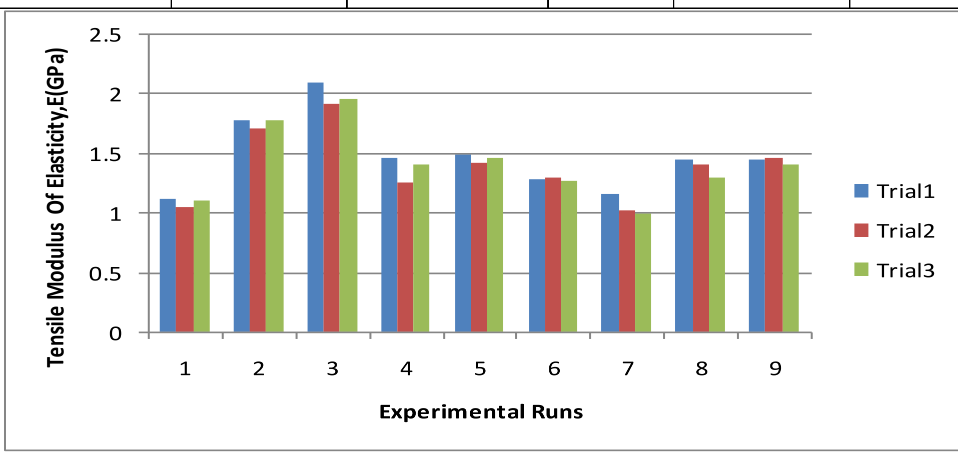


Fig1: Tensile Modulus of Elasticity, E (GPa) response of Ukam Plant Fibre reinforced CNSL composite chart and Experimental runs.

Optimization of the modulus of Elasticity, E (GPa) of Ukam Plant Fibre Reinforced cashew nut shell liquid composite

The optimum setting of control factors for the modulus of Elasticity is obtained applying Taguchi Robust design. The modulus of Elasticity, E is optimized so as to appreciate the possible optimum response for it and predict the significant factors affecting it. The result for the three trials of each experimental runs, the mean, mean squared deviation, signal to noise ratio, response signal to noise ratios table, mean of quality characteristics table, plot of signal to noise ratio against factor levels, plot of mean of means against factor levels and optimum response analysis is shown in fig.2.Fig 2 is the output in excel spreadsheet for a program written in Excel visual basic code windows for solving Taguchi L9 orthogonal problems in this paper for the three factors and three levels considered based on “larger- is- better” Signal-noise-Ratio.

OPTIMIZATION OF TENSILE MODULUS OF ELASTICITY,E(GPa) APPLYING TAGUCHI ROBUST

EXP. RUNS	ORIENTATION (+ - Degree)	VOLUME FRACTION(%)	ASPECT RATIO	TRIAL1	TRIAL2	TRIAL3	MEAN	MSD	SN ratio
1	0	10	8	1.113	1.052	1.11	1.091667	0.84082	0.752971
2	0	30	80	1.776	1.719	1.777	1.757333	0.324046	4.893937
3	0	50	160	2.105	1.914	1.966	1.995	0.252458	5.978109
4	45	10	80	1.468	1.259	1.403	1.376667	0.534313	2.722042
5	45	30	160	1.494	1.423	1.46	1.459	0.470332	3.275951
6	45	50	8	1.287	1.302	1.265	1.284667	0.606181	2.17398
7	90	10	160	1.165	1.026	0.992	1.061	0.900984	0.45283
8	90	30	8	1.449	1.403	1.299	1.383667	0.525644	2.793081
9	90	50	80	1.447	1.465	1.41	1.440667	0.482175	3.167951

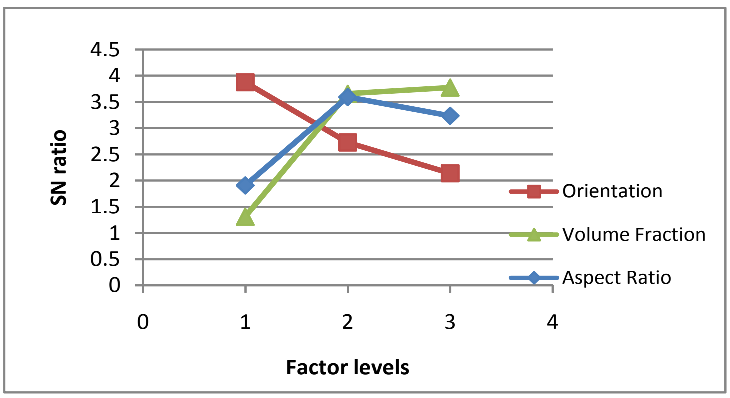
RESPONSE SIGNAL TO NOISE RATIOS

LEVEL	ORIENTATION (+ -Degree)	VOLUME FRACTION(%)	ASPECT RATIO
1	3.87500551	1.3092811	1.9067
2	2.72399108	3.6543229	3.5946
3	2.13795393	3.7733465	3.2356
DELTA	1.73705149	2.4640653	1.688
RANK	2	1	3

MEANS OF QUALITY CHARACTERISTICS

ORIENTATION (+_ Deg)	VOLUME FRACTION(%)	ASPECT RATIO
1.614667	1.176444	1.253333
1.373444	1.533333	1.524889
1.295111	1.573444	1.505
0.319556	0.397	0.271556
2	1	3

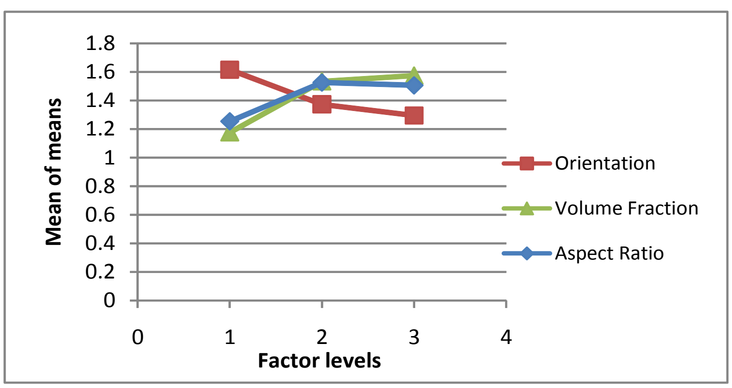
Evaluate



Main effect plots for signal-noise ratio

OPTIMUM RESPONSE ANALYSIS

Average Mean =	1.427741
A Optimum =	1.614667
B Optimum =	1.573444
C Optimum =	1.524889
Optimum Response =	1.857519 GPa



Main effect plots for means

Fig 2: Microsoft Excel Visual Basic output for Optimization of Tensile Modulus of Elasticity, E (GPa) response of Ukam Plant Fibre reinforced CNSL Composite applying Taguchi Robust Design

Results obtained from the Optimization of tensile modulus of Elasticity shows that Fibre volume fraction displayed stronger effects for both signal to noise ratio and means of quality characteristics than Aspect Ratio and Fibre orientation. Fibre volume fraction is therefore the most significant parameter in the optimization of tensile modulus of elasticity of ukam plant fibres reinforced cashew nut shell liquid composite.

The optimum settings of control factors and expected optimum modulus of elasticity are shown in table 4.The expected optimum modulus of elasticity is captured as 1.857519GPa.

Table 4: Optimum settings of control factors and expected optimum modulus of Elasticity (GPa).

Composite material	Control	Optimum level	Optimum setting	Expected optimum modulus of Elasticity
Ukam plant fibre reinforced CNSL	Fibre orientation (deg) Fibre volume fraction (%) Aspect Ratio(mm/mm)	1 3 2	0 50 80	1.857519GPa

Determination of yield stress, σ_y Response of Ukam Plant fibre Reinforced CNSL Composite

The yield strength of a material is the stress applied to the materials at which plastic deformation starts to occur while the material is being loaded. The notation used to represent the yield stress is either σ_y or s_y. The measured values from the experimental runs are as recorded in Table 5 below.

Table 5: The yield stress response (MPa) of Ukam plant fibre reinforced CNSL composite.

Experiment Runs	Fibre Orientation (deg)	Fibre volume fraction (%)	Aspect Ratio (mm/mm)	Yield stress Response (MPa) of samples		
				Trial 1	Trial 2	Trial 3
1	0	10	8	14.80263138	13.15790000	13.98026000
2	0	30	80	18.09210526	18.91447449	16.44736842
3	0	50	160	21.38517845	16.44736802	23.02631500
4	45	10	80	14.80263138	13.15789509	13.15789509
5	45	30	160	16.44736862	18.09210587	14.80263138
6	45	50	8	16.44736862	16.44736862	18.09210587
7	90	10	160	14.80263138	13.15789509	11.51315784
8	90	30	8	15.62500000	16.44736862	15.62500000
9	90	50	80	17.26973724	15.6250000	16.44736862

Determination of ultimate tensile strength Response of Ukam Plant Fibre Reinforced CNSL Composite

The tensile strength (TS) of a material is the maximum stress that a material can withstand while being uniaxially pulled or stretched before breaking or failing. It is also known as ultimate tensile strength (UTS) with units in MPa. The tensile strength is an important mechanical property utilized in the design of composite materials. The measured tensile strength Response (MPa) obtained from Tensile testing of Ukam Plant Fibre Reinforced Cashew Nut Shell Liquid (CNSL) composite is shown in table 6.

Observations made from the chart of fig3 shows that the third runs of experiment with processing factor settings of fibre orientation of 0 degree, volume fraction of 50% and aspect ratio of 160 had the maximum measured tensile strength response.

The least evaluated tensile strength response is observed at the third trial of the fourth and seventh experimental runs with tensile strength of 13.98026316MPa each.

Table 6: Tensile strength Response (MPa) of Ukam plant fibre Reinforced CNSL composite.

Experiment Runs	Fibre Orientation (deg)	Fibre volume fraction (%)	Aspect Ratio (mm/mm)	Tensile strength Response (MPa)		
				Trial 1	Trial 2	Trial 3
1	0	10	8	18.09210500	14.80260000	15.62500000
2	0	30	80	19.73684211	21.38157895	19.73684211
3	0	50	160	23.02631500	18.91447368	24.67105263
4	45	10	80	16.44736842	15.6250000	13.98026316
5	45	30	160	18.09210526	19.73684211	17.26973684
6	45	50	8	18.09210560	18.91447368	19.73684211
7	90	10	160	16.44736842	14.80263158	13.98026316
8	90	30	8	16.44736842	18.09210560	17.26973689
9	90	50	80	18.91447368	17.26973684	18.91447368

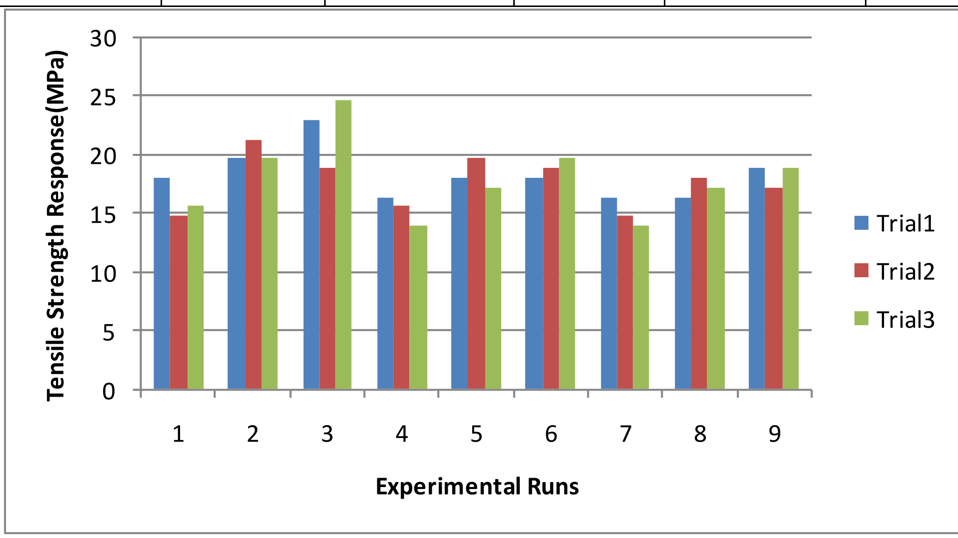


Fig3: Tensile Strength response (MPa) of Ukam Plant Fibre reinforced CNSL composite chart and Experimental runs.

Optimization of Tensile strength Response of Ukam Plant Fibre Reinforced CNSL composite.

OPTIMIZATION OF TENSILE STRENGTH RESPONSE (MPa)APPLYING TAGUCHI ROBUST DESIGN

EXP. RUNS	ORIENTATION (+ - Degree)	VOLUME FRACTION(%)	ASPECT RATIO	MPa TRIAL1	TRIAL2	TRIAL3	MEAN	MSD	SN ratio
1	0	10	8	18.09211	14.8026	15.625	16.17323	0.003905	24.08385
2	0	30	80	19.73684	21.38158	19.73684	20.28509	0.002441	26.12516
3	0	50	160	23.02632	18.91447	24.67105	22.20395	0.002108	26.76117
4	45	10	80	16.44737	15.625	13.98026	15.35088	0.004303	23.66225
5	45	30	160	18.09211	19.73684	17.26974	18.36623	0.002992	25.2408
6	45	50	8	18.09211	18.91447	19.73684	18.91447	0.002806	25.51945
7	90	10	160	16.44737	14.80263	13.98026	15.07675	0.004459	23.50767
8	90	30	8	16.44737	18.09211	17.26974	17.26974	0.003368	24.72599
9	90	50	80	18.91447	17.26974	18.91447	18.36623	0.002981	25.25621

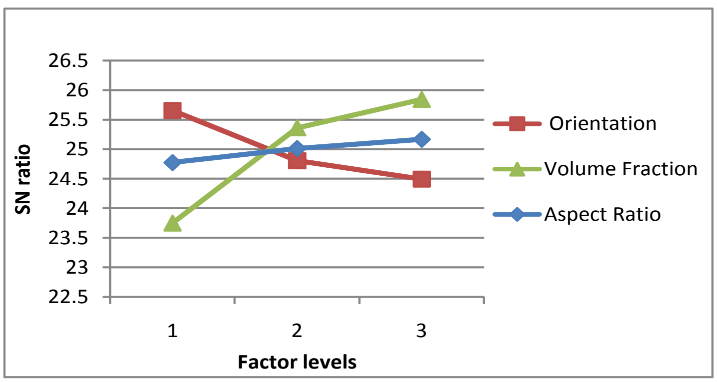
RESPONSE SIGNAL TO NOISE RATIOS

LEVEL	ORIENTATION (+-Degree)	VOLUME FRACTION(%)	ASPECT RATIO
1	25.6567257	23.751258	24.776
2	24.8074987	25.363983	25.015
3	24.4966255	25.845609	25.17
DELTA	1.16009903	2.0943508	0.3935
RANK	2	1	3

MEANS OF QUALITY CHARACTERISTICS

LEVEL	ORIENTATION (+_Deg)	VOLUME FRACTION(%)	ASPECT RATIO
1	19.55409	15.53362	17.45248
2	17.54386	18.64035	18.00073
3	16.90424	19.82822	18.54898
DELTA	2.649851	4.294595	1.096495
RANK	2	1	3

Evaluate

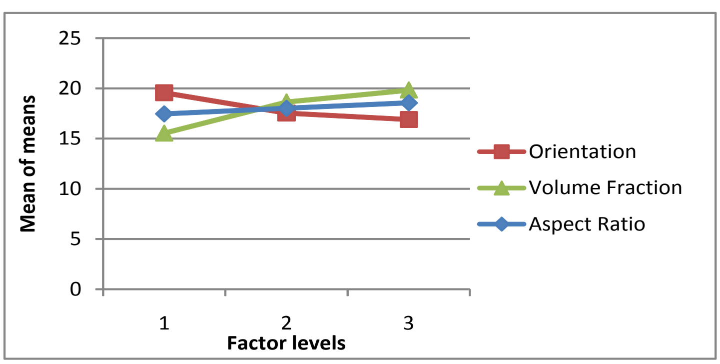


Main effect plots for signal-noise ratio

OPTIMUM RESPONSE ANALYSIS

Average Mean = 18.00073
A Optimum = 19.55409
B Optimum = 19.82822
C Optimum = 18.54898

Optimum Response = 21.92982 MPa



Main effect plots for means

Fig 4: Microsoft Excel Visual Basic output for Optimization of Tensile Strength Response of Ukam Plant Fibre reinforced CNSL Composite applying Taguchi Robust Design

The optimization of tensile strength response of Ukam Plant Fibre reinforced cashew nut shell liquid is obtained by applying Taguchi Robust design on a "larger- is- better" signal to noise ratio. The optimum setting of control factors, optimum response, mean effect plot against factor levels and signal to noise ratio plot against factor levels are evaluated using a program written in Excel visual basic code windows and executed via Excel spreadsheets. Results obtained from the optimization of the tensile strength response of Ukam Plant Fibre reinforced CNSL composite is shown in Fig.4.

The results obtained for the optimum setting of control factors and the expected optimum tensile strength for the optimization of tensile strength response of Ukam Plant Fibre reinforced CNSL composite is shown in table 7 below. The results showed that the optimum tensile strength is captured as 21.92982MPa at the optimum settings of 0 degree of Fibre orientation, 50% fibre volume fraction and the aspect ratio of 160.The optimum setting of control factors showed that the optimum tensile strength of the composite material is obtained when the fibres are arranged in the direction of applied tensile force.

Results obtained from the excel visual basic output for the optimization of tensile strength response of Ukam Plant Fibre reinforced CNSL composite of fig.4 showed that the fibre volume fraction displayed stronger effects than fibre orientation and aspect ratio. Fibre volume fraction can be said to be the most significant factor in the optimization of tensile strength response of Ukam Plant Fibre reinforced cashew nut shell liquid composite.

Results obtained from the regression model of Table 8 with Minitab release 16 software showed that the coefficient of determination R-sq is obtained as 92.1%.This simply indicates that the predictors explain 92.1% of the variance in the tensile strength response of Ukam plant fibre reinforced CNSL composite. The adjusted coefficient of determination R-sq (adj) is 87.4%.This accounts for the number of predictors in the model. Both values indicate that the model fits the data well.

Results obtained for the analysis of variance (ANOVA) of the regression model is shown in table 9.The p-value evaluated as 0.003 shows that the model estimated by the regression procedure is significant at the significance level of 0.05.

A residual plot is a graph that shows the residuals on the vertical axis and the independent variable on the horizontal axis. If the points in a residual plot are randomly dispersed around the horizontal axis, a linear regression model is appropriate for the data; Otherwise, a non-linear model is more appropriate (Ihueze et al, 2012).The plot of fig 5 showed that a linear model fitted for the mean tensile strength response is appropriate as the points in the residual plot are randomly dispersed.

Table 7: Optimum settings of control factors and expected optimum tensile strength.

Composite material	Control	Optimum level	Optimum setting	Expected optimum tensile strength
Ukam Plant Fibre reinforced CNSL	Fibre orientation (deg) Fibre volume fraction (%) Fibre Aspect Ratio (mm/mm)	1 3 3	0 50 160	21.92982MPa

Table8: Regression model for tensile strength Response

Predictor constant	Coef	SE Coef	T	P
Constant	15.5089 –	0.7639	20.30	0.000
Fibre orientation (deg)	0.029443	0.007518	-3.92	0.011
Fibre volume fraction (%)	0.10736	0.01691	6.35	0.001
Fibre Aspect Ratio (mm/mm)	0.007207	0.004449	1.62	0.166

S = 0.828640 R-Sq = 92.1% R-Sq(adj) = 87.4%

The evaluated regression equation for tensile strength is

Tensile strength= 15.5 - 0.0294 A: Fiber Orientation + 0.107 B: Volume Fraction + 0.00721 C: Aspect Ratio

Table 9: Analysis of variance (ANOVA) for Regression model for Tensile strength of Ukam Plant Fibre Reinforced CNSL composite

Source	DF	SS	MS	F	P
Regression	3	40.000	13.333	19.42	0.003
Residual Error	5	3.433	0.687		
Total	8	43.433			

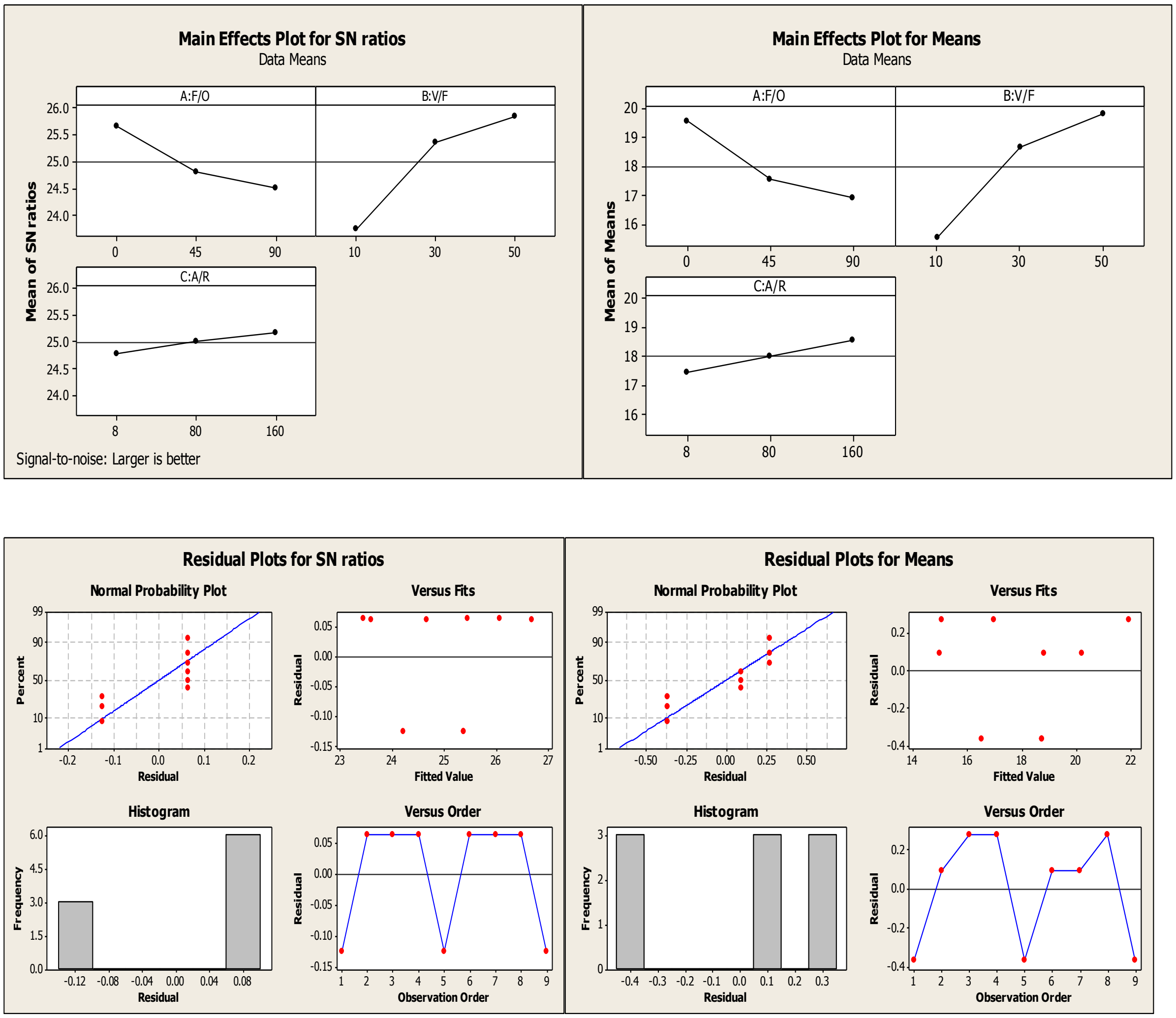


Fig 5: Main Effects plot for SN ratios and means; residual plots for SN ratios and Means.

Analysis of Optimum strain Response of Ukam Plant Fibre Reinforced CNSL composite

The value of strain at which the Ukam Plant Fibre reinforced CNSL composite material Fractures is known as strain at break, or strain at failure ε_f. The strain at break corresponds to the strain at ultimate tensile strength for the composite material under study. The evaluated strain at failure for Ukam Plant Fibre reinforced CNSL composite is shown in Table 10. Figure 6 shows that the range for the strain at failure is between 0.0125 and 0.01875.

Table 10: Strain at failure obtained from tensile test of ukam plant reinforced CNSL composite

Experiment Runs	Fibre Orientation (deg)	Fibre volume fraction (%)	Aspect Ratio (mm/mm)	Strain at Failure, ε_f x 10^{-3}		
				Trial 1	Trial 2	Trial 3
1	0	10	8	18.75000	17.18750	17.18750
2	0	30	80	16.406250	17.18750	15.62500
3	0	50	160	15.62500	14.06250	17.18750
4	45	10	80	14.06250	14.84375	13.28125
5	45	30	160	16.40625	17.18750	14.84375
6	45	50	8	17.18750	17.18750	17.18750
7	90	10	160	17.18750	16.406250	15.62500
8	90	30	8	15.62500	16.406250	15.62500
9	90	50	80	17.187500	15.62500	17.96870

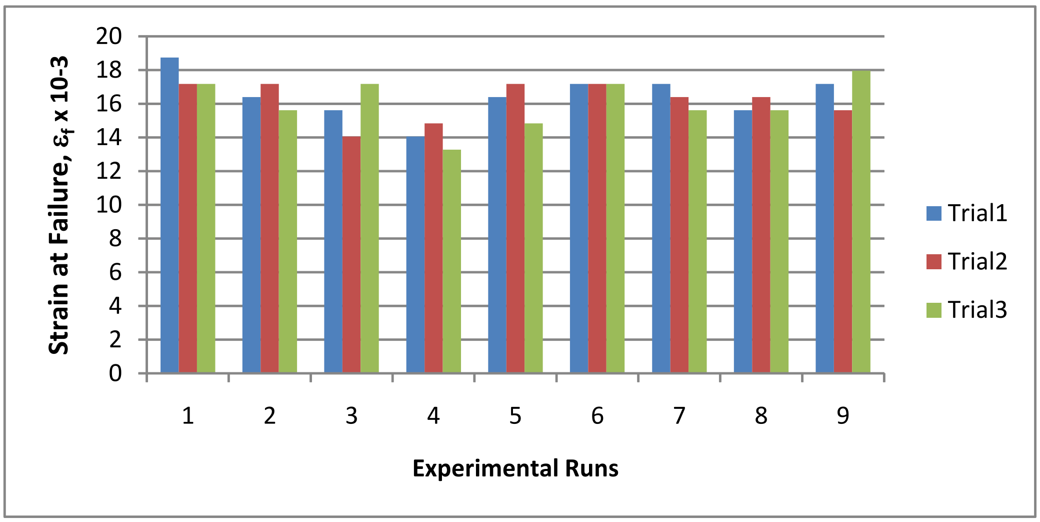


Fig6: Strain at Failure, ε_f x 10^{-3} of ukam plant fibre reinforced CNSL composite chart and Experimental runs.

Evaluation of modulus of Resilience of Ukam Plant Fibre Reinforced CNSL composite

The modulus is of Resilience is the strain energy density a material absorbs up to yield point. The derived formular for modulus of Resilience is

$$U_R = \frac{\sigma_y^2}{2E} \qquad (7)$$

E refers to the tensile modulus of Elasticity. This relationship is applied and the optimization of modulus of resilience obtained is shown in fig7

Optimization of modulus of Resilience of Ukam plant fibre Reinforced CNSL Composite

OPTIMIZATION OF TENSILE MODULUS OF RESILIENCE APPLYING TAGUCHI ROBUST DESIGN

EXP. RUNS	ORIENTATION (+ - Degree)	VOLUME FRACTION(%)	ASPECT RATIO	TRIAL1 (x10^-3)	TRIAL2	TRIAL3	MEAN	MSD	SN ratio
1	0	10	8	98.43572	82.28621	88.03953	89.58715	0.000127	38.97443
2	0	30	80	92.1521	104.06	76.1162	90.7761	0.000128	38.94253
3	0	50	160	108.5919	70.66769	134.8452	104.7016	0.000113	39.4559
4	45	10	80	74.63144	68.75703	61.7	68.36282	0.000218	36.61712
5	45	30	160	90.53411	115.012	75.04038	93.52884	0.000125	39.02871
6	45	50	8	105.0955	103.8848	129.3772	112.7858	8.1E-05	40.91619
7	90	10	160	94.04202	84.37144	66.81089	81.74145	0.000159	37.98075
8	90	30	8	84.24452	96.40625	93.97253	91.5411	0.000121	39.1873
9	90	50	80	103.0559	83.32445	95.92763	94.10266	0.000116	39.36969

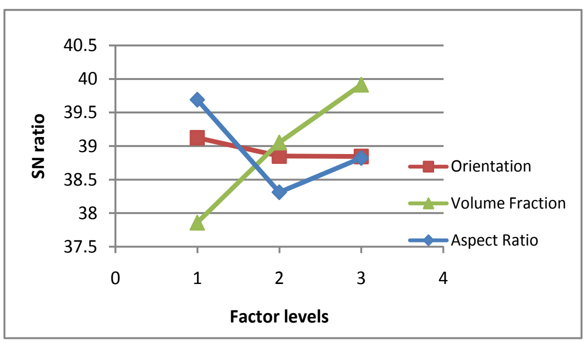
RESPONSE SIGNAL TO NOISE RATIOS

LEVEL	ORIENTATION (+-Degree)	VOLUME FRACTION(%)	ASPECT RATIO
1	39.1242854	37.857432	39.693
2	38.8540058	39.052844	38.31
3	38.8459109	39.913926	38.822
DELTA	0.27837753	2.0564919	1.3829
RANK	3	1	2

MEANS OF QUALITY CHARACTERISTICS

LEVEL	ORIENTATION (+_Deg)	VOLUME FRACTION(%)	ASPECT RATIO
1	95.02161	79.89714	97.97136
2	91.55917	91.94868	84.41386
3	89.1284	103.8634	93.32396
DELTA	5.893211	23.96622	13.5575
RANK	3	1	2

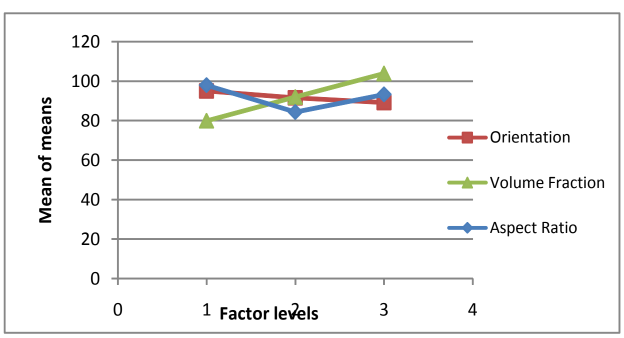
Evaluate



Main effect plots for signal-noise ratio

OPTIMUM RESPONSE ANALYSIS

Average Mean = 91.90306
A Optimum = 95.02161
B Optimum = 103.8634
C Optimum = 97.97136
Optimum Response = 113.0502 X10^-3J/m^3



Main effect plots for means

MODULUS OF RESILIENCE ANALYZED BY APPLYING THE FORMULA uR=Sy^2/(2 x E)

Fig7: Microsoft Excel Visual Basic output for Optimization of Tensile Modulus of Resilience (J/m^3) of Ukam Plant Fibre reinforced CNSL Composite applying Taguchi Robust Design

The optimum setting of control factors for tensile modulus of resilience of Ukam Plant Fibre reinforced CNSL composite is obtained applying Taguchi robust design of experiment on a “larger-is-better” signal to noise ratio. This is achieved using a computer program written in excel visual basic shown in fig.7

The optimum setting of control factors shows that fibre volume fraction is the most significant factor for the signal-to-noise ratio and the means of quality characteristics table. The optimum modulus of resilience is captured as 0.1130502 J/m^3.

Table 11: Optimum settings of control factors and expected optimum modulus of Resilience of ukam plant reinforced CNSL composite.

Composite material	Control	Optimum level	Optimum setting	Expected optimum modulus of Resilience (J/m^3)
Ukam Plant Fibre Reinforced CNSL	Fibre orientation(deg), A volume fraction (%), B Aspect Ratio (mm/mm), C	1 3 1	0 50 8	113.0502x10^{-3}

Determination of modulus of Toughness of Ukam plant Reinforced CNSL Composite

One measure of materials toughness is the modulus of Toughness. It is the total area under the stress-strain curve. The symbol is U_T.

Since the entire area under the stress-strain curve is irregular, the modulus of Toughness cannot be exactly calculated by a simple formular (Lindebierg, 2006). However according to Lindebierg (2006); and Handley et al (2012) the modulus of Toughness for ductile materials with large strains at failure can be approximated by the equation

$$u_T = \left(\frac{Sy + Su}{2}\right)\varepsilon_F \qquad (8)$$

Sy and Su represent yield stress and ultimate tensile stress respectively. And for brittle materials, the modulus of Toughness can be approximated from

$$u_T = \frac{2}{3} Su\varepsilon_F \qquad (9)$$

ε_f refers to the strain at failure .However, Irregular areas can be evaluated accurately by application of numerical integration methods like Simpson's 1/3 rule.

Third Order Function Study of Experimental data of tensile stress –strain Response of Ukam Plant Fibre Reinforced CNSL Composite.

Simpson's 1/3 rule is accurate for third order functions. The third order polynomial function is used to approximate the area from yield stress to ultimate tensile strength. The Values obtained for the third order Polynomial function from the experimental data are shown in Table 12..The third order polynomial regression equations tabulated were obtained for the three trials of the nine experimental runs using Microsoft excel.

Table 12: Third Order function generated from Tensile Response data.

Experiment Runs	Trial 1				Trial 2				Trial 3			
	x^3	x^2	x	C	x^3	x^2	x	c	x^3	x^2	x	C
1	$-3x10^6$	79916	675.1	0.012	$-3x10^6$	59388	801.6	0.036	$-4x10^6$	91311	638.3	0.001
2	$-6x10^6$	64938	1620	-0.119	$-3x10^6$	8653	1850	-0.046	$-3x10^6$	3401	1944	-0.016
3	$-8x10^6$	94129	1858	-0.040	2954	-98500	2675	0.080	$-7x10^6$	10535	1586	-0.091
4	$-6x10^6$	82211	1229	0.012	$-5x10^6$	70263	1068	-0.067	$-9x10^6$	11616	1045	0.086
5	$-4x10^6$	51497	1397	-0.041	$-6x10^6$	12331	805.3	0.012	-43480	10	1860	-0.323
6	$-4x10^6$	76030	937.8	0.034	$-5x10^6$	11952	658.9	0.000	$-2x10^6$	38099	1148	0.013
7	$-4x10^6$	81718	760.9	0.000	$-4x10^6$	10183	439.1	0.067	$-4x10^6$	87393	524	0.033
8	$-8x10^6$	13115	958.4	0.033	$-7x10^6$	14026	710.1	-0.009	$-3x10^6$	50957	1143	0.063
9	$-5x10^6$	94322	1020	0.031	$-3x10^6$	22032	1567	-0.028	$-3x10^6$	34328	1337	-0.086

Evaluation of modulus of Toughness of Ukam Plant Fibre reinforced CNSL Composite applying Simpson's 1/3 rule

Chapara and Canale (2006) analyzed the Newton cotes integration formular Simpson's 1/3 rule used to evaluate the area under the stress-strain curve from yield stress to Tensile strength in this research. The formular is

$$I = \frac{b-a}{6}\left[F(a) + 4F(a+b) + F(b)\right] - \frac{1}{90} f^{(4)}(\grave{\varepsilon})h^5 \qquad (10)$$

Where the error is $-\frac{1}{90} f^{(4)}(\grave{\varepsilon})h^5$. For third order function, the error is zero.

Applying this method, the result obtained for modulus of toughness is tabulated below

Table 13: Modulus of Toughness obtained from applying Simpson's 1/3 Rule.

Experiment Runs	Fibre Orientation (deg)	Fibre volume fraction (%)	Aspect Ratio (mm/mm)	Modulus of Toughness (J/m^3)		
				Trial 1	Trial 2	Trial 3
1	0	10	8	0.201458817	0.152912498	0.164696261
2	0	30	80	0.206012368	0.222523689	0.192090422
3	0	50	160	0.219952345	0.16637979	0.271884322
4	45	10	80	0.137611598	0.135981798	0.061868489
5	45	30	160	0.189965248	0.138454527	0.182097971
6	45	50	8	0.186832398	0.124156915	0.190556273
7	90	10	160	0.169234395	0.098995835	0.118424132
8	90	30	8	0.116525546	0.130300164	0.162162408
9	90	50	80	0.207374334	0.165183753	0.20335771

Optimization of modulus of toughness applying Taguchi Robust design for values obtained from Simpson's 1/3 Rule

OPTIMIZATION OF TENSILE MODULUS OF TOUGHNESS APPLYING TAGUCHI ROBUST DESIGN

EXP. RUNS	ORIENTATION (+ - Degree)	VOLUME FRACTION(%)	ASPECT RATIO	TRIAL1	TRIAL2	TRIAL3	MEAN	MSD	SN ratio
1	0	10	8	201.4588	152.9125	164.6966	173.0226	3.48E-05	44.58949
2	0	30	80	206.0124	222.5237	192.0904	206.8755	2.36E-05	46.2673
3	0	50	160	219.9523	166.3798	271.8843	219.4055	2.34E-05	46.30028
4	45	10	80	137.6116	135.9818	61.86849	111.8206	0.000123	39.11108
5	45	30	160	189.9652	138.4545	182.098	170.1726	3.67E-05	44.35595
6	45	50	8	186.8324	124.1569	190.5563	167.1819	4.04E-05	43.94122
7	90	10	160	169.2344	98.99584	118.4241	128.8848	6.94E-05	41.58516
8	90	30	8	116.5255	130.3002	162.1624	136.3294	5.69E-05	42.45207
9	90	50	80	207.3743	165.1838	203.3577	191.9719	2.8E-05	45.52407

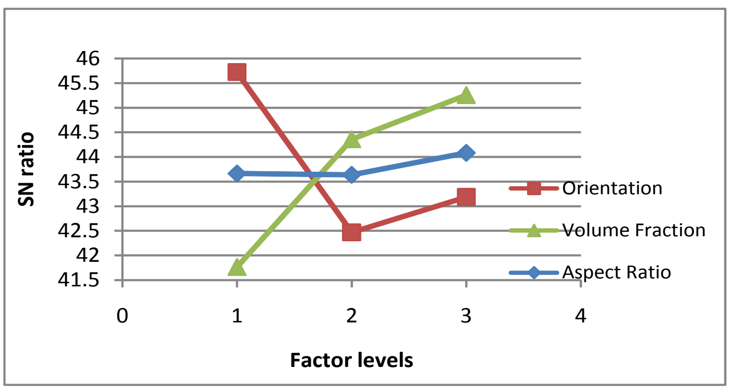
RESPONSE SIGNAL TO NOISE RATIOS

LEVEL	ORIENTATION (+-Degree)	VOLUME FRACTION(%)	ASPECT RATIO
1	45.7190218	41.76191	43.661
2	42.4694184	44.35844	43.634
3	43.1871019	45.255192	44.08
DELTA	3.24960327	3.4932823	0.4463
RANK	2	1	3

MEANS OF QUALITY CHARACTERISTICS

LEVEL	ORIENTATION (+_Deg)	VOLUME FRACTION(%)	ASPECT RATIO
1	199.7679	137.9093	158.8446
2	149.725	171.1258	170.2227
3	152.3954	192.8531	172.8209
DELTA	50.04285	54.94374	13.97632
RANK	2	1	3

Evaluate



Main effect plots for signal-noise ratio

OPTIMUM RESPONSE ANALYSIS

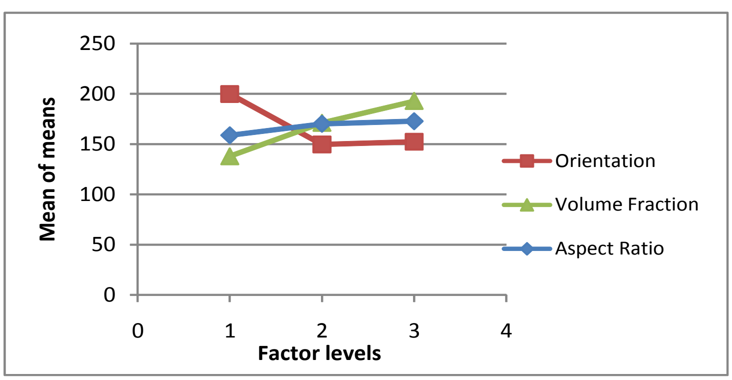
Average Mean = 167.2961

A Optimum = 199.7679

B Optimum = 192.8531

C Optimum = 172.8209

Optimum Response = 230.8497 X10^-3



Main effect plots for means

MODULUS OF TOUGHNESS ANALYZED FROM SIMPSON'S 1/3 RULE DATA

FIG 8: Microsoft Excel Visual Basic output for Optimization of Tensile Modulus of Toughness (J/m^3) of Ukam Plant Fibre reinforced CNSL Composite applying Taguchi Robust Design

Table 14: Optimum settings of control factors and expected optimum modulus of Toughness for the composite considering results from Simpson's 1/3 Rule.

Composite material	Control	Optimum level	Optimum setting	Expected optimum Modulus of Toughness (J/m^3)
Ukam Plant Reinforced CNSL	Fibre orientation (deg), Volume fraction (%), Aspect Ratio (mm/mm),	1 3 3	0 50 160	0.2308497

From the plot of signal to noise ratio against factor levels and plot of mean of means against factor levels Fibre, Fibre Volume Fraction displayed stronger effects than Fibre Orientation and Aspect Ratio. The optimum setting control of Table 14 shows that the material has optimum setting at Fibre Orientation of 0^0, Fibre Volume Fraction of 50% and Fibre Aspect Ratio of 160 (mm/mm) at the optimum modulus of Toughness of 0. 0.2308497MPa.

4.0. Conclusion

The optimum tensile properties of ukam plant fibre reinforced CNSL composite using Taguchi robust design have been studied with following observations.

- The expected optimum modulus of elasticity is captured as 1.857519GPa and fibre volume fraction is the most significant parameter in the optimization of tensile modulus of elasticity of ukam plant fibres reinforced cashew nut shell liquid composite.
- The optimum tensile strength is captured as 21.92982MPa at the optimum settings of 0 degree of Fibre orientation, 50% fibre volume fraction and the aspect ratio of 160.The optimum setting of control factors showed that the optimum tensile strength of the composite material is obtained when the fibres are arranged in the direction of applied tensile force and that fibre volume fraction can be said to be the most significant factor in the optimization of tensile strength response of Ukam Plant Fibre reinforced cashew nut shell liquid composite.
- The optimum setting of control factors for the modulus of resilience shows that fibre volume fraction is the most significant factor for the signal-to-noise ratio and the means of quality characteristics table. The optimum modulus of resilience is captured as 0.1130502 J/m^3.
- The optimum setting control for modulus of toughness for the bio composite material shows that the material has optimum setting at Fibre Orientation of 0^0, Fibre Volume Fraction of 50% and Fibre Aspect Ratio of 160 (mm/mm) at the optimum modulus of Toughness of 0. 0.2308497MPa that fibre volume fraction can be said to be the most significant factor in the optimization of tensile modulus of toughness response of Ukam Plant Fibre reinforced cashew nut shell liquid composite.

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