Nigerian Journal of Technology (NIJOTECH)
Vol. 41, No. 1, January, 2022, pp.123 –130
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
http://dx.doi.org/10.4314/njt.v41i1.16

Improvement of Quality Characteristics of an Epoxy-Based Composite Reinforced with Sisal (*Agave Sissalana*) Plant Fibre for Wind Turbine Blade Material using Taguchi Grey Relational Analysis

I. Iliyasu[1, *], D. S. Yawas[2], M. O. Afolayan[3], and S. Y. Aku[4]

[1,2,3,4]*Department of Mechanical Engineering, Ahmadu Bello University Zaria, Kaduna State,* NIGERIA

Abstract

Natural fibres are possible substitutes for glass fibre in composite production because of their light weight, ease of production and biodegradability. The present study involves the use of Taguchi grey relational analysis to optimize the production process parameters of an epoxy based composite reinforced with sisal fibre. The process parameters optimized are Percentage by weight of the sisal reinforcement, curing temperature, post curing time and compounding pressure. A Taguchi L_{16} orthogonal array was designed and sixteen experimental runs were performed based on the designed experiments. Tensile strength and flexural modulus (stiffness) were recorded for each experiment based on the average responses computed from the Taguchi grey relational analysis. From the response table of the grey relational grades, the optimal set of parameters for enhanced tensile strength and flexural strength performance of the sisal-epoxy composite were identified to be 35% by weight of fibre, 110^0C curing temperature, 1hr post curing time and 13MPa compounding pressure. An analysis of variance (ANOVA) was conducted to identify the predominant factor and established that percentage by weight W has the highest effect of 61 % on the GRG. The optimum composite material had the following values, Ultimate Tensile Strength 27.22 MPa, Flexural Strength 51.84 MPa. The DMA results of the material showed a glass transition temperature of 61.9^0C.

Keywords: Wind turbine blade material, Composites, Epoxy, Sisal plant fibre, Taguchi Method, Grey-relational Analysis (GRA), ANOVA, Multi-response optimization.

1.0 INTRODUCTION

The manufacturing cost of wind turbine blade is about 15-20% of wind turbine production cost [1]. The need for lighter and more effective blades cannot be over looked as this will decrease material requirements for other turbine components making overall cost lower. Majority of wind turbine blades are made of fibre glass reinforced with polyester or epoxy resin and in some cases construction using wood. Small wind turbines can be made from steel or aluminium, but they are heavy. The structural stiffness of blades is of increased importance, thus from a materials perspective, the stiffness-to-weight is of major importance [2].

Composite materials have one of the materials called the reinforcing phase embedded in the other material the matrix phase. This combines the strength of the reinforcement with the toughness of the matrix to achieve a desirable combination of properties. Composites used for typical engineering applications are advanced fiber or laminated composites, such as fibre glass, glass epoxy, graphite epoxy and boron epoxy-epoxy or other materials. This is because of their ease of production and light weight. However, there are often considerable problems with the use of glass fibre as reinforcement of plastics: these include high cost and density, non-recyclability, non–biodegradability, non-renewability and the emission of toxic gasses during its processing and handling [3]. Natural fibres offer the advantages of availability and environmental friendliness.

Epoxy is a thermoset material which represents around 80% of the market reinforced polymers. They have the advantages of low temperature cure, and lower viscosity which eases infusion and thus, allowing high processing speed [2].

According to the work by Sumaila [4] one of the possible substitutes for glass fibre from some common plant fibres is Sisal (*Agave Sissalana*) having 4.2 times the specific tensile strength, 5.9 times the percent elongation

*****Corresponding author **(Tel:** +234 (0) 8028782130**)**

Email addresses: ibroij@gmail.com (I. Iliyasu), dywas@yahoo.com (D. S. Yawas), tunde.afolayan@gmail.com (M. O. Afolayan), S. Y. Aku (syaku@gmail.com)

and 0.89 times the breaking force of glass fibre. Coupled with the availability of sisal it was picked as the reinforcement for this study.

Holmes [5] tested a novel wind turbine blade made from bamboo-poplar epoxy laminate, he was able to demonstrate that the material has high strength and stiffness and can replace other common composites. The bamboo having high strength and durability make it a promising material also for wind energy application.

Numerous decision-making techniques, such as analytic hierarchy process (AHP), data envelopment analysis (DEA), grey relational analysis (GRA) and technique for order of preference by similarity to ideal solution (TOPSIS), have been suggested in literature for investigating multi-response attributes [6]. Among them, grey relational analysis (GRA), proposed by Deng [7], is one of the foremost techniques applied when the nature of information is incomplete and uncertain. A combined Taguchi L_{16} orthogonal array and GRA approach were adopted for optimization of process parameters.

This study aims at optimizing the process parameters for the production of an Epoxy based composite reinforced with sisal fibre with potential for high Tensile (TS) strength and flexural modulus (FS) for wind turbine blade application. Four distinct levels were identified for four process parameters. Subsequently, sixteen experimental runs were conducted to obtain the data used for multi response of Tensile strength and flexural modulus. The S/N ratios and GRA were thereafter utilized for the analysis of the responses in order to obtain the optimal parameters. The most significant factors affecting the tensile strength and flexural modulus were identified using ANOVA.

2.0 MATERIALS AND METHODS

2.1 Experimental Design and Formulation

Optimization of process parameters to enhance mechanical properties of composites and ensure better performance are dependent on the selection of the most suitable production techniques, amongst which curing conditions and compounding pressures where considered as having influence on the material properties [8].
Tensile strength and Stiffness are the properties of interest in the production of material using sisal fibre as reinforcement for the epoxy matrix.

The Taguchi method is used mostly in the optimization of single quality characteristic [9]. The GRA is integrated to optimize the multi-response [7]. The number of process parameters and their levels for the Taguchi method are given in Table 1

Table 1: Control factors and levels

Control Factors	Units	Symbols	Levels			
			1	2	3	4
Weight of fibre	%	*W*	35	40	45	50
Curing Temperature	^{0}C	*T*	100	110	120	130
Post curing Time	hrs	*P*	1	1.5	2	2.5
Compounding Pressure	MPa	*C*	11	13	15	17

Table 1 shows four factors at 4 levels each, the L16 (4*4) orthogonal array of the Taguchi method. The responses are from the Tensile and flexural tests carried out. The tests were carried out following the ASTM standards using the Universal Materials Testing Machine cat.Nr.261 and Monsanto Tensometer s/no 9875 for the tensile and flexural tests respectively. Multi-Response Optimization Using GRA. This can also be used to dertemine similarity between seemingly irregular finite data [10].

2.1.1 Grey-relational procedure

For GRG data pre-processing may be performed to normalize the original reference sequences to a comparable sequence within the range of zero to one [11]. This data normalization pre-processing is termed grey relational generation.

The steps are:

i. Normalise the experimental results for the response variables
ii. Perform the grey relational generation and calculate the grey relational coefficients.
iii. Calculate the grey relational grades by averaging the grey relational coefficients.
iv. Analyse the experimental results using the grey relational grades and ANOVA.
v. Verify the optimal process parameters through confirmation tests [12].

To normalise the original sequence of the data, use the following relations;

a) Larger-the-better as:

$$X_i^*(k) = \frac{X_i(k) - minX_i(k)}{maxX_i(k) - minX_i(k)} \quad (1)$$

b) Smaller-the-better:

$$X_i^*(k) = \frac{maxX_i(k) - X_i(k)}{maxX_i(k) - minX_i(k)} \quad (2)$$

Where $X_i^*(k)$ and $X_i(k)$ are the sequence after the data pre-processing and comparability sequence respectively, K = 1,2……n; the sequence of experimental runs.

Next: Compute for the deviation sequence of the reference sequence $X_0^*(k)$ and the comparability sequence $X_i^*(k)$ as;

$$\Delta_{0i}(k) = |X_0^*(k) - X_i^*(k)| \quad (3)$$

Next: Use the deviation sequence for computing the Grey relational Coefficient and Grey Relational Grade as; GRC;

$$\varepsilon_i(k) = \frac{\Delta_{min} + \varepsilon\Delta_{max}}{\Delta_{oi}(k) + \varepsilon\Delta_{max}} \quad (4)$$

Where $\Delta_{0i}(k)$ is the deviation sequence of the reference sequence $X_0^*(k)$ and the comparability sequence $X_i^*(k)$; ε is the distinguishing or identification Coefficient between 0 and 1. If all parameters are given equal preference, ε is taken as 0.5, [13].

The GRG, γ_i

$$\gamma_i = \frac{1}{n}\sum_{i=1}^{n} \varepsilon_i(k) \quad (5)$$

Where γ_i represent the value of GRG determined for the ith experiment, n being the aggregate count of performance characteristics. Once the optimal level of the factors is determined using GRG the final step is to predict and verify the quality characteristics using.

$$\gamma_{predicted} = \gamma_m + \sum_{i=1}^{n} \gamma_o - \gamma_m \quad (6)$$

Where γ_o denotes the maximum of average GRG at the optimal level of factors and γ_m represents the mean GRG. The quality q indicates the number of factors affecting response values.

The grey relational grade indicates the degree of similarity between the comparability sequence and the reference sequence. If an experiment gets the highest grey relational grade with the reference sequence, it means that comparability sequence is most similar to the reference sequence and that experiment would be the best choice [14].

2.2 Analysis of Variance (ANOVA)

To investigate the significance of the parameters on the responses ANOVA was used. ANOVA table is widely used to analyze the interactions between factors and the effect of such interactions on the dependent variable [15].

2.3 Material and Specimens

Sisal fibre was obtained in large quantities from Nilest Botanical Garden, Samaru Zaria, Kaduna State. Sisal fibre is a lingno-cellulosic fibre and was used as the reinforcing material due to it's:

i. high surface area
ii. mechanical strength
iii. unique morphology

Epoxy resin (Epochem 105) was used as the matrix material. Epoxy resins are highly cross-linked polymers and this structure results in the material possessing various desirable properties such as:

i. High tensile strength
ii. Good thermal and chemical resistance
iii. Uncomplicated processing

Tetra Ethylenepentamine served as the hardener or curing agent as the curing agent. Sodium Hydroxide (NaOH) was used for the treatment of the sisal fibres. The epoxy resin, hardener (Tetra Ethylenepentamine) and Sodium Hydroxide were obtained commercially from Zayo-Sigma Chemicals Limited, Ojota, Lagos State, Nigeria. The epoxy resin has a specific modulus of 3.42 GPa and a density of 1100Kg/m^3.

The following criteria were considered in the selection of the material for the turbine blade:

i. Corrosion resistance
ii. Abrasive-wear resistance
iii. Cavitation resistance
iv. Machining properties
v. Cost

The equipment used in this research include:

i. Laboratory Milling Machine, Mekins Agro Products Ltd Model No 150 (Nilest Zaria)

ii. Digital weighing balance with precision of 0.001g
iii. Hydraulic Hot Press, Carver inc. hydraulic press 3851-0

2.3.1 Pattern (blank) preparation

The pattern consisting of three parts (base plate, frame and lid) was fabricated at Nigerian Institute of Leather and Science Technology Zaria, using mild steel with dimensions 200 x 120 x 6 mm as per ASTM standards. The pattern consists of three parts:

vi. Base plate
vii. Frame
viii. Lid

The purpose of the lid is to ensure even distribution of load on the mixture which is filled in the pattern.

2.3.2 Production of reinforced polymer matrix composite sample

The sisal fibres were extracted from the freshly harvested sisal leaves. The leaves were cut out and beaten. A metal comb was then used to extract strands of fibres from the beaten sisal leave. The fibres were cleaned in distilled water and sundried for 24 hours. The fibres were then treated in dilute Sodium Hydroxide (5%w/v NaOH) solution in order to remove surface impurities, modify the surface structure and increase the fibre surface area. The treated fibres were then dried in the sun for 24 hours and the fibre length was reduced to 2mm. The fibre length reduction was achieved by milling the fibres in a Laboratory milling machine and passed through a sieve of mesh 2mm. A mixture of the sisal fibre and Epoxy resin was used to produce 16 different samples of reinforced polymer matrix composite using Taguchi method. Compression Moulding was used to formulate the sisal fibre reinforced polymer matrix composites. This method was selected because of its fast set-up time, low initial set up costs, little material wastes and good surface finish. The prepared sisal fibres, epoxy resin and hardener were mixed for 5 minutes using a glass rod, the mixture was poured into an open, heated mould cavity. The mould was then closed and sufficient pressure was applied to force the material to fill up the cavity. A hydraulic ram was used to produce the sufficient force during the moulding process. The temperature, pressure and curing time were varied accordingly and maintained for each level of the formulation. After curing each sample it was removed from the mould and appropriately labelled.

2.3.3 Post Curing

The samples were post cured in a hot air oven according to the formulations for each level. The temperature of the oven was set to the required temperature for the sample curing, the samples were placed in the oven and allowed to stay in the oven depending on the post curing time for the experimental run.

3.0 RESULTS AND DISCUSSIONS

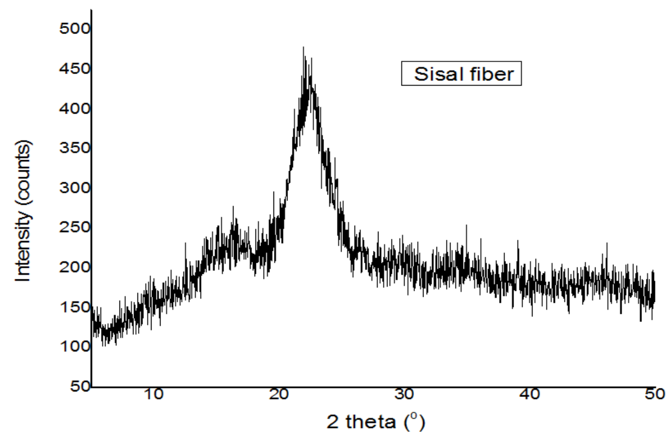

Figure 1: XRD patterns of as-received sisal fiber

Figure 1 shows the XRD pattern of the as-received sisal fiber. One broad peak was observed at around 24.50°, which can be assigned to (220) crystal planes of cellulose [16]. The broad reflection comes from the amorphous phase of the lignin present which is non-crystalline in nature. In addition, the broad peak as observed in the sisal fiber can also be attributed to inorganic impurities such as silica or calcium carbonate as posited by [17]. It is evident from these that the fiber is semi-crystalline in nature. The low crystallinity index (broad peak) reveals deficiencies in the reflections of the fiber cellulose crystals and presence of cementing materials, primarily lignin.

3.1 L_{16} Orthogonal Array

Table 2 shows the L16 orthogonal array and the average response for strength and stiffness for the 16 experimental runs.

3.3. Multi-Response Optimization Using GRA

The GRA was used to ascertain the rank of the experimental runs, Table 3 shows the grey relational grade for each experiment. The highest grey relational grade is the order of 1. The experiment number 4 is nearest optimum controllable parameters combination: Weight percentage of fibre 35% (W_1), curing temperature 130^{0}C (T_4), post curing time 2.5hrs(P_4) and compounding pressure 17MPa (C_4).

The means of the grey relational grade for each level of controllable parameters are in a response table for the GRG designed Table 4. These grades in the response table serve as a measure of the correlation between the reference and compatibility sequence of GRA. Higher values of the mean of GRG indicates a strong correlation [18]. From the response table of GRG, Table 4 the combination of optimal parameters which maximizes overall response was arrived at. These optimal parameters exist at W_1, S_2, T_1 and P_2. Hence the optimal settings for the composite process parameters are 35% by weight of fibre, 110^{0}C curing temperature and 1hr post curing time and 13MPa compounding pressure. To produce the composite with the best response of strength and stiffness required for wind turbine blades the above mentioned process parameters will suffice.

Table 2: L16 Orthogonal Array

Runs	Control Factors				Response Values	
	W(%)	*T(⁰C)*	*P(hrs)*	*C(Mpa)*	*Strength(ST)*	*Stiffness(FM)*
1	35	100	1	11	31.78	30.59
2	35	110	1.5	13	31.7	34.46
3	35	120	2	15	25.8	34.98
4	35	130	2.5	17	27.22	51.84
5	40	100	1.5	15	27.67	34.14
6	40	110	2	17	26.78	50.06
7	40	120	2.5	11	25.93	46.74
8	40	130	1	13	22.2	29.72
9	45	100	2	17	8.76	27.35
10	45	110	2.5	11	9.41	47.07
11	45	120	1	13	26.85	48.42
12	45	130	1.5	15	19.16	24.87
13	50	100	2.5	11	11.43	22.76
14	50	110	1	13	19.14	30.55
15	50	120	1.5	15	8.84	17.6
16	50	130	2	17	4.53	11.9

Table 3: Grey Relational coefficients, Rank of GRG and S/N ratios

Run	Grey Relational Coefficient		GRG	S/N Ratio of GRG	Rank
	TS	FS			
1	1	0.485	0.742	-2.592	6
2	0.994	0.535	0.764	-2.338	4
3	0.695	0.542	0.619	-4.166	8
4	0.749	1	0.875	-1.160	1
5	0.768	0.53	0.649	-3.755	7
6	0.731	0.918	0.825	-1.671	2
7	0.7	0.797	0.748	-2.522	5
8	0.587	0.474	0.531	-5.498	10
9	0.372	0.449	0.411	-7.723	13
10	0.379	0.807	0.593	-4.539	9
11	0.734	0.854	0.794	-2.004	3
12	0.519	0.425	0.472	-6.521	12
13	0.401	0.407	0.404	-7.872	14

Run	Grey Relational Coefficient		GRG	S/N Ratio of GRG	Rank
14	0.519	0.484	0.501	-6.003	11
15	0.373	0.368	0.371	-8.613	15
16	0.333	0.333	0.333	-9.551	16

Table 4: Response table of GRGs

Factors	Level 1	Level 2	Level 3	Level 4	Delta	Rank
W	0.7500	0.6883	0.5675	0.4023	0.3478	1
T	0.5515	0.6707	0.6330	0.5528	0.1194	3
P	0.6735	0.5640	0.5155	0.6550	0.1580	2
C	0.6158	0.6232	0.5485	0.6205	0.0747	4

Mean of GRG =0.6020

3.2 ANOVA for GRG

Anova was used to investigate which controllable parameter significantly affects the performance characteristic. This was accomplished by separating the total variability of the grey relational grades, which is measured by the sum of the squared deviations from the total mean of the grey relational grade into contributions by each controllable parameter and the error. Table 5 shows that percentage by weight *W* has the highest effect of 61.% on the GRG, followed by *T* 15%, *S* 9% and *P* 3% with minimal influence. What this implies is that the percentage by weight of the sisal fibre has the greatest effect on the strength and stiffness of the composite.

Table 5: ANOVA for GRG

Source	DF	Adj SS	Adj MS	F-Value	Contribution (%)
W	3	0.28173	0.093911	4.9200	61%
S	3	0.04265	0.014218	0.7500	9%
T	3	0.06739	0.022463	1.1800	15%
P	3	0.01538	0.005127	0.2700	3%
Error	3	0.05725	0.019084		
Total	15	0.46441			

3.3 Interfacial Characterization of Composite with Optimal Parametric Characteristics

3.3.1 SEM analysis

Plate I represents the SEM micrograph of the sisal/epoxy composite before and after tensile fracture. The micrograph before fracture shows the presence of sisal fibre in the matrix (small in size) which represents the proper mixing of the sisal fibre reinforcement with the epoxy matrix. It is also clear that there is little or no voids on the sisal/epoxy composite which results in good and enhanced mechanical properties of the composite. Also, the micrograph of the composite after tensile fracture exhibited no evidence of pullout in the epoxy matrix composite reinforced with sisal fibres which can result in an increased mechanical property of the composite. Hence 35% by weight of fibre, 110^{0}C curing temperature and 1hr post curing time and 13MPa compounding pressure sisal composite tends to have good mechanical properties.

3.3.2 EDS micro-analysis

The elemental analysis of the composite as shown in Table 7 is indicative of the presence of compounds with known chemical structure. The measured carbon to oxygen mass ratio (C:O) is around 4.36 whereas theoretically (based on the chemical formula) the C:O of cellulose is 0.9 and C:O of lignin is 2.9 [19] This is indicative that the lignin and hemicellulose were still detected in the sisal fiber after the composite fabrication process. Furthermore, incidence of N, and Si on the surface of the composite can be associated to the composition of the matrix and other additives during composite fabrication. The peaks of Mn, Na, Ca, Ti, K on the EDS table are weak indicating their presence as contaminations. High percentage of carbon on the EDS can be associated with inherent carbon in Epoxy.

Table 7: EDS of composite material

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
6	C	Carbon	74.34	65.15
8	O	Oxygen	17.06	19.92
7	N	Nitrogen	4.54	4.64
14	Si	Silicon	1.37	2.80
19	K	Potassium	0.67	1.90
22	Ti	Titanium	0.50	1.76
25	Mn	Manganese	0.42	1.67
11	Na	Sodium	0.84	1.41
20	Ca	Calcium	0.25	0.74

3.6 Result of dynamic mechanical analysis test on Composite with Optimal Parametric Characteristics

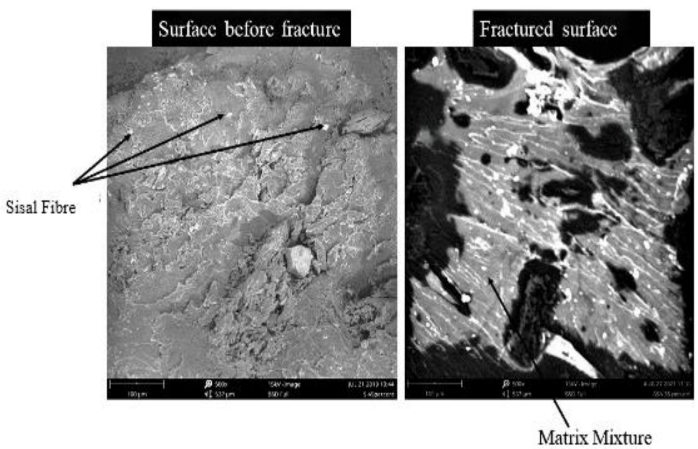

Plate 1: SEM of composite material

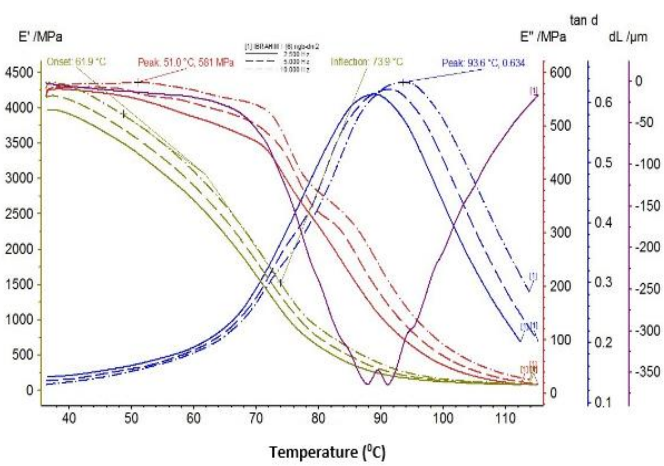

Figure 2: Storage modulus, loss modulus, and tan delta as a function of temperature

The glass transition temperature is critical in knowing a material's suitability for specific applications. The results of the DMA test on the sisal fiber-reinforced epoxy composite are presented in the plot of Figure 2 which shows the storage modulus, loss modulus, and tan delta (loss factor) presented as a function of temperature. The storage modulus at 40°C (approx. 4250 MPa) indicates the material stiffness. The drop in the curve at 61.9°C (onset temperature) marks the glass transition of the epoxy matrix and is related to the maximum in the loss modulus and loss factor curves at 51.0°C and 93.6°C. The material retained more than half (50%) of its strength up to around 73^0C, it then completely lost its strength at beyond 73^0C. The maximum change in length of the material was -350μm at about 90^oC.The results indicate that that the material will be suitable for the application intended (wind turbine blade) since the maximum likely temperature it will be expose to is about 43^0C the hottest weather in Nigeria(Maiduguri).

4.0 CONCLUSION

The aim of this study was to obtain the optimal set of process parameters which affects the multi-responses of tensile and flexural performance of an epoxy based composite reinforced with sisal fibre. The use of the orthogonal array with grey relational analysis to optimize the process with the multiple performance characteristics was reported in this paper. The multiple responses of enhanced tensile strength and flexural strength was studied using a Taguchi L16 orthogonal array and GRA approach. From the response table of the grey relational grades, the optimal set of parameters for enhanced tensile strength and flexural strength performance of the sisal-epoxy composite were identified to be 35% by weight of fibre, 110^0 curing temperature, 1hr post curing time and 13Mpa compounding pressure. The ANOVA for GRG indicated that percentage by weight *W* has the highest effect of 61.% on the GRG, followed by *T* 15%, *S* 9% and *P* 3% with minimal influence. The optimum composite material had the following values, Ultimate Tensile Strength 27.22 MPa, Flexural Strength 51.84 MPa, The DMA results of the material showed a glass transition temperature of 61.9^0C.

REFERENCES

[1] Jurecz, M., Pawlak, M. and Mezyk, A. “Optimization of Wind Turbine Blades”. *Journal of material processing Technology* 167, 2005, pp.463-471.

[2] Leon M., Kim B.,Helga N. P., Justine B., Malcolm M. and Bent F. S. “Materials for Wind Turbine Blades: An Overview”, *Materials Multidisciplinary Digital Publishing Institue*, 10, 2017, 1285; doi:10.3390/ma10111285.

[3] Njoku, R.E. and Obikwelu, D.O.N. “Swelling Characteristics and Tensile Properties of Natural Fibre Reinforced Plastic in selected Solvents”, *Nigerian Journal of Technology*, 27(2), 2008, pp. 57-63

[4] Sumaila, M. and Ibhadode, A. O. A. “Technical Properties of Some Plant Fibres Compared with Glass Fibre”. *International Journal of Engineering Reasearch in Africa*; 11, 2014, pp 11-26.

[5] Holmes, J.W.; Brøndsted, P.; Sørensen, B.F.; Jiang, Z.H.; Sun, Z.H.; Chen, X.H. “Development of a Bamboo-Based Composite as a Sustainable Green Material for Wind Turbine Blades”. Journal of *Wind Engineering and Industrial Aerodynamics,* 33, 2009, pp. 197–210.

[6] Pervez, M.N.; Shafiq, F.; Sarwar, Z.; Jilani, M.M.; Cai, Y. “Multi-response Optimization of Resin finishing by Using a Taguchi-Based Grey Relational Anlysis”. *Materials* 11, 2018, 426

[7] Deng, J. L. “Introduction to Grey System Theory”. *The Journal of Grey Systems*, 1, 1989, pp. 1-24.

[8] Carbas R. J. C., Marques E. A. S., Da Silva L. F. M. and Lopez A. M. “Effect of Cure Temperature on the glass Transition Temperature and Mechanical Properties of Epoxy Adhesives”. *The Journal of Adhesion*, 90:104-119, 2014. Taylor & Francis Group. LLC.

[9] Ng, C. F., Nik, M. M., and Shahrul, K. “Practical Application of Taguchi Method for Optimization of Processing Parameters for Plastic Injection Moulding:A Retrospective Review”. *Hindawi Publishing Corporation ISRN Industrial Engineering*, Article ID 462174, 2013. http://dx.doi.org/10.1155/2013/462174,

[10] Zhang, D.; Chen, M.; Wu, S.; Liu, J.; Amirkhanian, S. “Analysis of the relationships between waste cooking oil qualities and rejuvenated asphalt properties”. *Materials*, 2017, 10, 508.

[11] Manoharan, S.; Vijayan, K.; Vijay, R.; Singaravelu, D.L.; Bheemappa, S. “Development and characterization of novel fiber reinforced hybrid friction composites. In Green Composites”: *Materials, Manufacturing and Engineering;* Walter de Gruyter Gmbh: Berlin, Germany, 2017; pp. 69–114. ISBN 9783110435788.

[12] Hasani,H., Akhavan, S. T. and Amiei, G. “Grey Relational Analysis to Determine the Optimum Process Parameters for Open-End Spinning Yarns”. *Journal of Engineering Fibers and Fabrics*, 7(2), 2012, Pp 81-86.

[13] Ahmet, T. and Kenan, K. “Experimental investigation and multi- objective analysis on drilling of boron carbide reinforced metal matrix composites using grey relational analysis”. *ELSVIER. Measurement,* 47, 2013, 321-330

[14] Sonja J.,Drazen B., Luka C. “Application of compressed cold air cooling; achieving multiple performance characteristics in end milling process.” *Journal of Cleaner Production. Faculty of Electrical Engineering and Naval Architecture*. University of plit, Rudera Boskiva 32, 2015, Split, Croatia

[15] Cicek, A.; Kivak, T.; Ekici, E. “Optimization of drilling parameters using Taguchi technique and response surface methodology (RSM) in drilling of AISI 304 steel with cryogenically treated HSS drills, *Journal of Intelligent Manufacturing*, 26, 2015, 295–305.

[16] Morán, J. I., Alvarez, V. A., Cyras, V. P., & Vázquez, A. “Extraction of cellulose and preparation of nanocellulose from sisal fibers” *Cellulose*, *15*(1), 2008, 149-159.

[17] Barreto, A. C. H., Rosa, D. S., Fechine, P. B. A., & Mazzetto, S. E. “Properties of sisal fibers treated by alkali solution and their application into cardanol-based biocomposites” *Composites Part A: Applied Science and Manufacturing*, *42*(5), 492-500, 2011.

[18] Kasemsiri, P.; Dulsang, N.; Pongsa, U.; Hiziroglu, S.; Chindaprasirt, P. “Optimization of Biodegradable Foam Composites from Cassava Starch, Oil Palm Fiber, Chitosan and Palm Oil Using Taguchi Method and Grey Relational Analysis.” *Journal of Polymers and the Environment*, 25, 2017, pp. 378–390.

[19] Sgriccia, N., Hawley, M. C., & Misra, M.“Characterization of natural fiber surfaces and natural fiber composites” *Composites Part A: Applied Science and Manufacturing*, 39(10), 2008, 1632-1637.